Past and present soil use in Germany – an analysis of the social-ecological systems “agriculture” and “allotment gardening”

Dissertation

der Mathematisch-Naturwissenschaftlichen Fakultät

der Eberhard Karls Universität Tübingen

zur Erlangung des Grades eines

Doktors der Naturwissenschaften

(Dr. rer. nat.)

vorgelegt von

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Tübingen

2017

Gedruckt mit Genehmigung der Mathematisch-Naturwissenschaftlichen Fakultät der Eberhard Karls Universität Tübingen.

Tag der mündlichen Qualifikation:	18.12.2017
Dekan:	Prof. Dr. Wolfgang Rosenstiel
1. Berichterstatter:	Prof. Dr. Thomas Scholten
2. Berichterstatter:	Prof. Dr. Thomas Knopf

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Abbreviations

AMS	accelerator mass spectrometry
GMO	genetically modified organism
OSL	optical stimulated luminescence
S	Stuttgart
SES	social-ecological system
SFB	Sonderforschungsbereich (= Collaborative Research Center)
VS	Villingen-Schwenningen

1 Summary

Food security has been a recurring issue in the scientific community and among policy makers, and it affected societies in the past, for example during the World Wars. Agriculture and especially the production of cereals are important to provide the growing world population with enough food. This requires soils, which are suitable for cultivation, a climate in which the crops can successfully be cultivated, tools for cultivation, and the knowledge and management practices related to crop production. Agriculture, therefore, does not depend on a single natural resource, but on a ResourceComplex in which soil is central.

The relevance of soil and its use in society has been investigated using the framework of the Collaborative Research Centre (SFB 1070) RESOURCECULTURES. The focus is on the ResourceComplex “soil”, which consists of the central resource soil, and the resources crops, knowledge, technology in form of tools, management practices, and socio-cultural dynamics. The investigated RESOURCECULTURE concerns soil use in Germany from the Neolithic transition to today. The time span of several millennia necessitates a separation of the study into different social-ecological systems (SES) which depend on the ResourceComplex “soil”. Therefore, an SES concerning agrarian soil use from a prehistoric and historic perspective was investigated using the adaptive cycle metaphor. The research interest was to analyze changes occurring within the SES “agriculture”, which are observable in the variables of the ResourceComplex “soil”. With industrialization, the ResourceComplex “soil” is no longer only present in the SES “agriculture” but also in the SES “allotment gardening”. The different variables of the ResourceComplex “soil” were investigated using questionnaires in six allotment garden associations. The specific characteristics of the ResourceComplex “soil” in the two contrasting SESs were used to define a RESOURCECULTURE concerning the ResourceComplex “soil”.

The SES “agriculture” was analyzed using the adaptive cycle approach, which shows, that the SES is currently in its second cycle. Changes of the variables of the ResourceComplex “soil” indicate the different stages of the adaptive cycle and illustrate the complexity of the SES. The agrarian tools advanced from the spade to the ard to the plow, and management practices developed, such as crop rotation. Both had an impact on the soils of Central Europe, as the anthropogenic colluvial deposits show. With industrialization, the SES “agriculture” transforms and a second adaptive cycle begins. It relies on heavy machinery, industrialized fertilizer and herbicide production, and in part on genetically modified crops. The change of the SES “agriculture” led to more people living in urban agglomerations, where the ResourceComplex “soil” seems unimportant for society. However, it is substantial for the gardening community in the SES “allotment gardening”. There, soil knowledge and management practices are shaped by traditions. Experiments with the soil, plants and management practices lead to a specific gardening approach.

Today, the ResourceComplex “soil” is used professionally by farmers and leisurely by gardeners. Further, society depends on the ResourceComplex “soil” for food provisioning. Most people in industrialized countries, however, do not actively engage with the ResourceComplex, but have a passive influence on it, through socio-cultural dynamics. Still, their dependency on agrarian products, which require soils, allows the definition of a SOILCULTURE. This culture is shaped by the farmers, leisure gardeners, and society in general, who rely on the ResourceComplex “soil” for food security.

2 Zusammenfassung

Die Sicherstellung der Ernährung ist ein wiederkehrendes Thema in der Wissenschaftswelt und in politischen Kreisen. Ernährungssicherheit hat Gesellschaften in der Vergangenheit beschäftigt, wie beispielsweise die Bevölkerung Europas während der Weltkriege. Landwirtschaft, insbesondere die Produktion von Getreide, ist daher wichtig, um die wachsende Weltbevölkerung mit ausreichend Nahrungsmitteln zu versorgen. Die Landwirtschaft benötigt dafür Böden, die sich zur Kultivierung eignen, klimatisch günstige Ausgangsbedingungen, Werkzeuge und Maschinen für die Kultivierung und das Wissen sowie geeignete Bearbeitungspraktiken, die eine langfristige Landnutzung ermöglichen und die Ernährung sichern. Die Landwirtschaft ist daher nicht von einer einzelnen natürlichen Ressource abhängig, sondern von einem RessourcenKomplex, in dem Boden die zentrale Rolle spielt.

Die Bedeutung des Bodens und sein Gebrauch in der Gesellschaft wird im Folgenden mithilfe des theoretischen Rahmens des Sonderforschungsbereichs 1070 RESSOURCENKULTUREN untersucht. Der Fokus liegt hierbei auf dem RessourcenKomplex „Boden“, welcher aus der zentralen Ressource Boden besteht sowie aus Feldfrüchten, Wissen, Technologie in Form von Werkzeugen, Bearbeitungspraktiken und soziokulturellen Dynamiken. Die untersuchte RESSOURCENKULTUR betrifft die Bodennutzung in Deutschland vom Neolithikum bis heute. Die große Zeitspanne von mehreren tausend Jahren macht es nötig, die Studie in mehrere sozial-ökologische Systeme (social-ecological systems = SES) zu unterteilen, die vom RessourcenKomplex „Boden“ abhängen. Daher wurde ein SES untersucht, welches die landwirtschaftliche Bodennutzung aus einer prähistorischen und historischen Perspektive betrachtet. Hierzu wurden die adaptiven Zyklen (adaptive cycles) als theoretische Hintergundüberlegung genutzt. Die Forschungsfragen beschäftigen sich mit den Änderungen im SES „Landwirtschaft“, welche insbesondere die Variablen des RessourcenKomplexes „Boden“ betreffen. Im Rahmen der Industrialisierung gibt es dann nicht mehr nur die berufliche Beschäftigung mit dem RessourcenKomplex „Boden“ im SES „Landwirtschaft“, sondern auch eine Freizeitbeschäftigung mit dem RessourcenKomplex in der Form von Freizeitgärten, wie z.B. im SES „Kleingarten“. Die Ausprägungen des ResourcenKomplexes in den beiden SESs werden untersucht und zur Definition einer RESOURCENKULTUR genutzt, die mit Bodennutzung zusammenhängt.

Das SES „Landwirtschaft“ befindet sich gegenwärtig im zweiten „adaptive cycle“. Veränderungen des RessourcenKomplexes „Boden“ und seine Variablen zeigen die unterschiedlichen Stadien des „adaptive cycles“ an und illustrieren die Komplexität des SES. Die landwirtschaftlichen Werkzeuge entwickelten sich vom Spaten, zum Ard und weiter zum Pflug. Auch die Bearbeitungspraktiken veränderten sich mit der Zeit, wie z.B. durch die Einführung der Dreifelderwirtschaft. Beide Entwicklungen hatten Auswirkungen auf die Böden

Zentraleuropas, wie die anthropogenen Kolluvien zeigen. Nach der Industrialisierung hängt das SES „Landwirtschaft“ stark von schweren Maschinen, industriell erzeugten Pestiziden und Düngemitteln und teilweise auch von genetisch modifizierten Organismen ab. Die Veränderungen im Rahmen der Industrialisierung führten dazu, dass mehr und mehr Menschen in städtischen Gebieten leben, wo der RessourcenKomplex „Boden“ von untergeordneter Bedeutung für die Gesellschaft zu sein scheint. Jedoch nutzen Freizeitgärtner den RessourcenKomplex, z.B. in Form des SES „Kleingarten“. Dort sind das Wissen und die Praktiken geprägt von Traditionen. Experimente mit Boden, Pflanzen und Bearbeitungspraktiken führen zu einem individuellen Gartenmanagement.

Der RessourcenKomplex „Boden“ wird heute von den Landwirten professionell und von Freizeitgärtnern auf freiwilliger Basis genutzt. Da die Grundnahrungsmittel für die Gesellschaft aus der Landwirtschaft stammen, hängt das Wohlergehen der Gesellschaft vom RessourcenKomplex „Boden“ ab. Allerdings beschäftigt sich ein Großteil der Gesellschaft, insbesondere in den industrialisierten Ländern, nicht aktiv mit dem RessourcenKomplex „Boden“. Durch Kaufverhalten und andere soziokulturellen Dynamiken nehmen sie dennoch Einfluss auf den RessourcenKomplex. Durch diese Einflussnahme und die Abhängigkeit vom RessourcenKomplex „Boden“, kann eine BODENKULTUR definiert werden. Diese Kultur wird von den Landwirten geprägt, aber zum Teil auch von den verschiedenen Gärtnern, die den RessourcenKomplex „Boden“ in ihrer Freizeit nutzen, sowie von der Gesellschaft durch soziokulturelle Dynamiken.

3 List of publications

(1) SoilCultures - the adaptive cycle of agrarian soil use in Central Europe. An interdisciplinary study using soil scientific and archaeological research.
Manuscript 1, accepted as first author in Ecology and Society 2017
Co-authors: Jan J. Ahlrichs, Jessica Henkner, Thomas Knopf, Peter Kühn, Thomas Scholten

(2) BodenKulturen - die Bodennutzung in Mitteleuropa im Wandel der Zeit.
Manuscript 2, published as first author in Wessolek, G. (Ed.) (2015): Von ganz unten - Warum wir unsere Böden besser schützen müssen. Oekom, 259-272.
Co-authors: Peter Kühn, Thomas Scholten

(3) Allotment gardening in Southwest Germany - a comparative analysis of motivations and management practices
Manuscript 3, under review as first author in Agriculture and Human Values
Co-authors: Karsten Schmidt, Peter Kühn, Thomas Scholten

(4) Archaeopedology and chronostratigraphy of colluvial deposits as a proxy for regional land use history (Baar, southwest Germany).
Manuscript 4, published as co-author in Catena 2017, Volume 155, pages 93-113.
First author: Jessica Henkner
Other co-authors: Jan J. Ahlrichs, Sean Downey, Markus Fuchs, Bruce James, Thomas Knopf, Thomas Scholten, Peter Kühn

(5) Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory - A Case Study from the Western Baar, SW Germany.
Manuscript 5, published as co-author in Cracow Landscape Monographs 2016, Issue 2, pages 39-48
First author: Jan J. Ahlrichs
Other co-authors: Jessica Henkner, Karsten Schmidt, Thomas Scholten, Peter Kühn, Thomas Knopf

4 Introduction

Food security has been a recurring issue in the scientific community and among policy makers (Alexandratos, 1999; Blay-Palmer et al., 2016). It also affected societies in the past, as the examples of the Irish Potato famine (Fraser, 2003), the food scarcity in Germany during the Second World War (Buchheim, 2010), the development of Cuban urban agriculture (Altieri et al., 1999), or the famine in Ethiopia in 1999/2000 (Devereux, 2009) illustrate. While there are many reasons for food insecurity, e.g. crop failure (Fraser, 2003) or an uneven access to food due to global trade (Foley et al., 2011), food security heavily depends on agrarian products (Cassman et al., 2003; Funk and Brown, 2009). The cultivation of agricultural foodstuff requires soils, which are suitable for cultivation, a climate in which the crops can successfully be cultivated, tools for cultivation, and the knowledge and management practices related to crop production. The limited resource in this context is soil, because productive soils are not omnipresent, and need to be in climatically favorable areas. Soils, thus, are crucial to provide food security to a growing global population.

Food provisioning is an ecosystem service, as the Millennium Ecosystem Assessment (2005) shows. It defines four ecosystem services: provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment, 2005). These services are linked to human well-being and involve soils, as figure A of the Millennium Ecosystem Assessment (2005) indicates. This mentions nutrient cycling and soil formation as supporting ecosystem services, which are connected to food provisioning (Millennium Ecosystem Assessment, 2005). Soils, thus, contribute to the delivery of various ecosystem services, such as food production, climate regulation, and the conservation of biodiversity, but they are not necessarily represented in studies concerned with ecosystem services (Greiner et al., 2017). An approach which focusses on soil functions exists in the soil science community, which also shows the multifunctionality of soils (Greiner et al., 2017). According to Blum and Eswaran (2004) soils perform six functions, which are the production of biomass, water filtration, preservation of the gene reserve, provision of the physical basis for infrastructure, source of raw materials, and the protection of geogenic and cultural heritage. These functions are also mentioned in a Communication of the EC (2006), where the protection of these functions is stressed for socio-economic and environmental reasons. The socio-economic importance of soils, for example, can be seen in agriculture: Worldwide, farmers use the soils biomass production function (Blum, 2005; Blum and Eswaran, 2004) to fulfil the nutritional needs of society. The environmental impact of agriculture on the soil, on the other hand, can be seen through the impact of fertilizing practices on the soils water filtrations function. While agriculture relies on the biomass production function, it also affects the water filtration function of soils as well as the preservation of the gene reserve. The soils multifunctionality, thus, is influenced by agriculture, which simultaneously depends heavily on theses functions.

Agriculture and with it soil cultivation spread from the Near East to Europe during the Neolithic Transition (Bentley et al., 2003; Pinhasi et al., 2005; Whitehouse and Kirleis, 2014). As the first farmers in Europe settled on the Loess soils (Gerlach et al., 2012; Kadereit et al., 2010; Lüning, 2000), they seem to have chosen fertile soils easy to cultivate for their settlements. Today, the livelihood of societies worldwide still depends on agricultural products (Altieri, 2012; Angus et al., 2009). While farm management is mechanized and motorized (Bakken et al., 2009), soil cultivation remains a main task in agriculture and the farmers rely on the soils biomass production function to obtain a good harvest. However, soil degradation is a major threat to soils (Squire et al., 2015). Soil erosion or soil compaction as well as contamination with heavy metals and other threats are jeopardizing food security. Soil scientists, who are aware of the importance of soils, thus, try to promote soil awareness within society through actions such as the 2015 International Year of Soils (FAO, 2015) or the International Decade of Soils from 2015 to 2024 (IUSS, 2016) to make soils part of the international political and societal agenda. In Germany, the Federal Environmental Agency (Umweltbundesamt) yearly selects a soil type as “soil of the year” (UBA, 2015). This action of the Federal Environmental Agency promotes soils to a wider audience, by addressing new soil types each year and also discussing environmental or social issues connected to the specific soil type.

In 2017, the Hortisols were chosen as “soil of the year” (UBA, 2015). These garden soils are usually found surrounding monasteries or castles, where they give insight into past land management practices (UBA, 2015). They develop through the application of organic material, mixing of the topsoil through digging, and bioturbation (Blume et al., 2010). By choosing the Hortisol as soil of the year 2017, the Federal Environmental Agency addresses the contributions of gardens to the landscape in Germany. Further, gardens provide ecosystem services within settlements (Calvet-Mir et al., 2012; Langemeyer et al., 2016), such as climate regulation and water retention (Cameron et al., 2012), or habitats for flora and fauna (Andersson et al., 2007; Jansson and Polasky, 2010). Gardens might also lead to an increased food security today and in the future (Barthel et al., 2013).

In gardens today, soil is cultivated to produce small food quantities (Kortright and Wakefield, 2011). However, gardening is also seen as a recreational activity (Acton, 2011; Appel et al., 2011), and often has aesthetic purposes (Lindemann-Matthies and Marty, 2013; van den Berg and van Winsum-Westra, 2010). Gardening is practiced globally (Bell et al., 2016; Galluzzi et al., 2010), in backyards (Taylor and Lovell, 2014), in community (Ghose and Pettygrove, 2014) or allotment gardens (Nilsen, 2014), or through guerrilla gardening (Haide et al., 2011). Soil is, thus, not only an important resource for soil scientist and farmers but also for several people in industrialized societies, who use it through gardening. And even people, who do not actively work with soil, rely on its biomass production function to fulfil their nutritional needs.

Understanding the connections between soil and its users is, therefore, relevant for planning institutions, politicians and scientists to raise awareness of environmental issues concerning soils and to increase the acceptance of soil conservation measures.

4.1 ResourceComplex “soil”

The relevance of soil and its use in society has been investigated in the present thesis, applying the framework of the Collaborative Research Centre (SFB 1070) RESOURCECULTURES. The SFB 1070 focuses on the socio-cultural dynamics of resource use, where resources are not separated into “tangible” and “intangible” or “natural” and “cultural” (Bartelheim et al., 2015). Instead, the term ResourceComplex is applied, which comprises a combination of objects, individuals, knowledge and practices (Bartelheim et al., 2015; Hardenberg et al., 2017). ResourceComplexes develop around resources being determined as valuable by a society, and which allow the identification of specific RESOURCECULTURES (Bartelheim et al., 2015). This thesis focuses on the ResourceComplex “soil”, which consists of the central resource soil in combination with the resources plants (crops) to use the soils biomass production function. It further requires knowledge and technology to determine management practices and is influenced by socio-cultural dynamics (Figure 4.1). The concept of ResourceComplexes is applied methodically to investigate which variables are important and to understand connections between soil and society. The central resource or variable in the present thesis is soil, but the other resources constituting the ResourceComplex need to be considered to analyze developments in soil use. All variables of the ResourceComplex interact and influence one another, and should be investigated simultaneously. The concept of ResourceComplexes, thus, is the foundation and structure presented in this thesis.

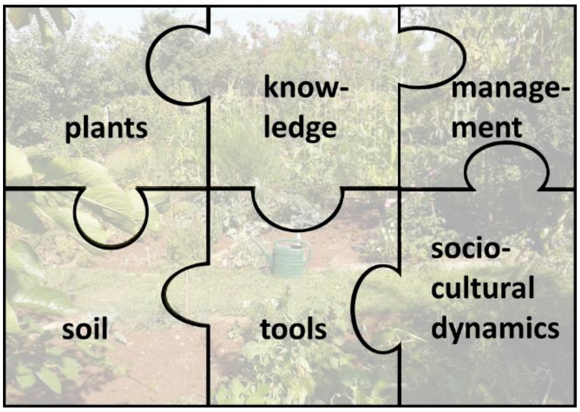

Figure 4.1: The ResourceComplex “soil”

4.2 Social-ecological systems

ResourceComplexes are part of social-ecological systems (SES), which were introduced by Berkes and Folke (1998b). They integrated social and ecological systems during a time, when both were commonly investigated separately, treating the respective other system as a black box and ignoring the interdependence of both systems. The SES approach includes humans in the analysis of ecosystems to understand the relationships between the two systems. It focuses on an adaptive management of the ecosystem, including feedbacks provided by the managing social systems (Berkes and Folke, 1998a, 1998b; Ostrom, 2009). It is one of several approaches to describe systems of humans and nature (Manfredo et al., 2014). Henderson et al. (2016), for example, work with coupled human-environment dynamics in their analysis of the feedbacks in the system forest-grassland-agriculture.

When using the SES-approach, a general terminology is needed for scientists across disciplines. Ostrom (2009), thus, provides a more specific framework for the SES-approach, which consists of the users, the governance system, the resource system and the resource unit. A resource system can refer to a protected park with a specific area, while a resource unit is defined as the objects within the resource system, which would be trees, shrubs and lakes in the park (Ostrom, 2009). The concept of Ostrom (2009) structures the discussion concerning SESs and is helpful for contemporary analyses where the governance system and users can be investigated among others through sociological and ethnological methods. However, for prehistoric and historic times, neither the governance system nor the motivations of the resource user can be thoroughly assessed, due to limited written sources (Teuber et al., 2015; Teuber et al., 2017). The political systems from the Neolithic to the Romans are insufficiently known, and even for Medieval Times the sources concerning governance are scarce. Further, the resource unit as a concept consolidates the separation of natural and social resources. As Ostrom (2009) divides natural and cultural or social variables, the user remains someone outside of the resource units. The SFB 1070 dismisses the distinction between “natural” and “cultural” resources by introducing the ResourceComplex as a concept. In the present study, the variables of the ResourceComplex “soil” structure the investigation of the SES “agriculture”. As knowledge, management practices and socio-cultural dynamics are intrinsic to humans, the resource user is included in the ResourceComplex. However, Ostrom’s resource user is not only part of the ResourceComplex “soil”, but also of several other ResourceComplexes with many different levels and scales. Ostrom’s user, thus, influences the ResourceComplex under investigation from the inside, through knowledge and management practices, but also as an external factor, through participation in other ResourceComplexes, e.g. the ResourceComplex “network”. The interaction of different ResourceComplexes leads to a complex SES (fig. 4.2), where social and natural variables are closely connected. The present study, thus, acknowledges the general concept of Ostrom (2009), for structuring the discussion concerning SESs. However, ResourceComplexes structure the research concerning SESs, to emphasize the close connection between natural and cultural resources.

The application of the ResourceComplex-concept to the SES-approach is also a reaction to the critique of Fabinyi et al. (2014), who state, that the “social” is not adequately defined and biased. Their analysis is that focussing on a functionalist approach, e.g environmental aspects as main reason for conservation efforts, neglects other cultural and socio-political reasons for the emergence of management institutions (Fabinyi et al., 2014). Further, research on SESs often focuses on institutions when investigating the social aspects and not on human agency (Fabinyi et al., 2014). The ResourceComplex concept aims at connecting social and natural resources. The ResourceComplex "soil" includes the soil user in the discussion by focussing on management practices and knowledge of the user concerning the resource. It further acknowledges socio-cultural dynamics, so that institutions are also present in the theoretical construction.

4.3 RESOURCECULTURE "soil use"

RESOURCECULTURES develop around a specific ResourceComplex. In this context, the term culture encompasses contested systems of meaning which are learned and shared as well as negotiated and expressed for example by common language or actions (Hardenberg et al., 2017). The investigated RESOURCECULTURE concerning the ResourceComplex "soil" developed in Germany from the Neolithic transition to today. This includes a time span of several millennia and encompasses several different SESs, which are all connected to the ResourceComplex "soil" (Figure 4.2). Therefore, an SES concerning agrarian soil use from a prehistoric and historic perspective was investigated, namely the SES "agriculture". Further, an SES focusing on contemporary soil use in leisure gardens, the SES "allotment gardening" was studied.

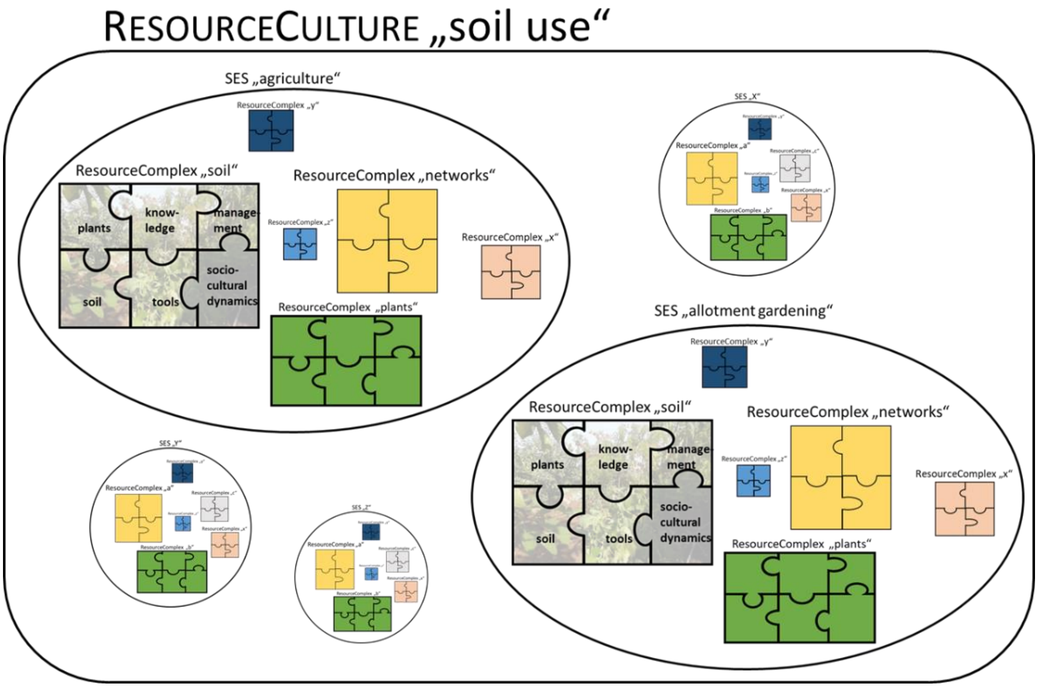

Figure 4.2: The RESOURCECULTURE concerning soil use is shaped by several SES. Each SES consist of several ResourceComplexes, which influence each other.

The investigation of the two SESs connected to the ResourceComplex “soil” aims at identifying a RESOURCECULTURE concerning soil use in Germany. The RESOURCECULTURE is also connected to other SESs, such as the SES “commercial horticulture”, the SES “agrarian technology”, the SES “soil use for infrastructure building”, the SES “environmental protection”, etc. However, the present thesis focuses on the investigations of two SESs, where soil use is connected to the biomass production function of soils. The characteristics of the SES “agrarian technology” are also evaluated in part through the literature review for the SES “agriculture”.

4.4 The ResourceComplex “soil” within the SES “agriculture”

The first part of the thesis focuses on agrarian soil use from the Neolithic to Modern Times. This (pre-) historic approach was chosen to understand the temporal aspects of the human-soil-interaction, because present conditions cannot be evaluated without knowledge of the past (Costanza et al., 2007). Several studies of prehistoric and historic agricultural practices exist focusing on specific (pre-) historic time frames (Knopf et al., 2012; Knopf, 2017; Lüning, 2000; Seidl, 2006) or technological advancements (Andersen et al., 2016; Lal et al., 2007). The present study investigates soil use in form of agriculture through an extensive literature review. It analyses the development of soil use from Neolithic times onwards to study changes of the SES agrarian soil use (Teuber et al., 2017), in the following refered to as SES “agriculture”.

The SES “agriculture” is not static but developed through time. This development is investigated by using the adaptive cycle metaphor (Holling and Gunderson, 2002) and the concept of panarchy (Gunderson, 2008; Gunderson and Holling, 2002; Holling et al., 2002b). Originally developed for ecosystem dynamics, the adaptive cycle metaphor shows that systems undergo four development phases: the r-phase of exploitation, the K-phase of conservation, the Ω-phase of release or creative destruction, and the α-phase of reorganization (Holling et al., 2002a; Holling and Gunderson, 2002). Three properties shape the cycle: the potential of a system for change, the degree of connectedness between internal variables and processes, and the adaptive capacity of a system (Holling, 2001). The adaptive capacity refers to the system’s resilience to unexpected shocks. Resilience is defined as the ability of a system to maintain its functions and remain in the stability domain it is in, despite a disturbance or shock (Holling and Gunderson, 2002).

Holling and Gunderson (2002) state that the process of reorganization starts with the α-phase. Potential and resilience are high. Connectedness is low. In the r-phase resilience is high, while connectedness is low. During the K-phase connectedness increases. Simultaneously resilience decreases. The system becomes vulnerable to disturbance. This vulnerability can cause creative destruction in the Ω-phase, if a disturbance occurs. The system then rapidly shifts from Ω to α. A new cycle begins with loose connections, high resilience and an increasing potential. In this phase different recombination become possible making the outcome of the reorganization unpredictable (Holling and Gunderson, 2002). The SES “agriculture” is undergoing these cycles. However, the adaptive cycle framework consists of different spatial and temporal scales, so that many adaptive cycles happen on smaller scales of the SES. In the time from the Neolithic to today local and regional developments affected the big adaptive cycle of agrarian soil use, e.g. during the Linear Pottery Culture (Gronenborn et al., 2014; Gronenborn et al., 2017). Another example for the application of the adaptive cycles on a smaller scale is the Irish potato famine, which resulted in the replacement or death of many due to a SES that was vulnerable to change (Fraser, 2003).

An important part of the adaptive cycle metaphor is that systems are not seen as static with only one stable state to which the system returns after a disturbance (Holling and Gunderson, 2002). Instead, multi stable states exist. If a disturbance is big enough, the entire system changes and ends up in another stability domain (Holling and Gunderson, 2002). Alternative stable states occur in natural systems and are influenced by human dynamics (Henderson et al., 2016). Whether an SES transforms, depends on the temporal and spatial scales on which changes or adaptations to perturbations or new challenges occur. According to Moore et al. (2014) SESs transform, if there is a recombination of the existing parts of the system in novel ways after a perturbation of the system. Adaptiations of one part of the SES are not sufficient to lead to a transformation (Moore et al., 2014). This is in accordance with Fath et al. (2015), who state, that many small scale adaptive cycles occur in the social parts of an SES during the r- and K-phase of a bigger adaptive cycle. This results in a prolonged K-phase of continued development and influences the interplay between fast and slowly changing variables (Fath et al., 2015). Further, Holling et al. (2002b) suggest, that three to five variables need to be analyzed to understand the complexity of a system. The change of one variable is, therefore, not enough to transform the system. The present work, thus, utilizes the components of the ResourceComplex “soil” to analyze the SES “agriculture”. It is proposed that changes in one variable, such as improvement of tools, do not lead to a transformation. Only when all variables change, the system is reorganized and a new adaptive cycle starts.

Central to the analysis of the adaptive cycle metaphor are technological developments that altered soil use, written records on agricultural practices, palynological analyses and traces of soil management practices that are visible in soil archives today. These represent the soil, plant and tool-aspects of the ResourceComplex “soil” and give insight into the socio-cultural dynamics, knowledge and management practices. The social aspects need to be viewed cautiously, due to limited sources prior to industrialization. The few existing sources are subjected to interpretation by researchers and, thus, ambiguous.

For the reconstruction of the SES “agriculture”, colluvial deposits are of great importance (Dreibrodt et al., 2010) to understand the central variable soil. While the term ‘colluvial deposit’ in the English language refers to slope materials in general, the German definition differentiates between natural and human induced processes (Ad-hoc-Arbeitsgruppe Boden and Bundesanstalt für Geowissenschaften und Rohstoffe, 2005; Leopold and Völkel, 2007). In general, the formation of colluvial deposits depends on soil erosion and accumulation processes (Dreibrodt et al., 2010). The assumption concerning anthropogenic colluvial deposits is that prior to land use in form of agriculture the soil in Central Europe was covered by vegetation and, thus, protected from erosion (Leopold and Völkel, 2007). The onset of agriculture resulted in bare soil, on which erosion occurred. The eroded material is transported down the slope and accumulates in depressions along the slope and at the base of the hill, leading to the formation of colluvial deposits (Lang, 2003). During recurring erosion events the accumulated material is either covered by further deposits or transported further downslope (Lang and Hönscheidt, 1999), where it accumulates again or is eventually transported to the receiving water (Fuchs et al., 2010). Thus, the colluvial deposits within a catchment area are important geoarchives. This thesis focusses on research of colluvial deposits in the context of soil erosion events that were initiated by agrarian soil use to investigate the soil variable of the ResourceComplex “soil”.

4.5 The ResourceComplex “soil” in the contemporary SES “allotment gardening”

In urban societies the soils biomass production function (Blum and Eswaran, 2004) is used frequently in miscellaneous forms of urban gardening, such as allotment gardens, community gardens or intercultural gardens (Barthel et al., 2013; Barthel and Isendahl, 2013; Müller, 2011; Tornaghi, 2014). Further, urban gardening is becoming increasingly popular in many cities worldwide (Alaimo et al., 2008; Barthel et al., 2014; Bell et al., 2016). The gardening community, thus, consists of home gardeners, allotment gardeners but also of people who garden on rooftops, in community and intercultural gardens. Some garden in pots and raised beds, where they manufacture the soil they cultivate according to the needs of the plants. Home- and allotment gardeners, however, work with the soil present on their land. They, thus, also have knowledge about the soils biomass production function and the soil-plant interaction. Therefore, the focus of the empirical part of the present study is on allotment gardens in southwestern Germany.

Allotment gardens developed during industrialization, the Great Depression and the World Wars to provide workers with plots for food production and recreation (Keshavarz and Bell, 2016; Nilsen, 2014). Initially seen as self-help measures (Nilsen, 2014), allotment garden associations (= Kleingartenvereine) are still common in many German cities and towns today, with 934 285 gardeners being member in the allotment garden association “Bundesverband Deutscher Gartenfreunde e.V.” (Bundesverband Deutscher Gartenfreunde e.V., 2017). This association has several rules and the federal law concerning allotment gardens (= “Bundeskleingartengesetz”) applies to all allotment gardeners (Bundesministerium der Justiz und für Verbraucherschutz, 1983). The law, a court order concerning the law, and the statute of the association state, that a third of the gardening area within an allotment must be used for food production (Bundesgerichtshof, 2004; Bundesministerium der Justiz und für Verbraucherschutz, 1983). The biomass production function of the soil is, therefore, important in the allotment gardening community. The gardeners need to cultivate the soil on a regular basis. Therefore, the ResourceComplex “soil” and its relevance for the SES “allotment gardening” is investigated. The ResourceComplex “soil” consists of the soil in the garden, the plants and tools used by the gardeners, the management practices and knowledge of the gardeners, and the socio-cultural dynamics within the gardening community but also between the gardening community and society in general (Figure 4.1).

The critique of Fabinyi et al. (2014) - the focus on institutions - is met with the ResourceComplex concept. In the SES “allotment gardening”, the ResourceComplex “soil” includes the gardener by focusing on management practices and knowledge. It also takes the institutions into account by investigating the rules of the allotment garden association and the laws concerning allotment gardening in Germany. It has to be stressed, that other ResourceComplexes are present in the SES “allotment gardening”, e.g. the ResourceComplex “networks” with the variables being the different gardeners, the management board of the garden, the institutions, and the infrastructure.

5 Objectives

This thesis seeks to investigate the ResourceComplex "soil" and its development through time. It applies the framework of the SFB 1070 to the research to define a RESOURCECULTURE concerned with soil use for Germany. A RESOURCECULTURE is a contested system of meaning (Hardenberg et al., 2017), with commonly learned and shared actions and language. The RESOURCECULTURE connected to soil use consists of the SES "agriculture" and the SES "allotment gardening". These two investigated SESs focus on the biomass production function of soil. With the time scale being several millennia, the analysis focuses on common features throughout time, which are the variables soil, plants, tools, knowledge, management practices and socio-cultural dynamics of the ResourceComplex "soil" (Figure 4.1). The definition of a RESOURCECULTURE relies on the SES "agriculture" and the SES "allotment gardening" with the study area being Central Europe, and more specifically Germany. The study focuses on the objectives:

i) How did the variables of the ResourceComplex "soil" change from the Neolithic Transition to today?

ii) What are the characteristics of the ResourceComplex "soil" today?

iii) Is it possible to define a RESOURCECULTURE concerning soil?

It is hypothesized, that the ResourceComplex "soil" developed through time and underwent several changes. The changes to the different variables of the ResourceComplex are observable in different archives and allow a reconstruction of the development of the ResourceComplex.

It is further hypothesized, that the ResourceComplex "soil" is important for farmers and other soil users such as gardeners, who have a profound understanding of the ResourceComplex itself. In the two investigated SESs the ResourceComplex has specific characteristics.

It is also hypothesized, that a RESOURCECULTURE exists, which is closely related to the ResourceComplex "soil" and its biomass production function.

6 Methodology

Several methods were used to analyze the ResourceComplex “soil” within the SES “agriculture” and the SES “allotment gardening”. The study area for both the (pre-) historic perspective and the present-day empirical study is Central Europe. However, the study area for the latter is limited to the southwestern part of Germany, to the state of Baden-Wurttemberg.

6.1 SES “agriculture” (Manuscript 1, 2, 4, 5)

For the prehistoric and historic perspective a literature review was conducted, focusing on Central European studies concerned with colluvial deposits, palynology, and archaeological surveys where agrarian tools and practices were investigated (Teuber et al., 2015; Teuber et al., 2017). Further, literature on several agricultural writers from Antiquity to today was investigated. These studies were analyzed using the SES-approach. The analysis focuses on the SES “agriculture” (Teuber et al., 2017) and on the ResourceComplex “soil” with its variables soil, plants, knowledge/technology. The development of the SES “agriculture” is evaluated with the help of the adaptive cycle narrative (Holling et al., 2002a; Holling and Gunderson, 2002).

Archaeopedological studies contribute to the understanding of the central resource soil. The focus is on anthropogenic colluvial deposits, which are analyzed soil scientifically.

Palynological and archaeobotanical research is used to understand the plant-aspect of the ResourceComplex “soil”. The crops cultivated in Europe mainly originated in the Near East and include emmer, einkorn, barley, pea and flax, which arrived in Central Europe during Neolithization (Bakels, 2014). Several studies were used to investigate the distribution of the different crop plants in the proximity of anthropogenic colluvial deposits (Dreslerová et al., 2013; Rösch, 1993, 1998, 2009; Schmidl et al., 2007), to determine changes of the plant-variable of the ResourceComplex “soil”.

Archaeological studies contribute to the understanding of the technological development in time, which is helpful for the analysis of the tool-variable of the ResourceComplex “soil”. Archaeological evidence for agrarian tools is scarce for pre-historic times, but several studies investigated the technological development (Andersen et al., 2016; Gringmuth-Dallmer, 2003; Lal et al., 2007; Mueller, 2015; Roggisch, 1989; Schultz-Klinken, 1981). The tools are also used as a proxy for changing management practices and changing knowledge. While a digging stick or spade requires a lot of work from the farmer, the development of the ard and later the plow in combination with the use of animals such as the ox and later the horse for pulling the ard or plow indicates changing management practices (Teuber et al., 2017). The ard and plow enabled the farmer to expand the area for crop cultivation. Those tools, further, facilitated farming on loamy to clayey soils, which are difficult to cultivate by relying only on a spade.

Management practices and knowledge as well as socio-cultural dynamics have been investigated through interpretation of the few written sources that exist for historic times up to the Modern Era. With Antiquity, the first written sources on agricultural practices appear in S-

Europe, which are copied during medieval times and contribute to our understanding of soil use in the past (Winiwarter, 2006). From the 19th century onwards, scientists, who are concerned with agriculture (Liebig, 1841; Thaer, 1880) but also with soils (Darwin, 1890; Evtuhov, 2006), further added to our understanding of soil use in history during the respective periods. However, since there are few or no written records of small-scale farmers or farm workers, the writings only give an insight into management practices and knowledge about soil. They do not portrait actual valuations of the past societies, since only a small percentage of people living in those societies contributed to the written sources. Further, the writers' intentions are not clearly known to present-day scientists, so that all texts are subject to interpretation. With the invention of the letter-press and due to the division of labor during industrialization, the sources of information increase. The abundant written sources from the 1950s onward enable a clearer interpretation of the variables knowledge, management practices and socio-cultural dynamics. The number of written sources and the diversity of opinions in the last decades enable a more complex analysis of the ResourceComplex "soil" and its role within the SES "agriculture" and the contribution of the different variables to the adaptive cycle.

The study region is rather large due to the limited sources for pre-historic and historic periods. Archaeological findings are not evenly distributed in Europe, so that the reconstruction of agrarian soil use requires findings from several parts of Central Europe. Most studies are from the area of present-day Germany. However, studies from the Alpine regions in the South to the Baltic region in the North were also considered to understand the development of the SES "agriculture". The western and eastern boundaries are Central France and Central Poland/Czech Republic.

The literature review was complemented by an archaeopedological study in the Baar region, which was part of the SFB 1070 project B02. In this project, archaeologists and soil scientists investigated the soil and culture dynamics of the Baar region from Neolithic times onwards. Besides recording archaeological sites and finds (Ahlrichs et al., 2016), colluvial deposits were investigated soil scientifically (Henkner et al., 2017). The colluvial deposits are analyzed to reconstruct past land use dynamics. Four sites in the Baar region were chosen for the analysis of colluvial deposits. The soil profiles were described in the field according to the German classification system KA 5 (Ad-hoc-Arbeitsgruppe Boden and Bundesanstalt für Geowissenschaften und Rohstoffe, 2005), and soil samples were taken. Analysis of the samples took place in the Laboratory of Soil Science and Geoecology of the University of Tübingen, and included the measurement of pH-values, Carbonate content, total C and N contents, and the grain size distribution (Henkner et al., 2017). The deposition time can be investigated using optical stimulated luminescence (OSL) dating, and accelerator mass spectrometry (AMS) ^{14}C radiocarbon dating. Therefore, samples for OSL were obtain with opaque steel cylinders, and charcoal fragments were collected in the field for AMS ^{14}C radiocarbon dating (Henkner et al., 2017). The dated samples provide a stratigraphy that enables a reconstruction of past land use.

6.2 SES "allotment gardening" (Manuscript 3)

The concept of ResourceComplexes was used as a tool while designing the contemporary empirical study and composing the questionnaire. After visiting several gardens and reading gardening literature, the crop variable was chosen as a constant. The most common food plants in the allotment gardening community are potato, onion, carrot, tomato, zucchini, kohlrabi, eggplant, cauliflower, broccoli, cabbage, salad, strawberry, currant, raspberry, blackberry, apple, pear, cherry, and different herbs such as basil, parsley, and chive. The gardening tools are also seen as a constant, with the most common tool being the spade, but also garden forks, hoes, and motorized garden tillers. The soil knowledge as well as the management practices were investigated using a questionnaire. The socio-cultural dynamics were studied using the framework of the allotment gardening association, the federal laws concerning allotment gardening, the information from the interviews with the gardeners, and newspaper articles. The central resource soil was investigated using soil scientific analyses but was also the focus of the questions in the questionnaire and during the interviews.

The study of the SES "allotment gardening" took place in the Baar region and in the state capital of Baden-Wurttemberg, Stuttgart, with the aim of comparing rural and urban allotment gardeners (= Kleingärtner) with each other. Both study areas belong to Baden-Wurttemberg and have a similar natural environment (Teuber et al.). Further, school systems as well as social factors are similar in both regions, so that a comparison between them is possible. The rural region chosen for the interviews was the Black Forest-Baar-Heuberg region with its center Villingen-Schwenningen (VS, Figure 5.1). This region was chosen due to the close cooperation with the SFB 1070 project B02 that also had a study area there. The closest urban area to the original study area is Stuttgart (S, Figure 5.2). This was chosen as the second region to compare allotment gardens from urban and rural contexts (Teuber et al.). In both regions, three allotment garden associations were investigated.

Field work took place in 2015 and 2016 after an in-depth literature research concerning the history of allotment gardens, allotment garden associations, urban gardening, community gardening, and garden management practices, as well as questionnaire design and methodology. This resulted in the development of a questionnaire that consisted of open questions, which were evaluated qualitatively, closed questions that were evaluated quantitatively, and semi-open questions, which were evaluated using quantitative and qualitative instruments (Teuber et al.). The questionnaire investigated several topics: the gardeners' knowledge about soils, the gardeners' motivation for gardening, the garden management practices of the respective gardener, the criteria used by gardeners to determine the soil quality in their plots, and the management practices concerning soil quality. The answer categories were chosen according to the results of previous studies (Adderley et al., 2004; Barrera-Bassols et al., 2009; Fry, 2000; Wahlhütter, 2011). Reasons for gardening were investigated by others as well, but most of the studies were published after or during the first survey year, so that they could not be considered during questionnaire design (Calvet-Mir et al., 2016; Scheromm, 2015). Only Clayton (2007) and Kim et al. (2014) provided input on possible motivations for gardening or gardeners knowledge of soils. Besides these topics, the usual questions concerning age, gender, educational background, etc. were asked. The questionnaire was interviewer administered. The interviews took place in the respective association, more precisely in the individual gardens. Within each association, the aim was to interview gardeners from each plot. However, not everyone was willing to participate, and in several garden plots, the gardeners were absent. Repeated visits on different days and times did not result in meeting these gardeners. Thus, approximately 30 % of the gardeners of each association were interviewed. This is in accordance with the questionnaire literature, which states that response rates are often below 50% (Baruch and Holtom, 2008; Porst, 2001), e.g. the study of Goddard et al. (2013) had a response rate of 24%. The results of the interviewer-administered questionnaires were analyzed using the statistical programming language R (R Core Team, 2016). Several tests were used, according to the respective measurement of scale (Teuber et al.). The chosen significance level is $\alpha = 0.05$ for all tests. The null hypothesis H0 is $\mu1 = \mu2$, in other words $\mu1 - \mu2 = 0$ (Bortz and Schuster, 2010). Thus, the alternative hypothesis H1 is $\mu1 \neq \mu2$ or $\mu1 - \mu2 \neq 0$. If $p < \alpha$, the H0 is rejected and H1 accepted. The two sample t-test (R Core Team, 2016) is used for ratio scale data. Since the variance has to be equal to use the test, a Fisher F test (R Core Team, 2016) is performed prior to the t-test. If the variance is not equal, Welch's t-test (R Core Team, 2016) is used. The nonparametric independent 2-group Mann Whitney U test (R Core Team, 2016) is used for ordinal scale data and ratio scale data for which a normal distribution cannot be assumed. Fisher's exact test is used for categorical data. The open and semi-open questions are evaluated qualitatively by analyzing the field notes and pictures taken (Teuber et al.).

Figure 6.1: The surveyed allotment garden areas in rural VS.

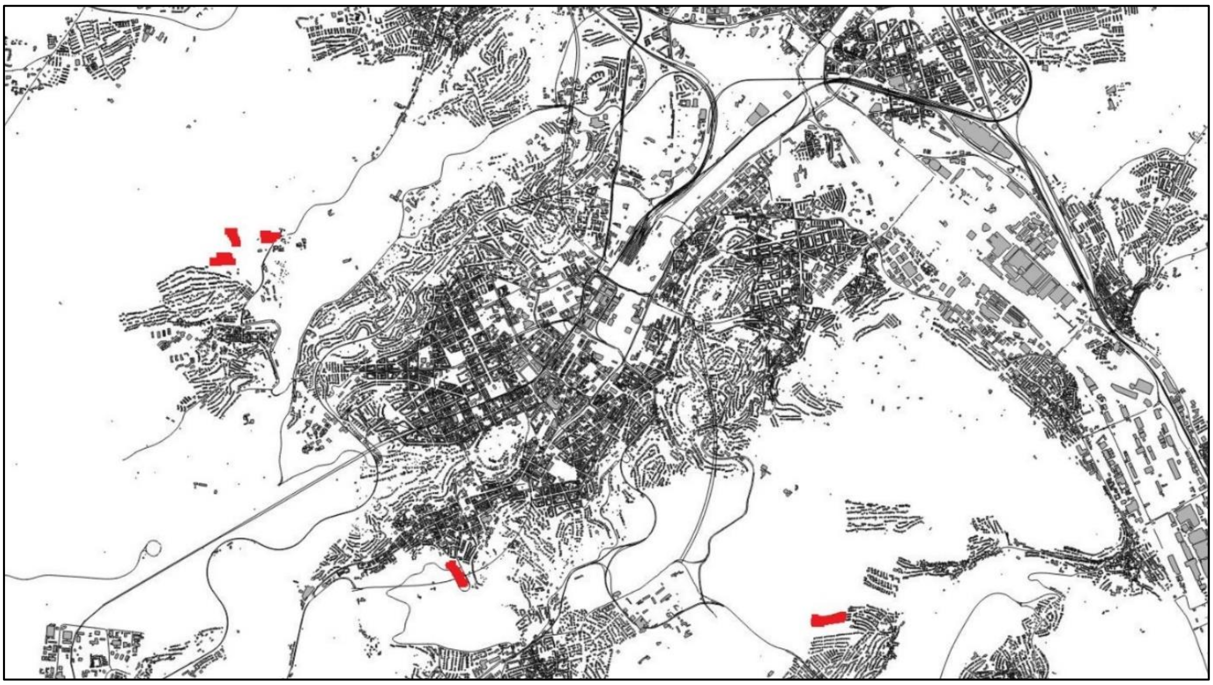

Figure 6.2: The surveyed allotment garden areas in urban S

In each allotment garden association, three soil samples were taken from unused green spaces, at depths of 0-10 cm and 10-20 cm, which were analyzed in the Laboratory of Soil Science and Geoecology of the University Tubingen. Analyses included pH-values, C/N-ratio and grain size distribution (Teuber et al.). The decision to sample from unused green spaces was made after observations and interviews had shown diverse management practices. Therefore, the unused soil was sampled to get the conditions of the soil prior to soil management practices, which include different fertilizing practices. According to the management board of each association, the official activity on the green spaces had been lawn mowing. However, the possibility exists, that gardeners distributed excess fertilizer or other soil amendments on the green space.

7 Results

7.1 The changing variables of the ResourceComplex “soil” in the SES “agriculture” (Manuscript 1, 2, 4, 5)

The adaptive cycle of the SES “agriculture” started with the Neolithic transition and went through one adaptive cycle from the Neolithic Transition to the Industrial Revolution (Teuber et al., 2017). The Neolithic Transition enabled people to settle down, using soil, new crops and new tools, thus, the ResourceComplex “soil”, to produce higher food quantities (Childe, 1936; Holling et al., 2002b). The SES “agriculture” underwent several minor changes from the Neolithic to the Industrial Revolution. Innovations such as metallurgy improved agrarian tools, which are one variable of the ResourceComplex “soil”. However, the changes were adaptations to one part of the ResourceComplex, which influenced the SES, but did not flip it into another stable state (Teuber et al., 2017). A second adaptive cycle started with the Industrial Revolution (Teuber et al., 2017). Industrialization affected the SES “agriculture” and the ResourceComplex “soil”. It led to a new adaptive cycle, with a reorganization of the variables of the ResourceComplex “soil”, and a transformation of the SES into another stability domain. This includes a clear division of labor and the industrialization of agricultural practices.

With the Neolithic Transition, the soil variable of the SES “agriculture” became important for the first farmers. The soil management practices, however, had an adverse effect on the soil, because it led to erosion on many agricultural fields throughout the first adaptive cycle. The resulting anthropogenic colluvial deposits are used to reconstruct the development of the SES “agriculture” (Teuber et al., 2015; Teuber et al., 2017). While anthropogenic colluvial deposits dating to the early periods of agrarian soil use are infrequently found (Dotterweich, 2008), other archives indicate agrarian soil use and subsequent erosion in Central Europe for that time (Dreibrodt et al., 2010). Further, the archaeopedological study in the Baar region found traces of agrarian soil use dating to the Neolithic (Henkner et al., 2017). The summed probability curve of the Baar region’s colluvial deposits indicate increased erosion during the Bronze and Iron Age, as well as in Modern Times (Henkner et al., 2017). This is in accordance with the findings of Dreibrodt et al. (2010), who state, that a first maximum of slope deposits in Central Europe occurred at the beginning of the Bronze Age, and a second one during Iron Age. However, they found a maximum during medieval times (Dreibrodt et al., 2010), which is present but not as pronounced in the Baar region (Henkner et al., 2017). Erosion and, thus, colluviation increased during Medieval Times (Zolitschka et al., 2003). Examples for colluvial deposits from SW-Germany include the Kraichgau where anthropogenic colluvial deposits date to 980–1330 CE (Kadereit et al., 2010), the Krumpenschloß in the Black Forest with anthropogenic colluvium developing between the ninth and 15th century CE (Knopf et al., 2012), and the case study of B02 (Ahlrichs et al., 2016; Henkner et al., 2017). The soil variable, thus, became increasingly prone to erosion.

The first written sources on agricultural practices in Europe date to Antiquity. They deal with the different variables of the ResourceComplex “soil”, e.g. Hesiod („Érga kaì hemérai“), Cato („De agri cultura“), Varro („Res rusticae“) and Columella („De re rustica“) (quoted from Winiwarter (2006)). The agrarian texts from European Antiquity show that the ResouceComplex “soil” and the variable soil were of interest for the scholars. The texts of the Roman agricultural writers were still copied in Medieval Times. Furthermore, Walafrid Strabo and Isidore of Seville contributed to the agrarian or horticultural literature (Winiwarter, 2006). While scholars wanted to improve or conserve the knowledge of agricultural practices, traditional soil cultivation practices were common (Dotterweich, 2013). During Medieval Times fertilization was part of agriculture (Behre, 2000). In Northern Europe, plaggen-manuring was practiced, and ridge and furrow was prevalent (Behre, 1976; Blume and Leinweber, 2004; Haasis-Berner, 2012; van Mourik et al., 2012). Furthermore, the three field system with fallow became common (Rösch et al., 1992). The soil fertility was, thus, important for the farmers and they tried to improve it through different measures.
The scientific analysis of soils increased during the 19th century, with the books of Albrecht Daniel Thaer, Justus von Liebig, Charles Darwin and Vasilii V. Dokuchaev (Darwin, 1890; Liebig, 1841; Thaer, 1880). Focus of Thaer’s work was agriculture and the relevance of crop rotation and humus (Feller et al., 2003b). Liebig worked on the development of a mineral fertilizer (Montgomery, 2010). Darwin investigated the importance of earthworms (Brevik and Hartemink, 2010; Brown et al., 2003; Feller et al., 2003a; Feller et al., 2006). Dokuchaev introduced the soil profile with its A-, B-, and C-horizons (Brevik and Hartemink, 2010; Evtuhov, 2006). The ResourceComplex “soil” had become a research topic (Teuber et al., 2017).

The crop variable is visible through research in archaeobotany, palynology and anthracology (Marquer et al., 2014; Nelle et al., 2010; Rösch, 1987). With Linear Pottery and Funnel Beaker Culture, six of the crops domesticated in the Near East arrived in Europe, where poppy was added as another crop plant (Bakels, 2014). Domesticated animals were also held in Central Europe (Doppler et al., 2015). Both, the plants cultivated and the animals used for food production relied on a small number of species (Bellwood and Oxenham, 2008). Different studies show, that crops are used in different proportions through time, but that the main crops are emmer, einkorn, wheat and barley (Bogaard et al., 2013; Dreßler et al., 2006; Rösch, 1993, 1998; Wieckowska et al., 2012). Only rye cultivation seems to occur later, during Medieval Times (Behre, 1992).

During the first adaptive cycle, the tools variable developed from the spade to the ard to the plow (Teuber et al., 2017). An excavation of an LBK well in Erkelenz-Kückhoven, near Cologne, revealed a spade dating to 5057 BCE (Mueller, 2015). New methods and tools developed during Bronze age, as plow marks in the soil, excavated ards at the Lago di Ledro, Northern Italy and in Walle, East Frisia, as well as rock carvings in Val Camonica, Northern Italy, and Boshuslän, Sweden, show (Behre, 1998; Egg and Pare, 1995; Fries, 1995; Schultz-Klinken, 1981; Tegtmeier, 1993; Zich, 1999). Further, cattle traction was established for pulling the ard or carts (Bartosiewicz 2013, Eggert and Samida 2013), e.g. facilitating soil cultivation. Agricultural technology developed during Roman times, e.g. the use of iron in spades (Mueller, 2015) or the "Roman plow" with iron shares (Lal et al., 2007).

The changes of the variables soil, crops, and tools, show, that the first adaptive cycle had a prolonged K-phase, due to innovations happening within or to other ResourceComplexes. Through the development of the ResourceComplex "metallurgy", which consists of the variables ore deposits, smelting furnaces, knowledge, tools, and processing procedure, new tools for soil cultivation were created. These enabled the farmers to cultivate more area in a shorter time, e.g. during the Roman Iron age with iron plow shares. However, while plowing was facilitated, the management practice of plowing depended on man and animal power. Animals, further, were not only needed for traction but also as a source for fertilizer. Fertilizing is an integral part of agrarian practices in the Medieval Time period, as discussed by Behre (2000). While fertilizing might have occurred earlier, as proposed by Bakels (1997), we find traces of fertilizing practices that date back to Medieval Times. The plaggen soils indicate that soil fertility was important. The farmers invested time and energy in these practices to achieve higher yields. This changes the knowledge and management variables, which in turn affects the soil. However, only when changes in all variables are observable, does the SES change its stability domain and a second adaptive cycle starts.

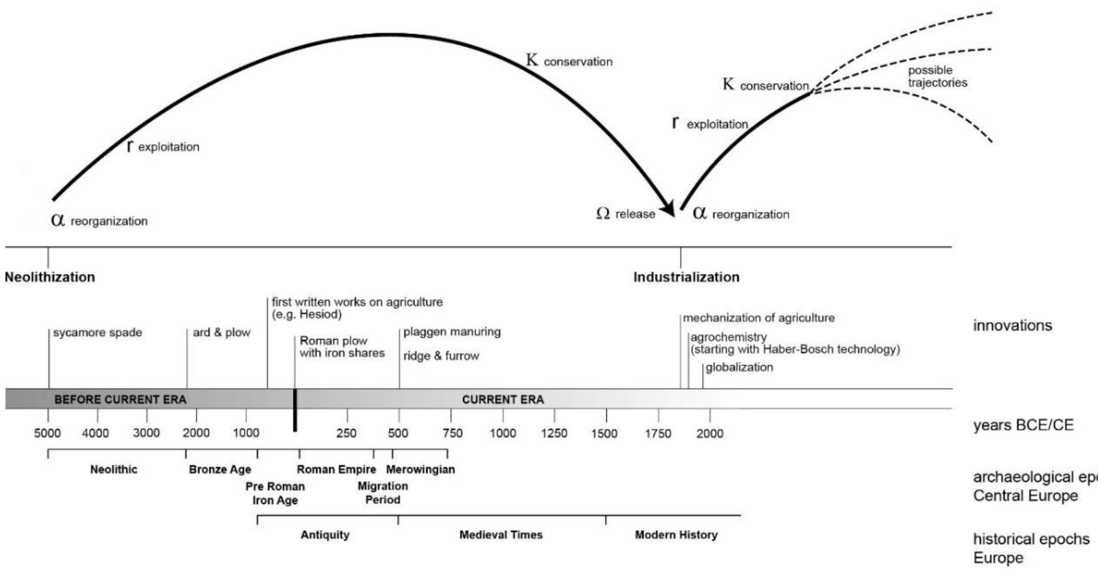

Figure 7.1: The adaptive cycle of the SES „agriculture" starting with Neolithization (Teuber et al., 2017).

The SES "agriculture" and the ResourceComplex "soil" changed considerably with industrialization (Teuber et al., 2015; Teuber et al., 2017). It moved through the Ω-phase of creative destruction and the α-phase of reorganization (Teuber et al., 2017). The variable knowledge and technology changed. New technological advances resulted in modern machines for soil cultivation (Hahn, 2011; Lal et al., 2007; Seidl, 2006) or for the industrialized production of fertilizer (Montgomery, 2010; Niedertscheider et al., 2014). Both enabled a separation of crop production and livestock farming (Lambin et al., 2001). The widespread use of fertilizer, pesticides, herbicides and fungicides increases the yields (Foley et al., 2005; Ponti et al., 2012), but also affects biodiversity (Benton et al., 2003; Henle et al., 2008) and leads to eutrophication of water bodies (Larsson and Granstedt, 2010; Monteagudo et al., 2012). The innovations also led to considerable changes of and within society. In Germany, fewer people work in the agrarian sector, because the industry and service sector employ most people (Statistisches Bundesamt, 2015b). While in 1950, 24.6% of the German population worked in agriculture (Statistisches Bundesamt, 2017), in 2014 only 1.5% of the workforce belonged to the agrarian sector (Statistisches Bundesamt, 2015b). These farmers retain agrarian soil knowledge, preserve traditional agrarian soil management practices and combine or substitute them with modern knowledge and practices. Further, through globalization, agricultural production is externalized to other countries, such as the soy bean production for livestock feed in S-America (Gollnow and Lakes, 2014; Morton et al., 2006). The remaining farms in Germany are managed by fewer people using industrialized methods for livestock and soil cultivation (Lal et al., 2007; Statistisches Bundesamt, 2015a; Vigne et al., 2012). The knowledge of soil use, which was present within society for most of human history, thus, is retained by few, especially by farmers practicing organic farming and by other people who are in direct and regular contact with the soil, such as gardeners.

The variable soil is still prone to erosion (Dotterweich, 2013; Verheijen et al., 2009) but also to other forms of degradation such as compaction (Hamza and Anderson, 2005; O'Sullivan and Simota, 1995), sealing (Artmann, 2016; Scalenghe and Marsan, 2009), nutrient depletion (Loveland and Webb, 2003), and contamination with e.g. heavy metals (Ottesen et al., 2013; Reimann et al., 2012).

The variable crops changed with the introduction of genetically modified organisms (Burachik, 2010; König et al., 2004; Rótolo et al., 2015). Furthermore, society depends on fewer crop plants (Cassman et al., 2003; Godfray et al., 2010; Kearney, 2010).

Currently, the SES "agriculture" is in its second K-phase (Teuber et al., 2017): Most of agricultural practices in industrialized countries but also in the developing world relies on heavy machinery, mineral fertilizers and the common crop plants. Soil degradation is omnipresent, not only in form of soil erosion but also through compaction, nutrient depletion, contamination, and sealing.

7.2 Characteristics of the ResourceComplex "soil" in the contemporary SES "allotment gardening" (Manuscript 3)

The investigation of the SES "allotment gardening" also relied on the ResourceComplex "soil". The variables socio-cultural dynamics, management practices and knowledge were investigated, at least in part, through a literature review. The literature review concerning allotment gardening included the federal law concerning allotment gardens (Bundeskleingartengesetz) as well as the written records of the allotment garden associations (Bundesverband Deutscher Gartenfreunde e.V., Landesverband der Gartenfreunde Baden-Württemberg e.V.), and information gained through interviews with the spokesperson of each of the 6 surveyed associations. The German federal law states specifically, that one of the main functions of the allotment gardens is food production with recreation as an additional function (Bundesministerium der Justiz und für Verbraucherschutz, 1983). Further, an allotment garden has to be within an area with other gardens in order to qualify as an allotment garden (= Kleingarten). The individual allotment is ≤400 m², the cabin has at most 24 m² and is not suited for permanent residence (Bundesministerium der Justiz und für Verbraucherschutz, 1983). The Bundesgerichtshof further specified the definition of the use of allotment (= kleingärtnerische Nutzung) and stated that a third of the area has to be dedicated to food production (Bundesgerichtshof, 2004). The Bundesverband Deutscher Gartenfreunde e. V. discussed this topic in one of their publications with focus on the legal aspects (Bundesverband Deutscher Gartenfreunde e.V., 2004). In all six surveyed associations, the spokespersons and the other members of the boards explained the requirement to use a third of the garden area for food production. However, there are differences in the enforcement of this rule. In several of the surveyed associations, the board visits the separate gardens repeatedly during the year, to ensure that the area for food production is big enough. There, the different areas are exactly measured. During one of the visits to a garden area, an observation was made, where the board counted not only the concrete slabs of the walkway but also the cabbage heads to ensure the right relation between food related plants and build-up area. In other associations, the board was less strict. There, the visits to the respective allotments happen once a year. If a gardener refuses to abide to the rules, the board will issue a warning. However, there seemed to be no hard consequences to the warning. As an example, in one of the visited gardens, the plots were not cultivated. The bare soil was only vegetated by an occasional weed. The plot remained in this condition throughout the garden year. The differences between the associations can be explained by looking at the options the board has in dealing with a non-cooperative gardener. The only possibility to enforce the rules is to terminate the contract with an individual gardener. If there is a waiting list for the allotments, this might be done, because a new gardener will be able to take over. However, in some areas, the board has no one on the waiting list for a garden. Terminating a contract in

that case is unlikely, because this would mean a deficit in the accounting department of the association.
The Gartenfreunde agree to garden environmentally friendly, as internet sources suggest and the individual board members state. A sustainable use of soil, water, air, animals and plants is emphasized in S (Bezirksverband der Gartenfreunde Stuttgart e.V., 2016). Chemical fertilizers are not allowed. Instead, compost and green manure should be used. Peat should be avoided to protect the environment (Bezirksverband der Gartenfreunde Stuttgart e.V., 2016). The board members of the different associations visited during the study also stressed, that fertilizing should be done environmentally friendly. NPK-fertilizers should not be used. Instead, a diverse set of management practices is suggested to the gardeners. However, one of the board members stated, that this cannot be checked because individual gardeners find very clever ways to hide the fact that they use NPK-fertilizer. Other board members also hinted that the gardeners might bypass this rule. Still, the board members in general see it as their responsibility, to promote environmentally friendly gardening. While the priorities are different, e.g. compost production or bee friendly gardens, the notion is present that the allotment garden association is acting sustainably. This is present in everyday life through courses on raised bed gardening and tree pruning. Further, manuals concerning compost production exist.

The empirical part of this thesis investigated allotment gardeners' motivations, management practices and soil knowledge in SW-Germany, and, thus, the variables management practices and knowledge, as well as the socio-cultural dynamics, at least in part. A total of 167 respondents participated, of which 71 were female and 96 were male. Most of the respondents in urban S and rural VS are retired or do not work (Teuber et al.). At least half of the respondents in both regions finished a secondary school (Teuber et al.). The motivations for gardening vary between the two regions (Teuber et al.), with parents or grandparents owning a garden and the provisioning with own fruit and vegetables as well as relaxation as main motivations to choose allotment gardening as a leisure activity (Table 7.1).

Tab. 7.1: Motivations for allotment gardening

	% S	% VS
Family tradition ($p = 0.002$)	54,6	78,6
Own fruit/vegetables ($p = 0.01$)	45,4	67,1
Relaxation ($p < 0.001$)	30,9	71,4
Friends ($p = 0.001$)	6,2	24,3
Creativity ($p= 0.01$)	4,1	17,1
Media ($p = 0.16$)	1,0	5,7
School ($p = 0.17$)	0,0	2,9
Other	89,7	74,3

89.7 % in S and 74.3 % in VS gave other motivations, such as getting out and enjoying nature, a personal history with garden or agriculture, the garden as a place for children or grandchildren, gardening as an activity for retirement or unemployment, and gardening to have a sense of community (Teuber et al.). Family tradition and own fruit and vegetables are more important in rural VS. However, in both regions many respondents stated that they had recreational reasons for choosing gardening as a leisure time activity (Teuber et al.).

The garden management practices were also similar, except for digging and pest control, which are of varying importance in the two regions (Teuber et al.). Digging is a yearly activity for 79.4 % in S and 82.9 % in VS. However, 15.5 % in S and 5.7 % in VS do not dig. Thus, most gardeners dig on a yearly basis. However, the no-digging approach, originating from no-tillage in agriculture, is more common in S. In both regions, some of the gardeners who apply the no-dig approach use raised beds instead, while others still work on a regular plot but stopped digging and use green manure or a gardening fork to loosen up the soil. Pest control is a yearly activity for 21.6 % in S and 2.9 % in VS, while 12.4 % in S and 57.1 % in VS do some pest control on a weekly basis. Pest control is more important in rural VS than in urban S (Teuber et al.). It includes several actions against snails or aphids: collecting snails off the plot, protecting plants through straw or sand usage or applying slug pellets, among others.

Soil knowledge and soil quality assessment were also part of the questionnaire. 57.7 % in S and 70 % in VS state that “I know different soils” applies to them. “I know the term soil erosion” applies to 68 % in S and 50 % in VS. There is a statistical difference between the two regions for the last statement (Teuber et al.). The statement “I’m able to assess whether the soil is good for the plants I want to grow” applies to 54.6 % in S and 45.7 % in VS. 78.4 % in S and 78.6 % in VS gave different soil properties for soil quality assessment rather than using the categories given in the questionnaire, which included soil color (17.5 % in S, 21.4 % in VS), vegetation present (32 % in S, 14.3 % in VS), and workability (23.7 % in S, 37.1 % in VS) (Teuber et al.). 59.2 % in S and 58.2 % in VS use soil texture for their soil quality assessment. 30.3 % in S and 25.5 % in VS figure out which plants grow through a trial and error approach. In both regions, 20 % stated that the soil management resulted in a good soil. Only 6.58 % in S and 7.27 % in VS assess the soil quality through scientific soil sampling (Teuber et al.).

The gardeners have several conservation measures to ensure a good soil quality or to improve the soils further. In VS, soil conservation measures were discussed in the qualitative last question, where 52.9 % of the gardeners wanted to talk about soil management more thoroughly as the original questionnaire intended. The results show, that 19 gardeners mentioned compost, 10 green manure, 9 manure from horses, cows or pigeons, 5 gardeners stressed the importance of loosening up the soil with a garden fork. In the urban area, all 97 gardeners were asked specifically about their soil conservation measures: 79.4 % use compost, 29.9 % loosen up the soil regularly, 16.5 % apply manure from a farmer, 5.2 % use green manure. Other measures of the urban gardeners to conserve soil quality include the use of horn meal or shavings (26.8 %), sand (20.6%), chemical fertilizer (19.6 %, at least from time to time), potting soil (16.5 %), organic fertilizer (11.3 %), Brennesseljauche (8.2 %), dig to ensure the soil quality (7.2 %), stone meal (6.2 %), crop rotation (6.2 %), chalk (5.2 %), egg shells (4.1 %), and coffee grounds (3.1 %). Several measures were only stated by one or two respondents. Two people stated that they mulch, build terraces, or distribute guano or ash, respectively. Single mentioned were the measures Bokashi, banana peel, malt pellet, raised bed, and peat.

The empirical study in SW-German allotment gardens showed that the ResourceComplex “soil” with its central resource soil is of great importance to the gardeners (Teuber et al.). The qualitative interviews that often took place after the interviewer-administered questionnaire shows the affinity of the gardeners toward soils and will be interpreted in the discussion part of this thesis.

The soil analyses in the laboratory of the University Tubingen show that the gardeners work with loamy to clayey soils (according to KA 5: Tu2, Ls2, Lu, Tu3, Lt3, Lt2). The pH-values vary between 5.3 and 7.2 and the C/N ratios vary between 9.3 and 12.7 (Teuber et al.). The analyses indicate soils, which are suitable for horticulture.

8 Discussion

The SFB 1070's definition of resources states that resources exist in combination with other resources, constituting a ResourceComplex (Bartelheim et al., 2015). This ResourceComplex consists of objects, persons, knowledge and practices (Hardenberg et al., 2017). The ResourceComplexes abolish the distinction between natural and social resources in the present thesis, but include the notion of Ostrom (2009), who states, that users, governance systems and resource units need to be considered. All these aspects are present in the ResourceComplex "soil". The combination of the different variables was necessary, because soil as a resource can only be used, if crops are known to the people using the soil, and tools are created to cultivate the soil. The work with soil, plants, and tools requires knowledge and management practices, which both depend on each other and are influenced by socio-cultural dynamics. One could argue that socio-cultural dynamics belong to the social part of a SES. While this is true, the context here is, that the socio-cultural dynamics are an integral part of the practices and, thus, have to be considered for the ResourceComplex as such. But not only the socio-cultural dynamics, also the knowledge and management practices belong to the ResourceComplex "soil". All these variables are needed for food production, even though they develop in close relation to the individual users and the governance system of the respective society, as is also indicated by Ostrom (2009).

The thesis investigated the ResourceComplex "soil" through time and its influence on the SES "agriculture" and the SES "allotment gardening". The ResourceComplex consists of the central resource soil in combination with crops, tools, knowledge, management practices and socio-cultural dynamics. The ResourceComplex "soil" is essential for food production. The concept of the ResourceComplex was used as a tool to analyze the SES "agriculture" and the SES "allotment gardening". Both SESs are comprised of several ResourceComplexes and both are part of a RESOURCECULTURE concerning soil. Through the investigation of the two SESs, differences and similarities between them were found. These define a RESOURCECULTURE connected to soil use.

8.1 The ResourceComplex "soil" and the SES "agriculture" (Manuscript 1, 2, 4, 5)

The concept of SES as well as the adaptive cycle metaphor were applied to the investigation of the development of agrarian soil use in Central Europe (Teuber et al., 2017). The SES "agriculture" depends on the ResourceComplex "soil", which consist of the natural resources soil and plants, but also includes humans through the knowledge and management practices, that are required to use the natural resources. It is, thus, not possible to distinguish between a social system and a natural system, because both are connected and interdependent. Therefore, the SES "agriculture" was the focus of the present thesis.

The SES "agriculture" developed with the Neolithic Transition, when people settled down and started to practice agriculture (Teuber et al., 2015; Teuber et al., 2017). The ResourceComplex "soil" was used to produce higher food quantities for the sedentary societies (Childe, 1936). The central resource soil became vulnerable to erosion (Lang, 2003; Leopold and Völkel, 2007). Analyzing the resulting colluvial deposits with soil scientific methods and OSL or ^{14}C-dating (Henkner et al., 2017) and combining the results with archaeological studies (Ahlrichs et al., 2016) leads to a more holistic understanding of the past. However, the dating of colluvial deposits with both OSL and radiocarbon dating provided mixed results, with the AMS ^{14}C-dates being older or younger than the OSL-dates (Henkner et al., 2017). Both methods need to be discussed to understand the problems of dating. The date provided by radiocarbon dating does not refer to the deposition of the charcoal in the soil profile, but dates the formation time of the analyzed object (Jull et al., 2013), in the case of colluvial deposits this refers to the growing period of the trees (Lang and Hönscheidt, 1999). As discussed by Henkner et al. (2017), wood is often processed before being deposited. Therefore, the charcoal pieces might date to earlier times than the OSL dating (Henkner et al., 2017), which provides data on the last daylight exposure of mineral grains (Lang and Nolte, 1999). The charcoal needs to be deposited on top of the mineral grains, before the charcoal and the mineral grains are covered by soil after an erosion event. Therefore, the charcoal might be older than the date provided through OSL-dating. Another reason for older charcoal ages is, that the sediment might be reworked due to recurring erosion events, leading to the development of a cascade system with temporary sinks along the hillslope (Fuchs and Lang, 2009; Lang and Hönscheidt, 1999). Younger AMS ^{14}C-dates in the same level as older OSL-dates can be explained through bioturbation (Henkner et al., 2017). Further, the calibration of the ^{14}C-dates (Jull et al., 2013) can lead to errors as well (Henkner et al., 2017). Luminescence dating also has error margins, e.g. insufficient bleaching of the mineral grains prior to burial, which leads to a remnant signal and an overestimation of the age of the deposition (Fuchs and Lang, 2009). Thus, the combination of both methods with archaeological data contributes to a more holistic reconstruction of land use within a certain area or region.

Another issue concerning the variable "soil" is that few colluvial deposits date to the Neolithic (Dotterweich, 2008), which might lead to a misinterpretation of the early agrarian soil use. Reasons for the scarcity of colluvial deposits from the Neolithic are, that the colluvial deposits might have been eroded again after the initial deposition (Lang and Hönscheidt, 1999; Zolitschka et al., 2003), or soil formation processes altered the deposits in a way that they are no longer recognizable as colluvial deposits (Dotterweich, 2008). It is also possible, that agrarian soil use was not as intensive and widespread as during the later times, e.g. during Bronze Age. Further, colluvial deposits not always correlate with the archaeological settlement pattern of a respective site, as the example of the Magdalenenberg in the study of Henkner et al. (2017) shows: the burial mound dates to 616 BCE (Knopf et al., 2015b; Knopf and Seidensticker, 2012), but so far no colluvial deposits date to that time (Henkner et al., 2017). Therefore, the reconstruction of agrarian soil use needs the cooperation of soil scientists with archaeologists and archaeobotanists to investigate changes concerning the landscapes. With more colluvial deposits dating to newer times, such as the Middle Ages (Henkner et al., 2017), the reconstruction of agrarian soil use through the analysis of colluvial deposits becomes more comprehensive.

The interdisciplinary work of soil scientists with archaeologists, historians, and archaeobotanists also give insight into the variable management practices of the ResourceComplex "soil". The analysis of celtic fields (Kooistra and Maas, 2008), ridge and furrow (Linke, 1979; Sittler, 2004; Wenzel, 2013), and plaggen manuring (Behre, 1976; Blume and Leinweber, 2004; Groenman-van Waateringe, 1992) with different methods shape the present understanding of the past management practices. However, the motivations of the farmers cannot be reconstructed, unless there are written sources explaining reasons for the management practices. Further, scientists are only able to analyze the result of the management practices, such as the ridge and furrows. These analyses allow an interpretation of the past methods and practices, but the actual management practice cannot be investigated.

The variable tool was investigated through a review of archaeological studies, which discussed archaeological finds connected to agrarian soil use. Archaeological finds are distributed over Europe, and the different settlements give an impression of the settlement patterns of a region. However, agrarian tools were rarely found in settlements and were also absent in hoard finds, e.g. in the agriculturally important hoard of Urach (Fries, 1995). Therefore, the study also relied on rock paintings, the analysis of ridge and furrow remains, as well as on traces of plows in the soil (Behre, 1998; Egg and Pare, 1995; Fries, 1995; Schultz-Klinken, 1981; Tegtmeier, 1993; Zich, 1999). This shows that interdisciplinary work is also important for the investigation of tools and their development. With metallurgy, new production methods for agrarian tools developed. This creates new possibilities for interdisciplinary cooperation, which includes metallurgical, archaeological and historical sciences.

The tool variable might also be used as a proxy for the knowledge variable, as technological development requires an increasing knowledge. The practice of tillage is used in most agricultural systems throughout history and on a global scale (Andersen et al., 2016; Gebregziabher et al., 2006; Lal et al., 2007; Mitchell et al., 2016; Schultz-Klinken, 1981). This requires tools suitable for soil cultivation and the knowledge to devise management practices that will result in a good yield. Further, certain knowledge is similar in all societies, as the omnipresence of the same crop plants, e.g. wheat and barley (Bakels, 2014; Rösch, 1998, 2009), indicates: people knew about the edibility of those plants and the requirements for their cultivation. It is argued here, that this knowledge developed within the social system but then became an integral part of the ResourceComplex “soil”. However, the knowledge variable cannot be investigated by itself without reliable written records. Even for Medieval Times, the written sources only represent the knowledge of the scholarly elite of the time and do not reflect the knowledge of the farmer. Therefore, the knowledge variable was not investigated by itself in the analysis of the SES “agriculture”.

The variable crop was investigated by reviewing the archaeobotanical research literature. This includes studies with palynological analyses, but also anthracology and the analysis of macro remains. Often, these studies also investigate archaeological sites or include soil scientific analyses (Dreslerová et al., 2013; Dreßler et al., 2006; Feeser and Furholt, 2014). Thus, the studies are interdisciplinary and contribute to a better understanding of the past development within a specific region.

The SES “agriculture” underwent two adaptive cycles so far. The first adaptive cycle started with the Neolithic Transition and lasted for several millennia. The second cycle started with the industrialization of agriculture after the Second World War and lasts until today.

The concept of the adaptive cycle is useful for the analysis of SESs through time, as it acknowledges different variables and their interactions (Gunderson and Holling, 2002). The different stages of an adaptive cycle show that systems of humans and nature (= SESs) are complex and develop through time (Holling and Gunderson, 2002). By using the adaptive cycle for the study of the SES “agriculture” it was possible to focus on the variables of the ResourceComplex. The interaction between the variables is complex and it is sometimes difficult to distinguish between the social and the natural. For this reason, the concept of ResourceComplex was applied, which acknowledges the intricate connections between humans and nature.

The adaptive cycle concept further recognizes that adaptive cycles occur on different temporal and spatial scales. These scales influence each other. If reorganization happens at one scale, conservative structures at a larger scale might provide a form of memory, so that reorganization happens along the same structures and processes that already shape the system at that scale (Allen et al., 2014). At the same time, processes of creative destruction can happen, which affect larger scales (Allen et al., 2014). This is also related to Fath et al. (2015), who state, that many small-scale adaptive cycles happen during the r- and K- stages of an adaptive cycle. All these examples indicate, that the adaptive cycle of the SES “agriculture” is embedded in a bigger cycle, which might store memory on the structure and processes, which will affect the development of the system after the creative destruction phase. Further, smaller scale adaptive cycles influence the big adaptive cycle of the SES “agriculture”, e.g. the adaptive cycle of the SES “metallurgy” affected the development of agrarian tools used in the SES “agriculture” (Teuber et al., 2017). The fast adaptive cycle of the SES “industrialization”, also had an impact on the SES “agriculture”: it led to new technology and an increasing knowledge, which in the end led to the creative destruction phase of the first adaptive cycle and the reorganization of the SES “agriculture” in its contemporary form. The adaptive cycle concept is, therefore, useful for scientific research, because it allows to focus on a certain SESs development, while it also considers the developments of other SESs, which can happen on different temporal and spatial scales. In combination with the ResourceComplex-concept, the SES and the adaptive cycle enables the scientists to structure their research concerning the investigated SES, while embedding it with other SESs.

8.2 The ResourceComplex “soil” and the SES “allotment gardening” (Manuscript 3)

The concept of ResourceComplexes served as a tool to investigate the contemporary SES “allotment gardening” in Germany. The two constant variables tools and crops proved to be chosen right, because no other tools were mentioned during the interviews and questionnaires. Further, no observations concerning other tools were made during the two summers spend in allotment gardens. While most surveyed gardeners cultivated common plants, several gardeners also grew peppers, chili, garlic, sweet corn, rutabaga, peaches, or melons. The crop variable can still be seen as a constant, as most plants were the ones mentioned earlier, such as potatoes or tomatoes.

The concept of ResourceComplexes was useful for questionnaire design because it helped to focus on certain variables. It further enabled the investigation of the ResourceComplex in the two regions by comparing the same variables. The results indicate, that differences between the gardeners in the urban and the rural region exist for the gardening motivation and the management practices (Teuber et al.). The soil knowledge is similar in the rural and urban allotment garden communities. The results of the soil analyses explain some of the statements the gardeners made during the interviews.

One aim of the present study was to ask for the motivation of gardeners in Germany to rent an allotment. The assumption after literature review was that food production is an important motivation for people to start gardening in an allotment. With food production in mind, the gardener invests time into soil cultivation, and, thus, has knowledge of the soil-plant interaction and might also develop management practices different from the modern agricultural practices. The questionnaire was intended to investigate, if food production is a motivation for gardening, or if other motivations exist in the allotment gardening community.

The motivations for gardening vary significantly. Family tradition is more important for the gardeners in VS than for the ones in S. However, 36.8 % in S and 44.2 % in VS stated a personal history with garden and/or agriculture in the “other” category of this semi-open question (Teuber et al.). A personal relation to gardens in the past is a motivation for gardeners to choose gardening as a leisure activity.

Own fruit and vegetables are another motivation for gardeners (Calvet-Mir et al., 2016; Scheromm, 2015; Teuber et al.). In VS, the food aspect seems to be important, as the explanations of the gardeners in the qualitative part of the study indicate:

"My potatoes last for ¾ of the winter." (VS, m, 71)

"I grow enough onions for the entire year." (VS, m, 79)

These two statements show, that the biomass production function of the soil is important for self-sufficiency, at least for certain foodstuff, such as onions and potatoes. Other gardeners do not have the self-sufficiency aspect present but connect a garden with vegetable plots and flavor:

"Gardening without vegetable patches? Then I don't need to garden." (VS, f, 58)

"I garden to have natural fruit and veggies… Vegetables from the own garden taste better." (VS, f, 74)

In S, only few respondents mentioned food production in the interviews, which is in accordance with the findings of Clayton (2007), who showed that food production is not necessarily a motivation for gardeners. The statements of the gardeners in S also refer to food quality and not solely to the food production function:

"If you grow it yourself, you know what's in it." (S, m, 62)

"We think our own vegetables taste better." (S, m, 61)

The statements from S and VS illustrate, that different priorities exist in the gardening community concerning food production. The rural allotment gardeners seem to value the soils biomass production function more than the urban allotment gardeners. This is interesting because the federal law concerning allotment gardens (Bundeskleingartengesetz) specifically states that a third of the area of an allotment needs to be used for food production. However, the gardeners in S, who cultivate food, often have food quality in mind when talking about gardens and food. Kortright and Wakefield (2011), Calvet-Mir et al. (2016), and Pourias et al. (2016) also suggest that food quality matters to the gardeners, and that growing food means controlling what is used for production. This quality aspect was directly mentioned by three gardeners in S and one in VS, who referred to organic food out of their garden. In general, food as interview topic was more present in VS, but food quality was seemingly important for the food producing gardeners in S.

Another motivation for gardening is relaxation which is more important in VS, than in S according to the motivation question (Teuber et al.). However, in the first qualitative question 88.7 % in S and 87.1 % in VS associated the term "garden" with "recreation". At the time of the interview, the gardeners in S connect their gardens with recreation and relaxation, but they did not necessarily have recreation as a motivation to start gardening. A further motivation for gardening in both regions is to get out and enjoy nature. This is also connected to recreation. Thus, gardeners in both regions, see their garden as a place to spend their leisure time (Teuber et al.).

Only 4.1 % in S and 17.1 % in VS garden to express own creative ideas (Teuber et al.). Since the rules of the allotment gardening associations are restrictive this limits creativity. Thus, gardeners who want to display their creativity probably choose other forms of gardening than allotment associations.

Calvet-Mir et al. (2016) suggest that gardens are places to learn about nature and transmit this knowledge to children or grandchildren. 16.1 % in S and 13.5 % in VS took up gardening for their children or grandchildren:

“We wanted to bring the grandchildren out into nature.” (S, m, 66)

“Showing our child, where food comes from.” (S, m, 42)

Calvet-Mir et al. (2016) also indicate that gardening activities have health effects and restorative functions. Several health-related statements show, that this notion was present in German allotment gardens as well:

“I have a job where I sit all the time, so the garden is a compensation to that.” (VS, m, 72)

“Gardening is motion.” (VS, m, 56)

“I get moving.” (S, m, 73)

“I garden as stress relief.” (S, m, 59)

The motivation to choose gardening as a leisure activity differ between the two regions. While the use of the ResourceComplex “soil” in terms of food production seems to be important in the rural region, the urban allotment gardeners have other motivations for renting an allotment, such as recreation or a personal history with garden and agriculture. Considering the federal law concerning allotment gardens (Bundeskleingartengesetz), this finding is surprising, because according to the law as well as the rules of the allotment garden association, food production is important and should be done on a third of the area of each allotment. There, thus, seems to be a varying degree of engagement with the ResourceComplex “soil” in the two regions. While the gardeners in the rural regions use the biomass production function of soils on a regular basis, this function seems to be of subordinate importance in the urban allotment gardens. Therefore, the knowledge and management practices concerning the ResourceComplex “soil” might vary between the regions.

Management practices are an integral part of the ResourceComplex “soil”. Therefore, the management practices in allotment gardens were investigated using a questionnaire. Several management practices such as digging, fertilizing and pest control as well as newer approaches, such as no-dig or raised bed gardening were included in the questionnaire. Most of the surveyed gardeners use traditional management practices, which include digging up the soil once a year. However, the no-dig approach is practiced by 15.5 % in S and 5.7 % in VS (Teuber et al.). This approach originated in agriculture where the no-tillage approach is connected to soil conservation methods (Aziz et al., 2013; Lal, 2013). It seems to be more common in S than in VS to stop digging on a yearly basis. Instead, raised beds are created or the soil of the vegetable plots is loosened with a gardening fork or by using green manure. A reason for the difference between the two regions might be that more gardeners in rural VS than in urban S garden because of a family tradition. If gardening was a common activity in a family, the now active gardeners might have learned the management practices concerning soil cultivation from the parents. Thus, they use the traditional management practices, which include digging, instead of newer approaches that can be found in the expanding gardening literature. Further, the age range of gardeners in S is bigger than in VS. Younger gardeners might have an open mind concerning new management practices. And if gardening was not a family tradition they might read about garden management practices in diverse sources such as newspapers, blogs or the extensive gardening literature and find the no-dig approach there (Teuber et al.). Further, the gardeners in urban S have easy access to universities, libraries, garden courses, and highspeed internet, which facilitates information exchange and learning.

Most of the gardeners' do not agree with the statement "I prefer chemical fertilizer from garden centers for my plants". While there is no preference for chemical fertilizer, it does not mean, that these kinds of fertilizers are not used. In S, 19.6 % of the gardeners stated, that they apply chemical fertilizers, at least from time to time. Generally, fertilizing is a yearly activity for 78 % in both regions. Most gardeners use a mixture of compost, manure, loosening up the soil regularly, horn meal and green manure to conserve or improve soil quality (Teuber et al.):

"We loosen up the soil regularly, because crusts develop after the rain. We also use compost and natural organic fertilizers." (VS, m, 64)

The male gardener from the rural region noticed natural processes occurring after the rain and developed his management practices accordingly. By loosening up the soil after the rain, the results of splash erosion are ameliorated. Compost and natural organic fertilizers further contribute to the availability of plant nutrients.

All gardeners use fertilizer when working with the ResourceComplex "soil", some even rely on multiple soil amendments to ensure a good yield:

"Compost is worked into the soil when digging up the plot in fall. Crop rotation is used, first beans than potatoes. I also use bark mulch, potting soil and horn meal." (S, m, 69)

"Soil improvement is necessary. We use manure from a farmer, compost, horn shavings, and bone meal. In fall, we sow mustard and dig it into the soil in spring." (VS, f, 74)

The female gardener from the rural region uses a mixture of fertilizing practices to ensure good nutrient availability in the soil. Green manure, in this case mustard, covers the soil during the winter and, thus, protects it against erosion and silting. Furthermore, the roots of green manure loosen up the soil. The oxygen level of soils is improved, the soil biota is activated and the amount of soil organic matter increases due to more plant remains being available. If *Fabaceae* (or *Leguminosae*) are used as green manure, nitrogen fixation increases the N-availability for plants. Weeds are suppressed and the plant remains of the green manure provide mulching in the spring:

"When I started gardening here, I used two truck loads of sand to improve the soil, because it is so loamy. Shredded plant material is worked into the soil to make it more crumbly. After the harvest, I plant green manure… People here just do not want to abandon digging. I'm mulching for years, it is much less work, because there are no weeds and the soil moisture increases." (VS, m, 65)

Mulching is another practice of the gardeners. Usually local organic material is used for mulching, such as grass clippings or leaves. However, wood chips are sometimes applied. The mulch helps to retain the soil moisture, suppresses weed growth and regulates the soil temperature.

Very few gardeners (3 in VS = 4,3 %) also have a spiritual or esoteric approach using moon calendars or homoeopathy which determine the management strategies.

"We garden after the moon calendar of Maria Thun. We use green manure for soil improvement." (VS, f, 74)

"I try homoeopathic gardening. Green manure is used instead of fallow. Green manure and compost ensure soil quality." (VS, m, 71)

The combination of these approaches with other management practices such as green manure and compost show, that gardeners have their own view of the ResourceComplex "soil", and some believe in cosmological influences. Most gardeners, however, rely on tradition and the knowledge, which they gained during years of practice, as the quantitative results (Teuber et al.) show and the following qualitative expressions indicate:

"The soil amendments peat, sand and manure from a nearby farmer resulted in a loose and dark soil... Crop rotation [using four different fields] is used for pest control and to ensure an equal use of the soil, it's also tradition… Rain leads to silting of the soil, so I loosen it up with a digging fork to make sure that the plant roots and the soil get enough oxygen... In fall, I dig up the soil so that the soil freezes through in winter. This results in a crumbly soil. In spring, I only loosen the soil up. Fertilizer is used directly in the hole when planting... I also distribute my compost on the plot." (VS, m, 79)

The management practice of this gardener is closely connected to traditional farm management, as the crop rotation shows. He further has an understanding of soil processes connected to garden management, as the comment about silting indicates. However, new techniques such as the no-dig approach are not present. Instead, the soil is dug up in fall and compost is distributed on the fields.

"I improve the soil with compost and coffee grounds which results in the best soil with a lot of earthworms. […] Crop rotation is necessary, otherwise nothing grows. […] Only when I have the feeling, that the soil is good, I start planting." (VS, m, 64)

This gardener combines traditional management practices like crop rotation and compost with coffee grounds, which are used frequently by modern urban gardening communities. He further realized that earthworms are important and seems to be proud of the earhworms in his vegetable plots.

"…the loamy soil retains water and plant nutrients. […] We loosen the soil up a lot, so that the soil stays loose and that there is air in the soil. One is not supposed to dig anymore, but I have to get air into the soil. We had a 2-year compost rotation in the past, but now we use a fast composter. […] I recently bought a book about compost and soil organisms." (VS, m, 67)

This comment shows the prevalence of traditional management practices, but also indicates that an interest in newer methods exists. The fast composter is already used, but the no-dig approach is rejected. While the first requires only a small change in the management and facilitates the work in the garden, the no-dig approach is rejected, due to the loamy soil, which (according to the gardener) requires constant digging and loosening.

Another form of not digging is the construction of raised beds.

"I do raised beds for 20 years now. The soil is dug up until you reach the subsoil. Tree cuttings, perennial plant remains, etc. are put in the hole. This is topped with horse manure and covered with the topsoil again." (VS, m, 63)

"I reconstruct the raised beds every 2-3 years. I also work in new soil." (S, m, 46)

The mixture of soil management practices is in accordance with Kim et al. (2014), who show a preference of compost and mulch over commercial fertilizers and pesticides in community gardens in Baltimore. However, Dewaelheyns et al. (2013) found that Flemish domestic gardeners rely on lime, compost and organic fertilizers, with the amount of fertilizer used in Flanders being excessive. The gardeners in the present survey seem to be similar to the community gardeners in Baltimore. While they use chemical fertilizer from time to time, the overall management practices rely on traditional soil amendments, which include compost and manure. Raised bed gardening is a new approach in the gardening community, which is only practiced by a few gardeners in this survey. It combines traditional management practices with new gardening methods: the organic material remains on the plot, because raised beds are constructed by using branches, leaves and grass clippings as well as compost, all of which originate in the respective garden.

Pest control is another important management practice within the gardening community. 12.4 % in S and 57.1 % in VS engage in pest control activities on a weekly basis (Teuber et al.). Pest control refers to actions against snails or aphids, and includes collecting the snails off the plot, organic remedies and the use of chemicals. Pest control is especially important, if a reason for gardening is food production:

"Snails are a big problem. 80 % of my beans were eaten by them last year. That spoils all the fun." (VS, m, 64)

"Most of my nasturtium froze this year; the rest was eaten by the snails." (VS, f, 74)

"I use snail pellets, otherwise I'd have no salad." (VS, m, 71)

These statements indicate a connection between pest control and food production. If the harvest matters, pest control is important. The results of the questionnaire suggest that food production is more important for the gardeners in VS than for the ones in S. Thus, the gardeners in rural VS are more interested in pest control.

The ResourceComplex "soil" includes the variable knowledge, which was also investigated with the questionnaire and through informal interviews. While soil cultivation is a major activity in the different gardens, the gardeners are not sure about their ability to assess soil quality. Only approximately half of the gardeners in both regions state that "I'm able to assess whether the soil is good for the plants I want to grow" (Teuber et al.). The gardeners gave descriptions about their indicators for soil quality assessment. These qualitative statements were grouped into "soil texture", "trial and error", "soil management resulted in good soil", and "scientific soil samples". Besides these, the variables most often used for soil quality assessment were the present vegetation and the workability of the soil (Teuber et al.). The answers indicate that the gardeners use criteria observable during normal gardening activities:

"…crumbly soil…" (VS, m, 71)

"Soil needs to be loose." (VS, f, 73) and (S, m, 75)

"It [soil] needs to feel right when touched." (VS, m, 67) and (VS, m, 56) and (S, f, 43)

"It [soil] should be sandy and loamy." (S, m, 75)

One gardener talked about a test that helps him determine the soil quality:

"It depends on the grip. I form a ball out of soil and drop it on the ground. If the ball falls apart, the soil is good. A mud pile is bad." (VS, m, 64)

This test as well as the statements given by the gardeners indicate that the gardeners rely on their experience with the soil in their gardens. This is further demonstrated by expressions related to experiments with soil and plants:

"If it does not grow, I plant something else next year." (S, f, 66)

"Learning by doing." (S, f, 56)

"Trial and error." (VS, m, 59)

"Testing and trying." (VS, f, 63), (VS, m, 45), (VS, f, 33), (S, m, 42) and (S, m, 59) among others

By dealing with soil and plants on a regular basis, the gardeners gradually gain knowledge concerning soil quality. They often experiment with plants and soil, which was also observed by Scheromm (2015). Only few gardeners assess the soil quality through scientific methods, for example by sending soil samples to a laboratory or using test kits from a garden center to determine pH-values. This shows that the soil knowledge of the gardeners relies on the experience the gardener has made in his garden in previous years. As Warkentin (1999: 3) puts it, soil knowledge and understanding is gained through trial and error processes and observation. This is also shown by the evaluation of the question concerning soil erosion: in S, the gardens are generally on slopes. The gardeners there know about soil erosion. In VS, the allotments are on plains. One of the allotment garden associations in rural VS is located next to a small creek, thus in an area prone to fluvial erosion. In this allotment garden association, the gardeners know the term soil erosion. When answering the question related to soil erosion, it seems that personal experience with soil erosion contributed to the soil knowledge of the respective gardener. This observation can also be applied to the experience with certain management practices.

The knowledge variable of the ResourceComplex “soil” is similar in both regions. Only for the soil erosion question, there are differences between urban S and rural VS. As has been discussed this might be due to the different landscapes in which the gardens are located. However, in both regions, the soil knowledge is closely connected to the soil present in the allotment and to experiences with this soil. This suggests that scientific soil knowledge is not present in the gardening community. Instead, the gardeners experiment with practices and gain their specific soil knowledge through experience. This knowledge seems to be closely connected to the soil and the plants used in a specific allotment and relies on personal experiments with soil and plants.

The variable soil of the ResourceComplex “soil” was investigated by collecting soil samples form unused green spaces in each allotment garden association. The laboratory analyses show that the gardeners work with loamy to clayey soils (Teuber et al.). The texture indicates soils that are difficult to work with, due to the loam or clay content. If these soils are dry, they are very hard, and if they are wet, they tend to be sticky. Both is challenging, if digging is a chore during those times. This explains why many of the gardeners complained about bad soil:

“Oje, soil like concrete…” (VS, m, 68)

“…bad soil, like concrete!” (VS, f, 71)

“…huge problem [Granatenproblem], very loamy-clayey [lettig] with little humus and heavy…” (VS, m, 76)

“…it’s hard work in the Black Forest…” (VS, m, 71)

“…very loamy and needs a lot of work.” (S, m, 61)

"…sometimes difficult to cultivate…" (S, m, 48)

"…as hard as stone…" (S, f, 56)

The gardeners usually did not consider other factors, which are important for soil fertility. When judging soil quality the pH-values and the C/N ratios should be determined (Canfield et al., 2010; FAO, 2006). The pH-values of the soil solutions in the different garden associations vary between 5 and 7 (Teuber et al.). The soil samples taken from unused green spaces are, thus, acid to moderately alkaline. While a pH-value >5 guarantees that no toxic concentrations of Al^{3+} and Mn^{2+} occur, the optimal pH value depends on the clay content and organic matter (Blume et al., 2010). Plant growth is generally possible for pH-values between 3 and 10, but most plants grow best at pH 6 to 7 due to a good nutrient availability at these values (FAO, 2006). The C/N ratio of productive arable land/grassland in Europe is between 10 and 15 (Blume et al., 2010). With a C/N ratio of 9 to 12 the soils within the associations provide good conditions for gardening, especially if management practices include the addition of organic material. As the qualitative interviews show, the gardeners in SW-German allotment garden associations use a variety of soil amendments, including the distribution of compost. With this management practice, the gardeners improve the soils and achieve good harvests.

While the variable soil was investigated using soil scientific research method, the importance of soil for the gardener was examined through a qualitative open question and in the interviews ensuing the questionnaire. The gardeners in the present study value soil:

"Soil…one works with it, it is important and needs care taking." (VS, f, 74)

"One hast to start working with the soil, then one can't stop. […] When I'm working with the soil, it is wonderful." (VS, m, 64)

"Is treated badly and little valued." (S, f, 54)

However, the awareness that soil is essential for society seems to be connected to own experiences:

"Earlier I thought about it as dirt. Now I know how important it is." (VS, m, 72)

This indicates, that people, who actively deal with the ResourceComplex "soil", are interested in soil related challenges and questions. They, thus, might be disseminators, who promote soil conservation to other groups in society.

Originally, the socio-cultural dynamics were investigated by a literature review concerning rules and regulations of and within the allotment garden communities. Spiritual approaches to gardening had either not been part of the reviewed literature, or had only been a cross-reference. However, during field work, a few gardeners in rural VS talked about cosmological aspects of garden life, more explicitly about gardening according to the moon calendar or homeopathy.

As Hardenberg et al. (2017) put it, resources are used to create, sustain or alter social relations and identities by acknowledging cultural ideas and practices. These cultural ideas and practices often contain a spiritual or cosmological level, e.g. the different resource definition of the Dongria Kond, the NGOs and the regional government in Odisha, India (Hardenberg, 2016). Since resources are part of ResourceComplexes, the spiritual or cosmological level can be present within a ResourceComplex. The spiritual or cosmological approach in the allotment gardening community of SW-Germany was not explicitly investigated due to the Western cosmology being centered around the monotheistic Judeo-Christian belief system (Sahlins, 1996). However, spiritual approaches to gardening exist in the rural allotment gardens, as 4.3 % of the gardeners consider the moon calendar when determining management practices. While Sahlins (1996) explains the origin of Western cosmology with a focus on Judeo-Christian cosmology, the use of moon cycles in gardening seems to imply, that values exist that are not solely based on this Western cosmology. Further, the suggestion of Hardenberg (2016) that the socio-cosmos affects social and cosmic relations concerning the use and valuation of a resource differs from the findings of this study. In the allotments, there was no further explanation concerning other spiritual practices. The gardeners only mentioned the moon cycles and the moon calendar provided by garden journals. Therefore, a socio-cosmos after Hardenberg (2016) cannot be identified due to the limited information available after the explorative study of the allotment garden community's relation to the socio-cosmos.

The ResourceComplex concept was applied in both regions to investigate the SES "allotment gardening". The aim was, to explore similarities and differences between the two regions. In many aspects, there are no or only small differences between the two regions, but the frequency of digging and pest control, as well as the motivation for gardening vary. In general, gardeners in S and VS rely on traditional management practices when dealing with the ResourceComplex "soil". However, more gardeners in S practice no-digging or raised bed gardening. This approach is also present in the rural region but not as common. A significant difference between the two regions is the motivation for gardening, and therefore the reason why people deal with the ResourceComplex "soil". Surprisingly, food production and therefore the biomass production function of the soil is not as important in the urban region as it is in the rural allotment gardening community.

The investigation of the ResourceComplex "soil" contributes to our understanding of the SES "allotment gardening". Many different variables exist in this SES and shape the contact of humans with the natural system. The gardeners invest time to work with soils and plants. This work requires knowledge and management practices, which are in part influenced by socio-cultural dynamics. The SES is shaped by traditional management practices and knowledge, which the gardeners gain through experiments with soil and plants.

8.3 The ResourceCulture concerning soil (Manuscript 1-5)

Investigating the ResourceComplex "soil" with interdisciplinary methods using research from archaeology, history, soil science, and palynology as well as conducting the field study in the allotment gardening community, showed that the ResourceComplex was and still is of major importance for different SESs concerned with food production. With industrialization, a change occurred that led to fewer people working directly with the ResourceComplex "soil", at least in the agrarian sector of an industrialized society such as Germany. Still, the ResourceComplex "soil" is important for the SES "agriculture" as well as for the SES "allotment gardening", where citizens in diverse urban agglomerations deal with it. While the ResourceComplex "soil" has distinctive characteristics in the different SESs, it is essential for food production and, thus, food security. It gained importance with the Neolithic Transition and it is still used today by farmers (Teuber et al., 2017), commercial horticulturists and by citizens through gardening (Teuber et al.). After its first establishment, the ResourceComplex "soil" was important for most of society for many millennia in the SES "agriculture" (Teuber et al., 2017). With industrialization, fewer people work professionally with the ResourceComplex "soil". However, the SES "agriculture" is important for society, because it produces the food required by a growing world population. We can, thus, distinguish between active and passive involvement with the ResourceComplex "soil", with farmers and gardeners being actively involved, while the general society passively engages with the ResourceComplex "soil". Through socio-cultural dynamics society influences the general variables of the ResourceComplex, e.g. through the purchasing behavior. Farmers and professional horticulturists, on the other hand, actively engage with the ResourceComplex "soil". Through their knowledge of soils and plants, they decide management practices and what machines and tools they use for cultivation. These decisions and practices in turn have an impact on soils and plants. Further, the professional soil users are subjected to socio-cultural processes, e.g. the preference of organic food by a growing proportion of society in wealthy industrialized countries. However, the farmers and horticulturists also affect policies through their organizations, e.g. through the Deutscher Bauernverband (= German Farmer's Association).

The ResourceComplex is also used by a wide variety of people in industrialized countries in form of leisure gardening, as the growing gardening community in the urban agglomerations of the industrialized North indicates (Morgan, 2015). This activity is done in various ways, such as in home gardens (Kortright and Wakefield, 2011), in community gardens (Holland, 2004), through guerilla gardening (Haide et al., 2011), or in allotment gardens (Teuber et al.). Some of these gardeners use the biomass production function of soils in their leisure time. For them, the ResourceComplex "soil" is important. However, not everyone gardens to produce own fruit and vegetables (Teuber et al.). Therefore, the ResourceComplex "soil" is of varying importance in the allotment gardening community and probably also in the gardening community in general.

On a much smaller scale, the involvement of the gardeners with the ResourceComplex in the SES “allotment gardening” is the same or at least very similar to the one of the farmers. While food production may not be the reason for gardening, soil cultivation and the interaction between soil and plants relies on the management practices, and is closely connected to the knowledge of the gardener. A major difference is, that the impact of the gardeners on the policy is more limited than the impact of farmers, because farmers have a big lobby and leisure gardeners do not. However, the similarities of the involvement with the ResourceComplex “soil” in both investigated SESs, allows the identification of a RESOURCECULTURE connected with soil use. While only a small proportion of society professionally works with the ResourceComplex “soil”, there is a growing gardening community, who engages with the ResourceComplex. The ResourceComplex “soil” in both SESs requires comprehensive knowledge and management practices that specifically relate to the soil and plants cultivated. For the cultivation, tools are necessary. Further, socio-cultural dynamics influence knowledge and management practices as well as the decision, which plants to grow. Besides these active contributions to the ResourceComplex “soil”, all of society has a passive involvement with the ResourceComplex through food consumption. Therefore, a SOILCULTURE still exists in industrialized Germany.

While society depends on the ResourceComplex “soil” and its contribution to the SESs “agriculture”, “allotment gardening”, and “commercial horticulture”, the central resource soil is not an integral part of public discussions. The knowledge, that soils ensure food security, provide potable water, have a high biodiversity, and supply society with building materials as well as resources needed by various industries, exists in the soil science community. People, who are engaged with the ResourceComplex “soil”, might also have some knowledge concerning these soil functions. However, the public discussions do not necessarily broach the issue of soil conservation. Instead, environmental issues connected to climate change seem to be on the political agenda. This can be seen by studying the political programs of the major German political parties for the German parliamentary elections of 2017: The program of the CDU/CSU (2017) mentions soil (= “Boden”) six times. Twice, this is related to soil erosion and, also twice, to agriculture (“bodengebundene und flächendeckende Landwirtschaft in bäuerlicher Hand”, “Grund und Boden sind die Produktionsgrundlage unserer Landwirte”). Twice it is used in a context not related to soil as a resource (“Boden gut gemacht”, “auf dem Boden des Grundgesetzes”) (CDU/CSU, 2017). However, climate is referred to 21 times in different contexts such as “Klimawandel”, “Klimaschutz” (CDU/CSU, 2017). The SPD (2017) also mentions soil six times: Twice it is related to soil as building site (“Spekulation mit baureifem Boden […] eine aktive Bodenpolitik”), once it has an environmental aspect (“Frische

Luft, gesunde Böden, saubere Gewässer...”), once it is related to responsible agriculture (“das Bundesbodenschutzgesetz”), and twice it has a territorial aspect (“Asylverfahren […] auf europäischem Boden”, “auf deutschem Boden nicht geben.”). Climate is mentioned more than 30 times, e.g. “Klimaanpassung”, “Klimapolitik” (SPD, 2017). BÜNDNIS 90/DIE GRÜNEN (2017), mentioned soil 22 times, but climate more than 140 times (similar climate aspects as above). Environmental aspects concerned with soil are common (“Boden, Luft und Wasser sauber bleiben”, “unsere Böden und Gewässer belasten”, “unsere Böden sind in Gefahr”, “überlastet unsere Böden mit Gülle und Pestiziden”) (BÜNDNIS 90/DIE GRÜNEN, 2017). Soil protection is also related to climate change (“Permafrostböden von Kanada bis Sibirien tauen”, and “intakte Moorböden”) (BÜNDNIS 90/DIE GRÜNEN, 2017). In the program of the FDP (2017), soil is mentioned 4 times, while climate is mentioned 30 times. The climate relations are similar to the ones of the other political parties. The term “soil” is related to technological development (“über Sensoren der Nährstoffgehalt im Boden messen”), a figure of speech (“Boden, auf dem Gewalt und Diskriminierung gedeihen”, “der Nährboden entzogen werden”), and to economy (“heimischer und maritimer Bodenschätze”) (FDP, 2017). DIE LINKE (2017) has 19 references to soil and more than 50 to climate, with the latter being in the above mentioned contexts. Soil is connected to housing (“einen bevorzugten Zugang zum Boden”, “Spekulation mit Boden und Wohnraum”, “Öffentlicher Boden darf nicht privatisiert”, “Bodenpreisdeckelung”), agriculture (“Bodeneigentum für regional verankerte Landwirtschaftsbetriebe”, “Anbausysteme fördern, die Boden, Tiere und Pflanzen…”), environmental aspects (“Bodenschutz ist Klimaschutz”, “Neuversieglung von Boden”), territorial aspects (“Boden der Bundesrepublik Deutschland”), or used as a figure of speech (“Nährboden bereitet”) (DIE LINKE, 2017). The program of the AfD (2017) has no reference to soil, but mentions climate 15 times. However, the climate references of the AfD (2017) differ from the positions of the other political parties, as anthropogenic climate change is questioned and unscientific populistic platitudes are common. The different programs show, that BÜNDNIS 90/DIE GRÜNEN and in part DIE LINKE are directly concerned with soil as a resource and with soil protection measures. While the other big political parties acknowledge soils in environmental contexts (except of the AfD), this is only done in a wrap up with other resources needing protection. Most often, the term “Boden” is used in other contexts or as a figure of speech. This implies, that SOILCULTURE cannot be used as a term for industrialized Germany, because soils are not present in public discourse. Reasons for this could be, that the people living in an urban agglomeration are not connected to the ecosystem services provided by the natural environment on which they rely for their livelihood (Deutsch et al., 2013; Folke et al., 2011). Without this connection, the knowledge about natural processes and the human dependency on these processes might not exist. The soil science community already tries to put soils on the political agenda through concepts such as “soil of the year”. While this is a good start, further steps are necessary to ensure soil conservation measures. The term SOILCULTURE might be useful to integrate the ResourceComplex “soil” into the political debate. If scientists and policy makers deal with the links within the ResourceComplex “soil” and the feedbacks between this ResourceComplex with other ResourceComplexes, the SESs connected to food production might be perceived differently in the social part of the respective SES. This might lead to different socio-cultural dynamics, which influence the development of the SESs in question and increase its overall resilience.

The two investigated SESs are an integral part of the SOILCULTURE. With a growing world population (Barnosky et al., 2016), and especially a growing urban population (Antrop, 2000; Deutsch et al., 2013), the two SESs as well as other SESs connected to food production, have to provide food security. However, the urban landscape is increasing, which threatens farmland and habitats of local wildlife (Seto et al., 2011). Through the growth of cities, valuable soils are sealed. These soils are no longer able to provide their ecosystem functions, such as biomass production or potable water provision. This requires an effective and resilient use of the remaining agrarian production areas, through a combination of traditional and modern management practices with new technologies. The practices as well as the new technologies need to be constantly evaluated by scientists and practitioners to minimize negative feedbacks between the ResourceComplexes of the SES “agriculture”. The concept of ResourceComplexes in combination with the SES approach can be helpful in these studies to focus on relevant variables and acknowledging the complexity of the SES itself.

As the urban area increases, urban agriculture in all its manifestations needs to be investigated by scientists and considered by urban planners for its potential to contribute to food security in and, ultimately, to the resilience of urban agglomerations. Urban gardening, as part of urban agriculture, is a movement within cities, that has several motivations (Calvet-Mir et al., 2016; Pourias et al., 2016; Teuber et al.), and also provides ecosystem services within urban agglomerations (Breuste and Artmann, 2015; Middle et al., 2014). Further, Barthel et al. (2010) suggest that social-ecological memory is shared in the gardening community and increases the resilience of the community by retaining knowledge on food production and ecosystem services. In the past, urban agriculture contributed to the resilience of cities such as Constantinople or the Maya settlements (Barthel and Isendahl, 2013). Allotment gardens also provided workers with land to increase their food security and provide a healthy leisure activity during and after industrialization (Nilsen, 2014). During the Second World War, victory gardens were part of the US domestic strategy, providing 40% of the domestic vegetable supply (Lawson, 2014). The contribution of today’s urban gardening and urban agriculture to food provisioning is estimated by several studies: Case studies in Havana, Cuba show, that urban agriculture can contribute to food security in times of crisis. After the fall of the Soviet Union, Cuba was faced with reduced imports which led to the establishment of urban gardens and urban agriculture, providing the urban population with 138 million kg of vegetables nationwide in 1996 (Altieri et al., 1999). However, a recent study found, that food security might be interpreted differently by governments and urban farmers: while the Cuban government wanted to reduce food imports through an increase of agricultural production, the urban farmers wanted to reduce their dependency on state-run supply (Leitgeb et al., 2016). Even though the Cuban case might be special due to the specific circumstances in which urban agriculture developed, other case studies also investigated the topic. The policy aspect was studied in the USA, where New York City, Chicago, San Francisco, Seattle and Detroit were compared with each other (Cohen, 2012). While urban agriculture is part of a wider food policy in the respective urban agglomeration, various public, non-profit, and private stakeholders participate in policy development for different reasons, such as creating gardens for low-income residents for them to improve their diets, or neighborhood improvements (Cohen, 2012). Other studies use GIS and statistics to calculate the possibilities of urban agriculture to contribute to food security. Orsini et al. (2014) calculated, that rooftop gardens could provide 12000 t y^{-1} of vegetables to the city of Bologna, if all possible rooftops were used for gardening. However, the analysis of Badami and Ramankutty (2015) shows, that urban agriculture might provide adequate vegetable yields for the urban poor in high-income countries, but does not contribute to food security in low-income countries. Further, urban agriculture does not necessarily have a focus on food production, as other purposes such as education or community building seem more relevant (Specht et al., 2016). While the actual contribution to food security has to be evaluated for each urban agglomeration, urban gardens and urban agriculture provide the urban gardeners or farmers with food that grows in their surroundings. Thus, transportation costs are reduced and the gardeners and farmers are reconnected to food production processes. Further, fruit and vegetable consumption of people actively involved in gardening might increase. Alaimo et al. (2008) showed that families of community gardeners in Michigan consumed fruit and vegetables 1.4 more times per day than people who had no community gardener in their family. Another study in Philadelphia also illustrates, that gardeners ate cole crops, okra, eggplant, peppers, tomatoes, herbs and summer squash more frequently than non-gardeners (Blair et al., 1991). However, as McCormack et al. (2010) propose, more research on this topic is needed, to evaluate if changes in diets occur with gardening and how much yield is obtained from urban gardens or urban agriculture.

The concept of ResourceComplexes can be applied to the analysis of the SESs "agriculture" and "allotment gardening". It facilitates the investigation of certain variables. Simultaneously, it allows to focus on specific variables while acknowledging the complexity of the SES in question. It, thus, can be used to structure further research. The concept of ResourceComplexes also allows the definition of RESOURCECULTURES. Through the present analysis, the ResourceComplex “soil” in combiniation with the SES approach enables scientists to study relevant varibles and promote the research to a wider audience through the framework of the SFB 1070.

9 Conclusion

The aim of the present thesis was to study the use of the ResourceComplex “soil” in Central Europe from the Neolithic Transition to today focusing on the biomass production function of soils. In order to achieve this, the development of the SES “agriculture” and the contemporary characteristics of the SES “allotment gardening” were investigated.

The SES “agriculture” and with it the variables of the ResourceComplex “soil” underwent several changes during the first adaptive cycle, which resulted in a transformation of the SES and a second adaptive cycle. During the first adaptive cycle, the tools advanced and management practices developed, that are still influencing agrarian soil use today, such as the plow and crop rotation. With the second adaptive cycle after industrialization, the SES “agriculture” and the variables of the ResourceComplex “soil” changed considerably. The SES now relies on heavy machinery, technological progress in form of GMOs and industrialized fertilizer and herbicide production, and it needs fewer people working with the soil. The change of the SES “agriculture” led to more people living in urban agglomerations, where the ResourceComplex “soil” is seemingly unimportant. However, the urban population depends heavily on the SES “agriculture” for food provisioning. Further, the ResourceComplex “soil” is important for the gardening community, even though food production has become a leisure activity in the industrialized urban agglomerations in Germany.

Today, the ResourceComplex “soil” is used professionally by farmers and leisurely by gardeners. However, the ResourceComplex “soil” has distinctive characteristics in the two investigated SESs. In the contemporary SES “agriculture” soil cultivation relies on modern technology, which often has detrimental effects on the soil variable. Heavy machinery compacts the soil, tillage facilitates erosion, and pesticide as well as herbicide use affect biodiversity within and outside of the soil. With agriculture relying on modern knowledge and technology, new concepts like the no-tillage approach are used by farmers around the world today. The crop variable in the SES “agriculture” is also influenced by modern technology, as the existence of GMOs shows. The SES “allotment gardening”, on the other hand, relies on traditional and simple tools for soil cultivation and common crop plants, from which seeds are sometimes harvested for reuse. Both SESs are also shaped by tradition. The gardeners’ management practices have been used in agriculture for centuries. The gardeners learned these practices either from their parents, grandparents or fellow gardeners, or through experiments with different practices. In the SES “agriculture” tradition is also important. Especially on organic farms, traditional management practices are typical for soil and plant cultivation. This shows, that the common characteristic of the ResourceComplex “soil” is, that traditional management practices and experimenting with the practices are used by the farmers and the gardeners alike. Differences between the two SESs exist as well. Modern technology and knowledge are used by the farmers who need to obtain a good yield to sustain their livelihood. For the gardeners, the yield might be important, but if they do not harvest enough foodstuff, they buy what they need in stores or on markets. They, thus, depend on the yields of the farmers and the SES "agriculture". Experimenting and traditions are, therefore, less risky for the gardeners. Further, the gardeners experiment with their practices on a small scale. They can invest a lot of time and energy into weeding or collecting snails off the plot. On the big scale of agriculture, this is not possible, which explains the dependency on pesticides and herbicides in the SES "agriculture". The ResourceComplex "soil", thus, has different characteristics in the two investigated SESs. However, society depends on the ResourceComplex "soil" for food provisioning. It is, therefore, possible to define a SOILCULTURE for contemporary Germany as well as through time. Even the people who do not work on farms or in gardens rely on the soils biomass production function and passively contribute to the ResourceComplex "soil" through socio-cultural dynamics. However, the SOILCULTURE is not part of public discourse, as can be seen by investigating the election program of the different political parties in Germany for the 2017 election. The term 'ResourceComplex "soil"' might be helpful for scientists to research and illustrate the close connections between the different variables. Scientists, politicians, and the different soil users, then, need to collaborate with each other on equal terms, to put the ResourceComplex "soil" on the agenda. This is necessary, because the central variable soil is endangered globally among others through soil erosion, soil compaction, and contamination with heavy metals. This threatens to impair its vital functions for humanity, such as biomass production or water filtration. However, soil conservation methods need to consider the other variables of the ResourceComplex, as well as interactions with other ResourceComplexes. This is a complex endeavor, which requires scientists from different disciplines to work together in interdisciplinary teams, while also considering other actors such as NGOs, citizen scientists, and policy makers.

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10 Appendix

(1) SoilCultures - the adaptive cycle of agrarian soil use in Central Europe. An interdisciplinary study using soil scientific and archaeological research.
(2) BodenKulturen - die Bodennutzung in Mitteleuropa im Wandel der Zeit.
(3) Allotment gardening in Southwest Germany - a comparative analysis of motivations and management practices
(4) Archaeopedology and chronostratigraphy of colluvial deposits as a proxy for regional land use history (Baar, southwest Germany).
(5) Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory - A Case Study from the Western Baar, SW Germany.

Manuscript 1

SoilCultures – the adaptive cycle of agrarian soil use in Central Europe. An interdisciplinary study using soil scientific and archaeological research.

Accepted by Ecology and Society on September 13th, 2017.

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Abstract

Today's global challenges, e.g. food security, are not unprecedented in human history. Starting with the Neolithic Transition, the agricultural sector and society underwent several cultural and technological changes and endured natural challenges. These challenges and changes are analyzed by using the adaptive cycle metaphor and the social-ecological system as tools to show the complexity of human-environment interactions and their development. The analysis relies on archaeological, pedological and botanical research, demonstrating the importance of interdisciplinary work. The agricultural system as a social-ecological system persisted in Central Europe for 7000 years and underwent an adaptive cycle from the Neolithic Transition to Industrialization. With agriculture's mechanization, a second adaptive cycle started. The resilience of agrarian soil use for thousands of years shows that agriculture, as a human-environmental interaction, is adaptive to change. Understanding past agricultural challenges and changes using archaeological and soil scientific data puts the present development into a new perspective. A cultural perspective on soils might trigger soil protection and sustainable land use in a technical as well as political domain. Applying social-ecological system and adaptive cycle concepts to this interdisciplinary reconstruction of agrarian soil use illustrates their usefulness for archaeology and soil science.

Key word: adaptive cycle; agriculture; archaeobotany; archaeology; historical overview; social-ecological system; soil science

Introduction

Global climate change, degradation and erosion of soils as well as rising social inequality and food insecurity comprise today's major human challenges (Tilman et al. 2002, Blum and Eswaran 2004, Luterbacher et al. 2004, Battisti and Naylor 2009, Lal 2010, Foley et al. 2011). Studies of past human-environment interactions show that these are not unprecedented in history (Costanza et al. 2007, Caseldine and Turney 2010, Büntgen et al. 2011). Agriculture, as a system based on human-environmental interaction, also has an impact on societies and the environment in Central Europe since its origin and spread from the Near East around 9500 BCE (Evans 2012).

The development of the agricultural system is analyzed using the concepts of the adaptive cycle and the social-ecological system (Gunderson and Holling 2002). The adaptive cycle is repeatedly used in research, e.g. on the bioenergy sector in Northern Germany (Grundmann et al. 2012) or on the resilience of two contrasting social-ecological systems (Carpenter et al. 2001). Dorren and Imeson (2005) used it to develop a framework on soil erosion for Southern Limburg. Beier et al. (2009) investigated Forest Management in Alaska, and Allison and Hobbs (2004) expanded the use of the adaptive cycle to economics in their analysis of the Western Australian Agricultural Region. Zimmermann (2012) used a specification of the adaptive cycle to improve the understanding of mobility structures in prehistoric Europe. These examples show dynamic social-ecological systems, and demonstrate that the adaptive cycle is a useful tool to investigate the development of such systems.

In the following, agrarian soil use as a social-ecological system will be introduced and analyzed using the adaptive cycle metaphor. Due to limited written sources for prehistoric times, the analysis focuses on archaeological, pedological, palynological and historical records that have been published by scientists of the respective disciplines. The aim is to investigate changes in agrarian soil use observable for the variables soil, crop and technology. Is the adaptive cycle useful to explain changes over several thousand years? What major changes led to a restructuring of the social-ecological system? Are the developments in the Neolithic comparable to Industrialization? If so, are there implications for soil use in the future?

Agrarian Soil Use as a Social-Ecological System

A social-ecological system (SES) is characterized by the integration of natural and social components (Berkes and Folke 1998, Berkes et al. 2003, Berkes 2004). SESs shape the world, and to understand them, it is necessary to split the bigger systems into smaller parts. However, the smaller systems remain part of other SESs. The present analysis focuses on agrarian soil use as a SES, which is part of a bigger SES and in turn can be broken up in smaller SES on any temporal or spatial scale. The adaptive cycle metaphor (Gunderson and Holling 2002) is used as a theoretical framework for the narrative of agricultural history in Central Europe.

The main variable of the SES agrarian soil use is soil, which has been used agriculturally since the Neolithic Transition. This use, or more precisely deforestation, has led to changes in the landscape and soil through erosion and accumulation processes. Under forests, the natural vegetation in Central Europe, erosion is minor because the roots of the vegetation stabilize the soil, preventing its erosion, and the canopy slows the rainfall (Pimentel and Kounang 1998, Geißler et al. 2012). Thus, the erosion and accumulation of soil material is connected to changes in the vegetation cover. Prior to the Neolithic transition this is related to climate events (Dreibrodt et al. 2010a). After the Neolithic transition, land use change induced by humans led to erosion and the development of so called colluvial deposits on foot slopes (Lang 2003, Leopold and Völkel 2007). The original reason of deforestation, e.g. clearance for fields or overgrazing, is difficult to determine, however, the analysis of colluvial deposits with 14C- and luminescence dating, archaeobotanical, and soil scientific research methods gives insight into the past (Eckmeier et al. 2007, Kadereit et al. 2010, Bogaard et al. 2013, Bakels 2014, Pietsch and Kühn 2014, Henkner et al. 2017). In international literature, the term colluvial deposit is unclearly connected to land use. Hereafter, the term anthropogenic colluvium will be used when referring to soils, which studies suggest to have formed due to land use change and agriculture.

Other variables of the SES agrarian soil use are climate and crops. Changes in crop plants are observable via archaeobotanical analyses (Rösch 1996). Crop refers to cereals, i.e. barley, wheat, rye, etc., and excludes fruit, vegetables and nuts. Climate change can be traced in ice cores, lake and ocean sediments, corals, tree rings, fossil leaves and changes in pollen communities (Caseldine and Turney 2010, Aranbarri et al. 2014). The effect of climate on the settlement pattern of a region is discussed by experts (Berglund 2003, Zolitschka et al. 2003). While it is likely that climate change had an impact on agricultural practices, the extent is not visible in the archives available for prehistoric times. Even with written sources, these refer to weather events and not climate per se. Therefore, climate effects on the SES agrarian soil use will not be considered here.

The observable variable concerning society is the technological development of tools. The variable knowledge is difficult to define for times when no written sources exist. It is assumed here that technological development is accompanied by an increasing knowledge. Knowledge/technology are used as one variable, which is traceable in archaeological finds.

Thus, as detailed above, this study focuses only on observable variables that can be appropriately analyzed in the SES agrarian soil use, specifically soil, crops, and technology.

The adaptive cycle of the SES agrarian soil use

The adaptive cycle was developed to explain ecosystem dynamics. It is composed of four phases, the r-phase of exploitation, the K-phase of conservation, the Ω-phase of release or creative destruction, and the α-phase of reorganization (Holling et al. 2002a, Holling and Gunderson 2002). This cycle is shaped by three properties: the potential of a system for change, the degree of connectedness between internal variables and processes, and the adaptive capacity of a system, its resilience as a measure of its vulnerability to unexpected shocks (Holling 2001). Holling and Gunderson (2002) state that the α-phase starts a process of reorganization during which potential and resilience are high but connectedness is low. During the r-phase resilience remains high and connectedness low. In the K-phase connectedness increases while resilience decreases. The system becomes more vulnerable to disturbance. Due to this vulnerability, a disturbance can cause creative destruction in the Ω-phase in which potential is low. The sudden shift from Ω- to α-phase leads to a new cycle with loose connections, high resilience and an increasing potential. In this phase, different recombinations are possible making the outcome of the reorganization unpredictable (Holling and Gunderson 2002).

The adaptive cycle shows that systems are dynamic. The SES agrarian soil use developed over time and while some processes led, for example, to a deterioration of soil properties, overall development enabled the SES to grow and diversify. With the help of the adaptive cycle narrative, the emergence of our present-day agricultural system is analyzed. Changes of or within the variables of the SES affect the adaptive cycle that shape the SES and determine its resilience or vulnerability to unpredictable shocks (Holling 2001).

The variables analyzed are soil, crops and knowledge/technology. Soil formation is a slow and complex process (Stockmann et al. 2014) and soil is therefore a slowly changing variable. However, erosion events can be fast and lead to abrupt changes of the variable concerning its further use (Auerswald et al. 2009). The anthropogenic colluvial deposits are used as archives of land use. The slowly changing variable crop affects the SES through the introduction of new crops, visible in archaeobotanical records (tab. 1, organized chronologically from Neolithic to Modern Times). The variable knowledge/technology influences the SES through fast changes implemented by humans, traceable in the archaeological record.

Societal changes, environmental factors or a combination of both can lead to disturbances of the SES resulting in a reorganization of the system. After the disturbance and release, the system is reorganized and a new phase of exploitation starts.

The SES agrarian soil use underwent one adaptive cycle from the Neolithic Transition to the Industrial Revolution (fig. 1). Through the use of soil, the introduction of crops and new agrarian tools during the Neolithic Transition, people settled down and produced higher food quantities (Childe 1936, Holling et al. 2002b). The Industrial Revolution marks the beginning of a second adaptive cycle with the industrialization of agriculture and food production, simultaneously changing society by increasing the work force of the secondary and tertiary sector. In between those two r-phases, the majority of society practiced agriculture (Evans 2012). The main crops of Central Europe remained similar to the ones introduced during the Neolithic, with the exception of potato or maize, introduced after the "discovery" of the American continent during the K-phase (Hawkes and Francisco-Ortega 1993, Rösch 1998, Rebourg et al. 2003). The soil cultivation depended on man and animal labor. The technology improved from the spade to the ard to the plow during the r-phase. While there was a succession of agricultural improvements, this development is similar to the r- and K-specialists that settle in a new habitat, as described by Holling and Gunderson (2002). Furthermore, Fath et al. (2015) state, that in social systems many small scale adaptive cycles occur during the r- and K-phase of a bigger adaptive cycle, resulting in a prolonged K-phase of continued development and influencing the interplay between fast and slowly changing variables. Fath et al. (2015) introduced a refined concept, consisting of the r-, K-, Klim-, Ω- and α-stage, and applied that to business management. The r-stage has innovations, provides the possibility to test the innovations, and the spirit is entrepreneurial. In the K-stage, knowledge on best practices exist, and the previously established standards are accepted. In the added Klim-stage, crisis plans come into action, which need technologies and cooperation to implement them. In the Ω-stage, improvisation is important and access to a minimum of resources is required, while new actors and new knowledge need to be accepted. In the subsequent α-stage experimenting and development of prototypes is a key competence, which requires certain resources and a willingness to try new paths (Fath et al. 2015). If this is applied to the adaptive cycles of agrarian soil use, it can be shown, that the r-phase of the first and the second adaptive cycle of agrarian soil use indeed was shaped by innovations and entrepreneurial or experimental spirit. In the following K-phases, the previously introduced innovations are accepted and best practice methods develop, e.g. the development and continuous use of the plow throughout the millennia. The Klim-stage could be represented by the development of motorized agrarian tools during industrialization, to facilitate work and free the workforce for the growing industry. In the Ω-stage, the new machines were accepted and in the α-stage experimenting with the new technology occurred and new pathways of agrarian soil use were explored. Further, the development of new tools during the first adaptive cycle was accompanied by smaller adaptive cycles within the social system, which in turn prolonged the K-phase of the big adaptive cycle agrarian soil use. In the sections that follow, the terminology of Holling and Gunderson (2002) will be used, excluding the Klim-stage of Fath et al. (2015). However, there will be references to the latter.

Analysis of the SES agrarian soil use in Central Europe

Beginning approximately 40,000 to 45,000 years ago the anatomically modern humans replaced the Neanderthals in Europe (Mellars 2004, Pinhasi et al. 2012, Hublin 2015). When the ice shields retreated after the Late Glacial Maximum (Hughes and Gibbard 2015), a new α-phase of the ecological system started with plant species and fauna spreading into the now ice-free space (Holling and Gunderson 2002), where soil formation processes started (Terberger et al. 2004). The adaptive cycle was influenced by climatic changes, and different species occupied these areas during the Early Holocene including hunter and gatherer populations (Bos 2001, Tinner and Lotter 2001, Crombé et al. 2011, Giesecke et al. 2011). During the Mesolithic, hunting and gathering was the subsistence form of life (Uerpmann 2007, Bailey and Spikins 2008, Tolksdorf et al. 2009, Prummel and Niekus 2011); the impact on the soil remained small. When humans settled down and developed agriculture, they influenced the adaptive cycles of local ecosystems and the SES agrarian soil use began.

The r-phase of the adaptive cycle: The Neolithic transition in Central Europe:

Agriculture and agrarian soil use spread from the Near East (Davison et al. 2006, Tresset and Vigne 2011). The time of the Neolithic Transition varies throughout Europe (Ammerman and Cavalli-Sforza 1971, Gkiasta et al. 2003, Coward et al. 2008). Several approaches exist on how this transition took place, e.g. people practicing agriculture moving in (demic diffusion) or spreading of the agricultural idea (cultural diffusion) over the continent (Haak et al. 2005, Davison et al. 2006, Larson et al. 2007, Gronenborn and Petrasch 2010, Lemmen et al. 2011, Zvelebil et al. 2012, Brandt et al. 2015). Whether demic or cultural diffusion happened, with the Neolithic Transition the SES agrarian soil use began. The Neolithic transition marks the onset of the reorganization (α-phase) and the start of the r-phase of the SES agrarian soil use in Central Europe (fig. 1). The SES variable soil became important to the sedentary people. They cleared forests for timber, fuel and fields, changing the water and nutrient cycles, and influencing soil formation processes (Bork et al. 2006, Kaplan et al. 2009, Gerlach and Eckmeier 2012, Ellis et al. 2013). On slopes, the clearing of forests led to erosion and the subsequent formation of anthropogenic colluvium in valleys and depressions along slopes (Leopold and Völkel 2007, Houben 2012, Mitusov et al. 2014). With the beginning of the Neolithic, an increase of slope deposits is visible in Central Europe (Dreibrodt et al. 2010b), e.g. at the Wetterau, Central Germany (Houben et al. 2013), and at Albersdorf, Northern Germany (Reiß et al. 2009). However, anthropogenic colluvial deposits dating to the Neolithic remain scarce, maybe because erosion was not widespread or because they were redeposited (Zolitschka et al. 2003) or later soil formation processes altered them. However, erosion events are also traceable in lake sediments, e.g. at Lake Belau, N. Germany, dating to the middle Neolithic (Dreibrodt et al. 2010b).

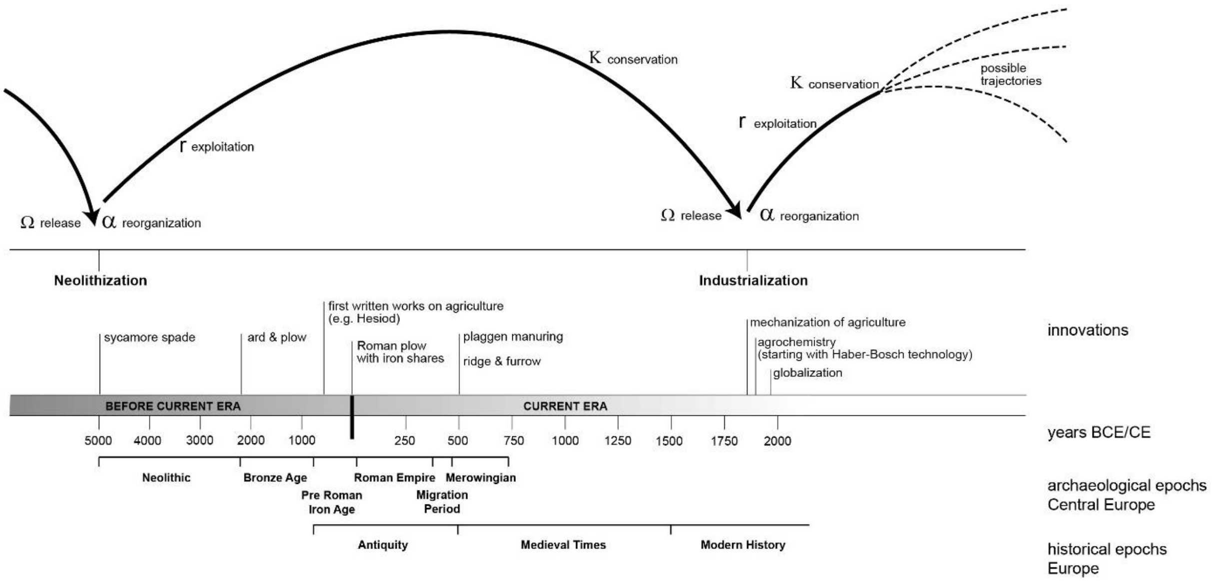

Fig. 1: The adaptive cycles of agrarian soil use in time, modified from Holling (2001) and Gronenborn et al. (2014).

The SES variable crops emerged during the Neolithic (tab. 1). Archaeobotanical analyses show a vegetation change with sedentariness (Rösch 1987). Most of the crops domesticated in the Near East arrived in Europe with the Linear Pottery Culture and the Funnel Beaker Culture (Bakels 2014). The crops grown are similar in all Central European regions (Coward et al. 2008), with einkorn, emmer, wheat and barley being most common (Herbig 2009, Bogaard et al. 2011, Bogaard et al. 2013). Domesticated animals were also present in Central Europe (Doppler et al. 2015).

The knowledge/technology variable of the SES is indirectly visible by archaeological findings: near Cologne, an excavated well of the Linear Pottery Culture revealed a spade made out of sycamore that dates to 5057 BCE (Mueller 2015). The spade is one of the earliest finds concerning soil cultivation, with the Linear Pottery Culture being the initial phase of the Neolithic (5500–2200 BCE) in Central Europe (Price et al. 2001, Eggert and Samida 2013). Another well excavated at the Baltic Coast of Northern Germany revealed Middle Neolithic artefacts, and archaeobotanical studies indicate agricultural land use (Brozio et al. 2014). The well was used during the Funnel Beaker Culture (4100–2800 BCE), the first sedentary culture in northern Germany (Kirleis et al. 2012, Brozio et al. 2014, Whitehouse and Kirleis 2014).

Soil quality and the proximity to fresh water seem to have been relevant for the settlement of regions (Lüning 2000, Rösch et al. 2002, Zolitschka et al. 2003, Fries 2005, Davison et al. 2006, Banks et al. 2013, Brozio et al. 2014). During the Neolithic, the SES agrarian soil use was in the r-phase of exploitation by transforming the landscape to adjust it to the new human needs connected to sedentariness. The arrival of the crop plants, the development of tools and the onset of erosion show the emergence of the SES agrarian soil use. However, during this phase of the general SES agrarian soil use Gronenborn et al. (2014) propose that the Linear Pottery Culture underwent an entire adaptive cycle. This demonstrates that the adaptive cycle consists of different spatial and temporal scales that influence the system as a whole, also taking into account the smaller and faster cycles within social systems that influence the variables of a bigger adaptive cycle (Fath et al. 2015). The adaptive cycle of the Linear Pottery Culture had an influence on the SES agrarian soil use but the changes within this cycle did not lead to an alteration of the SES itself.

After the Neolithic Transition, the SES agrarian soil use remained in the r-phase through Bronze and Iron Age. Plow marks in the soil, excavated ards in Northern Italy and East Frisia, as well as rock carvings in Northern Italy and Sweden, show new agricultural methods and tools (Schultz-Klinken 1981, Tegtmeier 1993, Egg and Pare 1995, Fries 1995, Behre 1998, Zich 1999). The use of metal started with the Bronze Age (2200–800 BC) and continued through the pre-Roman Iron Age (800–15 BC), which consists of the Hallstatt and the La Tène period (Eggert and Samida 2013). Main innovations are sickles during the Bronze Age and scythes during the Iron Age (Jockenhövel 1994, Egg and Pare 1995). The use of metal shows a technological development and an assumed increase of knowledge, leading to mining activities that exploited previously unused natural resources, e.g. in the Black Forest, SW-Germany (Gassmann et al. 2006). The change of the knowledge/technology variable is seen as a development from spade to ard to plow, that can be explained using the approach of Fath et al. (2015), that several small scale adaptive cycles can affect the r- and K-phase of a bigger cycle. However, this knowledge did not develop due to agrarian soil use but was used in an agricultural context later: the late La Tène hoard of Bad Buchau-Kappel in South Germany shows the diversity of iron objects with pliers, knives, sickles, scythes, etc. (Jockenhövel 1993), tillage tools were not found. In the agriculturally important hoard in Urach, Southern Germany, plow-shares were also absent (Fries 1995). The ards of the type Døstrup, found in Denmark, were used during pre-Roman Iron Age for soils under tillage, while the Walle type ard was used to break up formerly unused soils (Fries 1995). The latter and Early Iron Age ard shares found in the Netherlands (Sanden 1994) point to similar tillage practices in the Bronze and Iron Ages. The results show that metallurgy developed but was not initially used for agricultural purposes. However, in the Bronze Age cattle traction was established and used for pulling the ard or carts (Bartosiewicz 2013), e.g. facilitating soil cultivation.

The SES variable crops changed little from Neolithic to Bronze and Iron Age (tab. 1). However, the soil variable shows an increase of anthropogenic colluvial deposits at the beginning of the Bronze Age and again in the Iron Age (Dreibrodt et al. 2010b). Bronze Age anthropogenic colluvial deposits were found at Albersdorf, Northern Germany (Reiß et al. 2009), at the Frauenberg in Bavaria (Lang et al. 2003) and at the Wetterau, where colluviation also happened during the Early Iron Age (Houben et al. 2013). Turbidites in Black Forest lakes also begin in the Bronze Age (Rösch and Tserendorj 2011). The reason for the increased anthropogenic colluviation could be more settlements or increased deforestation for fuel purposes for metallurgy.

Research on Celtic fields in the Netherlands indicates an intensive agricultural system in the late Iron Age with shorter fallow periods, higher manuring intensity and changes in tillage practices (Spek et al. 2003). The change of management practices and the development of the Celtic fields shows a further development of agriculture (Jankuhn 1977). However, we argue that the SES agrarian soil use remained in the r-phase of exploitation. According to the adaptive cycle proposed by Holling and Gunderson (2002), the creative destruction and reorganization is a fast process. In the archaeological record, in pedological studies and in palynology, changes are observable. However, these changes are slow, happening over centuries rather than decades. They can be interpreted as tests of the new innovations, which are characteristic of the r-phase (Fath et al. 2015), with entrepreneurial spirit leading to evolving management practices using the innovations. The use of metal indicates a greater knowledge of metallurgy and facilitated work, e.g. bronze sickles and scythes for harvesting. However, the tools used for tillage probably remained similar to the ard found in Walle, East Frisia that dates to the Bronze Age as the ard shares in the Netherlands suggest (Schultz-Klinken 1981, Sanden 1994, Behre 2000). The development of these tools can be seen as a smaller adaptive cycle that occurred in the SES metallurgy and affected the SES agrarian soil use.

Transition to the K-phase: conservation of agriculture in Central Europe

In Antiquity, knowledge concerning agriculture was written down and documented. Greek and Roman scholars wrote the first European literary works on agriculture. Among them were Hesiod's „Érga kaì hemérai", Cato's „De agri cultura", Varro's „Res rusticae" and Columella's „De re rustica" (quoted from Winiwarter 2006). These works were mainly written for the owners of latifundia, i.e. large landowners (James et al. 2014). Columella described a test to determine soil fertility: after digging a hole, the dug soil was refilled. If the soil formed a mound, the soil was fertile; if the refill formed a hollow the soil was poor (McNeill and Winiwarter 2004). This approach tests the aggregate stability of a soil, which depends on soil texture, soil organic matter, biological activity and the mineral content of a soil. The texts show that the SES agrarian soil use moved toward the K- or conservation phase (fig. 1), with changes within smaller and faster sub-systems influencing the adaptive cycle (Fath et al. 2015). The traditions and land management practices were written down and the importance of “good” practices was stressed. However, it is important to note, that the knowledge documented in the literary works of the agrarian writers might not have been applied to agriculture north of the Alps (Deschler-Erb and Akeret 2011), necessitating historical, archaeological, palynological and pedological analyses to understand former land use changes.

During the Roman period, Central Europe underwent different developments. In the South and West, the Romans controlled the provinces Germania inferior and superior as well as Raetia (Ausbüttel 2011). The Roman influence led to the establishment of villae rusticae, Roman forts and towns (Heiligmann 1996, Wilson 2006). A villa rustica is an agrarian production center (Groot and Deschler-Erb 2015) and e.g. in Bavaria, Germany the production area belonging to one villa was approximately 50 ha (Leopold et al. 2010). In present-day South Germany, villae rusticae were usually established along the Roman roads, which made new areas accessible (Humpert 1995, Kerig and Lechterbeck 2004, Fingerlin 2008). For the area north and east of the Limes, there are few written sources, e.g. Caesars “de bello gallico” or Ptolemaios “Geographike Hyphegesis” (Nüsse et al. 2011). It should be noted, that those descriptions might reflect stereotypical depictions of barbarians (Erdrich 2001). The written sources show a Roman viewpoint, which is in itself valuable, but to understand the SES agrarian soil use and its adaptive cycle, we need to consider all variables. Therefore, interdisciplinary approaches are used, such as the study of the Vecht river valley, located in the present-day Dutch-German border area (van Beek and Groenewoudt 2011). Archaeobotanical analyses show a continuation of the crop variable (tab. 1). In SW-Germany, spelt was the most common crop (Rösch 2009).

Analyses at Lake Belau in Schleswig-Holstein and Lake Holzmaar in Rhineland-Palatinate (Dreibrodt et al. 2010b) show the contrast of the soil-variable between the two regions. While at Lake Belau soil erosion increased during pre-Roman Iron Age and decreased during the Roman period, leading to a slower input of material into the lake; the situation at Lake Holzmaar is different: the input of material during the period of the Roman Empire was greater than in the pre-Roman Iron Age (Dreibrodt et al. 2010b). Anthropogenic colluvial deposits dating to Roman times are also found at the Kaiserstuhl, SW-Germany (Mäckel et al. 2003). This shows how difficult it is to reconstruct general agricultural practices for Central Europe for that period. Furthermore, the increasing need for building material resulted in deforestation with its maximum extent around 250 CE (Büntgen et al. 2011), which affects soil erosion processes.

Agricultural technology was developed during Roman times leading for example to the use of iron in spades. In present day Germany, spades were found that date to the 1st to 3rd century and were fully made of iron (Mueller 2015). In Gallic provinces a plow with two small wheels pulled by 4-6 oxen was used (Schneider 2007). Virgil described the “Roman plow” around 1 CE, which had iron shares (Lal et al. 2007). The further development of existing tools and the existence of written sources concerning the agricultural practices indicate the K-phase where connectedness increases, including knowledge and technology needed for successful agriculture. The variable soil shows erosion and colluviation processes. However, agrarian soil use is still connected to animal and man power with similar tools. These tools have been improved but no invention happened that altered the actual practice of agrarian soil use.

The K-phase continued during Medieval Times (500–1500 CE), an epoch that comprises many different dynasties, societal and regional developments (Fried 2009). In Medieval Times, the texts of the Roman agricultural writers were still copied. Further, Isidore of Seville wrote a short encyclopedia, discussing plowing sequence and manuring, and Walafrid Strabo wrote a poem about 24 garden plants (Winiwarter 2006). This shows that certain groups of people wanted to conserve and improve the knowledge of agricultural practices, indicating the K-phase of the adaptive cycle. However, agricultural practices seem to have relied on traditional practices, which were not necessarily related to the documented knowledge (Dotterweich 2013).

It is suggested that rye became a crop plant during the Medieval period, even though traces of rye were found dating to the Neolithic (Behre 1992). The proportion of the different crops changes over time and from region to region, but the plants used are the ones introduced in the course of the Neolithic/Bronze/Iron Age/Roman Period (tab.1).

The soil variable was slowly treated differently, because fertilization became increasingly part of agriculture during Medieval Times (Behre 2000). Furthermore, the variables soil and knowledge/technology became interconnected. Plaggen-manuring was practiced in Northern Europe, ridge and furrow was prevalent (Behre 1976, Blume and Leinweber 2004, Haasis-Berner 2012, van Mourik et al. 2012), traces of which are found in the landscape today. For plaggen-manuring the topsoil of adjacent areas was cut and distributed on the agricultural fields, leading to the development of heath in the cutting areas while enabling the cultivation of winter rye on the fields (Pape 1970, Behre 2000). The ridge and furrow developed due to the change from the ard to the moldboard or heavy plow, which turned the soil in one direction towards the middle of the field, and permitted agriculture on heavy clay soils (Seidl 2006, Haasis-Berner 2012, Andersen et al. 2016). The micro-relief of the ridge and furrow fields enabled agricultural success in dry and moist years. On the ridge, harvest was good even in years with a lot of rainfall, while the furrow provided enough water during a dry year (Linke 1979). The three field system, growing two crops alternating with fallow, also spread and is observable in the archaeobotanical record (Rösch et al. 1992).

Erosion and colluviation increased during Medieval Times (Zolitschka et al. 2003, Dreibrodt et al. 2010b, Henkner et al. 2017). Mining activities led to a rapid deforestation but also to new regulations prohibiting forest clearing in certain areas (Steuer 1993). Deforestation for agricultural purposes continued, leading to erosion and the formation of anthropogenic colluvial deposits, e.g. in SW-Germany in the Kraichgau dating to 980–1330 CE (Kadereit et al. 2010) or in the Black Forest around the Krumpenschloß between the ninth and 15th century CE (Knopf et al. 2012). In the area of Göttingen, several refilled gullies were discovered in the 1950s (Bork 2006). Research suggests that in 1342, a heavy precipitation event in Central Europe caused erosion in the low mountain ranges that led to the formation of gullies, which were later refilled by pedosediments (Bork et al. 2006). This is supported by a study at the catchment of Lake Belau in Schleswig-Holstein (Dreibrodt 2005) and another study at the Wolfsgraben, Bavaria (Dotterweich et al. 2003, Schmitt et al. 2003). Investigations at the Frickenhauser See, Bavaria, show that between 1000 and 1870 CE intensive soil erosion took place (Enters et al. 2006). These archives thus show an intensification of land use. However, humans still practiced agriculture with the help of tools and animals used for traction, the SES agrarian soil use was not reconstructed as such but remained in the K-phase.

Soil erosion increased again during the 18th century (Dotterweich 2013), after a phase of land abandonment at the end of the Medieval Times (Dreßler et al. 2006, Fraser 2011), which might have happened due to a combination of erosion, crop failure and the plague. Extreme weather events were documented (Dreibrodt et al. 2010b), e.g. the flood of 1783/84 appeared in newspapers, letters and was recorded by meteorological stations across Central Europe (Brázdil et al. 2010). Analyses of sedimentation rates of the river Rhine’s catchment show increased sedimentation in floodplains and formation of anthropogenic colluvial deposits (Hoffmann et al. 2009).

During the 19th century, the scientific analysis of soil increased. Albrecht Daniel Thaer, Justus von Liebig, Charles Darwin and Vasilii V. Dokuchaev wrote their important works on soils (Liebig 1841, Thaer 1880, Darwin 1890, Evtuhov 2006). Thaer focused on agriculture and the relevance of humus and crop rotation (Feller et al. 2003b), Liebig tried to develop a mineral fertilizer (Montgomery 2010). Darwin focused on the formation of humus and the importance of worms (Brown et al. 2003, Feller et al. 2003a, Feller et al. 2006, Brevik and Hartemink 2010). Dokuchaev introduced the soil profile dividing it into A-, B-, and C-horizons, and stressed that soils should be seen as an independent research object (Evtuhov 2006, Brevik and Hartemink 2010). These works show that the variable soil had become a research topic. The variable knowledge was increasingly interlinked with the practical soil use, at least considering the landowners, not necessarily the peasants. The increasing knowledge eventually led to the development of new tools, which resulted in the creative destruction and reorganization of the SES agrarian soil use.

The Ω- and α-phase of the SES agrarian soil use and the beginning of a new cycle

With industrialization, the SES agrarian soil use moved through the Ω-phase of creative destruction and the α-phase of reorganization (fig. 1). The different variables changed considerably.

A change of the knowledge/technology variable is observable in new machines, but also resulted in global societal changes. Technological advances, such as the invention of the steam engine led to motorization and mechanization of agricultural practices (Bergmann 1970, Gessner 1976, Hahn 2011). The machine manufacturer Fowler invented the plowing engine (Seidl 2006), and the blacksmith John Deere marketed a plow that grew in importance with the invention of the tractor (Lal et al. 2007). Increasing knowledge and technology led to new fertilizers. Industrialized nitrogen production using the Haber-Bosch technology increased cereal yield in Germany between 1918 and 1938 by app. 50% (Niedertscheider et al. 2014). These developments were closely connected to the use of fossil fuels (Schumacher 1993). The use of new technologies changed the strong link between agriculture and animal husbandry, because animals were no longer needed for traction and manure (Lambin et al. 2001). Traditional crop rotation practices and fallow were also abandoned due to cheap nitrogen availability (Montgomery 2010). This development marks the r-phase of exploitation where growth is accomplished with new efficient technologies. The innovations are tested and entrepreneurial spirit dominates, as proposed by Fath et al. (2015). It also starts the process towards a knowledge-based society, which influenced the agricultural sector (Uekoetter 2012), and raised the work force in the secondary and tertiary sector (Hahn 2011), leading additionally to urbanization (Antrop 2004) and globalization (Robertson 1992, Levitt 1999). The global trade involves among others food, fertilizer, fodder, raw material needed for agriculture and agrarian technology. Information exchange is enabled by the internet and relatively cheap transportation. This global development means that we can no longer consider regional practices when analyzing the SES agrarian soil use.

The SES variable crop changed with the introduction of genetically modified organisms and the widespread use of pesticides, herbicides and fungicides. Fewer crop plants are used in agriculture today. The crops variable is closely related to the knowledge variable of society because genetically modified organisms developed through human interference (Tiedje et al. 1989, Anklam et al. 2002). Furthermore, society today depends on few crops, namely wheat, rice and maize (Cassman 1999), e.g. Triticum aestivum became the dominant crop in 1920s SW-Germany (Rösch et al. 1992). Monocultures of such crops are a new phenomenon, e.g. rice (Shen et al. 2004).

The soil variable is still prone to erosion but also to other forms of degradation such as compaction and nutrient depletion. Soil erosion increased with changes of plowing intensities due to bigger and more powerful machines, and the heavy machinery enhances soil compaction (Lal et al. 2007). In Europe, an erosion rate of more than 1 t ha-1 y-1 is regarded as unsustainable (Verheijen et al. 2009). Today, erosion in Europe ranges between 3 and 40 t ha-1 y-1, impairing the soil's productivity, which is becoming more important as the global population grows (Verheijen et al. 2009).

Another soil related aspect of the new adaptive cycle is the increase of global fertilizer use by 700% in the last 40 years (Foley et al. 2005), leading to changes in the N- and P-cycles (Smil 1999, 2000). While N can be generated using the Haber-Bosch method, most of the P used in agriculture is of phosphate rock origin and non-renewable. The mining of these reserves, mostly located in China, the USA and Morocco, has tripled since World War II (Cordell et al. 2009) and there has been a global increase of 20 % in P-fertilizer use between 2000 and 2008, (MacDonald et al. 2011). Losses of P and N affect off-site ecosystems, e.g. eutrophication of lakes and marine ecosystems, and influence global warming and biodiversity, e.g. through N2O, NO, NO3 and NH3 (Tilman et al. 2002, Lal et al. 2011). The C-cycle also changed with the dependency on fossil fuels, leading to an increase of atmospheric greenhouse gases from 280 ppm CO2-equivalent at the beginning of industrialization to 430 ppm in 2005 (Falkowski et al. 2000, Aertsens et al. 2013). Present fertilizer production relies on fossil fuels and contributes to the CO2 emissions, as does the use of agricultural machinery, land use change in form of deforestation, and fertilization (Canadell et al. 2007, West et al. 2010).

The dependence on fossil fuels indicates a growing rigidity of the SES, which would point towards the end of the K-phase of the adaptive cycle. However, innovative concepts combine the use of new technology and knowledge with alternative or traditional agricultural practices, e.g. carbon sequestration in soils. Agroforestry, hedgerows, low or no tillage and cover crops affect erosion, biodiversity, nutrient leaching, soil organic matter and C-sequestration (Aertsens et al. 2013). This points toward the small and fast adaptive cycles influencing the big adaptive cycle agrarian soil use and exploring alternative pathways to the challenges of the present. However, the global cropland under no-till is only 9% (Lal 2013). In present-day Germany, no-tillage is practiced on 1463 km², equaling 1.3%, while on 110775 km² conservation or conventional tillage is used (Statistisches Bundesamt 2016). This shows that even in a highly industrialized country, with rapidly increasing knowledge, no-till is only practiced by few. This supports the suggestion that we are in the K-phase of conservation because the majority of agrarian soil use depends on mineral fertilizers and tillage practices with big machinery. Whether a new Ω-phase is approaching depends on today's decisions.

These rely on studies conducted by different scientists, e.g. concerning the functioning of the N-cycle. A long-term field study in France showed, that cover crops reduced N-leaching, while no-till did not result in a significant N sequestration (Constantin et al. 2010). A study in New Zealand showed, that the effectiveness of cover crops on preventing N-leaching depended on sowing dates and on soil type, and is influenced by weather variability (Teixeira et al. 2016). The results suggest that site-specific practices and holistic management approaches are necessary to develop the agricultural sector towards more sustainability. However, interdisciplinary approaches are needed to communicate these new findings to soil users and society in general, which might also pave the way to greater food security and equality worldwide (Godfray et al. 2010, Lal et al. 2011, Altieri 2012, Scholten 2014). Further, the development in the social component of the SES needs to be investigated in order to determine the effect of small and fast adaptive cycles on the big adaptive cycle of the SES agrarian soil use.

Tab. 1: Several archaeobotanical studies that investigated the crops used in Central Europe in (pre-) historic times. The crops are named according to the study cited.

author	period	region	analysis	crops identified in analysis
Bogaard et al. (2013)	Neolithic	Europe (examples in this table from Central Europe)	whole grains from the same stratigraphic unit	einkorn (Triticum monococcum), emmer (T. dicoccum), free-threshing wheat, naked barley (Hordeum vulgare), lentil (Lens culinaris), pea (Pisum)
Kirleis et al. (2012)	Neolithic	N-Germany	charred plant remains	(naked) barley (Hordum vulgare), emmer (T. dicoccum), einkorn (T. monococcum), naked wheat (T. aestivum)
Bogaard et al. (2011)	Neolithic	Vaihingen, Enz, Germany	chaff (glume base)	einkorn (T. monococcum), emmer (T. dicoccum), 'new type', opium poppy (Papaver somniferum), feathergrass (Stipa)
Herbig (2009)	Neolithic	Lake Constance/Upper Swabia, SW-Germany	archaeobotanical (profile columns, surface samples)	emmer (T. dicoccon Schrank), einkorn (T. monococcum L.), tetraploid naked wheat (T. durum Desf./turgidum L.), naked barley (Hordeum vulgare ssp. nudum), opium poppy (Papaver somniferum L.), flax (Linum usitatissimum L.), single finds of pea (Pisum sativum L.), lentil (Lens culinaris L.)

Rösch (1987, 1993)	Neolithic to Bronze Age	Lake Constance, SW-Germany	pollen analysis	naked wheat (T. aestivum/durum), barley (Hordeum vulgare L.), emmer (T. dicoccum), einkorn (T. monococcum L.), flax (Linum usitatissimum L.), opium poppy (Papaver somniferum L.), spelt (T. spelta), millet (Panicum miliaceum), pulses
Rösch (1996)	Late Neolithic to Bronze Age	SW-Germany	pollen analysis, charred plant macro remains	einkorn (T. monococcum), emmer (T. dicoccum), naked wheat (T. turgidum s.l.), barley (Hordeum vulgare), spelt (T. spelta), millet (Panicum miliaceum)
Kanstrup et al. (2014)	Neolithic to Iron Age	Denmark	charred archaeobotanical cereal remains, isotope analysis	emmer (T. dicoccum), spelt (T. spelta), naked barley (Hordeum vulgare, var. Nudum)
Hubbard (1980)	Neolithic to Medieval period	Europe	analysis of charred remains and pottery imprints	Barley (Hordeum vulgare), emmer (T. dicoccum & dicoccoides), einkorn (T. monococcum & bocoticum), millet (Panicum miliaceum), oat (Avena sativa & strigosa), wheat (T. aestivum s.l.), rye (Secale cereale)
Mäckel et al. (2003)	Neolithic to Medieval period	Upper Rhine Lowlands, S-Black Forest, SW-Germany	pollen analysis, evaluation of fossil soils	4000 BC: cerealia
Hjelle et al (2012)	Neolithic to Medieval period	Norway	pollen analysis, charred grains	charred grains of Hordeum vulgare (present from Late Neolithic to Early Bronze Age), cerealia pollen, mainly Hordeum type, but also Avena and Triticum type (Early Iron Age)
Behre (1992)	Neolithic to Medieval period	Central Europe	carbonized grains, pollen diagram	rye (Secale cereale) rare in Neolithic, increasing during pre-Roman Iron Age and Roman period and great increase in the Middle Ages
Wieckowska et al. (2012)	Neolithic to modern times	Großer Eutiner See, N-Germany	pollen analysis	Triticum- and Averna-type pollen, Secale (Iron Age onward), Hordeum (Iron Age onward)
Dreßler et al. (2006)	Neolithic to modern times	Lake Dudinghausen, N-Germany	pollen analysis	Hordeum, Triticum, Secale (Medieval period onwars) --> cereal pollen increased in Modern times

Rösch (1998)	Neolithic to modern times	SW-Germany	review	T. dicoccum, T. monococcum, Hordeum vulgare, T. aestivum/durum, T. spelta (minor in Neolithic but increase in Bronze Age), Secale cereale (minor in Neolithic but increase in Bronze Age), Panicum miliaceum (from Bronze Age on), Setaria italica (from Bronze Age on), Avena (from Bronze Age on), Oryza sativa (from Late Medieval period on), Zea mays (from modern times on), Linum usitatissimum, Papaver somniferum, Brassica rapa, Camelina sativa, Cannabis sativa (minor from Iron Age on), Pisum sativum, Lens culinaris, Vicia ervilia (few in Neolithic and in Iron Age), Vicia faba (from Bronze Age on), Vicia sativa (few in Roman and High Medieval times)
Rösch and Tserendorj (2011)	Bronze Age	Huzenbacher See, SW-Germany	pollen analysis	cerealia, secale (Medieval period)
Gauthier and Richard (2009)	Bronze Age	Lake Bourget, France	pollen analysis	cerealia
Stika and Heiss (2013)	Bronze Age	Europe	review	barley, emmer, einkorn, spelt, free-threshing wheat, millet, oat, rye
Dreslerova et al. (2013)	Bronze Age to Early Iron Age	Czech Republic	charred plant macro-remains	emmer (T. dicoccum Schübl.), barley (Hordeum vulgare L.), millet (Panicum miliaceum L.), spelt (T. spelta L.), later also naked wheat (T. aestivum L./compactum Host./durum Desf./turgidum L.), very low numbers of oat (Avena sativa L.) and rye (Secale cereale L.)
Kerig and Lechterbeck (2004)	Bronze Age to Medieval period	Lake Steisslingen, SW-Germany	pollen analysis	Triticum, Hordeum, Cerealia, rye (Iron Age)
Rösch et al. (1992)	Roman to post-Medieval period	SW-Germany, N-Switzerland	review	Roman Period (1st-3rd century A.D.): Panicum miliaceum, T. spelta, Secale cereale, Hordeum vulgare, T. aestivum, T. monococcum; in native Germania T.

				monococcum, Hordeum vulgare and Secale cereale Late Roman period (3rd-5th century A.D.): one site investigated on upper Danube with Hordeum vulgare, T. speta and Avena sp.; T. aestivum, T. monococcum and Secale cereale (less than 10 %) Merovingian period (6th/7th century A.D.): Avena sp., Hordeum vulgare, T. spelta, T. aestivum, T. monococcum, Secale cereale Carolingian-Ottonian period (8th-10th century A.D.): T. aestivum, T. spelta, Avena sp., T. monococcum, Hordeum vulgare and Secale cereale High Medieval period (11th-13th centruy A.D.): Secale cereale, T. spelta, T. monococcum, Avena sp., Hordeum vulgare, Panicum miliaceum, T. aestivum Early modern period (16th-19th century A.D.): Panicum miliaceum, Avena sp., Hordeum vulgare, T. aestivum, Secale cereale, T. spelta
Rebourg et al. (2003)	1493/1539	S-Spain/Germany	literature review, genetic markers	maize (Zea mays ssp. mays): several introductions
Hawkes and Francisco-Ortega (1993)	1567/1574	Gran Canaria/Tenerife	literature review	potato (Solanum tuberosum/Ipomoea batatas)
Cassman (1999)	1967-1997	global	harvested area	wheat (T. aestivum L.), rice (Oryza sativa L.), maize (Zea mays L.)

Conclusion

The adaptive cycle narrative is useful to examine the changes occurring in a social-ecological system (SES), such as the changes of the agrarian soil use SES over the last millennia. The narrative helps understanding changes of and within the SES over time while focusing on important variables, in the presented case soil, crops, knowledge/technology. This approach could also be important for archaeological and soil scientific research in general, as the concept of SESs and adaptive cycles can be applied to broader developments within social ecological systems, as shown in this study. It might also be used to connect individual case studies to international contexts.

The adaptive cycle of the SES agrarian soil use started with the Neolithic Transition and sedentariness. During the Neolithic, the Bronze and Iron Age the adaptive cycle was in the r-phase. Innovative tools and ideas developed which enabled the societies to successfully practice agriculture. With Antiquity, the SES moves into the K-phase, where the knowledge concerning agricultural practices is documented by written sources and best practice methods are determined. During the Medieval and Modern Times, the general knowledge and agricultural knowledge in particular increases. Furthermore, agricultural tools are improved by e.g. using iron in plow shares, thus incorporating the adaptive cycle of the SES metallurgy. With industrialization, the SES moves through the Ω-phase of release or creative destruction and the α-phase of reorganization. The SES changed considerably with the α-phase, leading to a separation of animal husbandry and arable farming and a new r-phase after the mechanization of agriculture. This is comparable to the establishment of agriculture in the Neolithic due to the big innovations that changed the SES. The Neolithic transition led to sedentariness, so that first settlements and probably new societal structures developed. The Industrial Revolution enabled a diversified society with more people working outside the agrarian business due to the innovations of the r-phase. The knowledge and technology variable are interconnected in both r-phases, e.g. in the development of the plow and the Haber-Bosch method. After industrialization and mechanization, agrarian soil use no longer means work of animals and men, but work of machines. This has new consequences for the soil variable, comparable to the consequences of deforestation, which subjected the soil to erosion after the establishment of fields since the Neolithic. The new impact on soil includes compaction, nutrient depletion, and other forms of soil degradation. The crops used in agriculture were first introduced in the Neolithic. They were used in different proportions during the last millennia. With industrialization, new genetically modified organisms were developed, connecting the variables crop and knowledge/technology. The crop variable underwent another change, as we depend on a limited variety of crop plants for nutrition today.

A difference between the two adaptive cycles is the speed of the transition from r- to K-phase, which lasted several millennia in the first cycle but happened in the course of decades in the second. The increasing knowledge of the first K-phase, which started with the Greek and Roman agricultural writers and culminated among others with Thaer, Liebig and Darwin, eventually had a vast effect on surplus production and technological development that resulted in a reorganization of the SES and the second adaptive cycle. The knowledge is still increasing steadily and technological development has led to a high-tech agribusiness, depending on computers, GIS, fertilizers and more. These new developments also affect the soil and crops used. To investigate these effects interdisciplinary work is needed, to ensure the resilience of the SES agrarian soil use without detrimental effects on soil, crops, knowledge/technology, and climate. These interdisciplinary studies should include various disciplines, among others soil science, sociology, anthropology, climatology, but also history and archaeology, to understand the past developments of and within a region. The SES and adaptive cycle could be used to structure the research in advance, due to the focus on specific variables, while also including the systems approach and acknowledging the connection between natural and social systems. Further challenges for these studies include that small scale and fast adaptive cycles in the social system need to be investigated in order to understand the development of the big cycle of agrarian soil use. As we are in the K-phase of the adaptive cycle, small and fast adaptive cycles in the social system will determine how long the system remains in the present phase. If innovations and traditions are combined and lessons from the past, e.g. concerning erosion, are learned, the new K-phase might last for an extended time. However, if this does not happen, a new Ω-phase might result in a reorganization of the system with an unknown outcome. The variety of possible responses to global, regional and local challenges requires scientists from different fields to investigate the different variables of the SES agrarian soil use to understand the processes and interactions between and within the variables. This might contribute to the resilience of the SES and lead to new policies on a global scale. Interdisciplinary research helped us understand the adaptive cycle of the SES from the Neolithic to Industrialization. It is also necessary to develop a resilient agrarian soil use for the future.

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Manuscript 2

BodenKulturen – die Bodennutzung in Mitteleuropa im Wandel der Zeit

Published in Wessolek, G. (Ed.) (2015): Von ganz unten - Warum wir unsere Böden besser schützen müssen. Oekom, 259-272.

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Einleitung

Deutschland ist heute ein Industrieland mit einem vielerorts von Städten geprägten Landschaftsbild. Von den insgesamt 81,8 Millionen Einwohnern lebten 2011 rund 62,9 Millionen in städtischen bis mittelstark besiedelten Gebieten. Nur 18,9 Millionen Menschen besiedeln den ländlichen Raum mit einer Bevölkerungsdichte von weniger als 100 Einwohnern pro Quadratkilometer.[1] Im Jahr 2012 gab es insgesamt 41,6 Millionen Erwerbstätige, wovon 10,3 Millionen im produzierenden Gewerbe, 30,6 Millionen im Dienstleistungsbereich und 0,7 Millionen in der Land- und Forstwirtschaft und der Fischerei beschäftigt waren.[1] Diese Zahlen zeigen, dass heute dem ländlichen Raum mit 23,1 Prozent der Bevölkerung eine verhältnismäßig geringe Bedeutung als Wohnort und Arbeitsstätte zukommt. Die Landwirtschaft spielt inzwischen bei der Erwerbstätigkeit eine völlig untergeordnete Rolle. In 2011 trug sie nur 0,9 Prozent zur Bruttowertschöpfung Deutschlands bei.[2]

Diese Sachlage indes gilt nur für die jüngere Vergangenheit. Viele Jahrhunderte arbeitete der Großteil der Bevölkerung Europas in der Land- und Forstwirtschaft und stand so täglich mit dem Boden und den darauf wachsenden Feldfrüchten in unmittelbarem Kontakt. Das Kultivieren von Böden und das alltägliche Leben waren eng miteinander verflochten. Diese »BodenKulturen« existieren insofern auch heute, als der überwiegende Teil der Nahrungsmittel nach wie vor durch Anbau auf natürlichen Böden erzeugt wird. Aber unsere Beziehung zum Boden hat sich geändert. Viele erleben und bezeichnen Boden als »Schmutz« oder »Dreck«[3] und haben den Bezug zu unserer Lebensgrundlage verloren. Wie ist es dazu gekommen?

Dieser Frage wollen wir uns widmen und stellen dazu die Entwicklung der Landwirtschaft und des Bodenwissens in Mitteleuropa in einen historischen Kontext. Anhand verschiedener geschichtlicher Ereignisse (s. Bild 63) wird nachverfolgt, wie sich die Landnutzung und das Verhältnis der Gesellschaft zum Boden immer wieder gewandelt haben. Der Schwerpunkt liegt dabei auf dem Gebiet des heutigen Deutschlands.

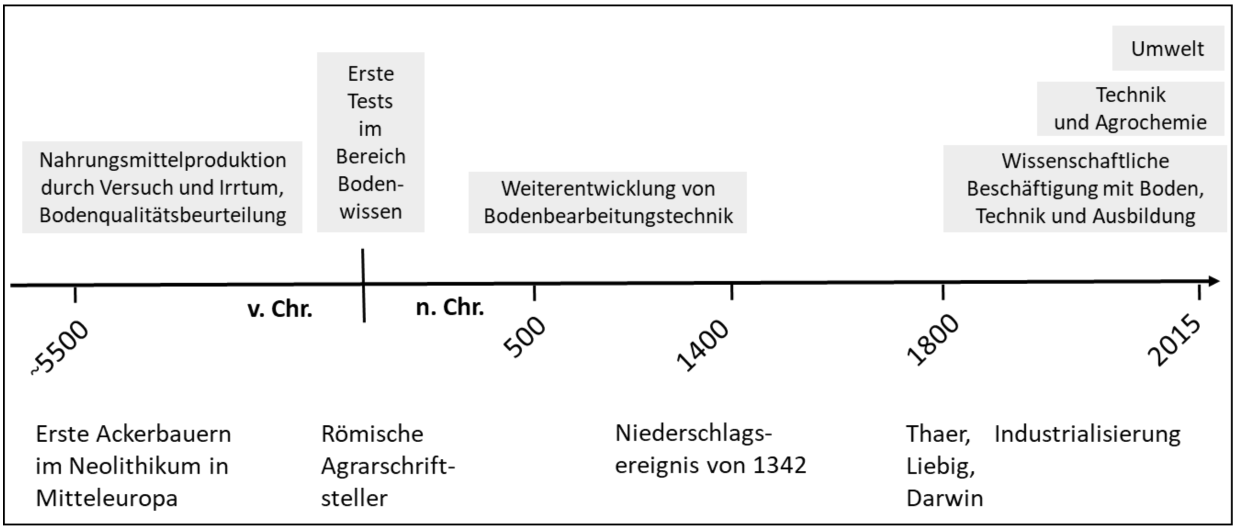

Bild 63: Zeitstrahl mit wichtigen Ereignissen in Bezug auf die Entwicklung der Bodennutzung durch den Menschen

Beginn der Bodennutzung durch den Menschen

Landwirtschaft und Bodennutzung nahmen ihren Ausgangspunkt in Mesopotamien und breiteten sich von dort in ganz Europa aus. In Mitteleuropa erschien die bandkeramische Kultur um 5500 v. Chr. und besiedelte zunächst die landwirtschaftlich produktiven Lössgebiete, außerhalb derer weiterhin Jäger- und Sammlergemeinschaften lebten.[4,5] Beginnend mit dem Übergang zum sesshaften Ackerbau veränderten die Menschen die Landschaften Europas nachhaltig, indem sie Land »urbar« machten. Sie rodeten Wälder, um das Holz für Hausbau und Energieerzeugung zu nutzen und Felder für den Ackerbau anzulegen.[6] Damit begann der Eingriff des Menschen in die natürliche Bodenverbreitung. Der Wasser- und Stoffhaushalt unserer Böden veränderte sich ebenso wie Prozesse der Bodenbildung.[7]

Die Rodung von Wäldern an Hängen führte vielerorts zu Erosion durch Wasser. Dabei wurden zunächst die humosen und nährstoffreichen Oberböden abgetragen, mit dem Oberflächenabfluss abtransportiert und anschließend am Hangfuß und in Senken in Form sogenannter Kolluvien abgelagert.[8] Bei Winderosion in trockenen Gebieten erfolgte die Abtragung flächenhaft auf exponierten Feldern mit anschließender Deposition im Windschatten von Hindernissen oder in Bereichen geringerer Windgeschwindigkeit. Diese Kolluvien kann man heute mit bodenwissenschaftlichen Verfahren (s. Bild 64) wie beispielsweise bodenchemischen Analysen, Mikromorphologie, Pollenanalyse, 14C- und Lumineszenz-Datierungen analysieren und so die Besiedelungsgeschichte eines Raumes rekonstruieren. Untersuchungen im Mittleren Schwarzwald und im Oberrheingraben etwa ergaben, dass im Wasenweiler Ried südlich des Kaiserstuhls die ersten Getreidepollen bereits während des Neolithikums auftauchten.[9] Ab 3000 v. Chr. sind sie dort durchgehend zu finden und weisen auf landwirtschaftliche Tätigkeit hin.[9] Auch im Einzugsgebiet des Rockenberg in der Wetterau begann die Kolluvienbildung rund 4400 v. Chr. und verdeutlicht den anthropogenen Einfluss auf das Gebiet.[10] Diese Ergebnisse lassen bereits erkennen, dass bei der Besiedelung bevorzugt Gunsträume erschlossen wurden.

Den Menschen im Neolithikum waren die Bodenqualität und damit die Eignung einer Region für die Versorgung mit Nahrungsmitteln durchaus bewusst und wichtig.[11] Ebenso von Bedeutung war die Nähe zu Wasser – zur Trinkwasserversorgung. In Ermangelung schriftlicher Aufzeichnungen können weitere Faktoren, die bei der Wahl von Siedlungsstandorten ebenfalls eine Rolle gespielt haben dürften, nur vermutet werden. Zu nennen wären hierbei ebene Flächen, mittlere Hanglagen und südexponierte Standorte.[11] Der heutige Stand der Forschung lässt eine vollständige Rekonstruktion der Besiedelung des neolithischen Mitteleuropa leider nicht zu. In jedem Fall aber bilden die Sesshaftigkeit und die Landwirtschaft die Voraussetzung für das Entstehen von Siedlungen und später Städten.[11]

Literarische Texte über die Landwirtschaft und den Boden zur Zeit der Römer

In der Antike entstanden die ersten literarischenWerke Europas, die sich mit guter landwirtschaftlicher Praxis befassten. Dazu zählen »´Εργα και ημ´εραι« (»´Erga kai hemérai«) von Hesiod, »De agri cultura« von Cato, »Res rusticae« von Varro und »De re rustica« von Columella.[12] Columella beschrieb in seinem Werk einen Test, mit dem die Bodenfruchtbarkeit herausgefunden werden konnte: Man grabe ein Loch und fülle dann die Erde wieder hinein. Entsteht dabei ein Haufen, ist der Boden fruchtbar; füllt der Boden die Grube nicht aus, ist er nicht gut.[13] Dieses einfache Verfahren prüft die Aggregatstabilität des Bodens, die von der Korngrößenverteilung, der organischen Substanz, der biologischen Aktivität und dem Mineralbestand des Bodens abhängt. Wenn die Erde die Grube nicht ausfüllt, heißt das, der Boden verdichtet sich beim Wiederauffüllen der Grube. Wasser kann dann schlechter in den Boden infiltrieren, und die Vegetation wird nicht ausreichend mit Luft versorgt. In der Folge fällt der Ertrag schlechter aus als bei einem Boden, der einen Haufen bildet. Dieser einfache Test zeigt, dass bereits vor rund 2000 Jahren die systematische Analyse von Boden begann, wobei die Frage der Bodenfruchtbarkeit im Vordergrund stand.

Die genannten römischen Texte können heute noch von uns nachgelesen werden, da man sie im Mittelalter oft abgeschrieben hat und auch heute weiter verlegt. Mithin maß man diesen bodenkundlichenWerken eine große Bedeutung bei, denn sonst hätte man sich den Aufwand erspart, den das Erstellen eines Textes vor der Erfindung des Buchdrucks erforderte.[12]

Boden und Landwirtschaft im Mittelalter

Das Frühmittelalter war von der Herrschaft der Merowinger und Karolingergeprägt, die zur Zeit Karls des Großen ihren Höhepunkt erreichte. Das Fundament der Wirtschaft Mitteleuropas bildete die Landwirtschaft.[14,15] Wie im Neolithikum wurden vornehmlich Standorte mit guten Böden besiedelt.

Dank langsam einsetzender Fortschritte in der Landbewirtschaftung fand allmählich eine Abkehr von der Subsistenzwirtschaft statt. Mussten doch Überschüsse produziert werden, um jene Teile der Bevölkerung zu versorgen, die in den entstehenden urbanen Zentren lebten und nicht mehr in der Landwirtschaft arbeiteten.[14,16] Die zunehmende Besiedelung – anhand archäologischer Befunde und Ortsnamen gut nachverfolgbar – lässt zudem auf ein Bevölkerungswachstum schließen, das zu einer Ausdehnung der Siedlungsstrukturen in Richtung der Mittelgebirge führte.[15,16] Städte waren bereits zur Zeit der Römer entstanden, darunter Aachen, Köln, Regensburg und Trier, die dann im Mittelalter an Bedeutung gewannen. Ab dem Mittelalter kam es zu einer deutlichen Arbeitsteilung, wobei zwar der größte Teil der Bevölkerung nach wie vor in der Landwirtschaft tätig war, es aber zunehmend Menschen gab, die im sekundären oder tertiären Wirtschaftsbereich arbeiteten.[15]

Die Besiedelung neuer Räume und das Bevölkerungswachstum waren nur möglich, weil die Versorgung mit Nahrungsmitteln gut war. Dies lag an einer sich verändernden Bewirtschaftungsweise. In Norddeutschland beispielsweise entstand die Plaggenwirtschaft und vielerorts findet man noch heute Wölbäcker, die ein Beleg dieser Änderungen sind.

Untersuchungen von tiefgründigen humosen Oberböden in Norddeutschland aber auch in den Niederlanden und Dänemark haben ergeben, dass diese Böden durch den Auftrag von Plaggen entstanden sind.[17-21] Dabei wurden Heide- oder Grassoden in Ställen als Einstreu verwendet und anschließend auf die Felder aufgetragen. Es entstand der Boden „Plaggenesch“, auf dem erfolgreich Landwirtschaft betrieben werden konnte. Die Flächen, von denen die Soden stammten, degradierten im Zuge der Plaggenwirtschaft allerdings und bedurften langer Erholungsphasen von bis zu 15 Jahren. Der Auftrag von Plaggen war notwendig, um die sandigen und nährstoffarmen Böden Norddeutschlands und in den Niederlanden erfolgreich für die Landwirtschaft nutzen zu können. Erst nachdem im 19. Jahrhundert kommerzielle Dünger billig verfügbar waren, konnten die Felder und damit die darauf wachsenden Pflanzen anderweitig mit Nährstoffen versorgt werden.[17] Die ältesten dieser Auftragsböden wurden auf Sylt gefunden und stammen aus der Späten Bronze Zeit, weshalb angenommen wird, dass die Nordfriesen als erstes die Plaggenwirtschaft zur Düngung ihrer Felder verwendeten.[19] Durch 14C-Datierungen und archäologische Untersuchungen konnte nachgewiesen werden, dass ab dem Mittelalter Plaggenwirtschaft auch in Nordwestdeutschland, Belgien und den Niederlanden betrieben wurde.

Einen weiteren Hinweis auf sich veränderte Bearbeitungsformen liefern die Wölbäcker. Diese sind unter Wald oder Wiesen erhalten geblieben und können daher heute noch Rückschlüsse auf die Bewirtschaftungsweise längst vergangener Zeit liefern.[22-24] Die damals verwendeten

Streichbrett- oder Beetpflüge wendeten die Scholle nur in eine Richtung. Da das Umsetzen und Wenden des Pfluges schwer war, legte man lange und eher schmale Äcker an. Nachdem man das Feld der Länge nach gepflügt hatte, wendete man den Pflug in einem engen Bogen und pflügte den Boden gegen die bereits umgeworfene Scholle in Richtung der Ackermitte. Dies wurde bei jedem Wenden wiederholt, so dass in der Ackermitte eine Wölbung entstand, während die Ränder des Ackers vertieft wurden. Die Pflugtechnik wurde auf ebenen Flächen aber auch an Hängen angewandt, wobei teilweise parallel zum Hang aber auch mit dem Hang gepflügt wurde.[25] Durch diese Vorgehensweise entstanden die Wölbäcker. Diese weisen ein Mikrorelief auf. In den entstehenden Mulden war auch in trockenen Jahren eine ertragreiche Ernte möglich, während die Wölbungen in feuchten Jahren von Vorteil waren. Die Orte, an denen nicht hangparallel sondern mit der Steigung gepflügt wurde, waren besonders erosionsanfällig, da Niederschlagswasser in den Mulden schnell abfließen und den fruchtbaren Boden mit sich abtragen konnte.[26]

Ein einschneidendes Ereignis für die Bevölkerung und die Landwirtschaft im Spätmittelalter war ein Starkregen, der zwischen dem 19. und dem 21. Juli 1342 in weiten Teilen Mitteleuropas Überflutungen verursachte.[27] Im Zuge des Bevölkerungs-wachstums hatte die landwirtschaftliche Erschließung in der ersten Hälfte des 14. Jahrhunderts ihre größte Ausdehnung erreicht, auch schwer zu bearbeitende Böden waren nach und nach unter den Pflug genommen worden.[3,28] Die Starkniederschläge trafen daher auf intensiv genutzte Flächen. An den landwirtschaftlich bestellten Hängen kam es zur schwersten bislang nachgewiesenen Bodenerosion im gesamten Holozän (11 700 Jahre bis heute), die in Mitteleuropa außerhalb der Alpen durch ein einzelnes Ereignis ausgelöst wurde.[7] Die Konsequenzen waren Ernteausfälle und Hunger, was zu Abwanderung und der Aufgabe von Siedlungen führte.[27] Als Folge der Siedlungsaufgabe kam es zur neuerlichen Bewaldung ehemals landwirtschaftlich genutzter Flächen.[29,30]

Die verheerenden Auswirkungen dieses Niederschlagsereignisses machen deutlich, wie wichtig ein bewusster und nachhaltiger Umgang mit dem Boden ist, und welch zentrale Rolle die Ressource Boden für Gesellschaften spielt. An vielen Mittelgebirgshängen trug der Starkregen die geringmächtige Bodendecke komplett ab,[7] wodurch eine weitere landwirtschaftliche Nutzung der Hänge auf Jahre hinaus nicht mehr möglich war. Auch heute sind global betrachtet insgesamt 1094 Millionen Hektar der Landoberfläche von Erosion durch Wasser betroffen, weitere 549 Millionen Hektar von Winderosion.[31] Jährlich erodieren 75 Milliarden Tonnen Boden. Am meisten betroffen davon sind landwirtschaftlich genutzte Flächen.[32] Das bedeutet, dass global gesehen rund 906 kg ha^{-1} a^{-1} Boden erodiert.[33] Nur 700 kg ha^{-1} a^{-1} Boden durchschnittlich bildet sich neu.[33] In der Bilanz verlieren wir durch Erosion jährlich unwiederbringlich mehr Boden als sich bilden kann.

Die Bodenerosion entzieht sich meist der Wahrnehmung, da nur nach Starkniederschlägen die Veränderungen an der Bodenoberfläche gut zu sehen sind (z. B. durch Sedimentaufträge). Gleichwohl sollten die Zahlen zu denken geben und uns verstärkt zu Bodenschutzmaßnahmen veranlassen, um eine standortgerechte, nachhaltige Landwirtschaft langfristig zu ermöglichen und Erosion zu vermeiden.

Wissenschaftliche Beschäftigung mit Boden und Landwirtschaft im 18. und 19. Jahrhundert

Ende des 18. Jahrhunderts begann die wissenschaftliche Auseinandersetzung mit dem Boden. Albrecht Daniel Thaer (1752–1828) schrieb sein vierteiliges Werk »Grundsätze der rationellen Landwirthschaft«, in dem es u. a. um die Beurteilung der Bodengüte anhand einfach zu beobachtender Boden- und Pflanzenmerkmale ging, um die Bedeutung des Düngers und des Humus für landwirtschaftliche Erträge und um die Vor- und Nachteile der Felder- und der Wechselwirtschaft in ihren unterschiedlichen Ausprägungen.[34] Justus von Liebig (1803–1873) befasste sich in seinem Werk »Die organische Chemie in ihrer Anwendung auf die Agricultur und Physiologie« mit der Pflanzenernährung und versuchte einen Mineraldünger zu entwickeln, um damit die von den Pflanzen aufgenommenen Nährstoffe im Boden zu ersetzen.[35] Seine Versuche und Theorien bilden bis heute den Ausgangspunkt der modernen Agrochemie.[3] Die Produktion chemischer Düngemittel wurde erst möglich, als Fritz Haber Anfang des 20. Jahrhunderts die Ammoniaksynthese gelang. Diese wurde von Carl Bosch an industrielle Erfordernisse angepasst und leitete den Wandel hin zur Verwendung chemisch produzierter Düngemittel ein.[3] Im Jahr 1881 erschien Charles Darwins (1809–1882) »The Formation of Vegetable Moulds Through the Action of Worms with Observations of their Habits«, was aus heutiger Sicht erstmals die Bildung von Humus thematisierte und wissenschaftlich untersuchte. Innerhalb eines Monats wurden 3500 Exemplare verkauft.[36] Die hohe Auflage und der rasche Vertrieb lassen darauf schließen, dass das Thema von großem Interesse in Gelehrtenkreisen war. Bereits 1838, also 43 Jahre vorher, hatte Darwin einen Aufsatz veröffentlicht, in dem er die Bedeutung der Regenwürmer bei der Bodenbildung erklärt.[37] Er beschreibt darin erstmals bodenbiologische Prozesse und stellt das Konzept der Bioturbation vor, also die Durchmischung von Boden durch Bodentiere.[36,38] Gegen Ende des 19. Jahrhunderts führte Vasilii V. Dokuchaev (1846–1903) das Bodenprofil mit der heute noch in der Bodenkunde verwendeten Unterteilung in A-, B- und C-Horizonte ein.[38,39] Damit gilt er neben Eugene Hilgard als der Begründer der modernen Bodenkunde.[39] Dokuchaev vertrat die Ansicht, Böden sollten als eigenständige Einheit der Naturwissenschaften untersucht werden und plädierte dafür, die verschiedenen Faktoren, die den Boden beeinflussen, bei der Bodenuntersuchung zu berücksichtigen.[38]

Die eingehende Auseinandersetzung Thaers, Liebigs, Darwins und Dokuchaevs mit dem Boden zeigt, dass der Boden nicht nur für die bodenbearbeitende Bevölkerung und Landwirtschaft eine Rolle spielte. Vielmehr standen Bodenfunktionen, Bodenentstehung und der Erhalt der Bodenfruchtbarkeit auch im Interesse derWissenschaft und der Gelehrten. Albrecht Thaer beispielsweise war Arzt und kein Landwirt. Er betrieb Gärtnerei als Hobby, bis er sich aus Interesse der Landwirtschaft zuwandte. Daraufhin schränkte er seine Tätigkeit als Arzt immer mehr ein, um sich der Landwirtschaftslehre zu widmen.[34] Liebig hatte sich als Chemiker zunächst mit Silber- und Quecksilberverbindungen befasst, bevor er sich, durch Alexander von Humboldt gefördert, der organischen Chemie und der Pflanzenernährung zuwandte.[35] Seine Forschung zu den Lebensvoraussetzungen von Organismen zeigt, dass es ein Verständnis für die Zusammenhänge von Nährstoffkreislauf und Pflanzenernährung gab.

Neben der Forschung spielte auch die Wissensvermittlung eine zunehmend wichtige Rolle. Nachdem die Bauern im Zuge der Bauernbefreiung in der ersten Hälfte des 19. Jahrhunderts zu Vollbürgern geworden waren und die allgemeine Schulpflicht zu einem höheren Bildungsstand der Bevölkerung geführt hatte, erhöhte sich der Bedarf an weiterführenden Bildungseinrichtungen.[34,40] So etwa gründete Johann Schwerz 1818 im Auftrag von König Wilhelm I. von Württemberg die Königlich Württembergische Unterrichts- und Versuchsanstalt in Hohenheim bei Stuttgart.[40,41] Für die bäuerliche Bevölkerung richtete man im gleichen Zeitraum Ackerbauschulen ein, die weniger elitär als Universitäten oder Akademien waren, und wovon die heutige Michelsenschule in Hildesheim die bekannteste ist.[40] Außerdem gab es Winterschulen, in denen im Regelfall über zwei Winter hinweg Naturwissenschaften, Produktionstechnik und Betriebsführung unterrichtet wurden – für die Söhne aus Familien, die nicht die finanziellen Möglichkeiten hatten, um ganz auf die Arbeitskraft jener zu verzichten.[40] Allmählich also fand eine Abkehr von rein mündlich überlieferten landwirtschaftlichen Methoden in den Familien hin zu einer stärker verschulten Landwirtschaftspraxis statt. Schulen, die sich mit der »rationellen Landwirthschaft«[34] befassten, breiteten sich aus, und die Bodenwissenschaften gewannen an Bedeutung. Darauf weisen auch die wachsenden Studierendenzahlen hin: An der Landwirtschaftlichen Hochschule Hohenheim beispielsweise studierten 1922 bereits 1000 Studenten.[41]

Industrialisierung und Globalisierung der Landwirtschaft

Nach dem Ende des Ersten Weltkrieges kehrte eine große Zahl von Soldaten nach Deutschland zurück, die durch die sogenannte »Innere Kolonisation« mit Siedlerstellen versorgt wurden. Davon versprach man sich eine Intensivierung der landwirtschaftlichen Produktion und gleichzeitig einen höheren Grad an Selbstversorgung in Deutschland.[40] Diese »Innere Kolonisation« war auch deshalb notwendig, weil das Deutsche Reich durch den Versailler Vertrag 14,3 Prozent seines Territoriums, vor allem große Teile Westpreußens und

Posens verloren hatte.[40,42,43] Beide hatten bislang durch ihre agrarische Überproduktion auch andere Teile Deutschlands mit Nahrung versorgt. Die neu geschaffenen Siedlerstellen sollten neben der Ernährungssicherung auch eine Stärkung der mittelständischen Bauern gewährleisten, um so die Abwanderung in Städte oder ins Ausland zu verhindern.[40] Eine Volks- und Berufszählung im Jahr 1925 ergab dann auch, dass 30,5 Prozent der Bevölkerung (9,8 Millionen) hauptberuflich im Bereich Land- und Forstwirtschaft, Gartenbau und Fischerei tätig waren, und weitere 4,1 Millionen Erwerbstätige nebenberuflich in diesem Wirtschaftszweig arbeiteten.[43] Der Vergleich mit den hier eingangs genannten heutigen Zahlen zeigt, wie sehr die Beschäftigtenzahl in diesem Bereich seitdem abgenommen hat: 2012 waren nur noch 669 000 in der Land- und Forstwirtschaft sowie der Fischerei beschäftigt,[1] also nur noch 1,6 Prozent der in 2012 Erwerbstätigen.

Bild 64: Bodenkundliche Untersuchung von Kolluvien auf der Baar in Baden-Württemberg, Universität Tübingen

Agrarpolitisch war nach dem Ersten Weltkrieg überdies eine Ausdehnung der Kleinstbetriebe und Kleingärten erwünscht, wodurch auch Städter »Freud und Leid der Landwirte«[39] erleben konnten und zur Versorgung mit Nahrungsmitteln beitrugen. Um die heimische Landwirtschaft zu unterstützen, wurde das Reichsministerium für Ernährung, Landwirtschaft und Forsten gegründet, das auf Reichsebene die Agrarpolitik bestimmte und Agrarprotektionismus betrieb, der 1925 zur Wiedereinführung der Agrarzölle führte.[42,43] Neben den agrarpolitischen Änderungen kam es in der Landwirtschaft der Weimarer Republik zu Änderungen im Rahmen der Industrialisierung, die zu einer zunehmend mechanisierten Landwirtschaft und einem höheren Verbrauch an mineralischen Düngemitteln führte.[42] Trotz dieser Änderungen und der Marktorientierung der Bauern blieben die Dörfer in den 20er Jahren eine Art Schicksalsgemeinschaft: Bei der Bodenbearbeitung kooperierten Vollerwerbsmit Nebenerwerbslandwirten, Nachbarschaftshilfe war wichtig und Dorfnormen diktierten den Alltag.[44] In den 30er Jahren kamen die Nationalsozialisten an die Macht, deren Blut und Boden-Ideologie an anderer Stelle in diesem Buch behandelt wird.

Nach dem Zweiten Weltkrieg gewannen die Boden- und Pflanzenbauwissenschaften deutlich an Bedeutung, galt es doch politisch, die Versorgung der kriegsgeschädigten Bevölkerung und der über acht Millionen Flüchtlinge aus den ehemaligen Ostgebieten Deutschlands sicherzustellen. Ab den 60ern nahm man dann auch die Situation der hungernden Bevölkerung in den Entwicklungsländern in den Blick.

Diese Aufgaben ließen sich nur durch eine Modernisierung und Intensivierung der landwirtschaftlichen Produktionssysteme bewältigen.[45] Schon 1950 erreichte die Produktion der Landwirtschaft in Deutschland Vorkriegsniveau, vor allem dank des Einsatzes von Mineraldüngern und Maschinen.[40] In der sowjetischen Besatzungszone kam es im Zuge der Bodenreform von 1945 zunächst zu einer Enteignung von Großgrundbesitzern und danach zu einer Kollektivierung und Industrialisierung der Landwirtschaft. Resultat waren landwirtschaftliche Produktionsgenossenschaften (LPG), deren Größe industrielle Produktionsverfahren ermöglichte. Anders als in der DDR blieben in der BRD bäuerliche Familienbetriebe erhalten. Auch sollten die landwirtschaftlichen Strukturen an sich geschützt werden.[40] Dennoch verringerte sich die Zahl der Beschäftigten in der Landwirtschaft stetig. Während um 1900 noch 38,2 Prozent der Erwerbstätigen in der Land- und Forstwirtschaft und Fischerei arbeiteten, waren es um 1950 in der BRD nur noch 24,3 Prozent und 2000 lediglich 2,5 Prozent (Tab. 3).[46] Obwohl immer weniger Menschen in der Landwirtschaft tätig waren, erfüllte diese die von der Politik, Gesellschaft und Wirtschaft zugeschriebene Aufgabe, nämlich die Versorgung der Bevölkerung mit preisgünstigen Nahrungsmitteln. Grundlage dafür war die massive Weiterentwicklung der Produktionstechnik. Versorgte ein Landwirt 1900 durchschnittlich 4 Personen, waren es in der BRD 1950 schon 10 und im Jahr 2000 dann 119 Personen.[46]

Sowohl bei der Pflanzen- als auch bei der Tierzucht hatte es unterdessen enorme Fortschritte gegeben, und überdies wurden im großen Stil Mineraldünger und Pflanzenschutzmittel im Ackerbau sowie Kraftfutter bei der Tiermast eingesetzt. Die mineralischen Düngemittel ermöglichten eine Spezialisierung auf Ackerbau, da man den Stallmist aus der Tierhaltung nicht mehr für die Düngung der Felder brauchte. So löste sich die jahrhundertelange enge Verbindung von Ackerbau und Viehhaltung auf. Auch die traditionelle Fruchtwechsel und

Brachwirtschaft zum Erhalt der Bodenfruchtbarkeit fand nicht mehr statt. Stickstoff als Düngemittel ersetzte die Regeneration der Böden und war billig verfügbar.[3] Auch die Motorisierung und Mechanisierung der landwirtschaftlichen Arbeitsschritte trug dazu bei, dass die wachsende Bevölkerung mit Nahrungsmitteln versorgt werden konnte. Man konnte Arbeitsschritte zusammenlegen und die Arbeitszeit für die Bestellung oder das Abernten eines Feldes extrem verringern, wodurch viel weniger Arbeitskräfte in der Landwirtschaft benötigt wurden.

Tabelle 3: Erwerbstätigkeit der Bevölkerung und Anteil der Erwerbstätigen im Bereich der Land- und Forstwirtschaft, Fischerei (Angaben in Mio.)

Erwerbstätige	Früheres Bundesgebiet			Deutschland	
	1970†	1980†	1990†	2000‡	2010◊
gesamt	26,0	26,9	29,3	39,0	41,0
Land- und Fortstwirtschaft	2,37	1,44	1,07	0,94	0,66

† [46] ‡ [52] ◊ [53]

All diese Entwicklungen hatten und haben jedoch auch negative Auswirkungen auf die Umwelt. Lange folgte man dem Grundsatz »viel hilft viel«. Sowohl Dünger als auch Pflanzenschutzmittel wurden häufig in sehr hohen Mengen aufgebracht.[47] Dies führte zur Belastung des Oberflächen- und Grundwassers und minderte die Biodiversität ganzer Landschaftsräume. Zudem hat sich die Landschaft selbst durch die modernen Anbaumethoden stark verändert. Nun dominieren größere Felder, die mit größeren Landmaschinen befahren werden. Sie ersetzen die kleineren Felder, auf denen früher eine vielseitige, abwechslungsreiche Landwirtschaft betrieben wurde.[47]

In dieser Zeit der rasanten technischen und wirtschaftlichen Entwicklung vor dem Hintergrund weltweit steigender Bevölkerungszahlen kam und kommt es verstärkt zur »Abkehr von der Scholle« – der Boden selbst steht nicht mehr im Mittelpunkt der Nahrungsmittelproduktion. Vielmehr übernehmen Technik und Agrochemie diese zentrale Rolle, wobei der Mensch vom Boden entfremdet wird. Einen weiteren Faktor stellt das zunehmende Hygienebewusstsein nach dem Zweiten Weltkrieg dar. Sauberkeit und die damit verbundenen technischen und chemischen Entwicklungen bewirken, dass der Boden langsam aber sicher mit Schmutz und »Dreck« assoziiert wird.

Umweltbewusstsein und Globalisierung.

Ende der 1960er Jahre wurde die Umweltproblematik der industrialisierten Wirtschaftsweise erstmals in der Politik diskutiert. So brachte die Regierung der BRD 1971 das Umweltprogramm auf den Weg.[28] Seitdem sind Umweltveränderungen wie Bodenerosion und Bodenkontamination, Grundwasserverschmutzung und die Funktion des Bodens als Senke und Filter für Giftstoffe auch Themen in den Bodenwissenschaften.[48]

Hier spielen neben den Veränderungen in der Landwirtschaft auch Veränderungen auf den internationalen Märkten eine Rolle. Im Blick auf die Außenhandelsentwicklung Deutschlands fällt auf, dass bereits im Jahr 1950 Waren im Wert von 4275 Millionen Euro ausgeführt wurden.[49] Davon entfielen rund 100 Millionen Euro auf Güter aus der Ernährungswirtschaft.[50] Die Einfuhr von Waren betrug 5815 Millionen Euro,[49] wovon 2563 Millionen Euro an Güter aus dem Bereich Ernährungswirtschaft entfielen.[51] Mithin war Deutschland trotz steigender Mechanisierung und Industrialisierung der Landwirtschaft nach dem Zweiten Weltkrieg zunehmend auf Nahrungsmittelimporte angewiesen. Der Vergleich mit 2013 zeigt, dass sich das Import- und Exportaufkommen Deutschlands stark gesteigert hat: 2013 betrug die Ausfuhr von Waren 1093115 Millionen Euro, die Einfuhr 898164 Millionen Euro.[49] Im Bereich der Ernährungswirtschaft wurden Waren im Wert von 66049 Millionen Euro exportiert[50] und Waren im Wert von 74646 Millionen Euro importiert.[51] Der Import von Gütern aus dem Bereich Ernährungswirtschaft überwiegt also nach wie vor, wobei der Export in diesem Bereich zugenommen hat. Auf dem Boden gewachsene Nahrungsmittel werden zunehmend zum Handelsgut oder sogar zum Spekulationsobjekt. Damit setzt sich die mit der Industrialisierung entstandene Entkoppelung von Boden und Daseinserhaltung fort.

Obwohl wir täglich Nahrung zu uns nehmen, scheinen heute Bodennutzung und Landwirtschaft von eher untergeordnetem gesellschaftlichem Interesse zu sein. Zwar sind Naturschutzthemen immer stärker in den Medien präsent, doch wird der Boden meist nur in Zusammenhang mit Klimaerwärmung erwähnt und nicht wirklich als eigenes Schutzgut. Auch dort, wo man den Zusammenhang von Globalisierung und Landwirtschaft thematisiert, bleiben die Bedeutung von Erosion und Versiegelung sowie von Bodenkontamination für die Nahrungsmittelproduktion häufig unbeachtet. Grund für dieses Desinteresse dürfte die Entfremdung großer Teile der Gesellschaft vom Boden sein.

Doch steht uns trotz Globalisierung und scheinbar unbegrenztemWachstum nur eine begrenzte Bodenfläche zur Verfügung. Einen Teil davon haben wir bereits unwiederbringlich zerstört.

Schlussfolgerung und Ausblick

Wie die Geschichte der Bodennutzung durch den Menschen zeigt, lebte viele Jahrhunderte lang ein großer Teil der Bevölkerung direkt von der Landwirtschaft und kam täglich mit dem Boden in Berührung. Man kann in diesem Zusammenhang insofern von einer »BodenKultur« sprechen, als hier eine direkte Abhängigkeit der Gesellschaft vom Boden bestand: Auf ihm wurde die Nahrung erlebbar angebaut. Eine schlechte Bodenbewirtschaftungspraxis resultierte in schlechtem Ertrag und Hungersnöten. Auch konnten, wie das Niederschlagsereignis von 1342 zeigt, Naturgewalten zu verheerenden Folgen für die Landwirtschaft und Umwelt führen. Die Landwirtschaft beruhte zudem viele Jahrhunderte auf der Dreifelder- bzw. Fruchtwechselwirtschaft mit Brachzeiten. Im Zuge der Industrialisierung wurde diese Wirtschaftsweise aufgegeben, und eine stete Intensivierung der Flächenbewirtschaftung setzte ein. Immer weniger Landwirte wurden benötigt, um die Bevölkerung mit Nahrungsmitteln zu versorgen. Dies alles führte dazu, dass der Boden immer mehr aus unserer individuellen und gesellschaftlichen Wahrnehmung entschwand.

Eines ist sicher: Erst durch die globalen Umweltthemen (Waldsterben infolge von Bodenversauerung) gibt es eine verstärkte ökologische, wirtschaftliche und kulturelle Beschäftigung mit dem Thema Boden, wie die Vielzahl an bodenkundlichen Publikationen in Fachzeitschriften zeigt. Auch die Medien greifen verstärkt umweltrelevante Themen auf. Dieser Trend setzt sich durch die vielschichtigen wissenschaftlichen Fragen zur Rolle der Böden im Kontext des Klimawandels bis heute fort. Eine auf Dauer zentrale Frage bleibt, wie und nach welchen Kriterien national und global ein nachhaltiger Umgang und damit auch ein verantwortbares Bewirtschaften und Handeln mit unseren endlichen Bodenressourcen erfolgen soll.

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Manuscript 3

Allotment gardening in Southwest Germany – a comparative analysis of motivations and management practices

Under Review in Agriculture and Human Values since August 2017

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Introduction

Gardening is a common free time activity. In 2016, 8.4 million people in Germany gardened several times a week (approximately 10% of the population), and 14.2 million people (17.3%) worked in the garden several times a month (statista 2017; Destatis 2017). These gardeners provide ecosystem services (Calvet-Mir et al. 2012; Breuste and Artmann 2015; Langemeyer et al. 2016), and, thus affect the resilience of settlements (Barthel and Isendahl 2013).

Several garden forms exist: Home gardening, community gardening, and allotment gardening. Home gardening means food production on own or rented property surrounding ones residence, including back/front yards and balconies (Kortright and Wakefield 2011; Taylor and Lovell 2014). However, not everyone who owns or rents a house uses their yard for gardening in terms of food production (Kortright and Wakefield 2011). Especially in industrialized countries, the yard often contains lawns, trees, and ornamental plants (Clayton 2007; Galluzzi et al. 2010; Smith et al. 2005), and front yards are increasingly paved (Perry and Nawaz 2008), requiring little maintenance effort.

Community and allotment gardening are often used synonymously or combined to mean urban gardening. In this paper, we distinguish between the two forms of gardening. Community gardening refers to plots that are used by a group of people who decide as a community what they want to do with the plots (Guitart et al. 2012; Spilková 2017; Drake and Lawson 2015). Allotment gardens (= German "Kleingarten") are parcels that are used for non-commercial food production, where each allotment lies within an area with several other allotment parcels, and the area has common institutions such as playgrounds or a clubhouse (Appel et al. 2011). The allotment garden parcels in Germany are rented by individuals or families, who decide management practices on their individual allotments, which are in accordance with the rules of the allotment gardening association and the existing laws. In Germany, a law states that one third of the allotment parcel has to be used for plots with the aim of food production (Bundesministerium der Justiz und für Verbraucherschutz 1983). In this paper, allotment gardening refers to the German "Kleingarten", where food production is necessary and related to soil use, which distinguishes it from other forms of urban gardening, where food production is not necessary and gardening can happen in pots instead of in the soil.

In Germany, allotment gardening has a long history (Nilsen 2014; Keshavarz and Bell 2016). It is still very common, with the biggest German allotment association having 947.137 members (Bundesverband Deutscher Gartenfreunde e.V. 2017). The present study investigates German allotment gardens in a rural and an urban region, following the discussion of Schupp and Sharp (2012) about the differences between rural and urban home gardening. Both regions are in SW-Germany, and the distance between them is only approximately 100 km. However, the urban region is the state capital of Baden-Wurttemberg with an urban lifestyle and a densely populated area, while the rural region is the town of Villingen-Schwenningen with less urban infrastructure, e.g. concerning public transport. The aim of the study is to compare allotment gardening between the two regions, which adds to the understanding of gardening motivations and practices in an industrialized country. The comparison, further, informs planners and practitioners, who develop programs or start new garden initiatives, about motivations, management practices and soil related knowledge of allotment gardeners.

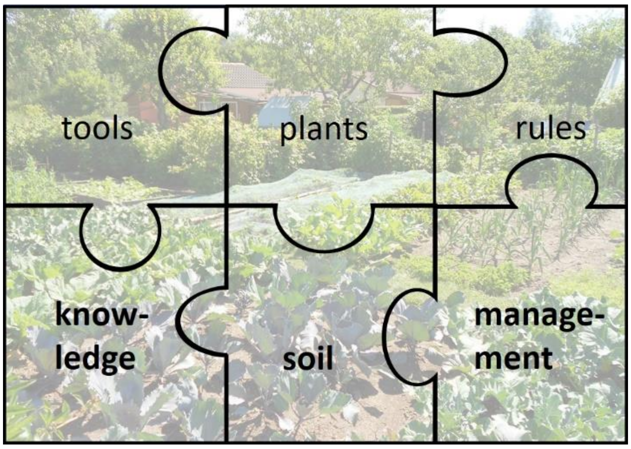

Fig. 1: The resource complex soil in German allotment gardens, the investigated components are displayed in bold.

So far, only few studies investigated the soil aspect in relation to gardening, even though soils are essential for food production (Koch et al. 2013). When it was done, the focus was on soil fertility and fertilizer use (Dewaelheyns et al. 2013) or on the knowledge of soil contamination (Kim et al. 2014). We therefore added the soil perspective to our study, to draw attention to soil as a natural resource. In an allotment garden, soil is used according to the gardener's knowledge and the existing allotment association rules to determine management practices to produce food using certain plants. This constitutes a resource complex, which is a combination of individuals, objects, knowledge and practices and enables the use of a specific resource (Bartelheim et al. 2015; Hardenberg et al. 2017). Resource complexes, thus, combine natural and cultural/social component, with soil and plants being natural ones and knowledge, practices and rules being social ones. The concept of resource complexes is used as analytical tool to understand the processes within social-ecological systems (Berkes and Folke 1998) and the resilience of these systems (Berkes et al. 2003).

This study investigates the resource complex soil (Fig. 1), where soil is the central resource, because it provides nutrients and water for the plants. Another important resource are the plants growing in the soil, as they are the result of the effort of the gardener. However, to utilize soil and plants, knowledge is necessary. This involves knowledge of edible plants as well as knowledge about soil cultivation and soil quality assessment. This knowledge leads to the establishment of management practices and rules, which in turn influence the other components of the resource complex, e.g. management practices such as raised bed gardening affects the soil. While all components of the resource complex are important and contribute to the specific form of the resource complex, the interaction of soils and plants is especially important, because without soil, plant production is very difficult and requires enormous amounts of fertilizer and energy, e.g. in hydroponics. Therefore, the focus of the study is on soil. This involves management practices concerning soil and knowledge of soil. We investigated these three components of the resource complex. We treated the components “tools”, “plants” and “rules” as constant. The tools, that were observed during the first garden visits, were different kinds of spades, garden forks, and, occasionally, motorized garden tillers. During field work, no differences in the tools were observed. No observation concerning differences in plant cultivation was made during the field work, with the exception of two peach trees, which were located in an urban allotment garden. However, the climate in the rural region is harsher than in the urban allotment gardens, which, probably, explains the presence of peach trees in the urban area. The rules concerning allotment gardening are the same in both regions, as all the surveyed gardens belonged to the same allotment garden association and are subjected to the same German laws.

The resource complex soil is important for the social-ecological system (SES) of allotment gardening, but it is also used in the SESs horticulture and agriculture. The use of the resource complex soil by German allotment gardeners contributes to the provision of ecosystem services in urban agglomerations and has the potential to increase the resilience of these agglomerations. The present study, thus, aims at analyzing the following objectives in a rural and an urban allotment garden context:

(i) What are the motivations for people to rent an allotment within a gardening association and actively use the resource complex?

(ii) What management practices are used by allotment gardeners?

(iii) Is soil knowledge present in the allotment gardening community? And, does the knowledge concerning soil quality differ from soil scientific criteria?

These objectives (Fig. 2) were investigated using a mixed method approach consisting of questionnaires, interviews and scientific soil sampling.

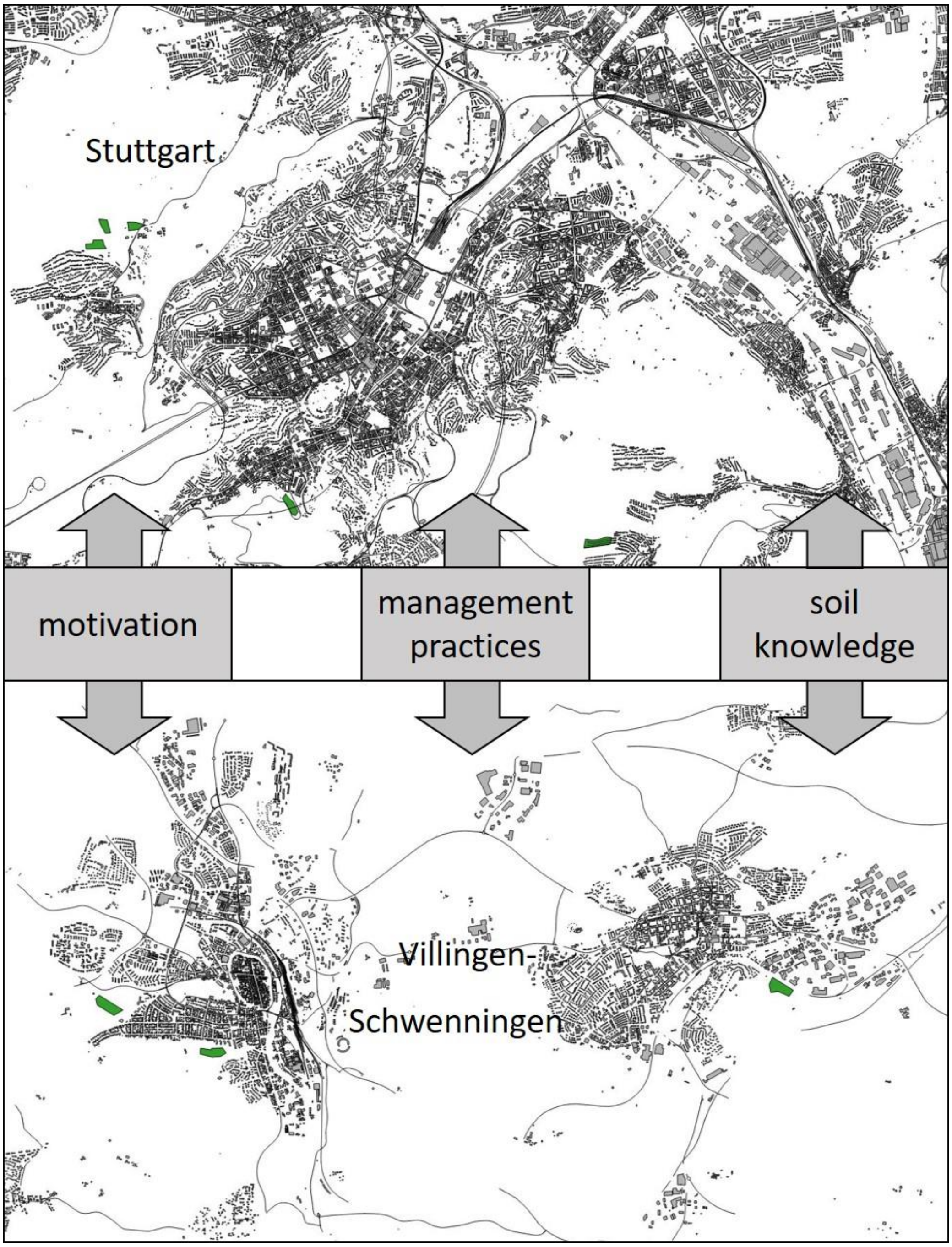

Fig. 2: Objectives investigated in this study in an urban (top) and rural (bottom) region (scale 1:50.000 for both).

Source: OpenStreetMap 2017

Motivation for gardening and the relation to ecosystem services and resilience

In recent years, gardening has become a research focus in several disciplines. Especially the motivation of the gardeners to choose this pastime was well investigated. Recurring motivations for gardening are food production (Kortright and Wakefield 2011; Calvet-Mir et al.

2016; Kiesling and Manning 2010; Guitart et al. 2012; Appel et al. 2011; Pourias et al. 2016), recreation (Acton 2011; Appel et al. 2011), creative expression (Kiesling and Manning 2010), health aspects (Kiesling and Manning 2010; Guitart et al. 2012), connecting to and learning about nature (Calvet-Mir et al. 2016; Kiesling and Manning 2010; Guitart et al. 2012), social-cultural relations (Calvet-Mir et al. 2016; Guitart et al. 2012), and to contribute to the environmental or political city scape (Calvet-Mir et al. 2016; Schukoske 2000). Understanding gardener's motivations for gardening is important to increase the provision of ecosystem services within settlements, because gardens provide a multitude of ecosystem services. Among these services are climate regulation and water retention (Cameron et al. 2012), habitats for flora and fauna (Andersson et al. 2007; Goddard et al. 2010; Jansson and Polasky 2010), provision of food and medicinal plants (Alaimo et al. 2008; Blair et al. 1991; Heistinger 2011), and recreation (Borgstedt 2011; Kaplan and Kaplan 1990). According to the Millennium Ecosystem Assessment (2005) these services have provisioning, regulating, cultural and supporting functions. In the context of this study, the provisioning and cultural functions of the ecosystem services are important.

In the past, provisioning was a major ecosystem service function of urban gardens (Barthel and Isendahl 2013; Barthel et al. 2013). During the Industrial Revolution, the World Wars and the Great Depression allotment gardens formed as self-help measure for nutritional, health and educational reasons in many countries, e.g. Germany and France (Nilsen 2014; Keshavarz and Bell 2016). Today, there is a decline of urban green spaces used for gardening and a subsequent loss of knowledge concerning food production (Barthel et al. 2013; Barthel and Isendahl 2013), and less direct contact to soil and plants. However, allotment gardeners use the resource complex soil regularly, and previous studies, e.g. Pourias et al. (2016), suggest, that food production is a main reason for gardening. This study investigates, if the provisioning ecosystem service function is the motivation for gardeners to choose this pastime.

The cultural ecosystem service function might also be present in the gardening community, as urban gardens and collectively managed parks are recreational places (Wolch et al. 2014) that provide a place to experience and value nature (Kim et al. 2014; Samways 2007). Acton (2011) and Appel et al. (2011) state that recreation is a major function of allotment gardens. This study investigates, if recreational motivations and the cultural ecosystem service function encourage SW-German allotment gardeners to choose this pastime.

The provision of ecosystem services in gardens contributes to the resilience of communities by e.g. retaining knowledge concerning food production (Barthel et al. 2013; Barthel and Isendahl 2013). Resilience here refers to the term 'ecological resilience', which is defined as the extent of disturbance a system can absorb before redefining its structure (Gunderson 2000; Holling and Gunderson 2002). This is essential for SESs such as urban agglomerations, which are prone to change, e.g. through climate change or changing economic situations. Gardens can contribute to the resilience of communities, because they provide a variety of ecosystem services such as provisioning of food and fresh water, but also a habitat for (native) flora and fauna. Gardeners, further, retain the social-ecological memory of food production (Colding and Barthel 2013; Barthel et al. 2014) in a society, where very few people work with the resource complex soil to produce foodstuff (Teuber et al. 2015). This memory can be accessed in times of crisis, as it has happened during the Second World War in form of the Victory Gardens in the USA (Lawson 2014), or in the allotment gardens in Germany (Nilsen 2014). Further, in gardens, societal aspects and nature are closely connected, as is discussed by Classens (2015). However, gardens are not on the agenda of policy makers (Dewaelheyns et al. 2014), even though they can expose citizens to natural processes (Jansson 2013; Miller 2005) and to urban ecosystem services (Gómez-Baggethun and Barton 2013). Putting gardens on political and social agendas and reconnecting society to nature might not only lead to more resilience within communities but also eventually to the emergence of environmental stewardship (Andersson et al. 2014). Therefore, this study investigates the motivation of the gardeners and connects them to the ecosystem services, especially to the provisioning and cultural functions (Millennium Ecosystem Assessment 2005).

Management practices in gardens

In the gardening community, a variety of management practices exists. In traditional garden management, the soil is dug up in fall, and loosened up in spring before sowing. Besides this, the no-dig approach (Aziz et al. 2013; Cannell and Hawes 1994), raised bed gardening (Caputo et al. 2016) or square foot gardening (Bartholomew 2005) are practices commonly used. As in agriculture, all these management practices can be done in an organic way or using the methods of conventional agriculture including fertilizer and pesticides (Mäder et al. 2002; Trewavas 2001). However, so far little is known about the management practices in allotment gardens in industrialized countries. We therefore ask, how the gardeners manage their allotment and compare rural and urban allotment gardening practices.

Soil knowledge of soil users and soil scientific knowledge

So far, research on soil knowledge of soil users is limited to ethnopedological research (Barrera-Bassols and Zinck 2003), which is usually done in the developing world (Barrera-Bassols and Toledo 2005; WinklerPrins and Barrera-Bassols 2004; Krasilnikov and Tabor 2010) by different disciplines such as social anthropology, agronomy, rural geography or soil science (Barrera-Bassols and Zinck 2003). The results of these studies are local classification systems, e.g. of the Yucatec Maya (Bautista and Zinck 2010), or farmer based knowledge of resource management (Price 2007). However, the knowledge of soil users in Germany has, to the knowledge of the authors, not been investigated. Therefore, this study investigates the soil knowledge of the allotment gardeners concerning soil erosion and soil quality assessment.

Soil erosion is linked to land use (Leopold and Völkel 2007; Lang 2003). It is a process endangering the food security on a global scale (Montgomery 2007). Prior to the establishment of agriculture, the natural vegetation protected the soil against water and wind erosion, because the roots stabilized and the canopy covered the soil (Pimentel and Kounang 1998). Starting with the Neolithic Transition, humankind settled down and cultivated the soil (Teuber et al. 2015), simultaneously removing the natural vegetation and facilitating first soil erosion processes (Dotterweich 2008). The use of advanced technology first during the 16th to 19th century and again after the industrialization of agriculture, led to increased erosion (McNeill and Winiwarter 2004). Today, soil erosion rates on arable land are greater than soil formation rates, even though the rates vary between different studies (Verheijen et al. 2009; Montgomery 2007; Cerdan et al. 2010; Lal 2003). Soil, therefore, needs protection, which requires an awareness in society concerning the process of soil erosion. We asked the gardeners, who work with soil on a regular basis, if they know about soil erosion and the negative impact on soil fertility and plant production.

Soil quality is important for obtaining a good yield. Knowledge about soil quality is influencing management practices and possibly increasing the yield. Several of the first soil scientists, therefore, investigated soil from an agrarian and production perspective (Thaer 1880; Liebig 1841). Today, soil scientists determine soil quality among others through the soils pH-value, the soil texture and the C/N-ratio. These soil properties indicate the suitability of a soil for plants (Abdul Khalil et al. 2015; FAO 2006b): The pH-value reflects soil formation processes and affects soil-dwelling organisms and the nutrient availability for plants (Blume et al. 2010; FAO 2006b). The soil texture determines among others the water retention capacity and together with the influence of lateral water or groundwater the oxygen level in soils (Vos et al. 2016; Blume et al. 2010). The C/N-ratio affects the N-availability for plants (Canfield et al. 2010). These soil properties were determined using soil samples from the different associations and analyzing these in the laboratory. Further, the allotment gardeners were asked, if they assess their soil's quality and if so, what criteria they use. The aim was, to investigate, if soil quality matters to the gardeners. The results of the soil sampling and the questionnaires were used to compare the soil quality assessment of the gardeners with a soil scientific evaluation of soil quality.

Methodology

Study site

The study was performed in Baden-Wurttemberg, in the rural Black Forest – Baar region (Villingen-Schwenningen - VS), and in the state capital Stuttgart (S). The Black Forest – Baar region has an area of 252 904 ha and a population of 476 635, equaling a population density of 188 persons per km² (Statistisches Landesamt Baden-Württemberg 2016). The Baar basin is a trough between the Black Forest and the Swabian Jura (Henkner et al. 2017). The continental climate has a mean annual precipitation of 700-800 mm y-1, and a mean annual temperature of 6-7°C with high temperature fluctuations during the day and year (Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg 2016). Cold air pockets are climatic features, which are associated with late frost and high frost frequencies (Frankenberg and Siegmund 1996).

The urban area of Stuttgart is 20 735 ha with 604 297 inhabitants, and a population density of 2859 persons per km² in 2014 (Landeshauptstadt Stuttgart 2015). It has an urban climate, which is further influenced by its location in a basin with differences in altitude of 260 m between basin bottom and surrounding ridges (Verband Region Stuttgart 2008). The average temperature in the city center is 10°C with an annual precipitation of 679 mm y-1, inversions occur regularly (Verband Region Stuttgart 2008).

Questionnaires

The questionnaire investigated the motivation of the gardener to start gardening, their management practices and their soil knowledge. Further, the common questions concerning age, gender, educational background, and employment status were asked. Questions investigating the background also included garden visits per week, travel time to the garden, and garden or farm ownership of grandparents and parents. The questionnaire started with a qualitative question, to facilitate the start of the questionnaire. This question asked for the associations of the gardeners with nature, garden, and soil. The answers to this question are used to put the results of the statistical analysis into a more holistic perspective. At the end of the questionnaire, many gardeners continued to talk about their garden, soil, and plants, so that qualitative interviews ensued. The information provided by the gardeners during these interviews are used to illustrate the use and knowledge of the resource complex soil.

The questionnaire asked for the motivation to choose gardening as a leisure activity. The motivations were investigated with a set of questions, which asked among others about the role of family tradition, food production and recreation. The respondents also had the chance to add further reasons for gardening. The answer possibilities were “yes” and “no”, therefore categorical variables.

The management practices were investigated with closed questions concerning the frequency of gardening activities, e.g. how often do you fertilize your plot? The answer categories were “never, “yearly”, “monthly”, “weekly”, and “daily”. This investigates management practices, such as digging, weeding and fertilizing. If digging is done yearly, traditional management practices are used. If digging is never done, this points towards new forms of management practices, such as raised bed gardening and no-dig. In all cases, the gardeners, who stated “never”, explained why they never dig, and showed the surveyor their raised beds or plots. Further, the preference for chemical fertilizer use was asked by using the statement “I prefer chemical fertilizer for my plants”. The respondents had to choose which of the categories “applies”, “applies in part”, “neither/nor”, “does rather not apply” or “does not apply” fits for them. In most cases, management practices were also a topic of the qualitative interviews after finishing the questionnaire.

Another set of questions investigates the gardeners’ soil knowledge, including soil erosion, soil quality assessment and the criteria used for this assessment. For the knowledge concerning soil erosion and the general knowledge of soil quality, the respondents were given statements with the answer categories applies to does not apply (s. “preference of chemical fertilizer”). Several criteria were given for soil quality assessment, e.g. soil color or the present vegetation. The respondents had the possibility to add their own criteria or tell the surveyor about specific tests they perform when assessing their soil.

After pre-tests with volunteers outside of the investigated sites, the questionnaires were used in an interviewer administered survey in six allotment gardening associations, three in rural VS and three in urban S. The response rate within the different allotment gardening associations was 25-30 %, with 70 gardeners participating in the survey in rural VS and 97 in urban S. All respondents provided verbal consent prior to participation. All interviewer-administered questionnaires were taken within the respective garden association and in the individual garden of the respondent. The surveyor was therefore able to get an impression of the gardening practices, e.g. presence of raised beds.

Statistics

The quantitative data collected with the questionnaire are evaluated using the statistical programming language R (R Core Team 2016). The answer frequencies are counted and given in percentages in the following.

Several different statistical analyses are used due to different levels of measurement. They test, whether the two groups are statistically similar (Tab. 1). The chosen significance level is $\alpha = 0.05$ for all tests. For ratio scale data, the two sample t-test (R Core Team 2016) is used. For ordinal scale data and ratio scale data for which a normal distribution cannot be assumed, the nonparametric independent 2-group Mann Whitney U test (R Core Team 2016) is used. In R this is done with the Wilcox test (R Core Team 2016). Fisher’s exact test is used for categorical data.

The open questions are evaluated qualitatively. The answers are grouped in new categories. Field notes and pictures were taken to capture information such as presence of raised beds, compost heaps or bird/insect friendly structures, diversity of flowering plants, or soil related information such as dry cracks in clayey soils.

Soil sampling and analyses

In each allotment gardening association, three soil samples at a depth of 0-10 and 10-20 cm were taken from an unused green space to determine soil texture, CN-ratio and pH-values. The interviews with the different gardeners had shown that management practices are diverse in all the associations. Therefore, sampling from an unused area took place, to obtain information about the non-amended soil condition.

The green spaces were chosen in accordance with the management board of each association to ensure that there had been no fertilizing in the last 5 years. In all cases, the board verified that the sampling area had not been used in the last 5-20 years. The only official activity on the green spaces was lawn mowing. Sampling took place in the summer of 2016.

Soil analyses were done in the Laboratory of Soil Science and Geoecology at the University Tübingen. Samples were air-dried and sieved < 2 mm.

For soil texture, wet sieving was used for grain sizes from 2000 µm to 20 µm using sodium diphosphate (Na4P2O7) as a dispersant. X-Ray granulometry with the SediGraph 5120 (Micromeritics) was used for grain sizes < 20 µm. Those samples containing appreciable amounts of humus were pre-treated with H2O2. Soil texture classes are given after the German description KA 5 (Ad-hoc-Arbeitsgruppe Boden and Bundesanstalt für Geowissenschaften und Rohstoffe 2005) and the WRB soil description guidelines (FAO 2006a).

Soil-pH was determined using a soil to solution ratio of 1:2.5 (CaCl2, H2O, with an electrode Sentix 81, WTW, pH 340) (Blume et al. 2010).

Samples < 2 mm were ground using a ball mill for determination of carbonate, C and N content.

Carbonate content was determined gas volumetrically using a Calcimeter (“Calcimeter”, Eijkelkamp, Giesbeek) for all samples with a pH > 6.8.

The element analyzer Vario EL III (Elementar) was used to determine total C and total N contents [mass %] with oxidative heat combustion at 1150 °C in a He atmosphere. Corg was calculated using Ctotal - (CaCO3 * 0.1200428) (DIN ISO 10694).

Results

Of the 167 respondents, 71 were female and 96 male. The female to male ratio is similar in both regions with 42 to 55 in the urban area and 29 to 41 in the rural area (Tab. 1). The age distribution (Fig. 3) was assessed in all allotments, but two respondents in S refused to answer.

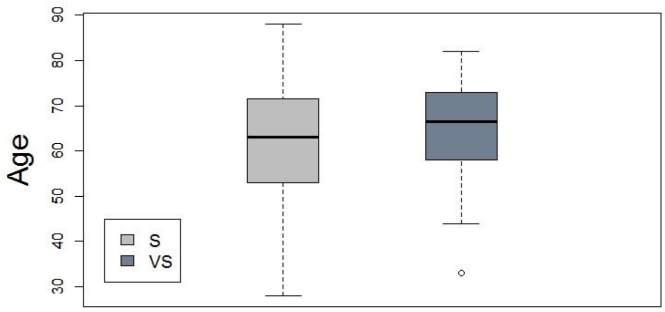

Fig. 3: Age of the gardeners in the urban (S, n = 95) and rural (VS, n = 70) region.

The educational background is similar in the urban and the rural surroundings (Tab. 1). 49.5 % in S and 56.5 % in VS attended a secondary school. The proportion of gardeners with university degree is almost double in S (16.5 %) compared to VS (8.7 %) and, in turn, the proportion of secondary school as educational background distinctly higher in VS. 20.6 % in S and 23.2 % in VS have a foreign school degree.

The employment situation is similar in both areas, with 52.6 % in S and 67.1 % in VS not working/retired. 36.1 % in S and 25.7 % in VS are fulltime employed.

For travel time, the average is used for evaluation. The mean travel time from the place of residence to the garden is 16 minutes (sd = 11.7 minutes) in the urban area, with a minimum of 1.5 minutes and a maximum of 70 minutes. For the rural area, the mean travel time is 13 minutes (sd = 6.9 minutes), with a minimum of 2.5 minutes and a maximum of 40 minutes.

The garden visits per week was often answered with an approximation, e.g. "I'm in the garden 2-3 times a week". For these, the average is used. Almost daily is attributed with 6 days a week. The weekly stay of the gardeners in their allotment ranges from once a week to daily, with a mean of 4 (sd = 2.07) and a median of 3.5 in S, and a mean of 5.3 times (sd = 1.89) and a median of 6 in VS, showing a difference between the regions (Tab. 1).

Table 1: Statistical tests with results of the analyses

Topic of question	test	category of question with result of statistic
Motivations for gardening	Fisher's exact test	parents and/or grandparents owning gardens (**p = 0.002**)
		own fruit or vegetables (**p = 0.01**)
		relaxation (**p < 0.001**)
		friends motivated me to choose the pastime gardening (**p = 0.001**)
		to express own creative ideas (**p = 0.01**)
		media coverage (newspaper articles, TV shows, internet) (p = 0.16)
		school lessons (p = 0.17)
	qualitative interpretation	other motivations
Management practices	Mann Whitney U test	digging (**p = 0.02**)
		pest control (**p < 0.001**)
		sowing (p = 0.46)
		fertilizing (p = 0.5)
		I prefer chemical fertilizer from garden centers for my plants (**p = 0.01**)
	qualitative interpretation	soil conservation measures
Soil knowledge	Mann Whitney U test	I know the term soil erosion (**p = 0.01**)
		I'm able to assess whether the soil is good for the plants I want to grow (p = 0.51)
	Mann Whitney U test/ qualitative interpretation	criteria to assess soil quality (p = 0.87)
personal data	two-sample t-test	age (**p = 0.04**)
	Welch's t-test	travel time (**p = 0.02**)
	Mann Whitney U test	garden visits (**p = <0.001**)
		education (p= 0.39)
		employment (p = 0.07)
	Fisher's exact test	gender (p = 0.87)
		school lessons (p = 0.30)
		parents had a garden (p = 0.09)
		grandparents had a garden (p = 0.29)
		parents were farmers (p = 0.14)
		grandparents were farmers (p = 0.1)

In S, 26.8 % of the respondents remember school lessons that were related to soil or agriculture, in the rural region this is the case for 34.3 % of the gardeners. 79.4 % of the respondents in S and 90 % of the rural respondents stated that their parents had had a garden. The grandparents of 68% of the urban respondents had a garden; the same was the case for 75.7 % in the rural area. Parents that were farmers applied to 32 % of the urban gardeners, and to 42.9 % of the rural. 45.4 % of the respondents in S and 55.7% in VS had grandparents that were farmers. There is no significant difference in the background between the two groups as far as school lessons and garden/farm ownership of the parents or grandparents are concerned.

Motivation for gardening in SW-German allotment gardens

The questions asked for several of the motivations, which were stated by other studies as reasons why people start gardening. Further, the respondents were able to add items to the list. Most often family tradition, own fruit and vegetables, as well as relaxation are the motivation for the surveyed gardeners to rent a garden in an allotment garden association. 54.6 % of the respondents in S, and 78.6 % of the respondents in VS state family tradition, e.g. parents and grandparents owning gardens, as a motivation for gardening in the allotment. Own fruit or vegetables are stated as motivation for gardening by 45.4 % in S and by 67.1 % in VS. Relaxation as motivation for gardening is important for 30.9 % in S and 71.4 % in VS. Friends that motivated the respondents to choose the pastime gardening are given as a reason by 6.2 % in S and 24.3 % in VS. Gardening to express own creative ideas is a motivation for 4.1 % in S and 17.1 % in VS. There are no statistical differences between the two groups concerning media coverage and school lessons as influencing factors for gardening, as only 1 % of the respondents in S and 5.7 % in VS are active allotment gardeners because media coverage in form of newspaper articles, TV shows or internet blogs raised their interest. School lessons raised interest in gardening for 2.9 % in VS and none in S.

Other motivations were frequently chosen, by 89.7 % in S and 74.3 % in VS (Tab. 2).

Table 2: Other motivations for gardening, % depends on the n (87 for S; 52 for VS), multiple answers possible.

	% S	% VS
getting out / enjoying nature	52,9	48,1
personal history with garden / agriculture	36,8	44,2
garden for own children / grandchildren	16,1	13,5
activity for retirement / unemployment	5,7	9,6
sense of community	1,1	7,7

Management practices in SW-German allotment gardens

79.4 % in S and 82.9 % in VS dig in their garden once or twice a year. 15.5 % in S and 5.7 % in VS do not dig at all, which is related to the no-till approach in agriculture. Pest control is done yearly by 21.6 % in S and 2.9 % in VS, while 12.4 % in S and 57.1 % in VS do some pest control on a weekly basis. Pest control here includes all actions against snails or aphids, such as collecting the snails off the plot, putting sand around plants or using slug pellets. For both digging and pest control, there is a significant difference between the groups.

In S, 79.4 % of the respondents' sow yearly and in VS, sowing is done yearly by 84.3 %. Fertilizing is a yearly activity for 78. 4 % in S and 78.6 % in VS.

A further question concerned the statement about the preference of chemical fertilizer use with the answer categories "does not apply" to "applies". 68 % in S and 85.7 % in VS chose "does not apply".

The non-structured interviews after the questionnaires showed that soil management is important to the gardeners. 52.9 % of the gardeners in VS described their soil management thoroughly, e.g.:

"The soil amendments peat, sand, and manure from a nearby farmer resulted in a loose and dark soil... Crop rotation [using four different fields] is used for pest control and to ensure an equal use of the soil, it's also tradition… Rain leads to silting of the soil, so I loosen it up with a digging fork to make sure that the plant roots and the soil get enough oxygen... In fall, I dig up the soil so that the soil freezes through in winter. This results in a crumbly soil. In spring, I only loosen the soil up. Fertilizer is used directly in the hole when planting... I also distribute my compost on the plot." (VS, m, 79)

"I garden according to the moon calendar of Maria Thun. Plants that fit together are planted together in crop rotation. Green manure, compost and organic fertilizers are used." (VS, f, 79)

"I do raised beds for 20 years now. The soil is dug up until you reach the subsoil. Tree cuttings, perennial plant remains, etc. are put in the hole. This is topped with horse manure and covered with the topsoil again." (VS, m, 63)

The urban respondents gave a list of soil amendments or practices used, with several measurements being used simultaneously. Among these, compost was used by most. Loosening up the soil regularly, the use of horn meal or shavings, and the use of sand were also very common. A fifth of the respondents in S admitted that they use chemical fertilizer, at least from time to time.

Besides compost, sand and loosening the soil with garden forks, gardeners in both regions use manure from a farmer, potting soil, organic fertilizer, Brennesseljauche (a brew where stinging nettle is added to water, after that mixture sat for a while, the brew is diluted and applied to the plot), mulching, and stone meal. Some gardeners dig to ensure the soil quality, use crop rotation, chalk, and green manure. Several measures were only stated by one or two respondents: terraces, guano, or ash, Bokashi, banana peel, malt pellet, and peat.

Soil knowledge of the gardeners in SW-German allotment gardens

68 % in S and 50 % in VS state that "I know the term soil erosion" applies to them. The statement "I'm able to assess whether the soil is good for the plants I want to grow" was used as a starting point for the block on knowledge about soil quality. 54.6 % in S and 45.7 % in VS state, that this applies to them.

When asked, how they assess soil quality, the gardeners described different soil properties rather than using the categories given in the questionnaire, which included soil color (17.5 % in S, 21.4 % in VS), vegetation present (32 % in S, 14.3 % in VS), and workability (23.7 % in S, 37.1 % in VS). 78.4 % in S and 78.6 % in VS used the "other" category; the following percentages depend on these numbers. These qualitative criteria are grouped into "soil texture", "trial and error", "soil management resulted in good soil", and "scientific soil samples". Soil texture is important for 59.2 % in S and 58.2 % in VS. A trial and error approach to figure out which plants grow and which do not, is used by 30.3 % in S and 25.5 % in VS. 20 % in both regions stated that their soil management resulted in a good soil. 6.58 % in S and 7.27 % in VS use scientific soil samples for soil quality assessment.

Scientific soil sampling

Soil samples were taken in all associations. In urban S, one of the three associations had three properties. Therefore, the association urban 3 had more soil samples analyzed (Tab 3). Soil texture varies between loamy and clayey. The pH-values are between 5 and 7. The C/N ratio has a range of 9 to 12.

Table 3: Results of the laboratory analyses.

Location	Depth [cm]	Sand [%]	Silt [%]	Clay [%]	pH	C/N
rural 1	0-10	5,77	36,6	56,7	6,9	10,2
rural 1	10-20	7,34	40,45	52,1	7,1	9,7
rural 2	0-10	20	33,32	46,5	6,7	10,1
rural 2	10-20	18,03	33,07	49,1	7,0	9,4
rural 3	0-10	25,98	49,71	24,1	5,6	10,0
rural 3	10-20	25,32	50,82	23,5	6,1	9,1
urban 1	0-10	7,72	52,42	39,9	5,3	10,0
urban 1	10-20	7,99	51,44	40,4	5,6	9,3
urban 2	0-10	19,12	45,56	35	7,1	11,6
urban 2	10-20	19,11	45,47	35,6	7,2	11,2
urban 3.1	0-10	17,71	36,24	46,1	6,4	11,9
urban 3.1	10-20	20,01	33,82	45,3	6,4	11,7
urban 3.2	0-10	35,82	32,45	31,5	6,6	12,0
urban 3.2	10-20	40,3	30,24	29,2	6,9	11,7
urban 3.3	0-10	18,07	50,07	32	5,7	11,4
urban 3.3	10-20	18,02	48,06	33,4	6,0	11,0

Discussion

The allotment gardeners in both regions are similar in age to the studies of Breuste (2010), who compared allotment gardeners from Salzburg, Darmstadt, Regensburg and Halle with each other. This is also in congruity with the home gardening study of Kiesling and Manning (2010). A reason for the older ages of gardeners could be that younger people might explore other forms of urban gardening, such as community gardens. This is shown in the study of Scheromm (2015), where 2/3 of the allotment gardeners and only 1/3 of the community gardeners are retired.

The travel time of the gardeners varies. However, the results show that most gardeners in the case study but also in the comparative analysis of Breuste (2010) live close to their respective gardens.

A significant difference (Tab 1) between S and VS exists in the garden visits per week. The gardeners in S do not visit their allotments as often as the gardeners in VS and the case study of Breuste (2010). A reason might be that urban S offers a more diverse set of free-time activities than VS. Further, food production is more important in rural VS, and requires frequent garden visits.

A similarity is, that approximately 20 % of the respondent in both regions are immigrants who have a foreign school degree. This shows, that gardening in an allotment is of interest for different groups in society, and might be used for social integration, which is also proposed by Taylor and Lovell (2014).

Motivation for gardening in SW-Germany, the relation to ecosystem services and resilience aspects

The motivations for allotment gardening, and thus for the use of the resource complex soil, vary significantly. More respondents in VS than in S stated family tradition as a reason for gardening in the allotment. However, in the category “other” 36.8 % in S and 44.2 % in VS stated a personal history with garden and/or agriculture. Thus, a personal relation to gardens in the past led many respondents to rent an own garden.

Food production is a reason for gardening in the present study but also in different studies concerning home gardens (Kortright and Wakefield 2011; Calvet-Mir et al. 2012; Kiesling and Manning 2010; Taylor and Lovell 2014) or urban gardening in general (Calvet-Mir et al. 2016; Pourias et al. 2016). In community gardens the food aspect seems less relevant (Spilková 2017; Guitart et al. 2012) or one of several equally important benefits (Drake and Lawson 2015). Scheromm (2015) also shows differences between allotment and community gardeners concerning the food production motivation. We show that food production is of varying importance in urban and rural allotment gardens. In rural VS, several statements of the allotment gardeners concerning their association with “garden” indicate that food production is important and in many interviews, the food topic was mentioned, e.g.:

“I garden to have natural fruit and veggies… Vegetables from the own garden taste better.” (VS, f, 74)

“My potatoes last for ¾ of the winter.” (VS, m, 71)

“I grow enough onions for the entire year.” (VS, m, 79)

“Gardening without vegetable patches? Then I don’t need to garden.” (VS, f, 58)

The respondents in VS often showed the surveyor around the plot and proudly presented their plants. In S, the respondents infrequently mentioned food production in the interviews or as a response to their association with “garden”:

“If you grow it yourself, you know what’s in it.” (S, m, 62)

“Organic food.” (S, f, 66)

In the survey of Clayton (2007), the benefits of ”producing herbs and food” is also less important than the other benefits given there. The present study indicates a bigger focus on food production in rural allotment gardens. The significant difference between the urban and rural allotment gardeners is especially interesting because the German law concerning allotment gardens states the importance of foodstuff production. The results of the questionnaire indicate that the provisioning ecosystem service function is a motivation for gardening in the rural area. There, the gardeners use the resource complex soil, because they want to produce their own food. In the urban region, food production and the provisioning ecosystem service are not the main motivation for gardening. However, the gardeners with the motivation of food production have knowledge on plants and soil and, thus, retain the social-ecological memory of food production. This memory is important, especially in times of crisis, to strengthen the resilience of urban agglomerations.

Calvet-Mir et al. (2016), Pourias et al. (2016) and Kortright and Wakefield (2011) showed that the quality of the food matters to gardeners in general, and that they can only control what they eat, if it is grown in the own garden. Three allotment gardeners in S but only one in VS directly mentioned the aspect of organic food. While food as interview topic was more present in VS, food quality is a concern to the gardeners in S who have food production as a motivation to rent an allotment and use the resource complex soil in their leisure time.

Relaxation as motivation for gardening is more important in VS, than in S. However, the term “garden” was associated with “recreation” by 88.7 % in S and 87.1 % in VS in the first qualitative question. Maybe gardeners in S connect their gardens with recreation and relaxation, but it was not the first motivation for them to rent an allotment parcel. Furthermore, another motivation for gardening in both regions is to get out and enjoy nature, which relates to a recreational activity, and was also shown in the study of Pourias et al. (2016). In both regions, the gardeners see their garden as a place to spend their leisure time. Thus, the cultural ecosystem service function is important for allotment gardeners in SW-Germany. The leisure aspect is also present in the study of Scheromm (2015).

60 % of the gardeners surveyed by Kiesling and Manning (2010) stated that a relative, friend or neighbor sparked their interest in gardening. Only 6.2 % of the respondents in S and 24.3 % in VS had friends as a reason for gardening in an allotment. So the present results differ from the results of Kiesling and Manning (2010). However, their study combined friends, neighbors, and families, while family tradition was separated in the present study.

Gardening to express own creative ideas is a motivation for 4.1 % in S and 17.1 % in VS. However, the rules of the allotment gardening associations are rather restrictive on what is permitted in the gardens. It is necessary that a third of the entire garden is dedicated to the cultivation of foodstuff. The gardeners have to plant foodstuff in their gardens and while the plant selection and arrangement can be very creative, there are boundaries on what is possible. Gardening in German allotments is therefore different to backyard gardens where there are fewer restrictions limiting the gardeners' creativity. This might explain that few gardeners in S and VS stated the expression of their creativity as a motivation for gardening.

Gardens are seen as places to learn about nature and transmit this knowledge to children and grandchildren, as Calvet-Mir et al. (2016) and Pourias et al. (2016) suggest. 16.1 % in S and 13.5 % in VS took up gardening for their children or grandchildren:

"Showing our child, where food comes from." (S, m, 42)

Calvet-Mir et al. (2016) and Pourias et al. (2016) also show that gardening activities such as weeding and pruning have health effects in terms of physical activity, and psychologically restorative effects. In the present study, several gardeners gave health related statements:

"I have a job where I sit all the time, so the garden is a compensation to that." (VS, m, 72)

"Gardening is motion." (VS, m, 56)

"I get moving." (S, m, 73)

"I garden as stress relief." (S, m, 59)

However, restorative functions were only mentioned by few allotment gardeners in the present study. The reason for that may be that food production and recreation are more obvious reasons for gardening and are therefore answers that come to mind more easily in a survey situation.

The results show, that the provisioning and the cultural ecosystem service function affect the decision of the gardeners to rent an allotment. However, food production is not the main reason to start gardening in an allotment, and differences between the two regions exist. The provisioning ecosystem service motivates more gardeners in the rural area to start gardening in an allotment. The cultural ecosystem service function is an important motivation for the allotment gardeners to rent their plot. While the motivations for gardening vary, the contribution of gardens to ecosystem services in urban agglomerations exist (Calvet-Mir et al. 2012; Breuste and Artmann 2015; Langemeyer et al. 2016). Besides the provisioning and cultural ecosystem service functions, the gardens have regulating and supporting ecosystem service functions (Millennium Ecosystem Assessment 2005), e.g. the regulating ecosystem service of pollination (Jansson and Polasky 2010). Further, gardens have the potential to increase biodiversity (Smith et al. 2005; Smith et al. 2006; Gaston et al. 2005), which is an important factor for the provision of ecosystem services in general (Millennium Ecosystem Assessment 2005). The contribution of allotment gardens to the resilience of urban agglomerations is, thus, not limited to retaining the social-ecological memory of food production, but also includes the provision of habitats to natural flora and fauna and, consequently, the protection of biodiversity.

Management practices in allotment gardens in SW-Germany

Several management practices exist to cultivate the soil. When asked about the different activities that are performed in a typical garden year, most of the gardeners stated traditional management practices, where digging is a yearly activity. However, 15.5 % in S and 5.7 % in VS stated that they do not dig at all. This is related to the no-till approach in agriculture and to raised bed gardening, which seems to be more common in S than in VS. A reason for the difference between the urban and the rural region might be that family tradition was the reason for gardening for more gardeners in VS than in S. If gardening is a family tradition than the management practices might have been conveyed from the parent to the now active gardeners. New methods and techniques, thus, have little effect on their garden management. Furthermore, in S the gardening community has younger people than in VS. The younger gardeners might read about garden management practices in newspapers, blogs or the extensive gardening literature and find the no-dig approach there. Another explanation for the presence of newer methods in the urban allotment gardens might be, that information in urban agglomerations is readily available through well-equipped libraries, the presence of universities, talks and presentations by experts, and a better infrastructure concerning high-speed internet access.

Another difference in the garden management practices concerns pest control, which 12.4 % in S and 57.1 % in VS do on a weekly basis. Actions against snails or aphids, such as collecting the snails off the plot, are important, if a reason for gardening is food production. As stated above, food production is a bigger topic for the gardeners in VS than in S. The gardeners in VS are, thus, more interested in pest control:

“Snails are a big problem. 80 % of my beans were eaten by them last year. That spoils all the fun.” (VS, m, 64)

“Most of my nasturtium froze this year; the rest was eaten by the snails.” (VS, f, 74)

“I use snail pellets, otherwise I’d have no salad.” (VS, m, 71)

These statements show that pest control is closely related to food production. If the amount of harvest does not matter, pest control is not as important. Pest control also seems to be of minor concern to the gardeners that participated in the survey of Scheromm (2015).

Most of the gardeners’ state, that “I prefer chemical fertilizer from garden centers for my plants” does not apply to them. While they do not prefer chemical fertilizer, this does not mean, that they do not use it. This is observable in S, where several gardeners use chemical fertilizer, at least from time to time. The results are in accordance with Kim et al. (2014), who show that community gardeners in Baltimore prefer composting and mulching over commercial fertilizers and pesticides. Dewaelheyns et al. (2013) also show that Flemish domestic gardeners use lime, compost and organic fertilizers. However, Dewaelheyns et al. (2013) investigated the amount of fertilizer use in Flanders to be excessive. The gardeners in the present survey do not prefer chemical fertilizers and use several management practices to ensure a good soil quality. The widespread use of compost, green manure, manure from horses, cows or pigeons, and loosening up the soil with a garden fork indicate a traditional gardening approach in both regions. However, a few respondents mentioned mulching, no-digging and raised bed gardening, illustrating that new methods are used in allotment gardens as well. Further studies are needed to investigate the actual soil conservation measures in the gardening community.

Soil knowledge of the allotment gardeners in SW-Germany compared with soil scientific knowledge

Soil cultivation is a major activity in the different gardens. However, the statement "I'm able to assess whether the soil is good for the plants I want to grow" applied to only half of the gardeners in both regions. The gardeners use different soil properties to assess soil quality. Approximately 78 % in both regions used other categories than the ones given in the questionnaire. These qualitative answers were grouped into "soil texture", "trial and error", "soil management resulted in good soil", and "scientific soil samples". Besides these, the present vegetation and the workability of the soil were most commonly used to assess the soil quality. The answers show that the gardeners use criteria that are observable during normal gardening activities:

"…crumbly soil…" (VS, m, 71)

"Soil needs to be loose." (VS, f, 73) and (S, m, 75)

"It [soil] needs to feel right when touched." (VS, m, 67) and (VS, m, 56) and (S, f, 43)

One gardener even described a test related to soil texture and moisture:

"It depends on the grip. I form a ball out of soil and drop it on the ground. If the ball falls apart, the soil is good. A mud pile is bad." (VS, m, 64)

The statements indicate that the gardeners rely on their experience with the soil present in their respective gardens, when assessing its quality. This experience is gained through experiments:

"Testing and trying." (VS, f, 63), (VS, m, 45), (VS, f, 33), (S, m, 42) and (S, m, 59) among others

Soil knowledge is gradually gained by dealing with the material on a regular basis. The results concerning the knowledge of the term soil erosion also show this: the gardeners in S, whose gardens are generally on slopes, state, that they know what soil erosion is. In VS, however, the gardeners' allotments are generally on plains. Only one allotment garden association is in an area prone to erosion. In this case, it is fluvial erosion that causes the loss of fertile topsoil due to a small creek next to the allotment garden association. There, the gardeners generally know the term soil erosion. The respondents thus relied on their personal and practical experience when answering the soil related questions. Often these experiences were gained through experimenting with plants and soil, which is similar to the results of Scheromm (2015). Only few gardeners use scientific research by sending soil samples to a laboratory or using test kits from a garden center to determine pH-values. The laboratory analyses show that the gardeners work with loamy to clayey soils. While these soils might be difficult to cultivate, the texture alone does not determine its fertility. Other factors are the pH-value which affects the availability of nutrients (FAO 2006b) and the C/N ratio (Canfield et al. 2010). The pH-values of the soil solutions in the respective garden associations vary between 5 and 7. This puts the soil samples taken from unused green spaces in the context of acid to moderately alkaline. The pH-value should be >5, so that no toxic concentrations of Al^{3+} and Mn^{2+} occur, but the optimal pH value depends on the clay content and organic matter (Blume et al. 2010). In general, plant growth is possible for pH-values between 3 and 10, but for most plants, nutrient availability is best at pH 6-7 (FAO 2006b). In Europe, the C/N ratio of productive arable land/grassland is between 10 and 15 (Blume et al. 2010). The C/N ratio of the garden soils has a range of 9 to 12 providing good conditions for gardening, especially if organic material is added. Decades of gardening in the same spots altered the original soils, so that several gardeners state that they have a good and crumbly soil now.

Conclusions and Outlook

The SES allotment gardening was investigated in contemporary German allotment garden associations by using the concept of resource complexes as an analytical tool. The use of the resource complex soil in the SES allotment gardening contributes to the provisioning of ecosystem services in settlements.

The results indicate different motivations for gardening between the two regions. The provisioning ecosystem service function is a bigger motivation for gardening in the rural region. The cultural ecosystem service function in form of recreation is used by all gardeners. Soil cultivation as a major task in the allotment gardening community relies on traditional methods, but new management practices are present in both regions. Soil knowledge relies on experience in the respective garden. These results indicate that in both regions the resource complex soil is used, but that differences exist. In the rural region, the resource complex soil is closely connected to food production and the provisioning ecosystem service function. In the urban region, the resource complex soil is used for recreational purposes and is also approached through newer forms of management practices.

The gardeners contribute to an increasing use of ecosystem services in urban agglomerations and can thus be considered stewards of the environment. The contribution of free time gardeners to the use and protection of ecosystem services in urban surroundings happens on a small scale. Nonetheless, it is an important activity because it fosters the engagement with nature and food production. It is, thus, a first step towards a more engaged citizenship, and towards the activation of more members of society for ecosystem stewardship. Knowing the motivations for the active use of the resource complex soil enables scientist, planners and practitioners to develop tools and programs, which encourage citizens to become active and contribute to a greener urban environment. Interdisciplinary work is necessary to further investigate who is gardening where, including all forms of gardening such as allotments, home- and community gardens. Through these actions, ecosystem services become visible to more people in an urban area, which possibly leads to an increasing social-ecological memory of food production processes. Further, it might facilitate the implementation of environmental protection measures within communities.

Gardening also draws the attention of the gardener to soil and the functions it provides. The variety of soil conservation measures shows, that gardeners care for the soil in their allotment garden. They experiment with practices and gain soil knowledge through regularly working with it. This indicates a certain interest in soil related subjects and, thus, is a possibility to increase the acceptance of soil conservation methods in the gardening community. Bottom-up approaches within the respective allotment gardens, discussions between soil scientists and gardeners on equal terms, or programs within communities can address this topic and possibly raise awareness for soil protection on bigger scales.

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Manuscript 4

Archaeopedology and chronostratigraphy of colluvial deposits as a proxy for regional land use history (Baar, southwest Germany).

Published in Catena 2017, Volume 155, pages 93-113.

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1 Abstract

Soils are the basis of our food production, supplying plants with nutrients and water. Farming leaves traces in the soil because cultivation can cause soil erosion. One result is the formation of colluvial deposits, which can be used as geoarchives of past human impacts on their terrestrial environment. The present study combines pedological and archaeological knowledge with chronostratigraphic analyses to infer deposition phases of colluvial material, thereby allowing the reconstruction of past land use and settlement activities in the Baar region, SW Germany. Local colluvial signals are interpreted as a regional proxy for increased soil erosion and colluviation. On the Baar, seven main deposition phases of colluvial material can be detected by 28 luminescence dates and 41 radiocarbon ages distributed through 26 soil profiles. Our results indicate increased colluviation in the younger Neolithic (~3800 BCE), the early to middle Bronze Age (~1550 BCE), the Iron Age (~500 BCE), the Roman Empire (~100 CE) and from the high Middle Ages onwards (>1200 CE, 1300 CE, 1600 CE). These dates and record of colluviation complement archaeological knowledge of the fundamental impact of human activities on the landscape due to sedentism and agriculture (early anthropogenic hypothesis). Our study shows that most periods of intensified colluvial deposition often, but not always, date to times with colder, more humid climatic periods. The spatial and temporal correlation of main depositional phases with archaeological finds points to land use as the determining factor of colluvial deposition, at least since Roman times.

2 Introduction

Today many landscapes and geographic regions are considered unfavorable for settlement or permanent use due to climate, soils, topography, and native plant communities, while others are classified as favorable. In central Europe, the concept of favorable and unfavorable regions refers to the environmental conditions and the time a region has been settled (Gebhardt, 2007). A favorable area (German: Gunstraum or Altsiedelland) is assumed to have been settled earlier than an unfavorable area. Reasons for an early settlement could include a more accessible landscape, fertile soils, warmer climate and sufficient rainfall for agriculture. Unfavorable areas are usually characterized as being less productive for agriculture, and therefore were supposedly settled later. However, the application of this definition to a research question needs to be explained in specific geographic and archaeological contexts. An interdisciplinary prehistoric archaeology and soil science project at the University of Tübingen is examining land use and settlement history in unfavorable areas in southwestern Germany. The focus is on soils that are a key resource for food production and human habitation. The technological capacity of human societies to use and modify soils has changed dramatically through time, as have the reasons for carrying out these activities. Soils itself preserve the signature of past human activities, as well as, paleoenvironmental conditions (James et al., 2014; Nicolay et al., 2014; Pietsch and Kühn, 2014).

Soils have been a research focus since the times of Thaer (in Kraft et al., 1880) and Liebig (1840), who studied agricultural land use. The first scientist to describe soils and their properties were Dokuchaev in Russia (Glinka, 1927) and Hilgard (1914) in North America. They suggested that soils result from interactions among parent material, climate, topography, biota and time. In 1941, Jenny (1994) explained soil formation in his quantitative pedology, which is based on these five functionally related soil forming factors. The theories and concepts of soil formation include the shape of the soil surface as an essential variable, at least since Milne (1935) published the concept of a catena. A catena or toposequence describes soils along a landscape sequence, where soil properties change gradually depending on geologic, geomorphic, atmospheric, or biologic processes (Wysocki and Zanner, 2006). However, none of these concepts explicitly include the effect of human activities on soil formation and erosion processes. This is changing; the term Anthropocene highlights a new geological epoch characterized by a significant transformation of the natural environment by humans (Crutzen and Stoermer, 2000; Lewis and Maslin, 2015; Ruddiman, 2013). Richter et al. (2015) describe how humans have altered soils chemically, physically, and biologically, transforming them into a human-natural system. This process started with the so called Neolithic Revolution – the transition from a hunting and gathering society to sedentism and the use of agricultural production. These changes in human settlement patterns, techniques for subsistence, and social organization subsequently triggered the Neolithic Revolution or Neolithic Demographic Transition, which saw higher carrying capacities and increased demographic growth rates (Bocquet-Appel, 2011; Downey et al., 2014). During this period, permanent land uses like farming, which involves digging, plowing, and harvesting, ultimately led to deforestation (Fyfe et al., 2015) and bare soils along slopes are prone to soil erosion. The eroded soil is deposited in depressions and along slopes, and called colluvial deposit. These deposits are important archives of the physical and cultural heritage of the region (Dreibrodt et al., 2010b;

Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW), 2008; Miehlich, 2009).

The German term Kolluvium is used when describing slope deposits formed by human induced or intensified soil erosion due to their land use (Ad-hoc-AG Boden, 2005; Kleber, 2006; Leopold and Völkel, 2007a). The characteristic corresponding land use is agriculture (Blume et al., 2010; Bork, 2006), but it could also be deforestation, mining, village establishment or infrastructure building. Hunter and gatherer populations also used the land and depended on the soil, but non-sedentary societies had smaller impacts on soil erosion and colluvial deposition than did agricultural societies (Miller, 2006). Thus, farming marks the beginning of a more intense and permanent anthropogenic land use that led to the formation of colluvial deposits. In this paper, the terms colluvium and colluvial deposit are used to describe soil landscape features formed by anthropogenic processes, including induced or intensified soil erosion by water and down slope deposition of eroded material. The term colluvial soil horizon describes a soil horizon out of colluvial material. These colluvial deposits are important resources to understand land use and settlement history (Emadodin et al., 2011; Leopold and Völkel, 2007a; Pietsch and Kühn, 2014). Further relocation of colluvial material, as well as absent, sustainable, or soil conserving land use lead to missing colluvial deposits. Soil formation, per the concept of Jenny (1994), takes place in periods of physical geomorphodynamic stability. If this stability is disturbed soil relocation occurs and pedogenesis slows dramatically. Environmental influences, especially precipitation variation and thunderstorm events associated with climate change, should be considered when interpreting and quantifying colluvial deposits as anthropogenic geoarchives (Dreibrodt et al., 2010a).

A colluvial deposit is always directly related to adjacent upward slope areas and thus it can be considered a local, high-resolution spatial phenomenon. The situation on nearby slopes can be different. If colluvial deposits are archives representing the impact of humans on their environment (Verstraeten et al., 2009), they can be used as a local proxy for the intensity and duration of human settlement, land uses, and migration during the Holocene (Dotterweich and Dreibrodt, 2011; Helbig et al., 2002; Leopold and Völkel, 2007b; Schroedter et al., 2013). Thus, we hypothesize that a geomorphological and spatially controlled sample of colluvial deposits can be taken as a regional proxy for land use history. Consequently, the research presented in this paper focusses on the following objectives:

(i) Analyzing the local chronostratigraphy and archaeopedology of colluvial deposits in different areas of the Baar region

(ii) Identifying main periods of colluvial deposit formation across the Baar region

(iii) Inferring possible causes of the formation of colluvial deposits as related to human land use history and climate

2.1 Regional setting of the Baar

The study area in southwest Germany comprises the granitic basement of the Black Forest to the west and the limestone escarpment of the Swabian Jura to the east (Fig. 1). In between is the Baar, a depression of older escarpments that includes the Danube River and its headwater streams, the Brigach and Breg. The entire study area is an unfavorable region, but compared to the Black Forest and Swabian Jura the Baar can be considered a favorable region for agriculture because it has fertile soils, often influenced by loess deposits (Kösel and Rilling, 2002; Lazar, 2005). The area was known as the breadbasket of the Baden region (Reich, 1859; Schröder, 2001). The Baar has an average elevation of about 700-800 m, and it has a lower relief intensity than the Black Forest and Swabian Jura. Mean annual temperature is 7 8 °C and mean annual precipitation is approximately 850 mm (Siegmund, 2006). Swabian Jura and Black Forest have lower average temperatures and higher annual precipitation; they are considered unfavorable for agricultural land use. In the low mountain range of Black Forest, soils tend to be more acidic, and the relief is higher, having peaks of up to 1000 m height. On the 750-900 m high plateau of the Swabian Jura, the supply of fresh water is limited because of low water storage capacity in the bedrock, and depends mostly on precipitation. Thus, this paper focuses on the Baar region, representing a rather favorable area for agricultural land use.

During the winter, stable atmospheric inversions occur in the Baar that can create heavy fog and many freezing days (122 ±10 days from 1994-1996); along with short periods of frost-free days (approximately 140 days) (Siegmund, 2006). The Baar region is therefore more unfavorable than regions to the south and north, such as the Upper Rhine lowlands or the Hegau region.

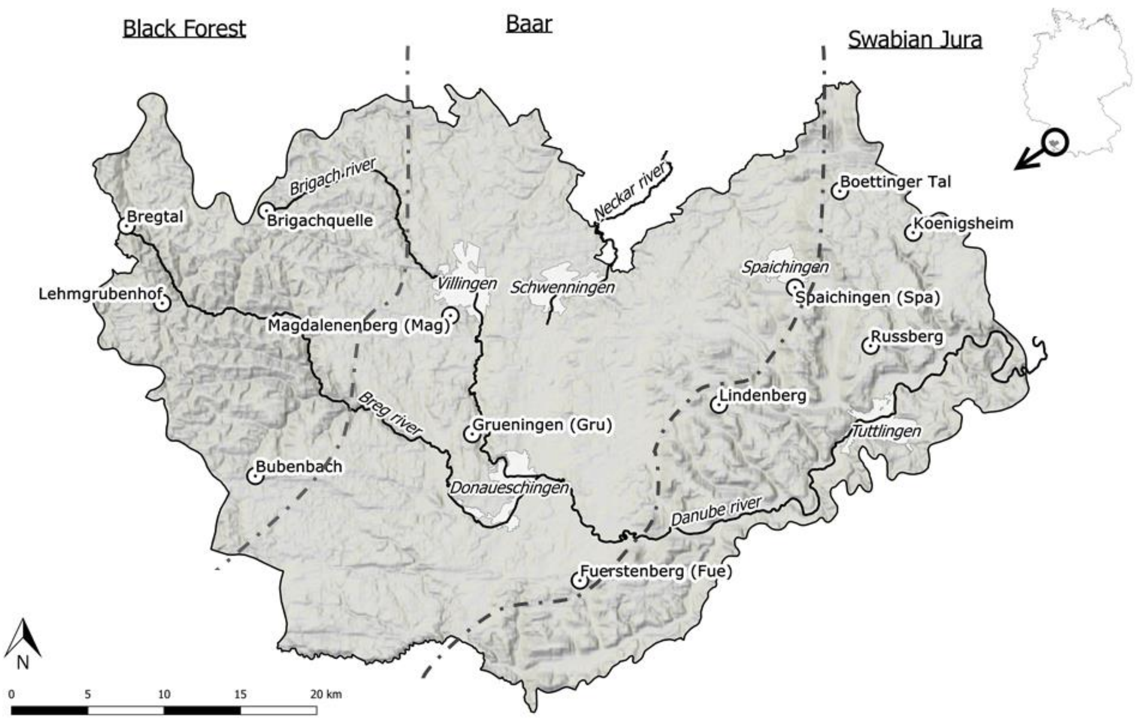

Fig. 1. SRTM image (Jarvis et al., 2008) of the study area in SW Germany, covering the eastern Black Forest in the west, the Baar in the center and the western Swabian Jura to the east (all separated by dash-dot lines). The study sites (marked with circles) Magdalenenberg (Mag), Grueningen (Gru), Fuerstenberg (Fue) and Spaichingen (Spa) are situated on the Baar; the others sites are located in neighboring regions. Modern settlements are given in italics.

Four sites on the Baar were chosen for archaeopedological and chronostratigraphic analyses because they provided the oldest archaeological findings in the Baar region, as known from literature. Since the locations were chosen in accordance with archaeological evidence (Tab. 1), we hypothesize that the phases of colluvial deposition can be linked to the local and regional settlement history. We, thus, use the colluvial deposits as a proxy for land use history. The four sites are: (1) The Magdalenenberg (Mag) site in the northwestern Baar close to Villingen, with its famous burial mound built of wood and earthen material dating to 616 BCE (Knopf, 2012). The location of the corresponding ancient settlement(s) is unknown. Archaeological findings indicate land use here since the Neolithic (Schmid, 1991; 1992). The bedrock is middle Triassic limestone, partially covered by loess containing Holocene slope deposits (Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau, 2013). (2) The Grueningen (Gru) site is located above the Brigach River near Donaueschingen. The dominant bedrock in the area is limestone covered by Pleistocene-to-Holocene deposits, containing admixtures of loess. (3) The Fuerstenberg (Fue) site is in the southern Baar and close to the transition to the Swabian Jura. It comprises slope deposits from late Jurassic limestone to early Jurassic clay-rich sediments covered by relocated loess. (4) At the site close to the town Spaichingen (Spa) the upper and middle slope is built up by limestone (middle Jurassic); the lower part consists of early Jurassic claystone and is covered by Holocene sediments.

Slopes and depressions at all four sites are covered by slope deposits, of periglacial or anthropogenic origin during the Quaternary, which are the parent material for soil formation (Kösel and Rilling, 2002). Regosols and Cambisols (according to the World Reference Base of Soil Resources, IUSS Working Group WRB, 2015) are the most common soil types on these sites. As a result of different pedogenic processes, Luvisols, Vertisols, and Gleysols occur as well.

2.2 Settlement and land use history of the Baar region

The cultural periods of SW Germany are given in Table 1 starting with the Neolithic Period at the beginning of agricultural activities within the study area. Each period is documented by artifacts found in a 2 km radius around the pedological study sites. Additionally, many finds are known from other sites in the Baar region (Schmid, 1991, 1992). On the western and southern Baar, two settlements from the first sedentary settlers and farmers of the Early Neolithic period, known as the Linear Pottery Culture, are identified (Nübling, 2005; Schmid, 1991; 1992). Stone tools from the Magdalenenberg and other sites indicate Early Neolithic activity on the western and eastern Baar (Schmid, 1991; 1992). Findings from the middle Bronze Age cluster around Donaueschingen and Villingen-Schwenningen, other finds from the Bronze Age are scattered across the Baar. During the Urnfield Period, the settlements were concentrated on the western Baar, and two settlement sites are known near Spaichingen (Hanöffner, 2005; Schmid, 1991, 1992). With the transition to the Iron Age, the number of known archaeological sites increases. During the Roman occupation settlements are known around Huefingen and Villingen-Schwenningen, while only a few farmsteads are found in the vicinity of Spaichingen (Paret, 1932; Schmid, 1992). In the eastern Baar, few settlements date to ±10 to 300 CE (Christ, 1960; Hübener, 1972; Spindler, 1977). In the Middle Ages, the number of archaeological sites markedly increases and the overall settlement pattern changes (Buchta-Hohm, 1996; Fischer, 1936; Revellio, 1935). Most archaeological sites are found in the valleys of the Brigach and Breg Rivers. In the east, south, and center of the Baar, settlements were rather loosely scattered. The distribution of the medieval sites is comparable to today's settlement pattern of the Baar.

3 Methods

3.1 Field

Field work for this study was carried out from 2013 to 2015. It included the description of 26 soil profiles, following the German soil classification system (Ad-hoc-AG Boden, 2005), the Food and Agriculture Organization of the United Nations (FAO) (2006), and the WRB 2015 (IUSS Working Group WRB, 2015). The German classification system includes the horizon designation M (M = Lat. Migrare, to migrate) for anthropogenic colluvial horizons lacking other pedogenic properties. Since it is important to differentiate colluvial horizons from others with different pedogenic development, we use the M horizon together with the FAO nomenclature. German soil types were translated into WRB using translation software (Eberhardt et al., 2013a, 2014). Soil properties like type and abundance of coarse fragments (e.g. limestone), redoximorphic features, root abundance and special features in the soil (pieces of charcoal or burned clay) were described according to Ad-hoc-AG Boden (2005).

The soil profiles are located along catenas reaching from the upper slope to foot slope positions. Catenas represent a sequence of soil profiles along a slope having different characteristics due differences in topography, elevation, drainage, erosion or deposition (Schaetzl, 2013). The locations of catenas and soil profiles were chosen to represent a stratigraphy of colluvial deposits in close proximity to known prehistoric activities, documented by prehistoric settlements or findings (Tab. 1). Dating was done on colluvial deposits showing the most detailed pedostratigraphy and being characteristic for the site. In order to prevent sampling bias for a specific time soil samples for dating were collected consistently from all soil horizons, where sampling was possible.

Tab. 1: Summary of archaeological finds sorted by cultural periods in SW Germany in a 2 km radius around each of the four study sites on the Baar. Questionable interpretation of the material is marked with a “?”. Not listed are many known undated stone and earth mounds.

Period (duration; references)	Site	Finds and records	Interpretation	References
Neolithic				
Early Neolithic (5500-5000 BCE; Lüning, 1996)	Mag	Flint tools	Single finds	(Schmid, 1991, 1992)
Middle Neolithic (5000-4400 BCE; Lüning, 1996)				
Younger Neolithic (4400-3500 BCE; Lüning, 1996)				
Late Neolithic (3500-2800 BCE; Lüning, 1996)				
Final Neolithic (2800-2150 BCE; Lüning, 1996; Stockhammer et al., 2015)				
Neolithic in general	Mag	Stone axe	Single find	(Hettich, 1984/85)

	Fue	Sherds, flint artifacts	Settlement?	(Revellio, 1933; Schmid, 1992)
	Spa	Scraper	Single find	(Nübling, 1990)
Bronze Age				
Early Bronze Age (2150-1550 BCE; Stockhammer et al., 2015)				
Middle Bronze Age (1550-1300 BCE; Della Casa, 2013; Müller and Lohrke, 2011)	Gru	Human remains, metal artifacts	Burial site	(Schauer, 1971; Wagner and Haug, 1908)
	Spa	Human remains, metal artifacts	Burial site	(Schmid, 1992)
Late Bronze Age (1300-1200 BCE; Della Casa, 2013; Mäder and Sormaz, 2000; Müller and Lohrke, 2011)				
Urnfield period (1200-800 BCE; Della Casa, 2013)	Gru	Sherds, bronze needle	Settlement?	(Knopf et al., 2015a; Knopf and Seidensticker, 2013)
	Gru	2 vessels	Deposition	(Ahlrichs et al., 2017 submitted)
	Fue	Sherds	Settlement?	(Wagner, 2014)
	Spa	Many sherds on several sites	Settlement?	(Schmid, 1991, 1992)
Iron Age				
Hallstatt Period (800-450 BCE; Guggisberg, 2008; Maise, 2001)	Mag	Burial mounds	Burial sites	(Spindler, 1977, 1996, 2004)
	Gru	Human remains, sherds, metal artifacts, etc.	Burial site	(Schmid, 1991, 1992)
	Fue	Sherds	Settlement?	(Wagner, 2014)
Latène Period (450 BCE-±1; Kaenel and Müller, 1999; Poppi, 1991)	Mag	Sherds in a pit	Settlement	(Weber-Jenisch, 1994)
	Mag	Sherds, coins, glass jewelry	Settlement?	(Weber, 1991/1992)
	Spa	Coin	Single find	(Fischer, 1936)
Roman Empire				
Roman Empire (±1 -375 CE; Eggert and Samida, 2013)	Mag	Coins	Single finds	(Christ, 1960)
	Mag	Terra-Sigillata fragments	Burial?	(Hettich, 1984/85)
	Fue	Sherds	Settlement?	(Revellio, 1933)
	Fue	Remnants of a building	Farmstead	(Fischer, 1936)
	Fue	Coins	Single finds	(Fischer, 1936; Wagner and Haug, 1908)
	Spa	Remnants of a building	Farmstead	(Paret, 1932)
	Spa	Sherds	Settlement?	(Schmid, 1992)
Migration Period (375-450 CE, Eggert and Samida, 2013)				
Middle Ages				
Merovingian Period (450-750 CE; Ament, 1977)	Mag	Bronze needle	Single find	(Hettich, 1984/85; Spindler, 1979)
	Gru	Several burials	Cemetery	(Buchta-Hohm, 1996; Wagner and Haug, 1908)
	Spa	Several burials	Cemetery	(Buchta-Hohm, 1996; Stoll and Gehring, 1938)
	Spa	Remnants of buildings	Village	(Paret, 1932)
	Spa	Human remains	Cemetery?	(Buchta-Hohm, 1996)

High Middles Ages (750-1250 CE; Sangmeister, 1993)	Mag	2 historical records	Fortification	(Buchta-Hohm, 1996)
	Mag	Historical record	Settlement	(Badische Historische Kommission, 1904b; Spindler, 1979)
	Gru	Historical records	Settlement	(Buchta-Hohm, 1996)
	Fue	Historical records	Settlement	(Badische Historische Kommission, 1904a; Wagner, 2014)
	Spa	4 historical records	Deserted village	(Buchta-Hohm, 1996; Heizmann, 1968; Paret, 1932)
Late Middle Ages (1250-1500 CE)				
Middle Ages in general	Gru	Aerial photo	Cemetery?	local archaeological records (Ortsakten)
	Gru	Aerial photo; Remnants of a building	Village	local archaeological records (Ortsakten)
	Gru	2 historical records	Farmstead?	(Badische Historische Kommission, 1904a)
	Gru	Earth walls	Fortification	local archaeological records (Ortsakten)
	Spa	Aerial photo	Settlement?	local archaeological records (Ortsakten)
	Spa	Sherds	Single finds	local archaeological records (Ortsakten)

A total of 339 bulk samples and 318 volumetric samples (each consisting of 3 x 100 cm3 subsamples) were taken from all horizons. From each colluvial horizon, the upper 5 cm were sampled separately, and colluvial horizons thicker than 20 cm were split into thinner sampling units. If we found pottery fragments in the soil, we collected and took them as indicators of a nearby settlement (Niller, 2001; Wunderlich, 2000). A lack of pottery fragments might indicate agricultural land use or deforestation (Mäckel et al., 2003).

3.2 Laboratory

Soil-pH was determined using a soil-to-solution (CaCl2, H2O, with Sentix 81, WTW, pH 340) ratio of 1:2.5 (Blume et al., 2010). Carbonate content was determined volumetrically by CO2 evolution using a Calcimeter ("Calcimeter", Eijkelkamp, Giesbeek). Total C and N contents [mass %] were analyzed using oxidative heat combustion at 1150 °C in a He atmosphere (element analyzer "vario EL III", Elementar Analysesysteme GmbH, Germany, in CNS mode). Soil organic C content (SOC) was determined using: SOC = Ctotal-CaCO3x0.1200428, soil organic matter (SOM) was calculated using the factor 1.72 (Eberhardt et al., 2013b). Bulk density [g cm 3] was gravimetrically determined (cf. Don et al., 2007). Texture was determined by X-ray granulometry using SediGraph 5120 (Micromeritics GmbH, Mönchengladbach) for grain sizes < 20 µm and combined sieving for grain sizes from 2000 µm to 20 µm.

To estimate depositional ages of the colluvial sediments, optical stimulated luminescence (OSL) dating was applied, using opaque steel cylinders with a diameter of 4.5 cm for sampling. For equivalent dose (De) determinations, the coarse grain (90-200 µm) quartz fraction was prepared and measured with a single-aliquot regenerative-dose (SAR) protocol after Murray and Wintle (2000). All luminescence measurements were carried out at the luminescence laboratory of the Justus-Liebig-University in Giessen, using a Freiberg Instruments Lexsyg reader (Lomax et al., 2014). For data analysis, the R luminescence package (Kreutzer et al., 2016) was used.

To avoid modern bleaching by bioturbation, the upper 30 cm of the profiles were not sampled for OSL dating. In consequence, colluvial deposition of the modern era might be underrepresented. This might also apply to older colluvial deposits, because of the generally better preservation of younger deposits. However, the general suitability of OSL dating on colluvial deposits, is shown in numerous studies, despite issues of partial bleaching (e.g. Fuchs et al., 2011; Fuchs and Lang, 2009; Kadereit et al., 2010). Most samples have good properties for luminescence dating, showing a bright luminescence signal. Therefore, small aliquots with a diameter of 1 2 mm were measured. In the case of skewness of the equivalent dose distribution a minimum age model was used. Skewness can result from partial bleaching or in situ redeposition.

AMS 14C radiocarbon dating of charcoal fragments found within the colluvial sediments was carried out at the laboratories of Erlangen, Jena, Mannheim, and Poznan. The pretreatment was done using the ABA (acid-base-acid) or, in case of samples measured in Jena, by an ABOx (acid-base-oxidation) procedure (Steinhof et al., 2017). The conversion of the 14C isotope ratios in calendar and calibrated dates was done with OxCal 4.2 using the IntCal13 calibration curve (Bronk Ramsey, 2009; Reimer, 2013).

The basic assumption for the interpretation of charcoal ages is that no relocation within the soil profile occurred. Occasionally, we encountered sample dates which appear to be out of sequence in relationship to other dated samples within a soil profile. In those cases, where the majority of dates formed a clear stratigraphic sequence, and certain charcoal samples date to much older or younger times than would have been expected due to their sampling location within the sequence, we assumed relocation of those sample by natural processes of bioturbation or redeposition. Age inconsistencies may also be due to the use or re-use of old timber because the samples date to the time when the tree grew, rather than the time when the wood was processed and used. These confounding effects can also explain charcoal ages which appear older than OSL ages. Another assumption is that the charcoal fragments are the result of consecutive inputs, most probably of anthropogenic origin, because single charcoal pieces are distributed throughout the soil profiles and not layered. If the pretreatment omitted all contaminations, the age of the charcoal represents the age of the layer plus the time span from growing to deposition, i.e. the charcoal age is an upper limit for the age of the colluvial horizon. The true age of the formation of colluvial deposits is not necessarily dated with the radiocarbon or luminescence method.

The radiocarbon calibration process can also introduce additional errors if particular dates are associated with problematic parts of the calibration curve ("wiggles" or non-linearities of the calibration curve), which result in extremely large and non-normal standard error estimates, even for very accurately dated samples. Finally, younger charcoal samples might be overrepresented because of better preservation and an increasing probability of destructive processes like erosion and weathering (Eckmeier et al., 2011; Lang, 2003; Surovell et al., 2009), which limits the explanatory power especially for older periods. Thus, radiocarbon ages from charcoal could be older, younger, or of the same age than OSL samples, depending on site taphonomy and date calibration dynamics. In addition, ten radiocarbon ages were omitted from the analysis because they dated soil organic matter, which gives older ages, since it originates from the older soil formation phase and was relocated with the colluvial material.

Only the available radiocarbon and OSL ages from colluvial layers with a high reliability, based on the comparison with luminescence ages and the stratigraphic context, were used for the calculation of the summed probability density (SPD) plots (Downey et al., 2014; Parnell et al., 2008). Soil pit locations were purposefully sampled from archaeological contexts; however, within each soil pit, soil material for dating was sampled from the top to the bottom of the vertical pit wall, and from within each identifiable and dateable layer. Because of this, the distribution of the date samples represents an unbiased, temporal sample and therefore the SPD curves from the 14C and OSL dates and error distributions are valid profiles of the colluviation intensity of these sites through time. To calculate SPDs, uncalibrated radiocarbon ages and errors were used and calibrated using the statistical software package Bchron (Parnell, 2016) and the calibration curve IntCal13 (Reimer, 2013). The SPD for the OSL dates was generated by sampling from a Gaussian distribution for each date where the mean was estimated as the date and the standard deviation was estimated as the OSL error distribution. The different age probability curves are summed and plotted.

4 Results

4.1 Stratigraphy and properties of colluvial deposits on the Baar

Colluvial deposits cover almost the entire area of the studied slopes, although they are expected to be limited to and thicker in foot slope positions (Ad-hoc-AG Boden, 2005). In this study, more than 130 colluvial soil horizons were described from 26 individual soil profiles, with an average of 5 colluvial horizons per soil profile. Most of the soils (#23 out of 26) were classified as Kolluvisols, the others as Rendzinas or Parabraunerde within the German

Classification System (Ad-hoc-AG Boden, 2005). Following the IUSS Working Group WRB (2015), 14 of the soils were classified as Cambisols, 6 as Regosols, and a few as Luvisols and Umbrisols.

Magdalenenberg

The catena at Magdalenenberg (Fig. 2) shows a characteristic distribution of colluvial deposits with an onset in the middle slope (between Mag4 and Mag3) and an increase in thickness and numbers of separate colluvial layers at lower slope positions (Mag1 and Mag2). Soil horizon boundaries are roughly parallel to the slope surface. Signs of former agricultural use (relic Ap horizon) are found on the plateau under forest (Mag6) and on the smoother middle and lower slope (from B1 downwards). Soil profile Mag1 was opened in 2010 (=Mag1_10) and again 2014 (=Mag1_14). The lowest colluvial horizons of Mag1 and Mag2 are underlain by in situ weathered material from limestone showing signs of water logging and clay relocation or periglacial slope deposits. The SOC content of the Mag1_14 soil profile decreases with depth from 4 % in the Ap to an average 1.15 % in colluvial horizons, and to 0.2 % in in situ horizons (Tab. 2). The Mesolithic OSL age (GI-0133) from the lowest colluvial horizon (2 M4) indicates pre agricultural soil erosion. The overlying M3 and M2 horizons formed in the late Mesolithic and younger Neolithic (GI-0132, GI-0131). Until the high Middle Ages, no colluvial horizons were formed, but archaeological evidence such as the Magdalenenberg burial mound point to human presence during this time (Tab.1). The upper 47 cm of the soil were accumulated from the high Middle Ages (750-1250 CE, GI-0130) onwards.

Tab. 2: Selected soil properties of Mag1_14: Haplic Umbrisol (Anthric, Aric, Clayic, Colluvic, Raptic)

Horizon	Lower boundary [cm]	Substrate genesis	SOC [%]	Further soil properties
Ap	25	colluvial	4.03	
M1	40	colluvial	2.20	
M2	60	colluvial	1.32	
M3	70	colluvial	0.64	10% limestones, redoximorphic features
2 M4	80	colluvial	0.45	10% limestones, redoximorphic features
3 CBsg	95+	weathered	0.20	

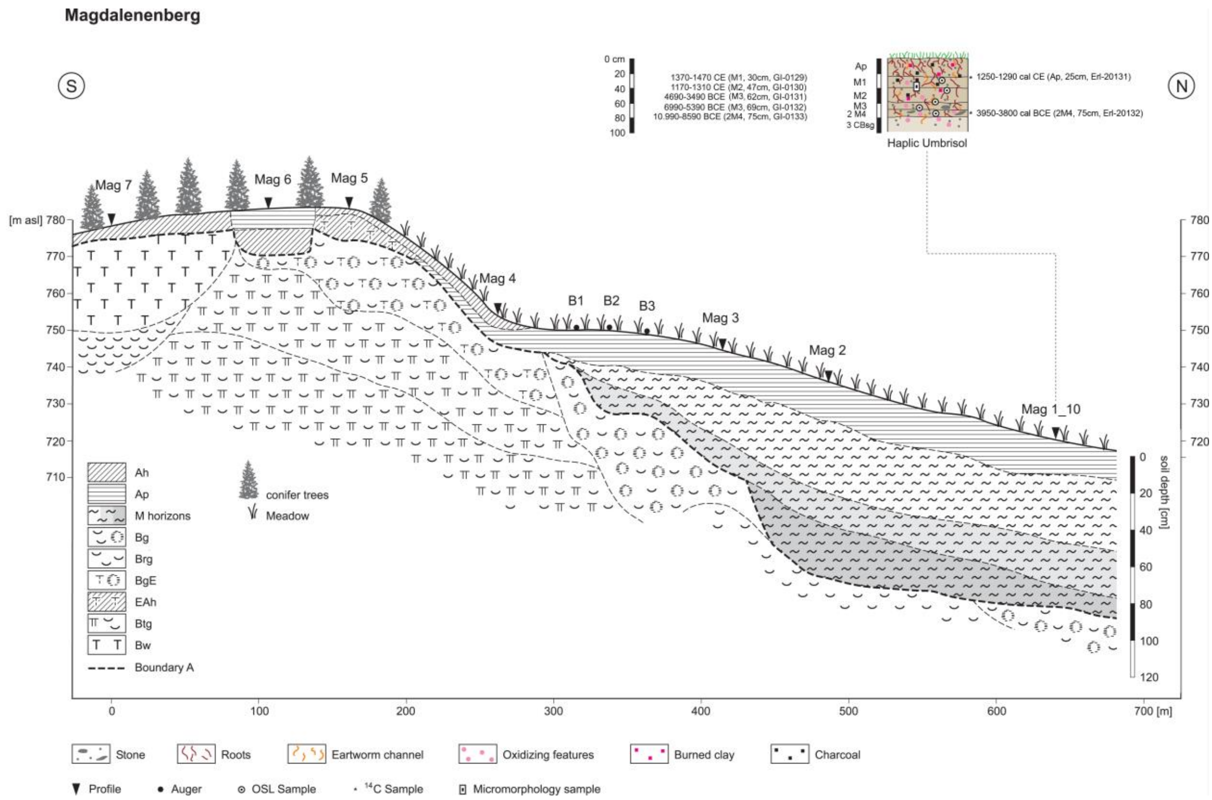

Fig. 2: Catena Magdalenenberg. The drawing of the catena is based on work from 2010; the profile Mag 1 displays the soil description of 2014.

Fuerstenberg

The catena on the southwestern slope of Fuerstenberg (Fig. 3) also shows a downslope continuum of the colluvial horizons. However, they are not necessarily parallel to the surface, but show a paleorelief with depressions, indicated by the boundary A. The colluvial cover at mid and lower slope positions (from auger Bf13 downwards) is built up by organic matter-rich material containing limestones, and can be differentiated in up to 6 colluvial horizons. Today the slope is drained and used for growing crops (wheat: Triticum aestivum, rapeseed: Brassica napus). The bedrock is covered by periglacial slope deposits from the late Jurassic limestone and overlying nearly 2 m thick colluvial deposits, indicating long anthropogenic land use. On the middle slope (between Bf47 and Bf13) there are two colluvial horizons, but then they increase again to four (Fue10, Bf50). A change of substrate and probably paleorelief occur between Bf13 and the soil profile Fue10. The upper slope soils are siltier, lighter brown, contain less SOC content, and are rich in limestone and CaCO3 content. The soil pH is about 0.5 units higher than on the lower slope. The profile Fue10 can be differentiated in four colluvial horizons, of which the deeper two horizons show a remarkable dark brown color and high SOC content. Further upslope (from Fue11 upslope) the thickness of the colluvial horizons declines rapidly and Regosols dominate the soilscape covered by grass. The late Jurassic escarpment above is covered by mixed hardwood and coniferous forest vegetation.

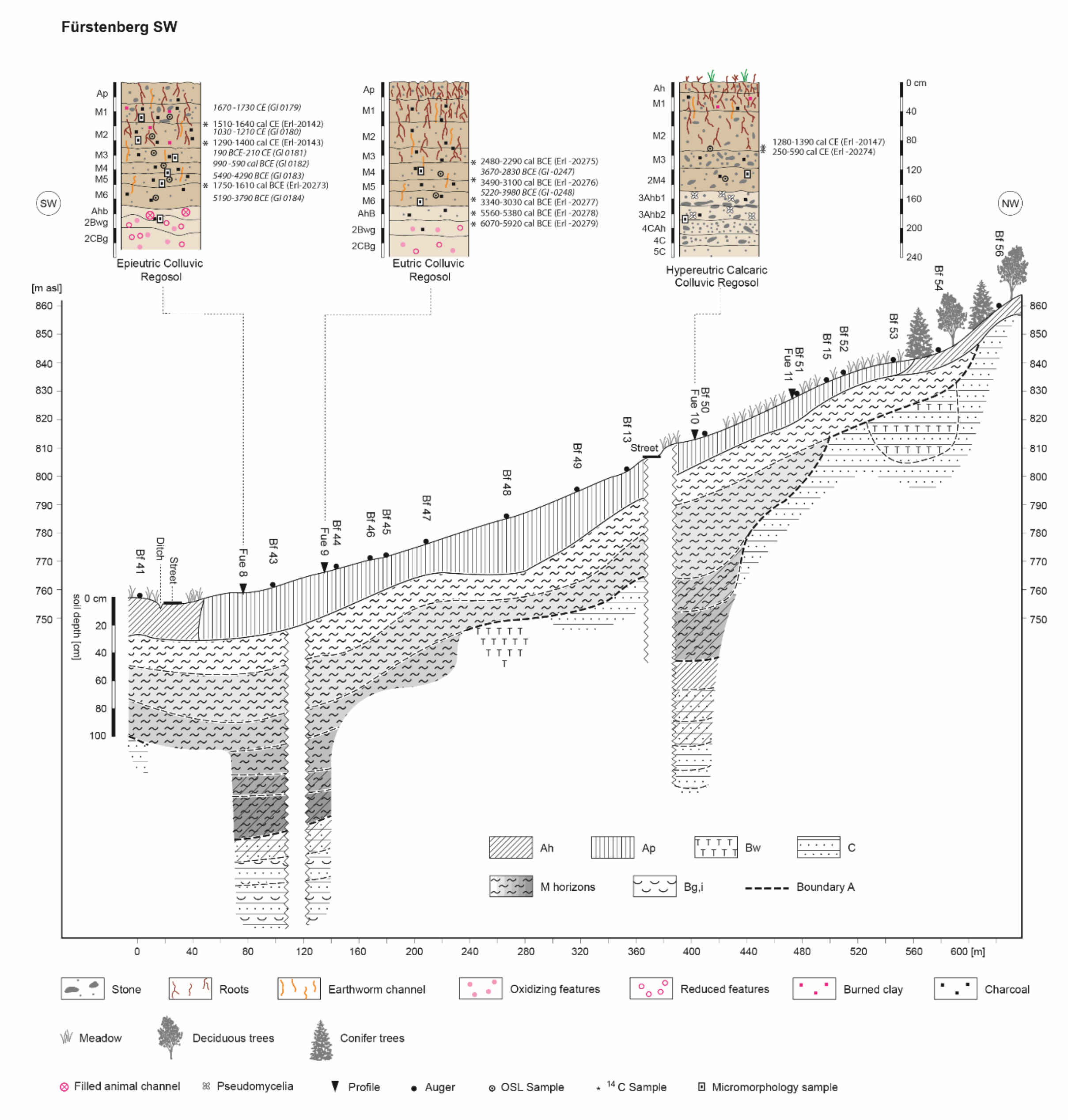

Fig. 3: Catena and soils at the south western slope of the Fuerstenberg.

Fue8 and Fue9 (Tab. 3), situated on the south facing footslope, are characteristic soil profiles of lower slope positions in the transition area to the Swabian Jura. Six colluvial soil horizons have formed from the Neolithic to modern times, having an average SOC content of approximately 2.3 %. On average, the colluvial horizons of Fue8 contain 1.9 % SOC. At the depth of 125-170 cm, a former relocated Ah surface horizon (M5 and M6, containing 2.04 % SOC) is buried and contains a charcoal piece dating to 1750-1610 cal BCE (130-140 cm, Erl-20273). The corresponding OSL age dates to 5490-4290 BCE (135 cm, GI 0183). Below approximately 190 cm non-colluvial horizons are developed in weathering products of the middle Jurassic. These horizons show vertic features. The profile Fue9 has a similar pedostratigraphy (Tab. 3), but dates to older time periods (Fig. 3, Tab. 7, Tab. 8) and contains more SOC in colluvial horizons (2.6 % SOC).

Tab. 3: Selected soil properties of profile Fue8: Epieutric Colluvic Regosol (Aric, Pantoclayic, Humic, Raptic, Bathythaptomollic) on the left and Fue9: Eutric Colluvic Regosol (Aric, Humic, Raptic, Anosiltic, Bathyclayic) on the right.

Horizon	**Lower boundary [cm]**	**Substrate genesis**	**SOC [%]**	**further properties**	**Horizon**	**Lower boundary [cm]**	**Substrate genesis**	**SOC [%]**	**further properties**
Ap	30	colluvial	3.02	10% limestones	Ap	25	colluvial	2.82	10% limestones
M1	55	colluvial	2.07	20% limestones	M1	55	colluvial	2.07	
M2	90	colluvial	1.68		M2	90	colluvial	2.01	
M3	110	colluvial	1.74		M3	110	colluvial	2.62	
M4	125	colluvial	1.62		M4	135	colluvial	3.12	
M5	140	colluvial	1.86		M5	150	colluvial	3.32	
M6	170	colluvial	2.22		M6	170	colluvial	2.96	
Ahb	185	weathered	1.33		Ahb	190	weathered	1.71	vertic
2 Bwg	200	weathered	0.60	Redoximorphic p.; vertic	2 Bwg	210	weathered	0.73	Redoximorphic p.; vertic
3 CBg	230+	weathered	0.31	Redoximorphic p.	2 Cbg	230+	weathered	0.35	Redoximorphic p.; vertic

The Fuerstenberg NW catena (Fig. 4) is more complex and is influenced by a fluctuating water table (from Bf57 to Bf 64). The lower slope is used for agricultural crops (wheat and corn: Zea mays). The middle slope is used as a pasture for sheep and as a mixed fruit orchard. The relief shows signs of a series of small, independent landslides. The upper mid-slope between Bf70 and Fue7 is terraced with signs of former plowing. Colluvial deposits are thicker and more differentiated just above the terrace step. Thickness and number of colluvial horizons decrease upslope to the next terrace. The colluvial horizons have high SOC contents and merge to a hortic horizon in the gentler upper mid-slope (Fue7). The steep upper slope from Bf73 upwards is covered by mixed hardwood forest and is dominated by Regosols.

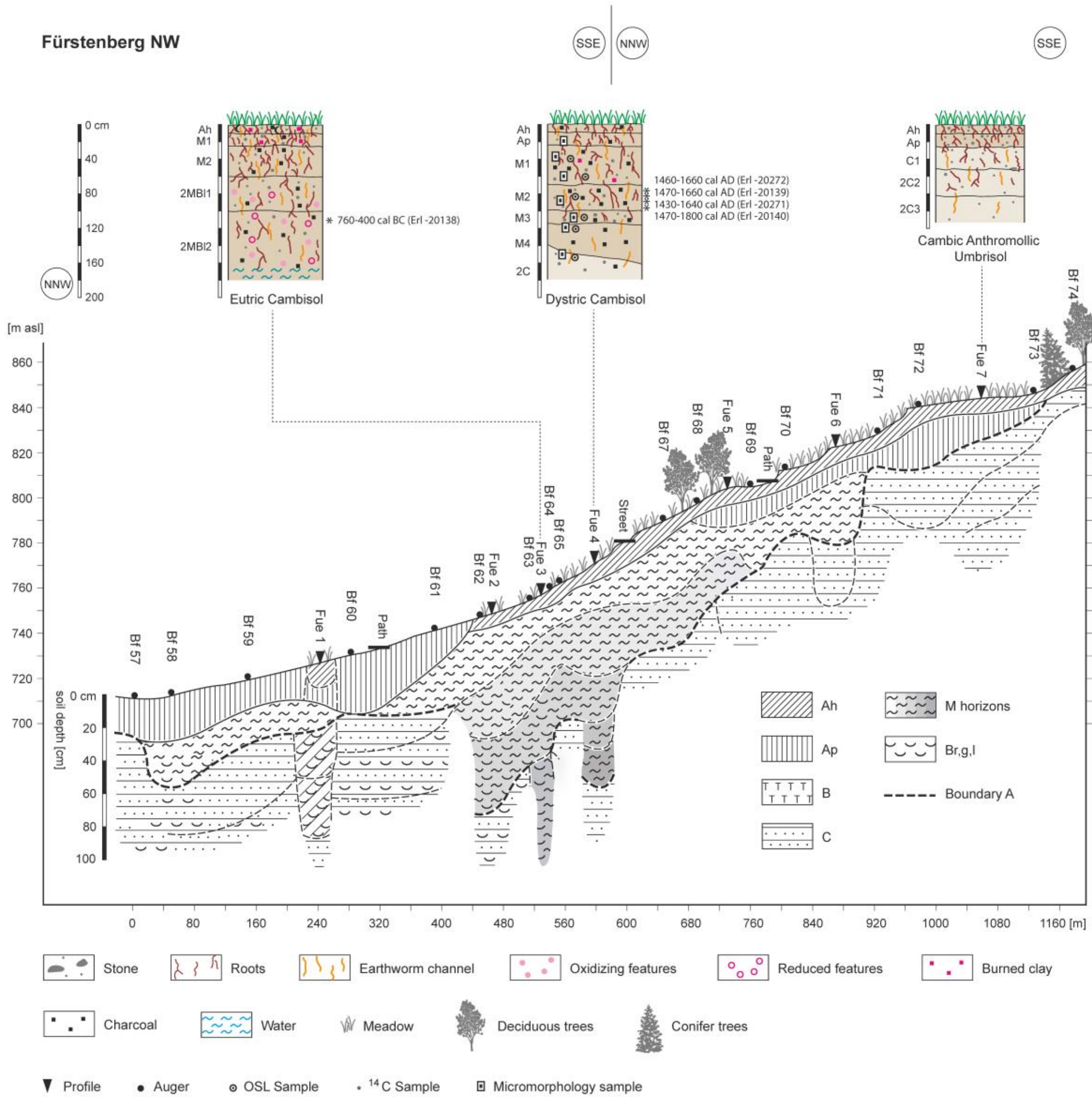

Fig. 4: Catena and soils on the NW slope of Fuerstenberg.

The paleorelief is highly variable along the slope. It is formed by land use and small scale landslides. The four colluvial horizons of soil profile Fue4 (Tab. 4) show only small differences in color, coarse fragment content and soil structure. The SOC content averages 2.7 %. The dating of charcoal pieces (Erl-20271- 20272, Erl-20139-20140; Tab. 8, Fig. 4) indicate a rapid formation of colluvial deposits in the late Middle Ages to the early Modern Period. Profile Fue3 (Tab. 4) is typical for poorly drained downslope positions, having a thick colluvial cover with about 1.9 % SOC and a strong groundwater influence resulting in gleyic properties below 60 cm. Dating of one charcoal piece from the lowest horizon (2 MBrl2, 110 cm) indicates colluvial formation around 560 cal BCE (Erl-20138).

Tab. 4: Selected soil properties of Fue3 (left): Eutric Endogleyic Cambisol (Pantoclayic, Colluvic, Humic, Raptic) and Fue4 (right): Eutric Protic Colluvic Regosol (Pantoclayic, Humic, Raptic).

Horizon	**lower boundary [cm]**	**Substrate genesis**	**SOC [%]**	**further properties**	**Horizon**	**lower boundary [cm]**	**Substrate genesis**	**SOC [%]**	**further properties**
Ah	10	colluvial	4.00		Ah	10	colluvial/ landslide	4.88	
M1	25	colluvial	2.75		Ap	25	colluvial/ landslide	3.49	
M2	60	colluvial	2.30		M1	70	colluvial/ landslide	2.54	
2 MBrl1	100	colluvial	1.54	15% pelites, redoximorphic features; gleyic	M2	100	colluvial/ landslide	2.53	
2 MBrl2	170+	colluvial	1.06	Reductimorphic colors; gleyic	2 M3	115	colluvial/ landslide	2.49	
					2 M4	140	colluvial/ landslide	2.14	
					3 C	170+	weathered	1.23	

Spaichingen

Colluvial deposits near Spaichingen (Fig. 5) show a complex relief development with up to seven colluvial horizons (Spa2), which are not parallel to the present surface and do not show a continuous development along the slope. The boundary A indicates a changing paleorelief and intense land use or anthropogenic shaping from the younger Neolithic onwards (Tab. 8). The catena shows that the thickness and number of colluvial horizons in the lower positions (auger Bs19-Bs12) are smaller compared to the soil profile Spa1. These sites are closer to the main drainage and next to a formerly open running drainage. In Spa1, an underground small creek was discovered at 2.2 m depth, which was buried by colluvial deposits already during the younger Neolithic (3950-3780 cal BCE, P 12878, Tab. 8).

Recent land use is similar to Fuerstenberg, with crop cultivation (wheat) on the lower slope and pasture on the middle slope. The upslope is covered by mixed hardwood and coniferous forest. The soils are artificially drained, and the current influence of groundwater and interflow is limited to below 160 cm.

The soil profile Spa2 (Tab. 5) has eight colluvial horizons with an average SOC content of 1.6 %. The lower two colluvial horizons are influenced by steady interflow and capillary fringe-induced redoximorphic features (MBl1 and MBl2). Reduced features are evident below 70 cm and increase in number with depth until the saturated zone is reached at 115 cm. The 3 Cr horizon consists of coarse periglacial slope deposit. Spa3 shows a similar pedostratigraphy but fewer horizons are present.

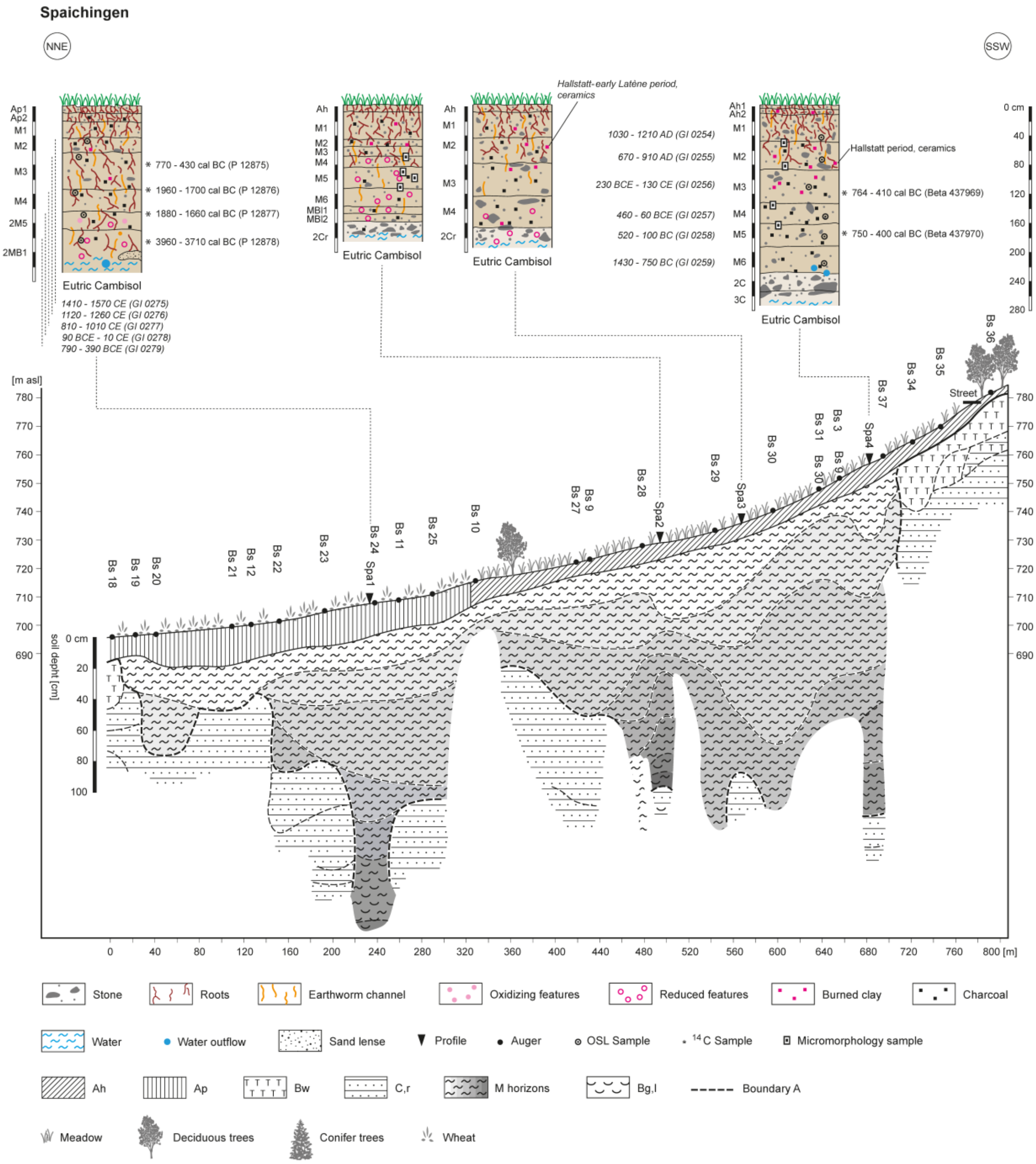

Fig. 5: Catena Spaichingen.

The finding of a sherd dating to the Hallstatt period at the base of the second colluvial horizon in Spa4 (Tab. 5) shows the relation between human activity and formation of colluvial deposits. The uppermost colluvial horizon (2 M1) of Spa4 can be dated to 1030-1210 CE (OSL dating, GI 0254), the underlying horizon also originates from the high Middle Ages (GI 0255). Both horizons contain 20-30 % limestones in contrast to the over- and underlying horizons. In addition to the sherd, two charcoal pieces were found in 120 and 176 cm depth (3 M3 and 3

M5) also dating to the Hallstatt period (Beta-437969, Beta-437970). The 3 M3 and 3 M5 horizons were dated to the Roman Empire and Iron Age (GI 0256, GI 0257). That means that an older sherd and charcoal pieces were incorporated into the colluvial deposit during Iron Age to Roman Empire. SOC content of colluvial horizons change minimally (~1.4 %), down to the 3 M6 horizon with 1.7 % SOC. This horizon can be dated to the Bronze Age (GI 0259). The slightly higher SOC content and the longer gap between the dates indicate a longer geomorphodynamic stable period. Colluvial material covers coarse periglacial slope deposits and loamy sediments without coarse fragments.

Tab. 5: Selected soil properties of Spa2 (left): Eutric Cambisol (Pantoclayic, Colluvic, Humic, Raptic, B athyloamic) and Spa4 (right): Eutric Cambisol (Pantoclayic, Colluvic, Humic, Raptic).

Horizon	lower boundary [cm]	Substrate genesis	SOC [%]	further properties	Horizon	lower boundary [cm]	Substrate genesis	SOC [%]	further properties
Ah	10	colluvial	4.04		Ah1	5	colluvial	5.50	
2 M1	48	colluvial	2.31		Ah2	12	colluvial	5.12	
2 M2	58	colluvial	1.16		M1	50	colluvial	1.45	30% limestone
2 M3	70	colluvial	1.21		2 M2	88	colluvial	1.42	20% limestone
2 M4	86	colluvial	1.52	reductimorphic colors	3 M3	135	colluvial	1.46	
2 M5	115	colluvial	1.65	reductimorphic colors	3 M4	162	colluvial	1.37	
2 M6	140	colluvial	1.50	reductimorphic colors	3 M5	195	colluvial	1.46	
2 MBl1	150	colluvial	1.30	reductimorphic colors	3 M6	231	colluvial	1.69	
2 MBl2	160	colluvial	0.99		4 C	255	periglacial deposit	0.28	85% limestone
3 Cr	180+	periglacial deposit	0.39	75% limestone	5 C	265+	weathered	0.13	

Grueningen

The gently inclining south facing slope (2-5%, Fig. 6) is used for crops, the lower slope as grassland. The upper part resembles a small plateau on which Bronze Age ceramics were found (Knopf et al., 2015; Knopf and Seidensticker, 2013). Pedogenesis was dominated by weathering of limestone and loess, which were translocated by solifluidal processes under periglacial conditions during the last glacial period. The periglacial layers are covered by colluvial deposits. There are three colluvial horizons at the middle slope (auger GB3, Gru8_10) but only one on the lower slope (GB5, GB6). Colluvial accumulation differentiates again at the south facing bottom slope and in the depression (GB7, GB8). No colluvial material can be found on the north facing lower slope (GB9).

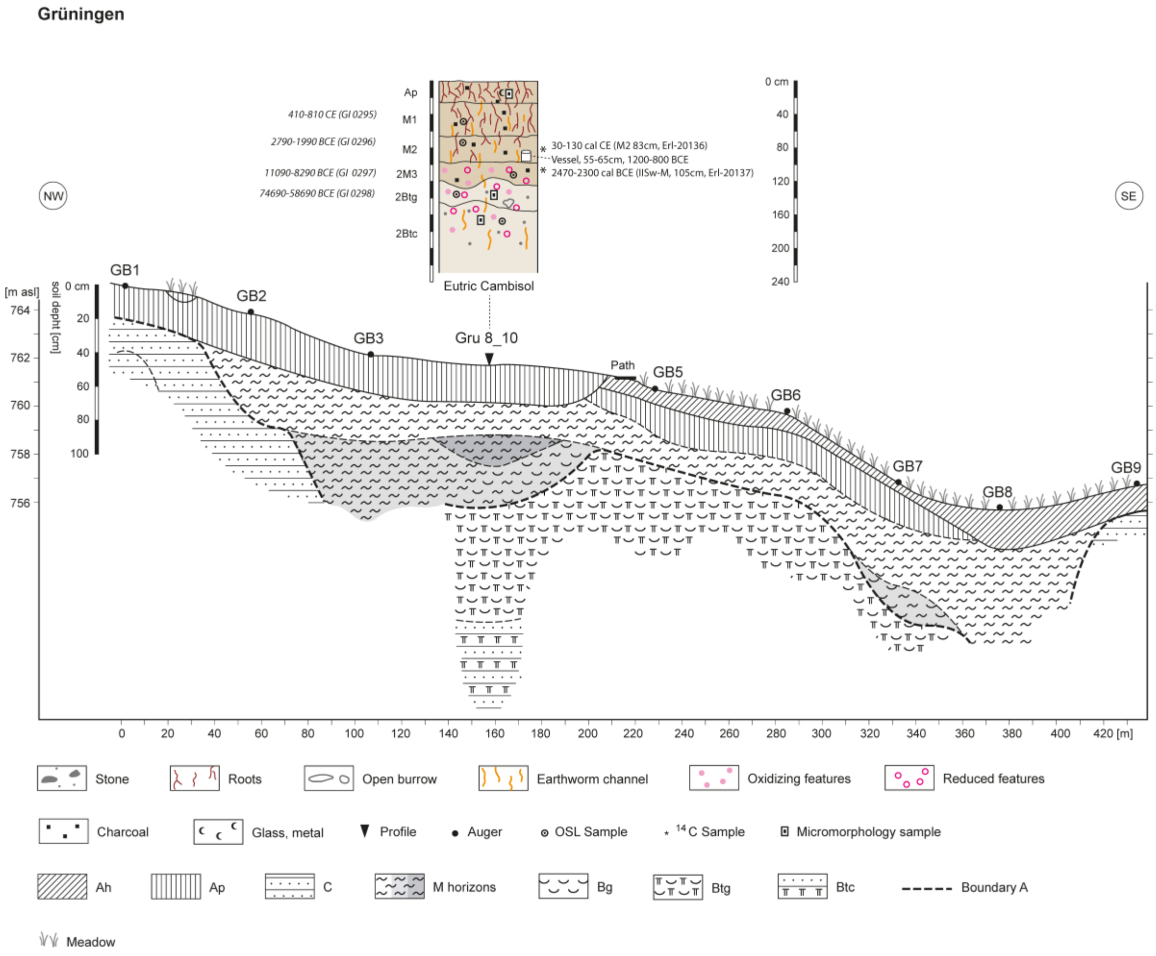

Fig. 6: Catena at Grueningen. The catena represents work done in 2010, the soil profile stems from 2014.

The soil profile Gru8 (Tab. 6) consists of three colluvial layers dating to 1040-1170 cal CE (MAMS 12275), the late Roman Empire (MAMS 12276), and the Bronze Age (MAMS 12277), pointing to continuous human habitation and land use since the Roman Empire. At the base of the second colluvial horizon (M2) two vessels were found. The smaller vessel was standing inside the bigger one. They date to the Urnfield period (Ahlrichs et al., 2017 submitted). Two divergent radiocarbon dates (MAMS 122277, Erl-20136) of the second horizon can be clarified by that age, because the horizon has to be older than the vessels. The charcoal yielding the younger age was most likely relocated by bioturbation. Therefore, this horizon is interpreted to have formed before 1620-1520 cal BCE (MAMS-12277). The complete soil profile shows redoximorphic features, and in the lower part, clay translocation. Redoximorphic features are particularly strong in the in situ soil horizon formed of periglacial loess-loam deposits.

Tab. 6: Selected soil properties of Gru8_14 (left): Eutric Cambisol (Geoabruptic, Aric, Colluvic, Endoloamic, Raptic, Siltic) and Gru9 (right): Endoskeletic Cambic Phaeozem (Anthric, Aric, Pantoclayic, Colluvic, Raptic).

Horizon	lower boundary [cm]	Substrate genesis	SOC [%]	further properties	Horizon	lower boundary [cm]	Substrate genesis	SOC [%]	further properties
Ap	25	colluvial	1.23		Ah	10	colluvial	3.41	
M1	65	colluvial	0.57		Ap	25	colluvial	2.83	
M2	96	colluvial	0.37		M1	50	colluvial	1.75	
2 M3	120	colluvial	0.33	redoximorphic features, Mg nodules	2 M2	85	colluvial	0.97	60% limestone
2 Btg	145	weathered	0.27	clay coatings, Mg nodules, redoximorphic features	3 M3	120	colluvial	0.84	
2 CBt	210+	weathered	0.17	clay coatings, Mg nodules, redoximorphic features	4 M4	160	colluvial	1.10	40% limestone rich
					5 M5	195	colluvial	0.63	
					6 Bw	210	weathered	0.36	20% limestones
					6 CBt	230+	weathered	0.56	60% limestone, clay coatings

Another soil profile (Gru9, Tab. 6) is located in a depression about 800 m to the east. The depression is filled with 2 m of organic matter-rich (1.3 % SOC) soil material. The profile consists of five dark brown colluvial horizons, including alternating limestone-rich layers. A radiocarbon age from 200 cm depth indicates the formation of the lowest colluvial horizon during the middle Bronze Age (Erl-20135). The limestone-rich layers are not dated, but the third colluvial horizon (3 M3) dates to the Roman Empire (Erl-20134) and the overlying first (M1) to early Modern Times (Erl-20133). Along the boundary of the depression about 2 m thick Luvisols were found. The surrounding catchment of the depression has a soil cover of about 20-30 cm thickness, with grassland used for hay.

4.2 Chronostratigraphy of colluvial deposits and archaeological finds

The AMS 14C and luminescence ages (Tab. 7, Tab. 8, Fig. 7) complement the archaeological record (Tab. 1) of settlements and land use in the Baar area. Considering differences among the Baar sites, the formation of colluvial deposits at Magdalenenberg and Fuerstenberg began during the Neolithic. At Fuerstenberg, the deposition phases indicate land use in the younger to final Neolithic, middle Bronze Age, Iron Age, Roman Empire, and the transition of late Middle

Ages to the early Modern Period (Fig. 7). The Magdalenenberg site has a gap in the colluvial stratigraphy from late Neolithic to high Middle Ages. In this case the excellent agreement of radiocarbon and OSL ages (GI0131, Erl-20132 and GI0130, Erl.20131, GI0129) provides a robust chronostratigraphy of the formation of colluvial deposits. The colluvial stratigraphy of Grueningen starts with the Bronze Age, with no signal in the Iron Age. The deposition of colluvial deposits at Spaichingen started in the Bronze Age and continued until the early Modern Times.

Tab. 7: OSL ages of colluvial deposits on the Baar. Age refers to the year of dating, rounded to 2010.

Lab code	Profile #		Horizon	Depth [cm]	De [Gy]	Age [ka ± 1 σ]	b2k [a ± 1 σ]	BCE/CE
GI0129	Mag	1_14	M1	30	2.33 ± 0.11	0.59 ± 0.05	580 ± 50	1370 - 1470 CE
GI0130	Mag	1_14	M1	47	2.97 ± 0.14	0.77 ± 0.07	760 ± 70	1170 - 1310 CE
GI0131	Mag	1_14	M2	62	25 ± 1.5	6.1 ± 0.6	6090 ± 600	4690 - 3490 BCE
GI0132	Mag	1_14	M2	69	30.5 ± 1.5	8.2 ± 0.8	8190 ± 800	6990 - 5390 BCE
GI0133	Mag	1_14	2 M4	75	40.6 ± 2	11.8 ± 1.2	11790 ± 1200	10990 - 8590 BCE
GI0179	Fue	8	M1	48	1.17 ± 0.08	0.31 ± 0.03	300 ± 30	1670 - 1730 CE
GI0180	Fue	8	M2	75	3.38 ± 0.1	0.89 ± 0.09	880 ± 90	1030 - 1210 CE
GI0181	Fue	8	M3	100	6.56 ± 0.22	2 ± 0.2	1990 ± 200	190 BCE - 210 CE
GI0182	Fue	8	M4	115	8.57 ± 0.35	2.8 ± 0.2	2790 ± 200	990 - 590 BCE
GI0183	Fue	8	M5	135	20.1 ± 0.9	6.9 ± 0.6	6890 ± 600	5490 - 4290 BCE
GI0184	Fue	8	M6	162	22.3 ± 0.7	6.5 ± 0.7	6490 ± 700	5190 - 3790 BCE
GI0247	Fue	9	M4	125	15.71 ± 0.54	5.26 ± 0.42	5250 ± 420	3670 - 2830 BCE
GI0248	Fue	9	M6	155	21.35 ± 0.96	6.61 ± 0.62	6600 ± 620	5220 - 3980 BCE
GI0254	Spa	4	M1	43	2.51 ± 0.19	0.89 ± 0.09	880 ± 90	1030 - 1210 CE
GI0255	Spa	4	2 M2	74	3.56 ± 0.17	1.22 ± 0.12	1210 ± 120	670 - 910 CE
GI0256	Spa	4	3 M3	112	6.09 ± 0.32	1.96 ± 0.18	1950 ± 180	130 BCE - 230 CE
GI0257	Spa	4	3 M4	154	7.28 ± 0.3	2.27 ± 0.2	2260 ± 200	460 - 60 BCE
GI0258	Spa	4	3 M5	180	7.68 ± 0.42	2.32 ± 0.21	2310 ± 210	520 - 100 BCE
GI0259	Spa	4	3 M6	218	9.95 ± 0.73	3.1 ± 0.34	3090 ± 340	1430 - 750 BCE
GI0275	Spa	1	M2	49	1.29 ± 0.17	0.52 ± 0.08	510 ± 80	1410 - 1570 CE
GI0276	Spa	1	M3	77	2.39 ± 0.09	0.82 ± 0.07	810 ± 70	1120 - 1260 CE
GI0277	Spa	1	M4	119	3.18 ± 0.13	1.1 ± 0.1	1090 ± 100	810 - 1010 CE
GI0278	Spa	1	2 M5	150	5.8 ± 0.2	2.2 ± 0.2	2190 ± 200	390 BCE - 10 CE
GI0279	Spa	1	2 MBl	183	7.62 ± 0.27	2.6 ± 0.2	2590 ± 200	790 - 390 BCE
GI0295	Gru	8_14	M1	48	4 ± 0.3	1.4 ± 0.2	1390 ± 200	410 - 810 CE
GI0296	Gru	8_14	M2	72	13.48 ± 0.66	4.4 ± 0.4	4390 ± 400	2790 - 1990 BCE
GI0297	Gru	8_14	2 M3	110	34.8 ± 3.22	11.7 ± 1.4	11690 ± 1400	11090 - 8290 BCE
GI0298	Gru	8_14	2 Btg	133	192.57 ± 16.55	68.7 ± 8	68690 ± 8000	74690 - 58690 BCE

Tab. 8: AMS 14C ages of charcoal fragments from colluvial deposits on the Baar. Uncalibrated ages are given as BP [a before 1950] and 14aN [‰]: Fraction of modern carbon (F14C), incl. normalization for d13C (Mook and van der Plicht, 1999; Reimer et al., 2004). Calibrated ages are given with 1σ (and 2σ) and rounded to 10 yr. Calibration was done with OxCal 4.2. 2016 and IntCal13.

° = excluded date, dated soil organic matter; *= excluded date.

Lab code	Profile #		Depth [cm]	Horizon	^{14}aN [‰]	δ^{13}C [‰]	BP [a ± error]	cal BCE/CE (1σ)	cal BCE/CE (2σ)	Median	cal BP (1σ)
Erl-20138	Fue	3	110	2 MBrl2		-25.5	2443 ± 42	cal BCE 740-410	cal BCE 760-400	cal BCE 560	2690-2360
Erl-20139	Fue	4	80	M2		-26.7	310 ± 36	cal CE 1510-1650	cal CE 1470-1660	cal CE 1560	440-300
Erl-20271	Fue	4	85	M1		-24.5	384 ± 46	cal CE 1440-1620	cal CE 1430-1640	cal CE 1510	510-330
Erl-20140	Fue	4	95	M2		-24.8	293 ± 40	cal CE 1520-1650	cal CE 1470-1800	cal CE 1570	430-300
Erl-20272	Fue	4	70-80	M1		-27.5	311 ± 47	cal CE 1510-1650	cal CE 1460-1660	cal CE 1560	440-300
Erl-20144 °	Fue	8	100	M3		-25.3	2884 ± 36	cal BCE 1120-1000	cal BCE 1210-930	cal BCE 1060	3070-2950
Erl-20146 °	Fue	8	130	M5		-25.9	5105 ± 42	cal BCE 3970-3800	cal BCE 3980-3790	cal BCE 3870	5920-5750
Erl-20273	Fue	8	130-140	M4		-24.3	3369 ± 50	cal BCE 1750-1610	cal BCE 1870-1520	cal BCE 1660	3700-3560
Erl-20145 °	Fue	8	150-160	M6		-26.6	4417 ± 46	cal BCE 3270-2920	cal BCE 3340-2910	cal BCE 3060	5220-4870
Erl-20141 *	Fue	8	20-30	M1		-28.7	-562 ± 35	cal CE 1890-1910	cal CE 1890-1910	cal CE 1900	60-40
Erl-20142	Fue	8	50-60	M1-2		-23.9	325 ± 36	cal CE 1510-1640	cal CE 1470-1650	cal CE 1560	440-310
Erl-20143	Fue	8	75-80	M2		-25.2	627 ± 34	cal CE 1290-1400	cal CE 1280-1400	cal CE 1350	660-550
Erl-20276	Fue	9	90	M2		-25.6	4557 ± 67	cal BCE 3490-3100	cal BCE 3520-3020	cal BCE 3240	5440-5050
Erl-20277	Fue	9	115	M3		-25	4477 ± 58	cal BCE 3340-3030	cal BCE 3360-2930	cal BCE 3190	5290-4980
Erl-20278	Fue	9	135	M4		-27.7	6526 ± 66	cal BCE 5560-5380	cal BCE 5620-5360	cal BCE 5490	7510-7330
Erl-20280 *	Fue	9	195	2 Bwg		-25.7	10879 ± 92	cal BCE 10900-10740	cal BCE 11050-10710	cal BCE 10830	12850-12690

Erl-20279	Fue	9	150-170	M6		-25.5	7129 ± 67	cal BCE 6070-5920	cal BCE 6210-5840	cal BCE 6010	8020-7860
Erl-20275	Fue	9	60-70	M1		-25.3	3918 ± 61	cal BCE 2480-2290	cal BCE 2580-2200	cal BCE 2400	4430-4240
Erl-20147	Fue	10	85	M2		-25.3	655 ± 37	cal CE 1280-1390	cal CE 1270-1400	cal CE 1340	670-560
Erl-20274	Fue	10	87	M2		-27	1622 ± 158	cal CE 250-590	cal CE 50-690	cal CE 410	1700-1360
Erl-20149 °	Fue	10	127	Ahb2		-25	3855 ± 37	cal BCE 2460-2210	cal BCE 2470-2200	cal BCE 2330	4410-4160
Erl-20148 °	Fue	10	95-100	Ahb1		-27.9	2581 ± 36	cal BCE 810-760	cal BCE 820-550	cal BCE 780	2760-2710
Erl-20281	Fue	11	27	M1		-24.9	782 ± 61	cal 1290	cal CE 1040-1390	cal CE 1230	760-660
Erl-20282	Fue	11	65	M2		-25.5	382 ± 48	cal CE 1440-1630	cal CE 1440-1640	cal CE 1520	510-320
P 13415	Gei	2	88	2 MBg2	0.697 ± 0.005		2899 ± 39	cal BCE 1200-1000	cal BCE 1260-920	cal BCE 1090	3150-2950
P 13418	Gei	2	144	3 MBg	0.603 ± 0.003		4070 ± 26	cal BCE 2840-2490	cal BCE 2860-2480	cal BCE 2620	4790-4440
Erl-20270 *	Gru	9	30	M1		-24.6	231 ± 45	cal CE 1630-...	cal CE 1510-...	cal CE 1730	320-...
Erl-20133	Gru	9	35	M1		-23.2	291 ± 32	cal CE 1520-1660	cal CE 1490-1670	cal CE 1570	430-290
Erl-20134	Gru	9	90	M3		-22.6	1950 ± 34	cal CE 1-90	cal BCE 40-cal CE 130	cal CE 50	1950-1860
Erl-20135	Gru	9	200	M6		-24.1	3251 ± 37	cal BCE 1610-1460	cal BCE 1620-1440	cal BCE 1530	3560-3410
MAMS 12275	Gru	8_10	40	M1		-18,7	909 ± 21	cal CE 1040-1170	cal CE 1030-1190	cal CE 1100	910-780
MAMS 12276	Gru	8_10	50	M2		-20,6	1569 ± 21	cal CE 420-540	cal CE 420-550	cal CE 480	1530-1410
MAMS 12277	Gru	8_10	72	2 M3		-23,7	3283 ± 25	cal BCE 1620-1520	CE 1190-cal BCE 1620-1500	cal BCE 1560	3560-3470
MAMS 12281 °	Gru	8_10	80-85	2 M3		-33.5	4061 ± 38	cal BCE 2840-2490	cal BCE 2860-2470	cal BCE 2600	4790-4440
Erl-20136	Gru	8_14	83	M2		-24.8	1918 ± 38	cal CE 30-130	cal CE 1-220	cal CE 90	1920-1820
Erl-20137	Gru	8_14	105	2 M3		-23.5	3889 ± 40	cal BCE 2470-2300	cal BCE 2480-2210	cal BCE 2380	4410-4250
Poz-36957	Mag	2	70	?			705 ± 30	cal CE 1260-1300	cal CE 1250-1390	cal CE 1280	690-650

Poz-36958	Mag	3	50	?			795 ± 30	cal CE 1220-1270	cal CE 1180-1280	cal CE 1240	730-680
Poz-36971 °	Mag	5	?	?			295 ± 30	cal CE 1520-1650	cal CE 1490-1660	cal CE 1570	430-300
Poz-36972 °	Mag	6	?	?			70 ± 35	cal CE 1690-1920	cal CE 1680-1930	cal CE 1850	260-30
Erl-20268 *	Mag	11	45	M1		-29.7	356 ± 975	cal CE 640-...	cal BCE 900-...	cal CE 1070	1310-...
Erl-20269 *	Mag	11	55	M2		-21.7	213 ± 53	cal CE 1640-...	cal CE 1520-...	cal CE 1760	310-...
Poz-36952	Mag	1_10	34	M1			635 ± 30	cal CE 1290-1390	cal CE 1280-1400	cal CE 1350	660-560
Poz-36953	Mag	1_10	49	M1			905 ± 30	cal CE 1040-1170	cal CE 1030-1210	cal CE 1110	910-780
Poz-36954	Mag	1_10	65	M2			4970 ± 40	cal BCE 3800-3690	cal BCE 3930-3650	cal BCE 3750	5740-5640
Poz-36955 °	Mag	1_10	?	?			1080 ± 30	cal CE 900-1000	cal CE 890-1020	cal CE 970	1050-950
Poz-36956 °	Mag	1_10	?	?			2170 ± 30	cal BCE 360-170	cal BCE 360-110	cal BCE 260	2310-2120
Erl-20131	Mag	1_14	25	M1		-25	746 ± 33	cal CE 1250-1290	cal CE 1220-1300	cal CE 1270	700-660
Erl-20132	Mag	1_14	75	2 M4		-25.2	5071 ± 51	cal BCE 3950-3800	cal BCE 3980-3710	cal BCE 3870	5900-5740
P 12875	Spa	1	80	M3	0.735 ± 0.003		2470 ± 22	cal BCE 760-530	cal BCE 770-430	cal BCE 630	2710-2480
P 12876	Spa	1	115	M3	0.646 ± 0.003		3510 ± 20	cal BCE 1890-1770	cal BCE 1930-1740	cal BCE 1830	3840-3720
P 12877	Spa	1	148	M5	0.652 ± 0.002		3437 ± 18	cal BCE 1860-1690	cal BCE 1880-1660	cal BCE 1740	3810-3630
P 12878	Spa	1	185	2 MBl	0.534 ± 0.002		5040 ± 18	cal BCE 3950-3780	cal BCE 3960-3710	cal BCE 3870	5890-5730
P 12879 *	Spa	4	112	3 M3	0.599 ± 0.002		4122 ± 19	cal BCE 2860-2620	cal BCE 2870-2570	cal BCE 2710	4810-4570
Beta-437969	Spa	4	120	3 M3	0.737 ± 0.003	-27	2450 ± 30	cal BCE 750-430	cal BCE 760-410	cal BCE 580	2700-2370
P 13413	Spa	4	120	3 M3	0.724 ± 0.004		2592 ± 31	cal BCE 820-670	cal BCE 840-540	cal BCE 780	2770-2620
P 12880 *	Spa	4	127	3 M3	0.631 ± 0.002		3696 ± 18	cal BCE 2140-2030	cal BCE 2200-1980	cal BCE 2090	4090-3980

P 12881 *	Spa	4	155	3 M4	0.585 ± 0.002		4307 ± 18	cal BCE 2930-2880	cal BCE 3020-2880	cal BCE 2910	4880-4830
Beta-437970	Spa	4	176	3 M5	0.739 ± 0.003	-23.3	2430 ± 30	cal BCE 730-410	cal BCE 750-400	cal BCE 510	2680-2360
P 12882 *	Spa	4	184	3 M5	0.551 ± 0.002		4791 ± 19	cal BCE 3640-3530	cal BCE 3650-3510	cal BCE 3570	5590-5470
P 12883 *	Spa	4	218	3 M6	0.496 ± 0.002		5631 ± 18	cal BCE 4510-4370	cal BCE 4540-4360	cal BCE 4460	6460-6320
P 12884 *	Spa	4	232	3 M6	0.535 ± 0.002		5032 ± 17	cal BCE 3940-3770	cal BCE 3950-3710	cal BCE 3860	5890-5720

The archaeological record of land use and settlements starts with Mesolithic finds at the Magdalenenberg site (Schmid, 1991, 1992). Neolithic artifacts were found at Magdalenenberg, Spaichingen and Fuerstenberg (Nübling, 1990; Schmid, 1991, 1992). Datings from these three sites yield a better chronological differentiation of time periods with intense land use than the discovered archaeological finds do. There is no archaeological evidence for human presence at the study sites during the early Bronze Age. In Grueningen, colluviation occurred earlier than known from the archaeological findings, indicating human presence as early as the middle Bronze Age. Many archaeological sites, including the Magdalenenberg, the largest burial mound in central Europe from 616 BCE (Knopf et al., 2015; Knopf and Seidensticker, 2013; Spindler, 2004), are known in the western Baar, but, no colluvial deposits date to the Hallstatt period. Colluviation dating to the Hallstatt period took place only in the eastern and southern Baar. Radiocarbon ages from Grueningen point to land use from the Roman Empire onwards. Samples dating to the Middle Ages correlate well with historical records. The town of Villingen, next to the Magdalenenberg site, was first mentioned in the written record around 800 CE (Jenisch et al., 1999). The town of Fuerstenberg existed on the plateau above the slopes studied here from at least 1175 until 1841 CE (Wagner, 2014). The AMS 14C dates of charcoal samples from Grueningen can also be correlated with historical records of the nearby village of Grueningen, which according to historical records existed from 1139 CE onwards (Badische Historische Kommission, 1904b). Dates from Spaichingen also agree with known archaeological sites (Buchta-Hohm, 1996; Paret, 1932; Stoll and Gehring, 1938).

The summed probability density (SPD) curves show peaks along a time axis of increased probability of dates from a specific time (Fig. 8). These dates are interpreted as being connected to colluviation. The peaks of the SPD curve of OSL ages decrease and widen with older ages, because of their wider error estimates. The OSL SPD shows an increase of dates in the middle to younger Neolithic in samples from the Magdalenenberg and Fuerstenberg site. The following peak around 500 CE comprises dates from Fuerstenberg and Spaichingen. This peak is higher and narrower than the preceding ones. The pronounced depression falls in the Migration and Merovingian period. Increased probability in the high and late Middle Ages is evident at all sites except Grueningen). Radiocarbon dates result in narrower and therefore higher SPD peaks. The oldest peak dates to the late Mesolithic at the Fuerstenberg. There are several pronounced individual peaks from the late Neolithic onwards, and they originate from the samples at Fuerstenberg, Grueningen and Spaichingen. The Magdalenenberg dates appear only in the younger Neolithic and the high-to-late Middle Ages. The increased probability of dates in the Middle Ages counts for all of the sites except Spaichingen, where only older charcoal was found.

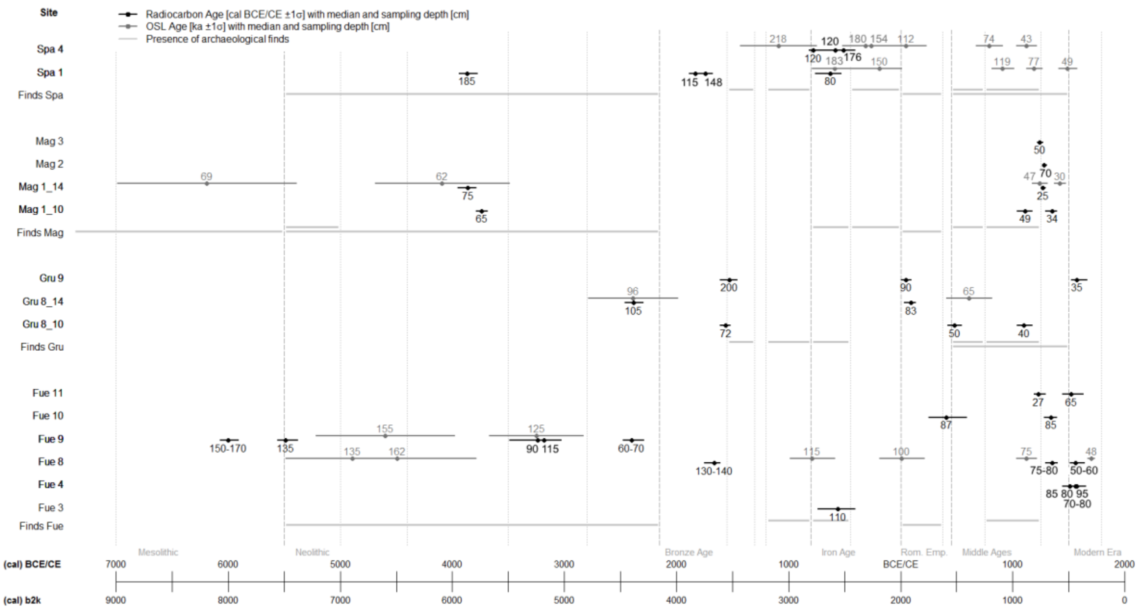

Fig. 7: AMS 14C and OSL ages of colluvial deposits across the Baar compared to known archaeological finds at each site from the Mesolithic to Middle Ages.

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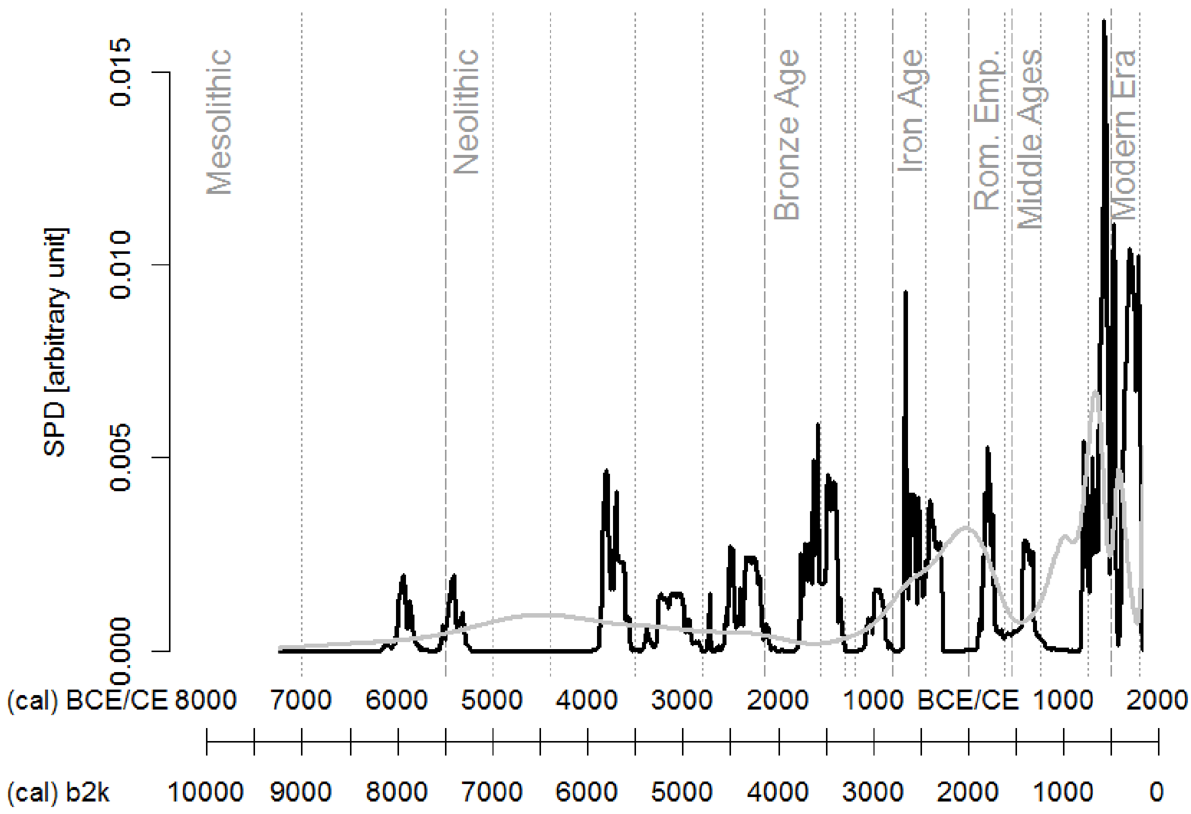

Fig. 8: Summed probability density (SPD) curves of ages from anthropogenic soil-erosion derived colluvial deposits. Grey line: OSL data (n=28), black line: AMS14C data (n=41).

5 Discussion

5.1 Main phases of formation of colluvial deposits across the Baar

Colluvial deposits present a high resolution spatial archive of the land use history of the area upslope, from which the material was eroded (Bettis, 2003; Emadodin et al., 2011; Leopold and Völkel, 2007a). The application of the catena concept at several sites provides 13 representative, well-stratified soil profiles for dating and further analysis.

Intensive land use seems to have started in the south and northwest of the Baar, since the oldest colluvial ages stem from the sites at Fuerstenberg and Magdalenenberg (Fig. 7, Tab. 7, Tab. 8). Based on a uniformitarian perspective, assuming that general climate differences within the region did not change during the Holocene, the earlier onset of permanent land use (most likely agriculture) might be explained by higher temperatures and fewer frost days compared to other parts of the Baar.

Summing up the SPDs of radiocarbon and luminescence ages, seven main phases of increased probability of colluviation can be differentiated as distinct maxima from several secondary peaks with lower probability (Fig. 9). The oldest peak dates to around 3800 cal BCE, i.e. the younger Neolithic (1), and is followed by smaller peaks of increased probability for colluvial formation during the late Neolithic to early Bronze Age. Temporary sediment sinks on slopes can accumulate colluvial deposit for a certain time before the material is eroded and transported further downslope, thereby resetting the physical signal for OSL dating which results in a younger age. This is known as the cascade model of colluvial formation, which might be an explanation for the minimal available information about Neolithic colluvial deposits (Lang and Hönscheidt, 1999). Increased colluviation is calculated for the middle Bronze Age (2) and Latène Period (3). The main deposition phase (4) around 100 CE is connected to the Romans and their land use. The following Migration period shows decreased colluviation. From the high Middle Ages onwards the probability of colluvia formation is doubled. Colluviation increases even more to the end of the high Middle Ages (5) and around 1300 (6) and 1600 cal CE (7).

In southern Baden, west of the Black Forest, Mäckel et al. (2002) found a similar colluviation sequence. During the early and middle Bronze Age, colluviation increased, which might be explained by a major increase in the area of open land during the transition from the Neolithic to the Bronze Age (Mäckel et al., 2003). This is in accordance with the presented SPD curve showing increasing colluviation in the Bronze Age. The increased colluviation can be interpreted as increased land use intensity, which often starts with deforestation. The phase of higher colluviation is followed by a decrease and a subsequent increase until Roman times. During the Migration period little colluviation occurred. Colluviation increases again from the Middle Ages to Modern Times.

A study from southern Germany, including the Baar, used 60 OSL ages and found three phases of increased soil erosion derived colluviation (Lang, 2003). These phases are in the Latène Period (2.1 ka) and the high Middle Ages (1.2 ka and 0.9 ka). Further minor peaks occur in the Urnfield Period, the final Neolithic and the early to middle Neolithic. The comparison shows that the increased colluviation probability in loess hills is different from the probability presented in this study. This might be explained by different land use dynamics with time and the properties of the soils. Hoffmann et al. (2008) studied phases of increased geomorphic stability and activity of different sediments in Germany and came up with phases of increased relative probability for geomorphologic activity dating to exactly the same time periods as the colluviation phases on the Baar.

5.2 Possible causes for the main phases of colluviation

Precipitation, topography, vegetative cover, plant species, and soil properties determine the general likelihood of soil erosion, but the most important factor is land use as influenced by and interacting with the above environmental aspects. Important elements of agrarian land use are tillage, field size and crop rotation (c.f. Bork, 1989); further human impact originates from deforestation for hunting, grazing, building of infrastructure, mining, or charcoal production.

The characteristics and ages of several colluvial deposits point to varying land use patterns since the Neolithic. At the Fuerstenberg and Magdalenenberg sites, the colluvial signal starts with the Neolithic, whereas in Spaichingen and Grueningen the oldest ages point to a human influence from the Bronze Age onwards. The type of land use cannot be determined from the occurrence of colluvial deposits alone, but it seems most likely that is was agrarian land use after deforestation, since there is no evidence of other land use activities like deforestation for hunting, grazing, building of infrastructure, mining, or charcoal production. The colluvial deposits contain only some ceramic sherds and charcoal pieces are not layered, but occur randomly distributed within soil horizons. This points to the sites being used for agriculture rather than as a settlement area (Häbich, 2009). The widely spread multilayered thick colluvial deposits containing only a few artifacts/ceramics, cannot be explained without invoking the presence and activity of humans increasing soil erosion. The simple differentiation between natural and anthropogenic processes causing colluviation based on the absence or presence of artifacts (Mäckel et al., 2003) cannot be adopted here.

A helpful concept is the boundary A by Edgeworth et al. (2015), which separates the natural ground surface from the human-modified soil profile or sediment stratigraphy. The boundary A in the soil profiles of the Baar region marks the transition between in situ soil with little or no human influence and the colluvial deposits (Fig. 2 to Fig. 6). Thus it gives an impression of the paleorelief, not considering later soil erosion of the colluvial material. It also illustrates the dimensions of the formative forces of humans on the landscape.

To illustrate the discussion of the potential causes of the identified seven main phases of colluvial deposition we compiled the key information in Figure 9.

The oldest main colluviation phase (1) falls in a wetter and colder period of the younger Neolithic (Haas et al., 1998; Jäger, 2002; Negendank, 2004). Therefore, the peak indicating higher colluvial deposition can be explained by higher erosion due to higher precipitation. 14C production rates point to variable solar activity reaching a local minimum during that time. Lower 14C production rates are often correlated with colder temperatures and higher amounts of ice raft debris in the northern hemisphere (Engels and van Geel, 2012; Kromer and Friedrich, 2007). Despite some reconstructions pointing to colder climate, alpine and continental glaciers did not advance (Koch and Clague, 2006). Climate reconstruction from the NGRIP GICC05 shows no clear pattern of δ 18O during that time (NGRIP Members, 2004). Nevertheless, despite the above mentioned factors, the onset of sedentism and agriculture seems to be the most likely trigger for colluviation. The first evidence of agriculture in the region stems from cereal pollen from the late Atlantic period (about 4850-3150 cal BCE). These cereal pollen were found in bogs just north of the study area and in the Black Forest: hazel (Corylus avellana), birch (Betula) and pine (Pinus) pollen increased and fungi of wheat (Triticum L.), rye (Secale cereale) or barley (Hordeum vulgare) appeared at the same time (Rösch, 2000). Results from dendrochronological studies date the beginning of the anthropogenic influence on the environment to 2700 BCE or even 4000 BCE (Kromer and Friedrich, 2007), the latter date strengthens the connection between human activities and the increased colluviation occurring in the younger Neolithic.

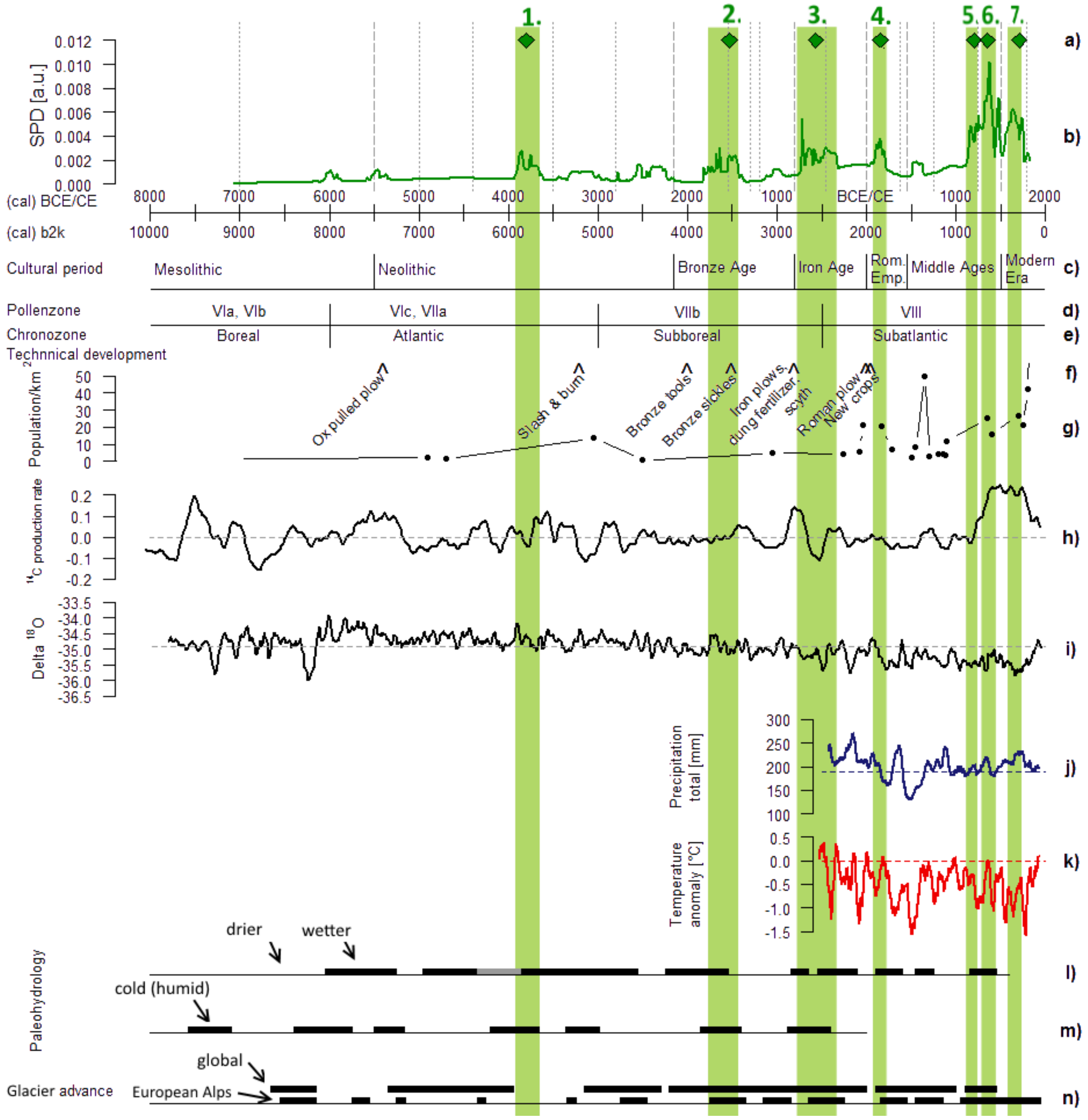

Fig. 9: Main colluviation phases of the Baar compared to paleoenvironmental data. a) Seven main colluviation phases; b) Combined SPD of radiocarbon and OSL ages from the Baar; c) Cultural periods in South Germany; d) Jesse-Godwin pollenzones after Godwin, 1975 in Anderson et al. (2007); e) Chronozones after Mangerud et al. 1975 in Anderson et al. (2007); f) Technical innovations (Lal et al., 2007; Tinner et al., 2003); g) Population density in central

Europe (Henning, 1994; Zimmermann, 1996); h) Anomalies of atmospheric 14C production rates compared to the mean (Kromer and Friedrich, 2007); i) δ 18 O [‰] record from NGRIP1, 100 year means compared to the mean of all δ 18 O values (GICC05, NGRIP Members, 2004; Vinther et al., 2006); j) Tree ring based reconstruction of precipitation from April to June in central Europe with respect to the 1901-2001 period (dashed line), 50 year means of yearly data (Büntgen et al., 2011); k) Tree ring based reconstruction of summer (June-August) temperature anomalies in central Europe with respect to 1990-2000, 50 year means of yearly data (Büntgen et al., 2011); l) Wet phases in central Europe (Jäger, 2002); m) Cold and humid phases in central Europe until 2000 BP (Haas et al., 1998); n) Glacial fluctuations during the Holocene (Koch and Clague, 2006).

The second main depositional phase (2) from the early to middle Bronze Age falls in the final phase of a cold and humid period (Haas et al., 1998; Negendank, 2004; Schönwiese, 1995). Lake levels were low (Magny et al., 2003) and glaciers advanced in the European Alps (Koch and Clague, 2006). The advance of glaciers can be taken as an indicator for longer cold and wet periods. The 14C production rates show an indifferent to positive trend during the time period (Kromer and Friedrich, 2007). This supports a climate change to a warmer and drier state. Population density was still very low and may not have had an influence on colluviation during this period, but the development of ards, bronze tools, and pulled plows seem to increase the sensitivity of soils at gentle rolling hills to erosion and colluvial deposition (Lal et al., 2007; Teuber et al., 2016; Tinner et al., 2003). This development in agricultural techniques may have intensified the formation of colluvial deposits. This phase of increased colluviation ends with the beginning of a dry period around 1400 CE (Haas et al., 1998; Jäger, 2002; Schönwiese, 1995). The luminescence ages clearly point to an increased base level of colluviation from that period onwards (approx. 1000 BCE-250 CE).

The increased probability of colluviation during the Iron Age (3) results from the data of the eastern and southern Baar and falls in a cold and humid phase (Haas et al., 1998; Jäger, 2002; Schönwiese, 1995) with decreasing land use intensity (Dotterweich, 2008), advancing Swiss glaciers (Glaser et al., 2005; Koch and Clague, 2006), low 14C production rates (Kromer and Friedrich, 2007) and δ 18O levels (NGRIP Members, 2004). Climate reconstruction from pollen points to a strong decrease of summer temperatures during that phase, but also lower summer precipitation (Büntgen et al., 2011). This rather unfavorable climate might have resulted in the formation of spatially different intensities of colluvial deposit development. During the Iron Age, smelting of iron ore may have been a likely land use consuming much wood or charcoal, if mined and refined in the region. This technology would have been used in kilns at local spots, rather than on a wider landscape, leading to deforestation but not necessarily to charcoal deposition in soils. Dotterweich (2008) assumes lower percentages of fields and grasslands compared to woodlands and forests during that time, which could strengthen the idea of naturally occurring small forest fires or deforestation for smelting as a source of the few charcoals in the western Baar. Colluviation seems to have taken place in Spaichingen in particular and marginally in Fuerstenberg, but no Iron Age datings could be obtained from the western Baar so far.

The colluviation phase (4) during the Roman Empire (around 100 CE) is also reported in other studies and areas (James et al., 2014; van der Leeuw and The ARCHAEOMEDES research team, 2005). This is the only phase falling into a rather dry and warm period, the so called Roman optimum (Büntgen et al., 2011; Haas et al., 1998; Schönwiese, 1995). The increased probability of colluviation can be correlated with Roman progress in agricultural techniques, improving settlement infrastructure (van der Leeuw and The ARCHAEOMEDES research team, 2005), increasing population (Zimmermann, 1996), the use of limestone to make cement, and higher land use intensity (Dotterweich, 2008; Jäger, 1994). Contradictory to a warming climate, Jäger (2002) reconstructed a wet phase, and Koch and Clague (2006) suggested glacier advance in the European Alps. Those differences might be due to local climatic phenomena. The following climate pessimum and the decline of population density during Migration time (Zimmermann, 1996) led to decreased colluviation across the Baar.

A minor peak of increased colluviation in the Merovingian Period is coeval with the population density peak, which is otherwise not clearly mirrored in the colluvial stratigraphy. Zimmermann (1996) offers corrections to population density for that time, which could point to a wide range of population density across the area, leading to large differences on a small spatial scale. This might support the observation that the highest population density (up to that time) only led to a minor increase of colluviation (around 600 CE) at the investigated sites.

Toward the end of the high Middle Ages (5) colluviation increased strongly and led to a doubled probability of the formation of colluvia from then onwards, which agrees with elevated population density (Zimmermann, 1996) and increased soil erosion (Bork, 1989). Human influence during the Medieval Climate Optimum in the high Middle Ages is visible in the OSL SPD and also in the vegetation record. Near the Magdalenenberg site, walnut (Juglans regia) remains and pollen were found (Rösch, 1999), which indicate relatively high temperatures or possibly trade connections to a region, where walnut trees grew naturally.

Heavy rainfall events and intensive land use for agriculture are supposed to have been the main triggers for soil erosion and formation of colluvial deposits around 1300 CE in central Europe (Bork, 1998; Dotterweich, 2008; Dotterweich and Dreibrodt, 2011), when additionally, the area of arable land reached a local high (James, 2013; Lang et al., 2003). Catastrophic events (e.g. heavy rainfall and flooding, drought, war, epidemic diseases) seem to have had a major shaping impact on landscapes (Dotterweich and Dreibrodt, 2011). Precipitation reconstruction shows an increase (Büntgen et al., 2011; Jäger, 2002) and temperatures reconstructed from trees dropped (Büntgen et al., 2011). 14C production rates increase from the high Middle Ages to the Modern Era (Kromer and Friedrich, 2007), but that is hardly reflected in climate parameters. Only about 100 years later in the late Middle Ages, the area covered by forests reached a local peak, but forest was then continuously reduced in favor of agricultural land (Dotterweich, 2008; Jäger, 1994; James, 2013). From the Middle Ages onwards, continuous agricultural land use can be shown through pollen analysis; mainly rye (Secale cereale), wheat (Triticum aestivum), spelt (Triticum spelta), and hemp (Cannabis sativa) were grown across the Baar (Sudhaus, 2005).

Increased probable colluviation around 1300 cal CE (6) and 1600 cal CE (7) follows increasing and rapidly declining population density (Henning, 1994). Human population declines in the cold and wet period of the beginning of and later during the pronounced Little Ice Age (Jäger, 2002; Schönwiese, 1995) with advancing glaciers in the Alps (Glaser et al., 2005; Koch and Clague, 2006) and high lake levels (Magny et al., 2003). But despite the unfavorable climatic conditions, agricultural land use (fields and grassland) reached a peak in the late Middle Ages (Dotterweich, 2008; Jäger, 1994). The increased colluviation might be explained by the need for further intensification of land use and increasing plowing depth for higher yields (Benecke et al., 2003; Dreibrodt et al., 2010a; Lang and Hönscheidt, 1999). This shows that environmental factors as triggers for soil erosion and the formation of colluvial deposits became less important. Human presence and agricultural techniques become more and more important and progressively control slope processes (Hoffmann et al., 2008; Hudson et al., 2015; Kaplan et al., 2009; Verstraeten et al., 2009; Zolitschka et al., 2003).

6 Synthesis

Colder humid phases, in general, seem to be correlated with higher accumulation of colluvial material. In the southern and western Baar the oldest colluvial deposits date to the beginning of the Neolithic. In the eastern Baar and on top of a plateau, human influence is detectable from the Bronze Age onward. SPDs show main depositional phases for the Baar region in the younger Neolithic, the early to middle Bronze Age, the Iron Age, Roman Empire and from the high Middle Ages onwards. But colluviation is not a linear process, but is based on erosion and intermediate storage of soil material on slopes (Fuchs and Lang, 2009), so that the main deposition times found here have to be seen as an approximation of periods with increased human activities. We demonstrated that a number of variables, particularly climate, population density, and land use control soil erosion and accumulation from the Neolithic to Iron Age. During that time, reconstructions of climate parameters point to climate being the main controlling factor and population density and land use being indirect factors.

From the Roman Period onward, human activities are the main drivers of soil erosion and thus for the formation of colluvial deposits. The sensitivity of landscapes to erosion is mainly controlled by land use, since land use disturbs the vegetation cover and loosens the soil, thereby making soils, especially on slopes, prone to soil erosion. Climate and population pressure are indirect factors forcing changes in the intensity and kind of land use (Lang, 2003; Zolitschka, 2002; Zolitschka et al., 2003). In this context rainfall finally triggers soil erosion. Therefore the formation of colluvial deposits can be seen as a pseudo-natural (Häbich, 2009) or quasi-natural process (Rathjens, 1979) because it results from anthropogenic actions, but the process itself is natural.

7 Conclusions

Analyzing multilayered colluvial deposits in the vicinity of archaeological finds adds human activities and their influence on landscapes to the reconstruction of geomorphodynamic (un)stable periods. Phases of geomorphodynamic instability can be correlated with the phases of formation of colluvial deposits. We conclude that colluvial deposits can be used as a local proxy with a high spatial resolution regarding land use. However, to go from a local to a more general signal for a region a comparative evaluation of the local colluvial information is necessary to extrapolate colluvial deposition phases, possible driving forces, and human activities to a broader region. Thus, based on the colluvial chronostratigraphy of the four investigated sites on the Baar and including archaeological and paleoenvironmental information the general land use history of the Baar can be reconstructed.

Archaeopedological analyses of 26 soil profiles (with 130 colluvial layers) including 69 OSL and AMS 14C ages of sediments and charcoal fragments demonstrated that colluvial deposits, in combination with other archaeological and environmental data, can be used as a regional proxy for inferring land use on the Baar. The main findings lead to the following conclusions:

- Multilayered colluvial deposits can be found even at upper slope and mid-slope positions, caused by the unknown palaeorelief and the site-specific land use history.
- Pedological and chronological data create a more accurate picture of past human activities, and they complement archaeological knowledge about settlements and human activities in a region.
- Main depositional phases are reconstructed from site specific pedo- and chronostratigraphies. In the southern and western area of the Baar the formative element of human activities on landscapes started with the beginning of the Neolithic. In the eastern Baar and on a plateau in the western Baar, human influence is detectable particularly from the Bronze Age onward.

- SPDs show main depositional phases for the Baar region in the younger Neolithic, the early to middle Bronze Age, the Iron Age, the Roman Empire, and from the high and late Middle Ages onwards. This points to land use change and more intense land use on the Baar in different time periods.
- The increased colluviation probability of the Baar region is different to the probability of gentle rolling loess regions. This might be explained by different land use dynamics with time and soil material and different paleoenvironmental conditions.
- The correlation of SPDs with other environmental variables, like paleoclimate, shows that most phases of intensified colluviation occur in periods with higher precipitation and lower temperatures.
- Additionally, colluviation seems to follow population density, as shown for the Roman Empire and the Migration periods. This points to a coupled influence of climate and humans controlling colluviation, at least from the Romans onward when population reached a certain threshold.
- Colluvial deposits do not indicate the activity of foraging societies, since colluviation needs time and intense land use to manifest human activity. The onset of colluviation in the Neolithic fortifies the early anthropogenic hypothesis and the influence of human induced land use change on soil erosion and accumulation and thereby landscape change.

Our results show that the integrated application of archaeological, pedological, and paleoenvironmental analyses and knowledge, i.e. archaeopedology, helps to get a better understanding of regional land use patterns in time and space. Regional archaeopedological analyses display the human potential to change and modify landscapes, and demonstrate this as early as prehistoric times.

Author contribution

Jessica Henkner, Peter Kühn, Thomas Scholten, Thomas Knopf and Jan Ahlrichs designed the study and JH carried it out. JH prepared the manuscript with contributions from all co-authors. Markus Fuchs was responsible for OSL dating. Sean Downey contributed the script to calculate the SPDs and helped with the interpretation. Bruce James and Sandra Teuber contributed particularly to the interpretation and discussion of the results.

Acknowledgements

This study is part of the Collaborative Research Center 1070 ResourceCultures (SFB1070) financed by the German Research Foundation (DFG). The study was also supported by the

Graduate School of the University of Maryland, College Park and the Institutional Strategy of the University of Tübingen (DFG, ZUK 63).

We are grateful to many student helpers and technical assistants from the Tübingen University, who worked in the field and the lab, especially Christoph Behnke, Dominik Birkenmaier and Rita Mögenburg. We are especially grateful to Kurt Rilling and Michael Kösel from the Landesamt für Geologie, Rohstoffe und Bergbau for great input and discussions in the field. The many farmers, who supported our work by allowing us to work on their land, are acknowledged. Thanks to Dr. Einar Eberhardt for support with the translation of KA5 classification to WRB and FAO. Thanks go to Richard Szydlak, who drew the catenas after drafts by JH. Johanna Lomax and Andrea Junge (all Justus-Liebig-University Gießen) supported the luminescence dating. Thanks to Barret Wessel, who made useful comments on the manuscript. We also thank two unknown reviewers for their helpful comments and suggestions.

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Manuscript 5

Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory - A Case Study from the Western Baar, SW Germany.

Published in Cracow Landscape Monographs 2016, Issue 2, pages 39-48

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Abstract

The first results of an interdisciplinary research project are discussed: It explores the pre- and early historic settlement dynamics between favorable and unfavorable landscapes in SW Germany using an integrated archaeological/ archaeopedological approach with a focus on colluvial deposits. The study area extends from the eastern slopes of the Black Forest across the Baar to the southwestern part of the Swabian Jura. We provide evidence for continuous land use at the boundary of the Black Forest from the Younger Neolithic onwards. Land use even in gentle rolling areas such as the Baar triggered soil erosion leading to a coverage of archaeological sites with younger sediments at foot-slope and mid-slope positions. We detected phases of land use during the transition from the early to the middle Bronze Age and the Roman period – for which no archaeological indications were available so far. Our combination of different disciplines appeared as a major advantage for the exploration of low mountain areas. Our results also question the commonly held notion, according to which modern marginal areas were perceived as marginal areas in prehistory as well.

Keywords

Landscape Archaeology, Archaeopedology, Colluvial deposits, Baar, Black Forest

1. Introduction

The Black Forest is one of the most famous examples of low mountain ranges, which are commonly the classic marginal areas in Central Europe (Denecke 1992: 9–10). It is the largest and highest low mountain range in Germany. Considering the natural conditions and the historical records, since the early 19th century it was a general agreement that the Black Forest was not continuously inhabited before the High Middle Ages (Brückner 1980: 159–160; Sick 1992; Schaab 2003: 7–12). Thus the Black Forest was thought to have been the last marginal landscape in SW Germany to be settled. Hence it is called "Jungsiedelland", i.e. late-settled landscape (Gradmann 1948; Gradmann 1964a: 56–89).

This view was generally supported by archaeologists until the 1990s, arguing that the Black Forest was an impenetrable primeval forest, which people avoided whenever they had the chance to do so. Archaeological finds were either ignored or interpreted as evidence of occasional expeditions (Wahle 1973: 6, 10; Sick 1992: 49–53; Schaab 2003: 5–8). Often demographic pressures and conflicts were hypothesized of being the main triggers for enforced movements into the Black Forest (Kullen 1989: 42–43; Schmid 1991: 80–81). However, until the 1990s, no field surveys were conducted to test this hypothesis (Valde-Nowak and Kienlin 2002: 40).

In the early 1990s excavations of Mesolithic open air sites provided evidence for early human presence in the Northern Black Forest (Pasda 1994). They also show that the visibility of the archaeological sites is restricted in low mountain ranges, on the slopes by dense forests and in the valleys due to recent deposits (Pasda 1998). When systematic field surveys were carried out on the western side of the Black Forest in 1999 and 2000, numerous Mesolithic and Neolithic sites were located (Valde-Nowak and Kienlin 2002; Kienlin and Valde-Nowak 2004). Archaeobotanical studies provide additional evidence for early anthropogenic activities in the Neolithic and an unambiguous land use in the following Bronze and Iron Ages in the Northern Black Forest (Rösch 2009; Rösch et al. 2009). It was also possible to connect the land use from the Latène period to the extraction and smelting of iron ores (Gassmann et al. 2006). In addition pollen profiles and alluvial clay deposits are known from the Middle Black Forest holding out the prospect of land use during the Bronze and Iron Ages in this area (Häbich et al. 2005; Sudhaus et al. 2008). Knopf et al. (2012) were able to demonstrate the research potential of colluvial deposits, which provided evidence for intensive land use in the 9th–10th century AD on the east-facing slopes in the Middle Black Forest. Colluvial deposits are the correlate sediments of soil erosion at the base of hill slopes implying considerable human impact on the landscape (Kadereit et al. 2010). They function as archives and can be studied in order to assess the anthropogenic influence on soil, topography and vegetation, i.e. to reconstruct the landscape (Leopold and Völkel 2007; Vogt 2014).

The research from the last two decades opens the demand for a reassessment of the theoretical concepts of marginal and late-settled areas, since these areas were settled earlier than commonly assumed (Andersson 1998; Coles and Mills 1998; Svensson and Gardiner 2009; Holm et al. 2009; Schreg 2014). In this paper we describe two soil profiles on the western Baar and correlate their colluvial stratification with the archaeological record in order to investigate the continuity of the pre- and early historic land use in this region.

2. Research Project and Study Area

The interdisciplinary research project “Favour – Disfavour? Resource development in marginal areas” is within the framework of the Tübingen CRC 1070 “Resource Cultures” (Bartelheim et al. 2015). We use methods from archaeology and soil science in order to investigate pre- and early historic settlement dynamics between favourable and unfavourable regions. One of the objectives is to decipher the period of times during which these regions were developed and what resources were involved in this process. The project seeks to overcome traditional narratives such as conflict situations, demographic pressures and climatic changes as main triggers for movements into unfavourable regions.

The study area extends from the eastern slopes of the Middle Black Forest across the Baar to the south-western part of the Swabian Jura. Due to its continental climate, fertile soils and low terrain intensity the Baar is considered as an old-settled landscape, i.e. “Altsiedellandschaft”. With reference to the agricultural potential of the Baar, both the Black Forest and the Swabian Jura represent unfavourable landscapes, characterized by high annual precipitation (750–1000 mm), low temperatures (4–7 °C) and infertile soils (Siegmund 1999; Kösel and Rilling 2002). Winter and frost periods last several weeks longer compared to the Baar region (Gradmann 1964b: 48–87). Steep slopes and acidic soils are typical for the Black Forest, whereas the high plateau of the Swabian Jura is a landscape mainly dominated by Karst, hence water storage is restricted (Gradmann 1964b: 265–319).

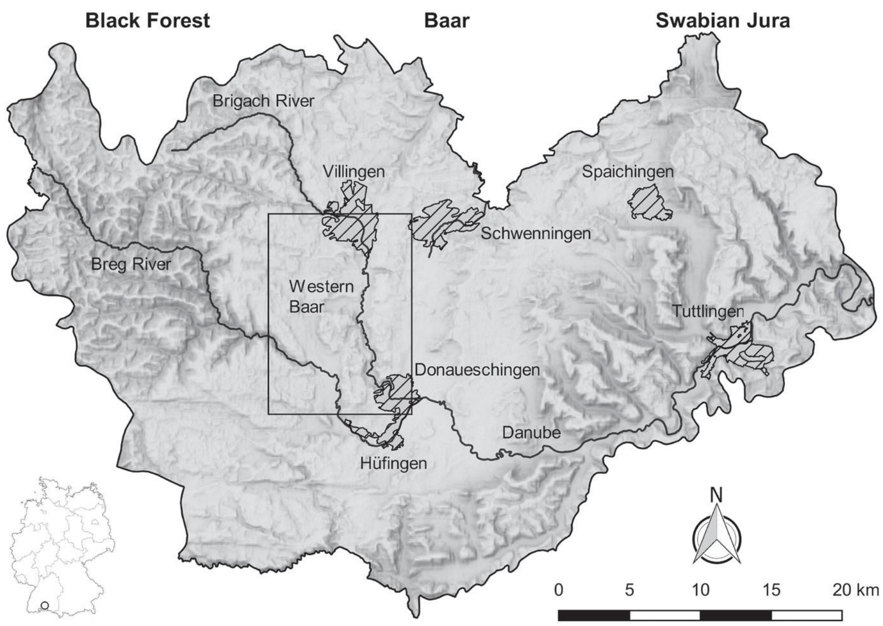

Fig.1. Study area of the research project "Favour – Disfavour? Resource development in marginal areas".

2.1. Research methods

For the archaeological investigation of the study area a database was set up in 2014, based on local archaeological records from State Office for Cultural Heritage Baden-Württemberg and a literature review. It contains 1826 sites covering the period from the early Holocene until the 12th century AD. This database was used to select locations for the investigation of colluvial deposits in the study area. Pieces of charcoal from the colluvial deposits were used for AMS radiocarbon dating. These 14C ages provide the maximum age of colluvial deposition. Since the locations for the pedological investigations were selected on the basis of archaeological data, we are able to discuss the 14C ages of the colluvial sediments on a regional level. However, it is difficult to determine the exact kind of land use strategies, which triggered the formation of the colluvia. Thus the term "land use" cannot be specified here.

2.2. Archaeological research in the baar

In the second half of the 19th century the topographer E. Paulus conducted field surveys in the study area. He was able to map several hitherto unknown prehistoric burial mounds as well as farmsteads and roads from the Roman period (Paulus 1882). At the beginning of the 20th century a comprehensive catalogue of the known prehistoric and early historic finds was published (Wagner 1908). After the First World War, P. Revellio led the archaeological research in the Baar until the 1950s. He collected material at construction sites and carried out rescue excavations as well as field surveys (Revellio 1932; Schmid

1991: 22). Between 1932 and 1935 H. Stoll carried out field surveys in the vicinity of Spaichingen and on the high plateau of the Swabian Jura (Stoll and Gehring 1938). In addition, he wrote a manuscript about the prehistory of the Baar, which was not published due to his early death (Goessler 1948: 442). In the mid-1930s E. Fischer discussed the distribution of the prehistoric sites in relation to the favorable and unfavorable conditions of the natural environment (Fischer 1936). On the occasion of the excavation of the Hallstatt period grave mound Magdalenenberg K. Spindler (1977) published an additional paper on the settlement history. In the 1980s the last comprehensive reappraisal of prehistoric sites, accompanied by field surveys around Villingen-Schwenningen and Grüningen, was done by B. Schmid (Schmid 1991: 22,

75–76). Lately, surveys were conducted between 2010 and 2012 in the vicinity of the Magdalenenberg and Grüningen (Knopf 2012; Knopf and Seidensticker 2012). In the southern part of the Baar the Fürstenberg was systematically surveyed (Wagner 2014).

2.3. Colluvial deposits at the Magdalenenberg and Grüningen

Considering the numerous mentioned archaeological surveys the sites Magdalenenberg near Villingen and Grüningen were chosen to analyze colluvial deposits. Both sites are located in the western Baar, close to the Black Forest (Fig. 2).

The soil profile 1 at the Magdalenenberg is located downslope on the north facing slope of the Magdalenenberg itself (Knopf et al 2015). The soil consists mainly of colluvial material, underlying periglacial material originates from the Lower Muschelkalk. Different colluvial soil horizons point to different phases of human land use. Almost all 14C ages are in accordance with the colluvial stratigraphy (Tab. 1). An exception in this respect is sample Poz-36954. It was taken at a depth of 65 cm, but is older than the sample Erl-20132 from a depth of 75 cm. Since the physical ages of all samples are correct, it seems likely that this older charcoal sample was rearranged, e.g. due to bioturbation. The upper 70 cm of soil show some redoximorphic features and are affected by clay illuviation and the transportation and accumulation of organic matter. The abundance of redoximorphic features increases with depth, which indicates a water influenced horizon. Today the land is used as a mowing meadow, but the 80 cm colluvial deposition indicates more intense land use over the last nearly 6000 years until 1000 years ago (Tab. 1).

Soil profile 8 from Grüningen shows a very similar picture, but is still used for crop production (Tab. 2). It is situated on a southeast facing slope. The soil consists of 120 cm colluvial material with underlying loess (wind-transported silt-sized sediment in a periglacial environment). The underlying geology (upper Muschelkalk, Trochitenkalk Formation) does not influence soil development because it is covered by loess. The charcoal in the deepest colluvial horizon dates to 2472–2278 cal BC (Erl-20137). The time difference to the upper horizon comprises about 2000 years. This difference is also visible in the distinct redoximorphic features of the lower horizon. Two charcoal samples from the same colluvial horizon are contradicting (Tab. 2). The sample MAMS-12277 was taken at a depth of 72 cm and dated to 1620–1500 cal BC. However, sample Erl-20136, which was taken at a depth of 83 cm and is significantly younger, i.e. 2–177 cal AD. During our fieldwork we discovered artefacts dating to 1300–800 cal BC (Urnfield period) in this profile at a depth of 80 cm. Thus the sample Erl-20136 must have been moved by bioturbation downwards into the older colluvial deposit.

Both sites show a long history of land use alternating with periods of extensive land use visible through the differentiation of the horizons.

Table 1. Soil profile from Magdalenenberg (Mag 1).AMS14C ages using charcoal.

Horizon [FAO 2006]	Depth of Horizon [cm]	Age [uncal BP]	Age [cal AD/BC (95,4%; 2 Sigma)]	Labcode	Sampling Depth [cm]
Ap	-25	746 ± 33	1221–1290 cal AD	Erl-20131	-25
Ah1	-60	635 ± 30	1284–1399 cal AD	Poz-36952	-34
Ah1		905 ± 30	1037–1207 cal AD	Poz-36953	-49
Ah2	-70	4970 ± 40	3929–3654 cal BC	Poz-36954	-65
2Bshg	-80	5071 ± 51	3790–3760 cal BC	Erl-20132	-75

Calibrations were done with OxCal 4.2 (IntCal13)

Table 2. Soil profile from Grüningen (Gru 8). AMS 14C ages using charcoal.

Horizon [FAO 2006]	Depth of Horizon [cm]	Age [uncal BP]	Age [cal AD/BC (95,4%; 2 Sigma)]	Labcode	Sampling Depth [cm]
Ah1	-65	909 ± 21	1037–1183 cal AD	MAMS 12275	-40
Ah1		1569 ± 21	427–543 cal AD	MAMS 12276	-50
Ah2	-96	3283 ± 25	1620–1500 cal BC	MAMS 12277	-72
Ah2		1918 ± 38	2–177 cal AD	Erl-20136	-83
2Bgh	-120	3889 ± 40	2472–2278 cal BC	Erl-20137	-105

Calibrations were done with OxCal 4.2 (IntCal13)

2.4. Correlation with archaeological data from Magdalenenberg and Grüningen

The medieval 14C-datings from upper horizons of the profile 1 from Magdalenenberg (Mag 1) correlate with archaeological finds and historical records. Phases of high (Poz-36953) and late medieval (Poz-36952 and Erl-20131) land use can be associated with the town of Villingen, which was first mentioned in 817 AD and is close to the site (Jenisch 1999: 35). These deposits may also be related to close-by fortifications from the high-medieval period (Spindler 1979: 371–372; Buchta-Hohm 1996: 122–123). New is the evidence of late Neolithic land use (Poz-36954 and Erl-20132). So far, two Neolithic sites with small finds are known from the immediate vicinity (Fig. 2). In the course of construction works in 1969 several flint implements were discovered less than 1 km to the northeast probably dating to early Neolithic (Schmid 1991:

25). In addition a stone axe was found in 1983, when a farmer prospected one of his fields (Hettich 1984/85). Furthermore, there is a collection with 19 stone axes in the Museum of Villingen. However, the provenience of these finds has not been documented (Schmid 1992: 125–126). While these findings could suggest at best a temporary use of this area, it is now possible to detect an unambiguous phase of land use in the Younger Neolithic through the analysis of colluvial deposits (Knopf and Seidensticker 2012). It seems likely that this land use was accompanied by a long-term existing settlement in the area as well as an increased penetration of the eastern slopes of the Middle Black Forest, which are only a few kilometres away (Fig. 2). This assumption is supported by findings from other parts of the Black Forest. Pollen profiles from the Northern Black Forest indicate a human impact during the Younger Neolithic (Rösch 2009: 342). The surveys of Valde-Nowak and Kienlin (2002: 45–47) provided evidence for an intensified phase of land use during the Younger and Final Neolithic on the western side of the Black Forest as well.

A correlation with adjacent Iron Age settlements has not been possible so far. South of the Magdalenenberg pottery fragments, glass jewellery and so-called "rainbow cups" were collected in the late 1970s and early 1980s, dating to the Latène period (Hettich 1984/85; Weber 1991/92). Another settlement is known from the Gerberstr. 76 in Villingen (Weber-Jenisch 1994). There are two possible explanations for the absence of colluvial deposits from the Latène period in profile Mag 1. The site from Gerberstr. 76 is about 2 km away (Fig. 2). Thus it is possible that the people living there used other fields for agriculture. It should also be borne in mind that the colluvial deposits from Mag 1 only represent the land use from the corresponding slope area on the northern side of the Magdalenenberg. For this reason it cannot be ruled out that the southern slope was agriculturally used during the Latène period. No colluvial deposits date to the Hallstatt period. However, archaeobotanical analysis of sediments from the Magdalenenberg itself revealed that the area was used as pasture land at that time (Fritz 1980: 95–96).

With regard to the mentioned archaeological field surveys profile 8 (Gru 8) from the area west of Grüningen provided surprising results. The medieval colluvial deposit from this profile (MAMS 12275) fits to the earliest historical record of Grüningen from the 12th century (Buchta-Hohm 1996: Tab. 1).

The previous phase of land use during the Merovingian period (MAMS 12276) correlates with contemporaneous cemeteries from the Brigachtal valley (Wagner 1908: 107–108) and Wolterdingen (Buchta-Hohm 1996: 123; Fig. 2).

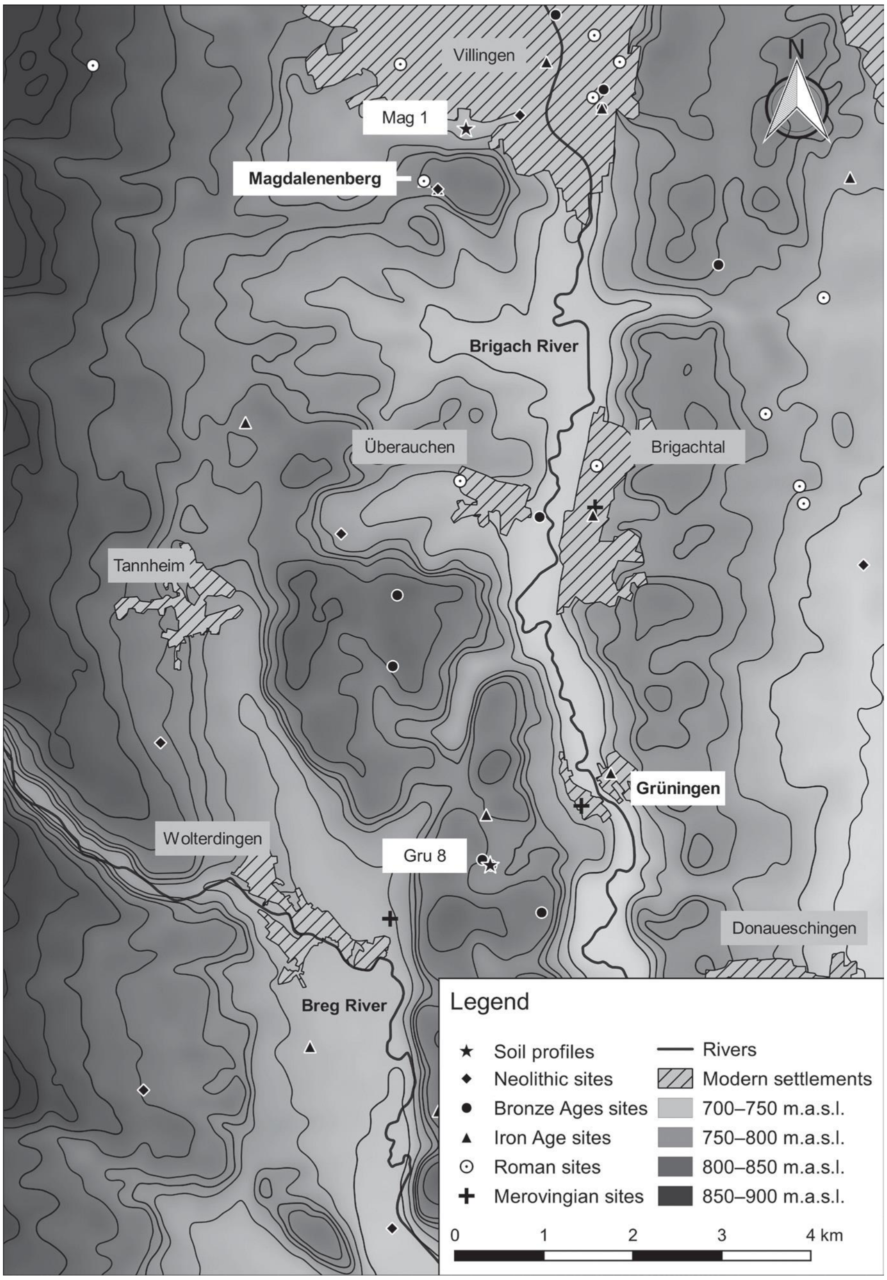

Figure 2. Soil profiles and archaeological sites in the western Baar.

Unexpectedly, a phase of Roman land use could be detected, sample Erl-20136 dates to the transition from the early to mid-Roman period (Sangmeister 1993: 122). From the nearby area there are no archaeological finds known from this period. The closest Roman sites are located ca. 3–5 km away in Bräunlingen and Überauchen (Thom 1969: 5, 74–75; Fig. 2). However, this colluvial deposit from Gru8 indicates a possible Roman farmstead around Grüningen, which probably was involved in the supply network for the Castrum a few kilometres south in Hüfingen (Mayer-Reppert et al. 1995).

Since the choice of location for Gru8 was oriented towards a potential settlement from the Urnfield period located on the upper slope, colluvial deposits from this period were expected. Indeed the profile revealed a phase of land use from the Bronze Age. Surprisingly the AMS 14C age from sample MAMS 12277 indicates a phase of land use during the 15–17th century cal BC, i.e. at the transition from the early to the middle Bronze Age (Della Casa 2013 : 211). This is in contrast to the archaeological evidence for the Bronze Age settlement of this area (Ahlrichs et al. 2016). The closest known sites from the Early Bronze Age are located in the valley of the Danube (Oberath 2000). The same applies to the nearest Middle Bronze Age settlement, located 4 km to the north-east in the Brigach valley (Schmid 1992: 122–123; Fig. 2). About 1.2km southeast of Gru8 a late Middle Bronze Age burial (Schmid 1991: 37) was discovered and excavated in the 1850s (Schmid 1992: 11–12). Therefore the burial took place at a time when the colluvial deposits already existed. Apart from this site some stone and earth mounds are known from the vicinity, which have not been excavated so far (Knopf et al. 2015). Assuming that land was used in the immediate surroundings of the settlements, there might be at least one settlement dating to the transition from early to middle Bronze Age nearby profile Gru8 (Fig. 2).

Profile Gru 8 does not have a phase of colluviation from the Urnfield period but it contained a deposition of ceramics from this period. It was discovered in 2014, with the base at 80 cm depth and consists of a 16.5 x 15 cm large vessel in which a 6.8 x 7.5 cm small cup was found. No additional artefacts or human remains were found. The intentional deposition of the two vessels is probably related to the contemporaneous settlement in the upper slope area. These kinds of depositions are also known from other settlements from this period (Ahlrichs et al. 2016).

Finally, the thickness of the colluvial deposits from Mag 1 and Gru 8 is not only an indicator for phases of land use. The colluvial stratigraphy also provides source critical information for the question, why there are no archaeological correlates for certain phases of land use, despite the numerous field surveys. The depth of the colluvial deposits shows that the relief intensity is sufficient enough to reduce the visibility of archaeological sites in the field, even if the slope gradient is not high. So far this has only been considered for river valleys with steeper slopes (e.g. Paret 1961: 154–156; Wahle 1973: 2).

3. Concluding Remarks

The integrated combination of archaeological and pedological methods provides unambiguous evidence for continuous phases of land use on the western Baar, starting at the latest in the Young Neolithic and lasting until the Middle Ages. Considering the archaeological evidence and the colluvial stratigraphies from Magdalenenberg and Grüningen it seems possible that the Neolithic settlement of the western Baar has been accompanied by a penetration into the Black Forest – perhaps for summer pasture. The thickness and the fine stratigraphy of colluvial deposits indicate that even in areas with gentle slopes such as the western Baar, there might be more archaeological sites that are overlain by younger colluvial deposits.

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Scientific publications and conference contributions

Scientific papers (peer-reviewed)

- Teuber, S.; Ahlrichs, J. J., Henkner, J., Knopf, T., Kühn, P., Scholten, T. (2017): SoilCultures - the adaptive cycle of agrarian soil use in Central Europe. An interdisciplinary study using soil scientific and archaeological research.
  accepted by Ecology and Society on September 13th, 2017
  [first submitted June 2016]
- Teuber, S., Kühn, P., Scholten, T. (2015): BodenKulturen - die Bodennutzung in Mitteleuropa im Wandel der Zeit.
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- Teuber, S., Schmidt, K., Kühn, P., Scholten, T. (xxxx): Allotment gardening in Southwest Germany - a comparative analysis of motivations and management practices
  under review in Agriculture and Human Values [submitted August 2017]
- Henkner, J., Ahlrichs, J. J., Downey, S., Fuchs, M., James, B., Knopf, T., Scholten, T., Teuber, S., Kühn, P. (2017): Archaeopedology and chronostratigraphy of colluvial deposits as a proxy for regional land use history (Baar, southwest Germany).
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- Ahlrichs, J. J., Henkner, J., Teuber, S., Schmidt, K., Scholten, T., Kühn, P., Knopf, T. (2016): Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory - A Case Study from the Western Baar, SW Germany.
  published in Cracow Landscape Monographs 2016, Issue 2, pages 39-48

Other publications

- Hansen, L., Tarpini, R., Gassmann, G., Abele, J., Hartmayer, R., Teuber, S., Scholten, T., Krausse, D. (2017): Ländliche Siedlungsstellen im Umland des "Fürstensitzes" Heuneburg
  Published in Landesamt für Denkmalpflege (2017): Archäologische Ausgrabungen in Baden Württemberg 2016

Conference contributions:

- Teuber, S., Schmidt, K., Kühn, P., Scholten, T. (2017) Bodennutzung in Kleingärten. Presentation at the DBG-Conference 2017 in Göttingen, Germany.
- Teuber, S., Kühn, P., Scholten, T. (2017): Soil use in gardens as chance to socially promote the Sustainable Development Goals. PICO-presentation at the EGU General Assembly 2017, Vienna, Austria.
- Teuber, S., Kühn, P., Scholten, T. (2017): Gardens, Soils and Science. Presentation at the workshop "Knowing Soils: An Anthropology of Agricultural Knowledge" of the Collaborative Research Center 923 "Threatened Order – Societies under Stress", Tübingen, Germany.
- Teuber, S., Scholten, T. (2016): Kleingärtner und Boden – Wahrnehmung und Nutzung. Presentation at the Symposium "Wahrnehmung und Bewertung von Böden in der Gesellschaft", Karlsruhe, Germany.
- Teuber, S. (2016): Innovations and traditions in garden management practices – curse and blessing for private gardening. Poster presentation at the conference "Resources in social Context(s): Curse, Conflicts and the Sacred" of the Collaborative Research Center 1070, Tübingen, Germany.
- Teuber, S., Kühn, P., Scholten, T. (2016): The role of soil quality and soil conservation for private gardening in South-West Germany. Presentation at the EGU General Assembly 2016, Vienna, Austria.
- Teuber, S, Scholten, T. (2015): Ethnopedologische Analyse der gesellschaftlichen Bodennutzung und des Bodenwissens in Südwestdeutschland. Presentation at the DBG-Conference 2015, Munich, Germany.

Acknowledgements

First, I want to thank my supervisor Prof. Dr. Thomas Scholten for giving me the opportunity to become part of his workgroup and offering me the possibility to design my own PhD-project. Thank you for your support, trust, constructive feedback, and your general help during this exciting and challenging time.

I am grateful to Prof. Dr. Thomas Knopf for evaluating this thesis. Thank you for the conversations and the support during the last years.

It has been a great experience, to be associated with the Collaborative Research Center 1070. Many thanks go to the board and administration, namely Prof. Dr. Martin Bartelheim, Prof. Dr. Roland Hardenberg, Prof. Dr. Jörn Staecker, Dr. Anke Scholz and Shyamala Subramanian. Further, I want to thank PD Dr. Sabine Klocke-Daffa for her work as spokesperson for the Mini-Graduiertenkolleg “Netzwerke und RessourcenComplexe”. I also thank all members of the Mini-Graduiertenkolleg for the fruitful discussions and the helpful feedback. In particular, I want to thank my roommates during the time at the SFB-house, Pia Hilsberg, Karin Pfister, Marc Schwenzer and Daniel Steinberg. Thank you for the discussions and the coffee breaks. I, further, thank all my colleagues and friends from the SFB 1070, especially Jessica Henkner, Anne Merker, Marco Krätschmer, Janina Diekmann, René Kunze, Jan Ahlrichs, Jörg Widmaier, Christina Vossler-Wolf and Xenja Herren, for their support and help as well as for the distraction and the good times.

Special thanks go out to Sabine Flaiz, Rita Mögenburg and all the student helpers of the Laboratory of Soil Science and Geoecology. I am grateful for the help of Mario Ahner, who made it possible to get the soil samples ready for last minute CNS-analysis.

I also want to thank Dr. Peter Kühn, Dr. Karsten Schmidt and Dr. Steffen Seitz for their constant support, help and feedback. Their office doors were always open and the discussions helped me a lot. I, also, thank everyone of the soil science work group for the good times at the institute, at conferences, in the field and in the lab.

Last but not least, I thank my family for their trust and constant support during the last years.