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ORIGINAL ARTICLE

# Intensification of agriculture in southwestern Germany between the Bronze Age and Medieval period, based on archaeobotanical data from Baden-Württemberg

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**Abstract**

A system of farming with an alternation of land use between being cultivated or left fallow as grassland (*Feldgraswirtschaft*) developed in southwestern Germany since the Bronze Age. It involved fallow periods, where the arable land is left without crops in order to let it recover its fertility for several years while becoming grassland. This led to regeneration of the topsoil humus, which could later be mobilized by cultivation. With later farming systems, the supply of nutrients needed for crops could also be provided by manuring, which allowed shorter fallow periods but required the production of manure. Such cultivation systems with short or even without fallow phases and with intensive manuring are known from the medieval period as one, two or three field systems of agriculture and their development was an important step towards the intensification of farming. The current study considers on-site plant macrofossil data from archaeological sites as well as the off-site pollen data from cores in Baden-Württemberg in order to recognize the main changes towards agricultural intensification through time from the Bronze Age up to medieval times. The various landscape types included in the study area also reveal their different agricultural histories of intensification. In lowlands with good soils, the intensification can be recognized earlier and more strongly than in uplands or other marginal areas. The main shift towards intensification took place in the Roman period, which is also confirmed by written sources of the time that mention manuring as well as a kind of two field system and alternation between grassland and arable land.

**Keywords** Archaeobotany · Pollen · Agriculture · Cultivation system · Intensification · Southwestern Germany

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## Introduction

Agricultural intensification can be technically defined as an increase in agricultural production per unit of inputs, which may be labour, land, time, fertilizer, seed, feed or cash, and usually occurs when there is an increase in the total amount of agricultural production that results from a higher productivity of inputs (Kenmore 2004). Since the introduction of agriculture, the process of its intensification has led to more productive farming systems, enabling human populations to grow and to establish increasingly larger settlements as well to develop more and more specialized and complex economies.

One of the important limiting factors of growing crops and their productivity is the maintenance of soil fertility, as any cropping also results in soil depletion by removal of the essential minerals such as nitrogen, phosphorus and potassium, and also by breakdown of organic matter necessary for its fertility. Before the introduction of chemical fertilisers, the nutrients lost through the harvest were replaced by additional organic matter either from manure, or from humus regeneration during fallow phases. This added organic matter breaks down into humus, releasing plant-available minerals, a process which is stimulated by tillage.

Agriculture of the time up to the early modern period therefore involved a regular alternation between cultivated fields and fallow land left to renew the soil fertility (Franz 1970; Schulze 2014). According to written sources (Boserup 1965), early forms of agriculture were extensive, involving long fallow periods and low energy inputs per unit area, and they only became more intensive as a result of technological changes such as better ploughing techniques. During long fallow phases enough organic matter was accumulated so that manure was not necessary. This is the principle of shifting cultivation systems, the Neolithic slash-and-burn as well as prehistoric agriculture (Andreae 1955; Rösch et al. 2017). For both of these, due to long-term fallow periods, the availability of usable arable land as well as the total yield from this land was restricted. The early type of farming economy with relatively long fallow phases was practised in southwestern Germany from the Bronze Age onwards. If the fallow period is reduced and the lack of organic matter can be compensated for by manure, the crop yield of the arable land will increase. Such systems with short or even without fallow phases, crop rotation and intensive manuring are known from the medieval period as one, two or three field agriculture. The *ewiger Roggenbau* (permanent rye cultivation), practised on the poor soils of northwest Germany during the Medieval period, is a good example of such a one field system (Behre 2000). The three field system was mainly used during the High Medieval period. Here there were two seasons with crops and one as fallow. According to written sources, the three field system with intensive manuring is even mentioned in the *Capitulare de villis* of Charlemagne in the early 9th century (Strank and Meurers-Balke 2008). Organic matter from woods, scrub and heathlands, the common pasture ground, was mixed with animal dung to make manure to spread on the fields to compensate for the nutrients lost by the harvest, described by Menke (1995) as a nutrient redistribution system.

The transition from the Bronze Age crop and grassland alternation to farming using manure was an important step towards the intensification of agriculture, enabling an increase of population. It implied a shorter fallow phase and a longer cultivation phase combined with manuring. However, it is still unclear when the main agricultural intensification occurred in southwestern Germany and how this transition took place through time in the different landscape types of the region.

The type of cultivation system and the duration of its fallow phase can also be indicated by the crop weeds. The present-day crop weeds and many of the past ones are annuals. However, weed remains from stored cereal products of the Medieval period gave evidence that many perennial plants also grew in the cornfields then (Karg 1995). Perennial taxa now considered to be mainly grassland plants cannot tolerate regular and heavy tillage. The longer the fallow phase, the more perennials can grow and survive during the shorter cultivation phase. Perennials dominate in natural grasslands and also grow in semi-natural meadows or pastures on previously cultivated land. However, permanent meadows or pastures do not appear to have been established before the historical period (Körber-Grohne 1993; Hejcman et al. 2013; Poschlod 2017). Grassland plants grew in the past on fallow land, with a regular shift between crop cultivation and fallow, used as pasture, so that they could survive and benefit from less intensive tillage. We can therefore assume that they were encouraged by longer fallow and shorter arable phases. Their decrease in archaeobotanical remains can indicate the transition to a field system involving more thorough ploughing and agricultural intensification. According to historical sources, during the Iron Age La Tène period, the hand ard was replaced by the mouldboard plough which turns the soil (Leser 1931). This development enabled more intensive tillage which in turn led to the reduction of perennial taxa in the fields.

A typical grassland plant of today and crop weed in the past is *Plantago lanceolata.* It can show a shift between cultivated land and pastures (Burrichter 1969; Behre 1981). The proportion of Cerealia to *P. lanceolata* pollen can be used to indicate the relation between cultivated and fallow land, in which Cerealia is an indicator of crops and *P. lanceolata* an indicator of pasture on fallow land (Lange 1971, 1975, 1976). In general, its fluctuations in time may indicate the changes of the relation between cultivated and fallow land. To test this hypothesis for southwest Germany, we have used the large archaeobotanical datasets of on- and off-site evidence from Baden-Württemberg to consider both plant macrofossil and pollen evidence covering the period between the Bronze Age and Medieval times.

## Materials and methods

### On-site data

On-site data analysis was based on plant macro remains from archaeological excavations including lake sites in Baden-Württemberg, using the ArboDat database of the archaeobotanical laboratory of the Landesamt für Denkmalpflege Baden-Württemberg (LDBW, state cultural heritage organisation) (Kreuz and Schäfer 2002). At present around five million mostly published records of charred macro remains of weeds and grassland taxa are available in the database, representing around 5,000 samples and 3,000 features taken from more than 200 sites with dry preservation conditions. The archaeological sites in southwestern Germany are not evenly distributed, but concentrated typically in the lowlands which were densely settled since early prehistory, but rather sparsely in the uplands (Fig. 1).

These archaeobotanical remains were extracted by water sieving and hand flotation. Sieve sets with mesh sizes of 8 mm, 4 mm, 2 mm, 1 mm and 0.5 mm were used. For hand flotation, a sieve with mesh size of 0.063 mm was used. After sieving and flotation, the samples were dried in an oven at 50 °C. Plant macro remains were sorted under a binocular microscope and identified using the modern reference collection of the LDBW archaeobotanical laboratory and relevant identification literature.

In this study, we focused on typical grassland taxa which were also part of the ancient agricultural systems such as *Trifolium repens*, *Prunella vulgaris*, *Phleum pratense*, *Trifolium pratense*, *Chrysanthemum leucanthemum* and *Plantago lanceolata*, taking into account their present syntaxonomy, phytosociological behaviour and frequency of their charred seeds in archaeobotanical samples from the study region. The frequency of the taxon in percent of features where it occurred was calculated through time from the Bronze Age to the early modern period, from 2200 BC to AD 1850, differentiated into archaeological and historical periods (Table 1).

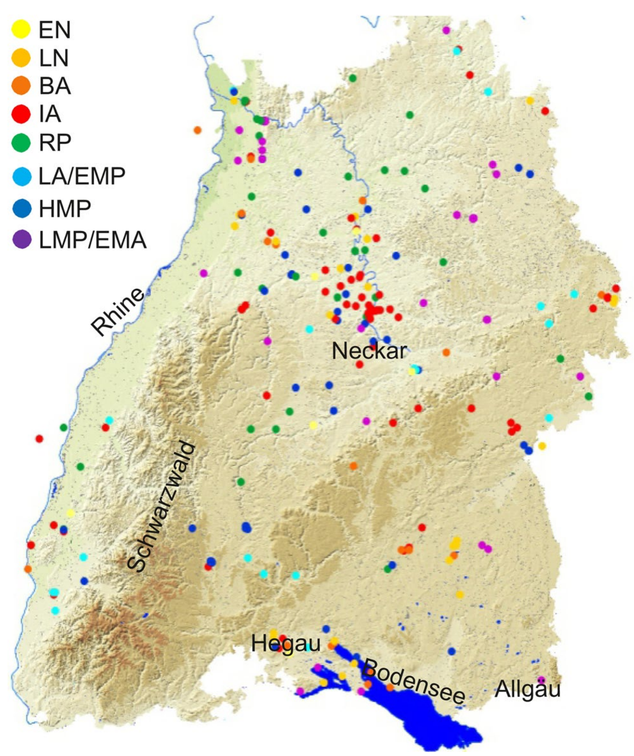


**Fig. 1** Distribution of the sites considered for their on-site data in southwestern Germany, dated to the periods from early Neolithic to early modern age (1500–1850). *EN* Early Neolithic, *LN* Late Neolithic, *BA* Bronze Age, *IA* Iron Age, *RP* Roman period, *LA/EMP* Late Antiquity/Early Medieval period, *HMP* High Medieval period, *LMP/EMA* Late Medieval period/early modern age

## Off-site data

At present there are around 60 well-dated pollen profiles available from central Europe (Rösch et al. 2020a, b, accepted), more than half of them from southwestern Germany (Table 2). In this paper the palynological data from nine sites, mostly lakes, located in the different landscapes of southwestern Germany (Fig. 2) has been evaluated. The pollen samples were prepared for analysis following the standard procedure with addition of *Lycopodium* spores, applying hot HCL, 10% KOH, HF, acetolysis and finally mounting in glycerine. The pollen sum in each subsample was usually more than 1,000 terrestrial pollen grains. Pollen identification was based on the reference collection of the LDBW archaeobotanical laboratory, pollen keys (Punt et al. 1976–2009; Moore et al. 1991; Beug 2004) and image atlases (Reille 1992). Pollen samples are summed up to time intervals of 500 years between 5500 and 3000 BC and 200 years between 3000 BC and AD 1800. The longer time slices in the Neolithic period were necessary in order to reach a statistical consistency.

From all of the large and diverse pollen datasets we selected the proportions of Cerealia (without *Secale cereale*) and *P. lanceolata* pollen frequencies as a proxy for the changes in the balance between cultivated and fallow land through time. This can be expressed by the so called Cerealia/*P. lanceolata* index (C/PL index) and is calculated

**Table 1** The main archaeological and historical periods mentioned in the text and their dates

| Period | Age | Duration (years) |
|---|---|---|
| Early modern age | AD 1500–1850 | 350 |
| Late Medieval | AD 1300–1500 | 200 |
| High Medieval | AD 1000–1300 | 300 |
| Early Medieval | AD 750–1000 | 250 |
| Late Antiquity | AD 260–750 | 490 |
| Roman period | 15 BC–AD 260 | 275 |
| La Tène | 475–15 BC | 460 |
| Hallstatt | 800–475 BC | 325 |
| Late Bronze Age | 1300–800 BC | 500 |
| Middle Bronze Age | 1700–1300 BC | 400 |
| Early Bronze Age | 2200–1700 BC | 500 |
| Final Neolithic | 2600–2200 BC | 400 |
| Late Neolithic | 3300–2600 BC | 700 |
| Younger Neolithic | 4300–3300 BC | 1,000 |
| Middle Neolithic | 5000–4300 BC | 700 |
| Old Neolithic | 5500–5000 BC | 500 |

**Table 2** The pollen sites discussed in this study

| No | Site | N | E | m (a.s.l.) | Reference |
|---|---|---|---|---|---|
| 1 | Mainau-Obere Güll | 47° 42′ 20″ | 9° 11′ 01″ | 394 | Rösch and Wick (2019a) |
| 2 | Mindelsee | 47° 45′ 20″ | 9° 01′ 22″ | 406 | Rösch (2013) and Rösch et al. (2014a, b) |
| 3 | Buchensee-Südost | 47° 46′ 01″ | 8° 59′ 05″ | 431 | Rösch and Wick (2019b) |
| 4 | Böhringer See | 47° 45′ 48″ | 8° 56′ 18″ | 409 | Lechterbeck and Rösch (2020) |
| 5 | Litzelsee | 47° 46′ 08″ | 8° 55′ 50″ | 413 | Rösch and Lechterbeck (2016) |
| 6 | Steisslinger See | 47° 47′ 57″ | 8° 55′ 01″ | 450 | Lechterbeck (2001) |
| 7 | Hornstaad-Bodensee | 47° 41′ 45″ | 9° 00′ 31″ | 394 | Rösch (1992, 1993, 1997) |
| 8 | Nussbaumer See | 47° 37′ 01″ | 8° 49′05″ | 434 | Haas and Hadorn (1998) and Rösch (1983) |
| 9 | Husemer See | 47° 37′ 22″ | 8° 42′ 21″ | 409 | Rösch unpubl |
| 10 | Schleinsee | 47° 36′ 48″ | 9° 38′ 07″ | 474 | Müller (1962), Geyh et al. (1971) |
| 11 | Degersee | 47° 36′ 45″ | 9° 39′ 02″ | 478 | Kleinmann et al. (2015) and Merkt and Müller (1978) |
| 12 | Muttelsee | 47° 37′ 07″ | 9° 40′ 15″ | 492 | Merkt and Müller unpubl. report (1979) |
| 13 | Zeller See/Bodensee | 47° 43′ 14″ | 8° 58′ 25″ | 395 | Rösch (1991) and Giovanoli (1990) |
| 14 | Wangen/Bodensee | 47° 39′ 39″ | 8° 56′ 22″ | 395 | Rösch (2002) |
| 15 | Gnadensee | 47° 42′ 35″ | 9° 03′ 41″ | 395 | Ryabogina and Rösch unpubl |
| 16 | Königseggsee | 47° 55′ 57″ | 9° 26′ 58″ | 627 | Fischer and Rösch (2018) unpubl |
| 17 | Stadtsee/Bad Waldsee | 47° 55′ 24″ | 9° 45′ 30″ | 583 | Merkt and Müller unpubl. and Fischer et al. (2010) |
| 18 | Grosser Ursee | 47° 45′ 11″ | 10° 01′ 32″ | 695 | Rösch et al. (2020a, b) |
| 19 | Herrenwieser See | 48° 40′ 09″ | 8° 17′ 47″ | 830 | Rösch (2012) |
| 20 | Glaswaldsee | 48° 25′ 37″ | 8° 15′ 46″ | 839 | Rösch and Heumüller (2008) |
| 21 | Mummelsee | 48° 35′ 56″ | 8° 12′ 06″ | 1,028 | Tserendorj unpubl |
| 22 | Schurmsee | 48° 36′ 51″ | 8° 19′ 13″ | 795 | Tserendorj unpubl |
| 23 | Wilder See am Ruhestein | 48° 34′ 14″ | 8° 14′ 25″ | 910 | Rösch (2009a, b) |
| 24 | Huzenbacher See | 47° 34′ 32″ | 8° 20′ 58″ | 747 | Rösch and Tserendorj (2011a, b) |
| 25 | Buhlbachsee | 48° 30′ 06″ | 8° 14′ 45″ | 790 | Tserendorj unpubl |
| 26 | Ellbachsee | 48° 29′ 03″ | 8° 18′ 21″ | 770 | Rösch unpubl |
| 27 | Feldsee | 47° 52′ 17″ | 8° 01′ 59″ | 1,109 | Fischer unpubl |
| 28 | Titisee | 47° 53′ 39″ | 8° 08′ 43″ | 846 | Fischer unpubl |
| 29 | Schluchsee | 47° 49′ 08″ | 8° 09′ 09″ | 930 | Rösch (2017) |
| 30 | Bergsee | 47° 34′ 20″ | 7° 56′ 09″ | 382 | Knopf et al. (2016) |
| 31 | Aalkistensee/Maulbronn | 48° 59′ 41″ | 8° 45′ 41″ | 227 | Rösch et al. (2017) |
| 32 | Hardtsee/Hegau | 47° 44′ 24″ | 8° 45′ 1.8″ | 436 | Rösch and Lechterbeck in prep. |

as a percentage of *Plantago* pollen in relation to the sum of Cerealia and *Plantago* (Rösch et al. 2020a, b, accepted). The interpretation of the Cerealia/*Plantago* index is based on the assumption that shorter fallow phases should result in more land under cultivation and smaller areas under grassland or fallow and therefore that this would be reflected by more cereal pollen as well as less *Plantago* pollen in the corresponding pollen record.

## Results

### On-site macrofossil evidence

*Trifolium repens* is classified according to its phytosociology as a species typical of the Cynosurion communities of fertilized pastures (Oberdorfer 1957) and it occurs frequently in different types of grassland. Its appearance in the archaeobotanical record of southwest Germany is seen first during the Late Bronze Age (1300–800 BC). Afterwards, its frequency increases up to more than 8% of all samples until the La Tène period (Iron Age, 475–15 BC), then it decreases abruptly in the Roman period and remains low despite a slight rise again during Late Antiquity (AD 260–750) and the Early Medieval period (AD 750–1000) (Fig. 3).

*Prunella vulgaris* has similar phytosociological behaviour to *T. repens* and also shows a very similar pattern in its frequency through these archaeological periods (Fig. 3). During the La Tène its frequency reaches the highest value with more than 9%, but in the Roman period (15 BC–AD 260) it decreases again noticeably.

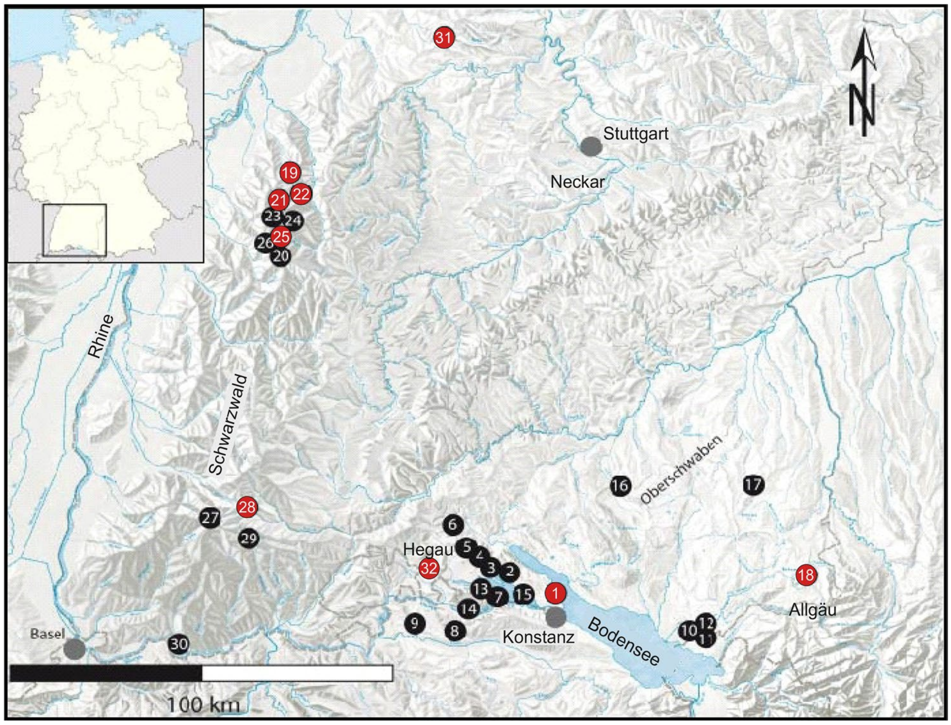


**Fig. 2** Location of study sites considered for off-site evidence in Baden-Württemberg. Sites analysed for this study are marked in red

*Phleum pratense*, another typical member of the Cynosurion communities, has plenty of occurrences in the Early and Middle Bronze Age (EBA, MBA 2200–1700 BC, 1700–1300 BC), but its highest frequency of more than 45% occurs in the samples from the La Tène, then dropping dramatically to less than 5% in the Roman period (Fig. 3). Later, it becomes even less frequent.

*Trifolium pratense* now grows in fertilized grassland, as a character species of the Molinio-Arrhenatheretea class. It appears first in the Late Bronze Age and its frequency reaches the highest value of 14% during the La Tène. In the Roman period it decreases drastically from 14% to less than 1%, then remaining infrequent despite a weak increase during Late Antiquity and the Early Medieval period (AD 750–1000) (Fig. 4).

*Chrysanthemum leucanthemum* occurs today mostly in Mesobromion communities in unfertilized or only slightly fertilized grassland. The frequencies of this species for the various periods show a rather similar pattern to *T. pratense* with the highest frequency in the La Tène and the lowest in the Roman period (Fig. 4).

*Plantago lanceolata* is a character species of the Molinio-Arrhenatheretea class of fertilized grassland. Its archaeobotanical finds increase in frequency from the Late Bronze Age to La Tène and decrease strongly in the Roman period, having the lowest values there (Fig. 4). After an increase during Late Antiquity and the Early Medieval another slight decrease follows. *P. lanceolata* can be also considered as a link between the on-site and off-site evidence.

## Off-site pollen evidence

The pollen records discussed here were selected as representative for the different landscape types such as lowland, upland, woodland and marginal areas (Fig. 2 in red, Table 2). At Mainau (395 m a.s.l.; site 1 in Fig. 2, Table 2), a 45 ha island on the western side of Bodensee (Lake Constance) near the city of Konstanz, for the Neolithic, both Cerealia and *Plantago lanceolata* have quite low pollen percentages, but show a C/PL index value (proportion of Cerealia to *P. lanceolata*) higher than 80% (Fig. 5a). An increase in *P. lanceolata* during the Bronze Age results in an index value of around 20%. For the Late Bronze Age the *Plantago* curve has low values and causes an increase in the C/PL index up to 30%. After a short decline during the La Tène period which is caused mostly by a reduction in the Cerealia curve, the index exceeds 40% for the Roman period caused by quite high Cerealia values. From the Early Medieval period onwards, the index value decreases slightly, caused first by an increase in *Plantago*, then by less Cerealia in the early modern age.

In the following profiles, changes of C/PL index during the Neolithic and after the Medieval period are quite similar to those noted from Mainau and therefore will not be mentioned in detail.

Großer Ursee (695 m; 18) is a lake in a kettlehole, up to 9.8 m deep and covering 19.5 ha, near Isny in the Allgäu region to the west of Bodensee. At this site *P. lanceolata* as well as Cerealia percentages are so low before the La Tène

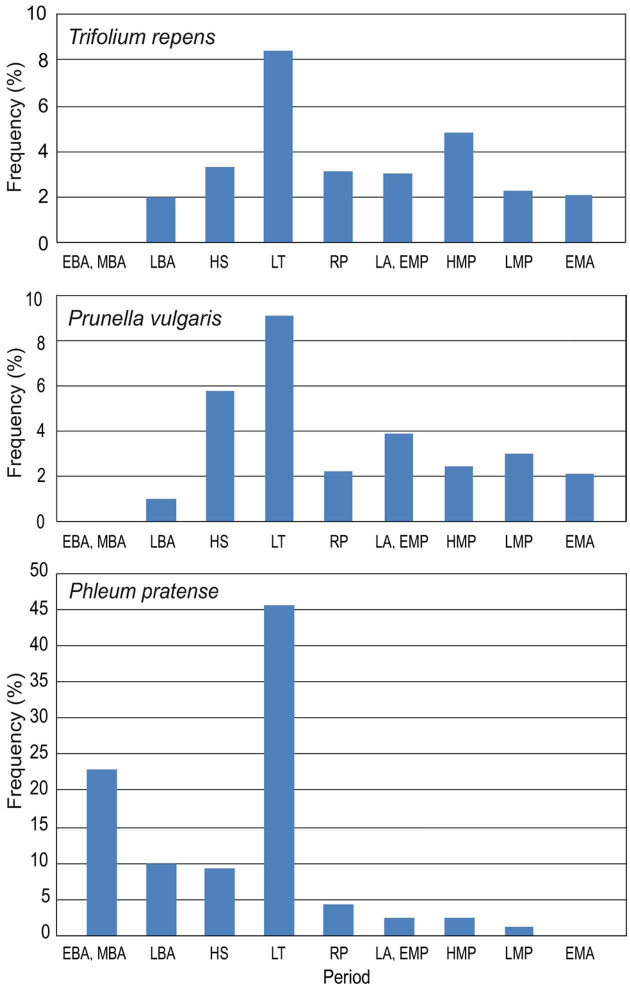


**Fig. 3** Occurrence of *Trifolium repens*, *Prunella vulgaris* and *Phleum pratense* macrofossils in archaeobotanical samples through time, shown by frequency as percent of sites where they occur. *EBA, MBA, LBA* Early, Middle and Late Bronze Age, *HS* Hallstatt period, *LT* La Tène, *RP* Roman period, *LA* Late Antiquity, *EMP, HMP, LMP* Early, High and Late Medieval period, *EMA* Early Modern Age

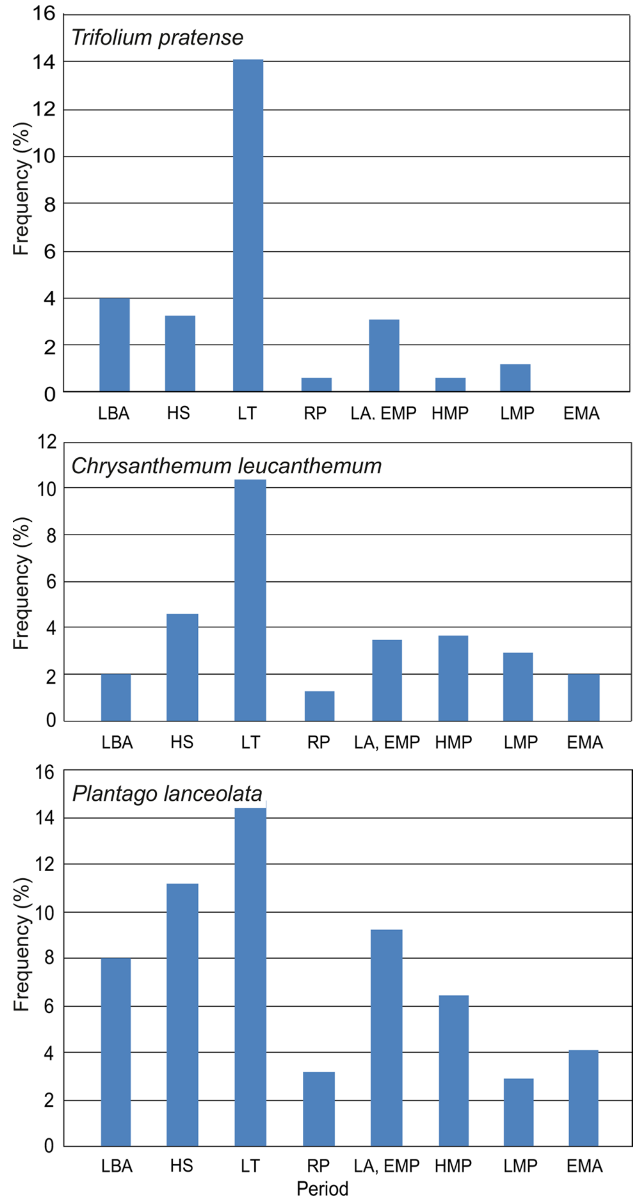


**Fig. 4** Occurrence of *Trifolium pratense*, *Chrysanthemum leucanthemum* and *Plantago lanceolata* macrofossils in archaeobotanical samples through time, shown as percent of sites where they occur; abbreviations as for Fig. 3

period, that there was probably no local land use related to field cultivation then. An increase in *Plantago* for the La Tène shows an index value lower than 15% (Fig. 5b). For the Roman period, as a consequence of the lower *P. lanceolata*, the index climbs up to 20%. After an Early Medieval decline, the index value increases again for the High Medieval period (AD 1000–1300), when values of both *Plantago* and cereals become higher.

Herrenwieser See (830 m; 19), Gemeinde Forbach, northern Schwarzwald (Black Forest) is a proglacial mountain lake formed in a glacial cirque. It is up to 9.5 m deep and covers 1.2 ha and its situation resembles that of Großer Ursee (Fig. 5c). For the Neolithic, the low percentages of *P. lanceolata* and Cerealia cannot be regarded as proof of local human occupation. A slight increase in *Plantago* for the Early and Middle Bronze Age causes a decrease in C/PL index. For the Late Bronze Age, Cerealia pollen becomes more abundant and the index value increases. For the Hallstatt (800–475 BC) and La Tène periods, *P. lanceolata* and cereals increase, showing more or less constant index values. A distinct increase in the C/PL index for the Roman period is mostly caused by a decrease in *Plantago*. Afterwards the index value remains mostly constant, but percentages of *P. lanceolata* and Cerealia are highest for the High Medieval period.

Mummelsee (1,028 m; 21) is up to 17 m deep and 3.7 ha in size, on the western mountainside of the Hornisgrinde,

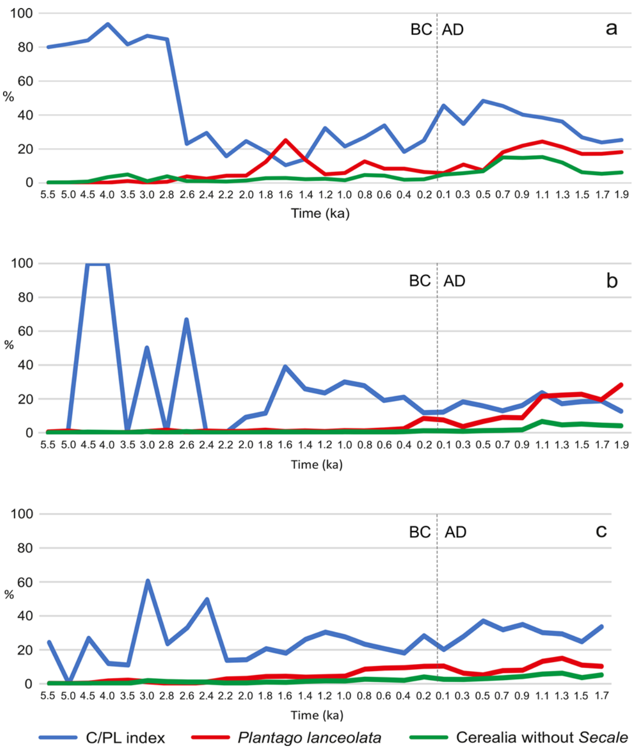


**Fig. 5** Percentages of Cerealia (without *Secale*) to *Plantago lanceolata* (C/PL) index values, through time, based on pollen records. **a** Mainau; **b** Großer Ursee; **c** Herrenwieser See

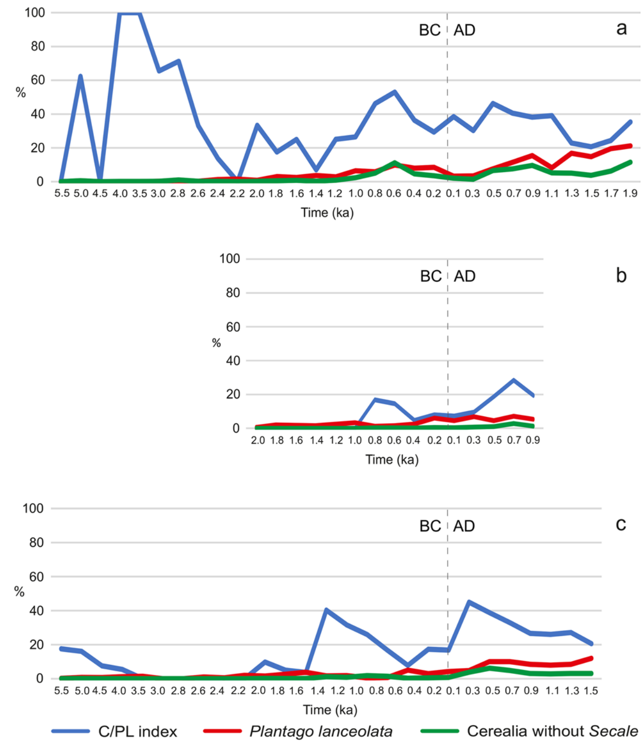


**Fig. 6** Percentages of Cerealia (without *Secale*) to *Plantago lanceolata* (C/PL) index values, through time, based on pollen records **a** Mummelsee; **b** Buhlbachsee; **c** Schurmsee

and is the largest lake in the northern Schwarzwald and the highest site considered in this study. Due to its location and size the lake has an almost regional pollen catchment. For the Late Bronze Age the low cereal pollen values are responsible for the high index value (Fig. 6a). Changes in the ratios of *P. lanceolata* and Cerealia pollen lead to variation of C/PL index value for the La Tène and Roman periods. An increase in *P. lanceolata* for the High Medieval Period causes a decrease in index value.

Buhlbachsee (790 m; 25) is a glacial cirque lake in the northern Schwarzwald, on the western edge of Baiersbronn, up to 4.5 m deep and covering 1.3 ha. At this site the lower *P. lanceolata* in the Middle Bronze Age results in a higher C/PL index (Fig. 6b). For Late Antiquity the index value increases too, but Cerealia and *Plantago* both increase. However the pollen record suggests that the first human land use in the surroundings probably occurred in the Middle Bronze Age. For the Roman period the index value remains low but constant.

At Schurmsee (795 m; 22), another glacial cirque lake in the northern Schwarzwald with surface of 1.5 ha and up to 13 m deep, a quite high C/PL index value can be observed for the beginning of the Late Bronze Age which is caused by a decrease in *P. lanceolata* (Fig. 6c). An increase in *Plantago* and decrease in Cerealia pollen causes the low value of the index for the La Tène period. The highest C/PL index value occurs for the Roman period and decreases thereafter gradually through the medieval up to the early modern period (AD 1500–1850).

At Titisee (846 m; 28), a large lake with an area of ca. 1 km$^2$ and maximum depth of 39 m formed from the Feldberg moraine in the southern Schwarzwald, for the Early Bronze Age the proportions of *P. lanceolata* increase, causing a rise in the C/PL index values (Fig. 7a). This can be considered as an indicator of the first land use activity with fallow phases. For the Hallstatt and La Tène, the *Plantago* pollen increases again, although with a low index value. A decrease in *P. lanceolata* and an increase in Cerealia leads to a rise in the index values for the Roman period, while they decrease for the Early Medieval period and increase again in the High Medieval.

The Hegau is a landscape with fertile soils and a warm climate located to the west of Bodensee, which was settled early on. From there, a profile from Hardtsee (436 m; 32) was studied (Fig. 7b). The C/PL index value decreases for the Late Bronze Age, afterwards for the Hallstatt it increases strongly and for the Roman period its second distinct increase occurs.

Aalkistensee (227 m; 31) is a lake with an area of 12 ha and maximum depth of 1.5 m formed by a sinkhole in the

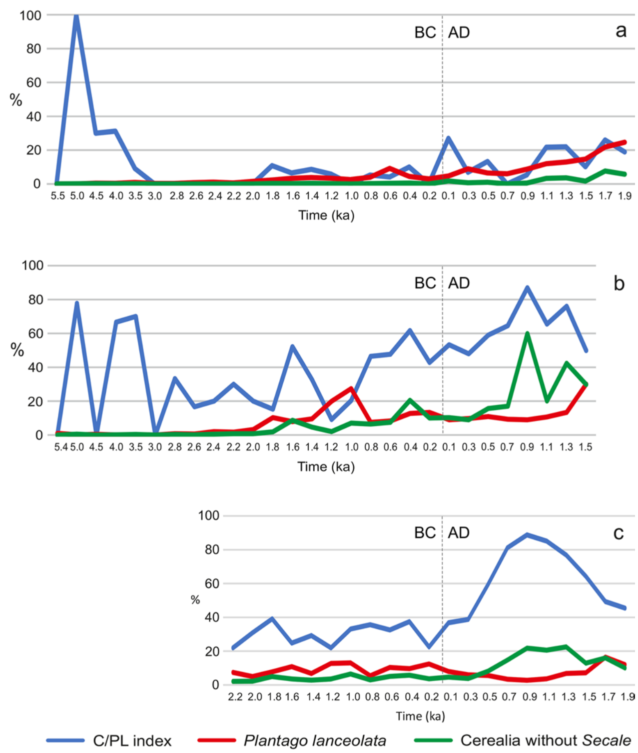


**Fig. 7** Percentages of Cerealia (without *Secale*) to *Plantago lanceolata* C/PL index values through time, based on pollen records. **a** Titisee; **b** Hardtsee; **c** Aalkistensee

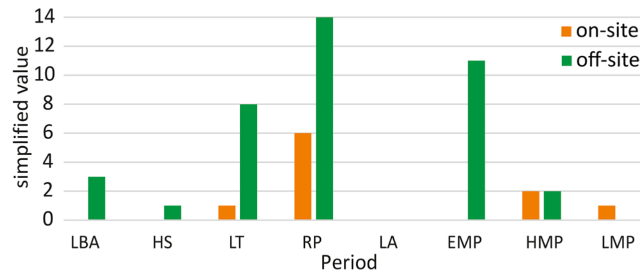


**Fig. 8** Relationship between the on- and off-site datasets through time as comparison of percentages of macrofossil and pollen occurrences shown by summarised values; abbreviations as for Fig. 3

ground. It is the last site considered and situated in the Enzkreis near Kloster Maulbronn, a monastery on the fringes of the early settled loess landscape of Kraichgau. The profile dates back to the end of the Neolithic (Fig. 7c). The C/PL index value is rather high for the Bronze Age, Hallstatt and La Tène periods, increasing distinctly for the Roman period onwards and with its highest value for the end of the Early Medieval period. For the time of the monastery (AD 1147–1504), the index value decreased, caused firstly by an increase in *P. lanceolata* and then by a decrease in Cerealia at the end of the monastic period.

## Discussion

All of the grassland plants from the on-site records of charred macro-remains which are typical for fallow land decrease clearly after the Hallstatt and La Tène periods in the Iron Age. Therefore the on-site evidence points to the Roman period as the main period of agricultural intensification in southwestern Germany as shown by a shortening of fallow phases which would also have involved manuring (Fig. 8). This process had possibly started already in the La Tène period in some parts of the region. The reduction of perennials among the arable weeds could also have been caused by more intense or deeper tillage with better ploughs. In the 1st century the Roman historian and naturalist Pliny the Elder mentioned the mouldboard plough which facilitated a complete turning and mixing of the topsoil (König et al. 1995). Other evidence supporting the hypothesis for agricultural intensification in the Roman period may come from zooarchaeology, with evidence that the cattle in the Roman period were among the tallest in history, much taller than those of the Iron Age and Medieval period (Valenzuela-Lamas and Albarella 2017; Trixl et al. 2017). This may be a result of intentional breeding to increase animal size and power, as this was needed for more intense tillage. Furthermore, the Roman Empire probably influenced the adjacent regions such as Baden-Württemberg, particularly as its level of economic prosperity would have affected the economy and agriculture of neighbouring lands. An example of such economic impacts is given by an archaeobotanical study from the Rome region (Sadori and Susanna 2005). After the economic collapse of Late Antiquity and the Early Medieval period, a secondary but less distinct intensification of agriculture happened during the High and Late Medieval period.

The off-site data from the ratio of Cerealia and *P. lanceolata* pollen indicate the strongest intensification of agriculture during the Roman period, but it is already strong for the La Tène and rather strong for the Early Medieval period. According to historical sources, during the La Tène period the hand ard was replaced by the mouldboard plough which has the advantage of not only loosening, but also turning the soil (Fries 1995; Fries-Knoblach 2005). This technological development enabled more intensive working of the soil and this would also have restrained the growth of perennial weeds. The cultivation systems with more arable land, reduced fallow time and intensive manuring led to the medieval one, two and three field farming (Rösch et al. 2017, 2020a, b, accepted). These activities would have been helped by the favourable climate during the Medieval Climate Optimum, from ca. AD 950 to ca. 1250 (Mann et al. 2009).

At many of the sites the signs of intensification are already visible during the Late Bronze Age and Hallstatt periods. This was already suggested by several pollen studies on early human impact related to ancient agriculture and other land use activities in the foothills north of the Alps, in the Bodensee, northern and southern Schwarzwald and Oberschwaben regions (Müller 1962; Geyh et al. 1971; Merkt and Müller 1978; Rösch 1983, 1990, 1991, 1992, 1993, 1996, 1997, 2002, 2009a, b, 2012, 2013, 2017; Giovanoli 1990; Haas and Hadorn 1998; Lechterbeck 2001; Kerig and Lechterbeck 2004; Rösch and Heumüller 2008; Fischer et al. 2010; Rösch and Tserendorj 2011a, b; Rösch et al. 2014a, b, 2020a; Kleinmann et al. 2015; Knopf et al. 2016; Rösch and Lechterbeck 2016; Rösch and Wick 2019a, b; Lechterbeck and Rösch 2020). These studies confirm the observation that in the early settled lowlands with fertile soils and favourable environmental conditions, earlier and more intensive agricultural activities can be detected from pollen data than in upland areas or those with less favourable environments and/or less fertile soils (for example, Behre 2010). This is also well in accordance with the evidence from the Schwarzwald, which represents an unfavourable or even marginal landscape for farming. An exception is Mummelsee in the northern Schwarzwald, where the strongest intensification of land use is shown in the lake pollen record for the Late Bronze Age. However, considering the site location and size, these pollen spectra most probably do not reflect local human impact, but may be the result of long-distance pollen transport from better farmland in the lowlands near the Rhine valley.

The main intensification of crop growing observed for the Roman period was most probably connected with the need for increasing crop production and to grow surplus food. The arable land area which had presumably already increased in the previous periods could become more productive also thanks to the input of extra organic matter from manure. This is well in accordance with the first written evidence for manuring as well as for alternation between arable and fallow land during the Roman period by the Roman historian Columella (Ash 1941). It is very likely that the Romans practised a well-developed and highly sophisticated system of farming not only in Italy but also introduced it to the northern provinces. Recent bioarchaeological studies from northeastern Gaul (France) confirm this hypothesis (for example, Aguilera et al. 2017). Such stable isotope analyses of archaeobotanical remains consider the $\delta^{15}N$ values in crops as an indication of the intensity of manuring. The $^{15}N$ isotope values can indicate how much plant-available nitrogen was available in the soil during growing, and this depends on the conversion rate from organic fixed nitrogen to water soluble nitrogen by mineralisation (Bogaard 2012; Fiorentino et al. 2015; Styring et al. 2017). This rate is also strongly influenced by the soil quality and is higher in light, rather warm soils (for example with southern slope exposure) than on heavy, wet soils under cooler conditions. A case study on Iron Age cereals from southern Germany pointed out that such types of soils affect the growth of cereals, something which was known to ancient farmers, and also the area of cultivated land was larger compared to earlier periods (Styring et al. 2017).

The on-site macrofossil datasets clearly indicate that the main agricultural intensification occurred in the Roman period, whereas some of the off-site pollen records show distinct hints of earlier intensification before the Romans. This difference is caused by the different nature and informative value of the selected evidence. The on-site data show an average for the sites and their features in a given period across Baden-Württemberg, thus reflecting the general regional tendency. The pollen profiles, however, reflect the local situations and the agricultural activities of their surroundings within the pollen catchment areas. Especially in the early settled lowlands with fertile soils, the intensification phases occur earlier than in the hilly regions and/or those with poorer soils. The intensification phases were related to increases of the available cultivated area by shortening the fallow phase, possibly in response to population growth. These measures were most probably not accompanied by systematic manuring and therefore proved unsustainable. As a consequence, prehistoric populations especially during the Bronze and Iron Age often abandoned their farms and villages, and the woods re-established themselves, at least for a short period, which is indicated by peaks of pioneer trees like *Betula* in many pollen profiles as significant evidence for such events (Rieckhoff and Rösch 2019).

## Conclusions

On-site plant macrofossil data as well as off-site pollen data from Baden-Württemberg, considered as representative of cultivated land use in southwestern Germany, enable us to distinguish the main shifts towards agricultural intensification from the Early Bronze Age onwards or for the last ca. 4,000 years. In the Bronze Age, arable farming developed as a rotation between cultivated land and fallow grassland. There were long fallow periods, lasting for several years, during which the topsoil humus regenerated and could then be cultivated to make the nutrients there available to plants.

The current study suggests that the main intensification of agricultural activities started in the La Tène period and continued during the Roman period. This is indicated by a decrease of perennial arable weeds as observed in the on-site macrobotanical evidence from the region. Pollen datasets can provide Cerealia to *Plantago* index values as a proxy for the changing relationship of cultivated land to fallow land through time and these also show evidence of the strongest agricultural intensification in the Roman period, but there were also some intense activities in the earlier periods such as the Late Bronze Age and La Tène period. During Late Antiquity, agricultural intensification was slowed, but then in the Early Medieval period it accelerated again, also involving intensive manuring. This intensification of cropping implies a shorter duration fallow, longer cultivation phase, manuring and better ploughing. Such medieval cultivation systems are called one, two or three field agriculture. The transition to these systems from the simple prehistoric rotation between cultivation and grassland was an important step towards the intensification of agriculture. It enabled higher crop production which allowed the population to increase.

The studied sites situated in various parts of the landscape also show differences in their agricultural histories of intensification. At the early settled lowland sites with fertile soils and favourable conditions, as in the Hegau, agricultural activity can be recognized earlier in the off-site archaeobotanical record and more intensely than in the uplands such as the Allgäu.

Our study also has implications for archaeobotanical research on prehistoric agriculture in central Europe by raising the significance of the relationship between the on-site and off-site data and applying the C/PL index value as a land use proxy for archaeobotanical research work.

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