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► To cite this version:

Sébastien Lepetz, Véronique Zech-Matterne. Agro-pastoral systems during the late Iron Age and roman period in Northern Gaul. Les campagnes du nord-est de la Gaule, de la fin de l'âge du Fer à l'Antiquité tardive, 2018, pp.327-400. hal-02489525

HAL Id: hal-02489525

<https://hal.science/hal-02489525>

Submitted on 24 Feb 2020

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Investigations were carried out within the ERC advanced grants RurLand programme (Grant Agreement n° 338680)
directed by M. Reddé, EPHE, France



École Pratique
des Hautes Études

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This article was translated from a book chapter produced by the authors :

Lepetz S. and Zech-Matterne: 2018 – Systèmes agro-pastoraux à l'âge du Fer et à la période romaine (chapitre 6) in : Michel Reddé (éd.), *Gallia Rustica 2. Les campagnes du nord-est de la Gaule, de la fin de l'âge du Fer à l'Antiquité tardive*, Ausonius, Collection Mémoires (50), Bordeaux, p. 327-400.

To quote:

Lepetz S. and Zech-Matterne: 2018 – Agro-pastoral systems during the Late Iron Age and Roman period in northern Gaul (English version) - Systèmes agro-pastoraux à l'âge du Fer et à la période romaine (chapitre 6) in : Michel Reddé (éd.), *Gallia Rustica 2. Les campagnes du nord-est de la Gaule, de la fin de l'âge du Fer à l'Antiquité tardive*, Ausonius, Collection Mémoires (50), Bordeaux, p. 327-400.

Translation: Elisa Colas. Copy-editing: Jill Cucchi

This paper discusses land use, crop husbandry practices and breeding during the Late Iron Age and Roman period, based on the animal and vegetal remains recovered from archaeological sites. Investigations were carried out within the ERC advanced grants RurLand programme – covering the rural lands of north-eastern Gaul, from the Late La Tène period to Late Antiquity¹. Although the RurLand project integrated the adjacent parts of Belgium, Luxemburg, the Netherlands, Germany and Switzerland that were included in ancient Gaul, we focussed purely on north-eastern France; the other regions having already been the subject of recent overviews (Lepetz & Zech-Matterne 2017). Moreover, for France, the enquiry could be based on an extensive, updated state of documentation. Archaeobotanists and zooarchaeologists, working within the framework of preventive archaeology, added information to the elaborated databases, and exhaustiveness was aimed for. All the sites that had undergone archaeobotanical and archaeozoological studies were compiled: 655 settlements for archaeobotany and 908 for archaeozoology.

Due to a variety of publications, numerous zooarchaeological and carpological overviews for northern France² have brought to light elements that are vital to the understanding of rural production and the consumption of foodstuffs: however, none have sufficiently compared and reconciled the data and considerations about two fields of study: animals and plants³. It therefore seems possible to go further by endeavouring to determine the best way to holistically approach bones and seeds; the issue is both epistemological and practical: we will focus on the second aspect here.

The studies mentioned above, and many others, have extensively described the species involved in rural activities: domestic mammals and birds, cereals, pulses and fruit, but there is no need to revisit these taxa in detail here. Aside from the new plants and animals that appeared in the north of France at the end of the Iron Age and during the Roman period, such as several fruit trees (e.g. pomegranate, almond, medlar, olive, umbrella pine), aromatic herbs and spices (e.g. coriander, pepper, cumin), vegetables and pulses (calabash, white lupin, chickpeas) and animals (e.g. deer, peacock, etc), that are indeed

1. (Grant Agreement n° 338680; dir. M. Reddé, EPHE, France (Reddé dir. 2018)

2. See e.g. Méniel 1984; Méniel *et al.* 2009; Lepetz 1996b; Groot 2008; Pigière 2009; Matterne 2001; Derreumaux 2012, Lepetz & Zech-Matterne 2017.

3. For Iron Age see Malrain *et al.* 2002 and for the Roman and Medieval periods Lepetz *et al.* 2002; Lepetz & Matterne 2003; Ferdière *et al.* 2006, together with the recent book related to rural economy in Roman Britain (Allen *et al.* 2017) with specific chapters by M. Allen and L. Lodwik.

important to the history of these regions, the specific basis on which rural production sites were organized had been the same for hundreds and perhaps thousands of years: cattle, pigs, sheep and goats, equids, chickens, barley, emmer, einkorn, spelt, free-threshing wheats, millets, Celtic bean, bitter vetch, peas, common vetch, lentils, common flax, opium poppy, gold-of-pleasure, etc., and later on rye, oats, chickling vetch/pea and hemp (Fig. 1 and 2)⁴. However, the relative importance of these species has varied over time and space, with new balances being reinvented at every shift, feeding on the indigenous substrate and the development of new uses – be they created, elaborated, borrowed or adopted.



Fig. 1: Diversity of the plant species mentioned in this article: wheats.
Credits V. Zech-Matterne, Ch. Bouchaud, F. Toulemonde.

These shifts were subject to the cross-influences of economic, demographic, technical, cultural and political transformations. Nonetheless, an important issue must be raised in terms of method. Carpology, one observation tool at our disposal, is dependent on how the vegetal remains were preserved. In comparison with vegetables, root crops or forage plants, cereals are better preserved as charred remains; thus, crop analysis is mainly based on them. We are fully aware that near the cereal and pulse fields there may have been hay meadows or improved leys. These areas required just as much work as those dedicated to cereals, and they too promised to turn a profit; however, small-seeded legumes, hay or fodder last unpredictably and this remains are difficult to interpret.

Many questions came up during the reconstruction trial of an ancient agrarian system (Fig. 3) and we followed two leads for analysis: the first was to determine if changes in production scales were perceptible through our disciplines, and then to determine which crucial factors could limit or favour their potential growth.

The first stage of the undertaking consisted in obtaining a comprehensive view of the main animal and plant species grown in the study zone. We broached the issue in two ways: first through multivariate statistical analysis, and secondly by mapping the relative frequency of the main species involved according to their respective contribution to statistical projections. This work highlighted the existence of barriers associated with natural constraints and the limits of territories specifically oriented towards a particular type of production, without going so far as monocropping. The following issues concern the evolution of domestic animal heights and their potential link with animal diet. Studying animal and human food means that the role and benefits of soil-enrichment on production capacity must also be studied.

4. All figures by S. Lepetz and V. Zech, if not specified otherwise.



Fig. 2: Diversity of plant species mentioned in this article: cereals other than wheat, oleaginous. Credits V. Zech-Matterne, F. Toulemonde.

1. Is there complementarity between livestock and crop choices?

The first objective was to determine if there were any preferred livestock-crop combinations. Therefore, Correspondence Analysis (CA) was undertaken (Fig. 4) to ensure greater objectivity in identifying the animal or plant species that constituted the agricultural basis for the different periods in question. It also enabled us to better evaluate the relative importance and distribution of secondary species. Subdivision into three phases was established right from the start, so that time was not a parameter of the analysis. We specifically sought to highlight the regional partition of species and the possibility of similarities in animal and plant distribution, which could indicate complementarity between livestock and crop choices.

For the zooarchaeological assemblages, data was established from the number of remains of the four main taxa⁵. For the carpological assemblages, base data corresponds to the minimum number of individuals (MNI) per taxon for sites where the number of domestic species reached at least 100 remains, excluding the indeterminate *Cerealia* and *Fabaceae sativae* taxa (Fig. 5). Because sites that have undergone both zooarchaeological and archaeobotanical analyses are quite rare (15 % of the corpus), it was not possible to compare the information on a production unit scale; thus, the assemblages were grouped on a wider scale. Ten case study areas grouping the territories with coherent geological, pedological and geographical characteristics were defined. They are the same ones used in Lepetz & Morand, 2017 (Fig. 6). A total of 1100 assemblages (representing over 810,000 faunal remains⁶ and almost 560,000 carporemaines) were taken into account. Analyses were broken down into three periods: the first globally encompasses the end of the second Iron Age up to the transition between the La Tène D2b and the Augustan Age (200–30 BC); the second phase corresponds to the High Empire period (30 BC–AD 275) and the third corresponds to Late Antiquity (AD 275–500).

For the zooarchaeological analyses, urban sites were not used because they presented too great a variety of features (slaughter waste, craft waste, and very varied socio-cultural contexts), which made the batches of bones overly dissimilar and not directly comparable. There was no carpological data for zone I, which reduced the areas for which data comparison was

5. "Myos" database, set up for the RurLand programme.

6. The MNI (Minimum Number of Individuals) is calculated in different ways. Here, the number of complete seeds was added to the number of fragments divided by two.



Fig. 3: Evocation of the questions raised when attempting to reconstitute an ancient agrarian system.

possible to just nine. For the three phases, the dataset available for carpological study were 60, 100 and 34 settlements, respectively. To the degree that the CA tends to reinforce the role of rare species in the structuring of data, certain plant taxa were eliminated because there were too few. Species with a total number of remains of less than 10 for each of those periods were ignored, as were those whose total numbers were between 10 and 30 remains, in relation to a single or pair of contexts (this frequency is considered to be too low). Data analysis highlighted strong and enduring livestock-crop associations, and species whose importance changed from one zone to another during the chronological sequence.

Zone	Régions	The cités (essentially)	Number of archaeozoological assemblages	Number of archaeozoological remains	Number of carpological assemblages	MNI of botanical remains
A	Artois	Atrebates, Nervii	88	90159	15	9123
B	Channel coast	Morii	14	8586	6	3713
C	Somme Valley	Ambiani	110	58459	31	53391
E	Centre of the Paris Basin: the Marne Valley, Oise Valley, Plaine de France, middle Valley of the Seine, Seine-Yonne confluence	Parisii, Bellouaci Meldi, Suessions, Senones	391	347998	65	306825
F	Lower valley of the Seine	Veliocasses, Caletes	49	42842	4	55657
G	Alsace plain	Triboques, Rauriques	28	28773	25	40855
H	Moselle Valley	Mediomatrique, Leudes	35	44997	17	28858
I	Saône and Doubs Valley, Dijon region	Lingones, Eduens, Sequani	33	65169		
J	Upper Seine Valley, Yonne Valley	Senons, Tricasses	44	39716	5	1451
K	Champagne, Perthois	Remi, Tricasses	116	83971	24	59683

Fig. 4: Number of sites and remains taken into account in each of the workshop areas, as defined in the analysis.

<i>Triticum aestivum/turgidum</i>	free-threshing wheats
<i>Triticum aestivum</i> s.s.	bread wheat
<i>Triticum spelta</i>	spelt
<i>Triticum dicoccum</i>	emmer
<i>Triticum monococcum</i>	einkorn
<i>Triticum dicoccum/spelta</i>	hulled wheats
<i>Triticum</i> sp.	wheats
<i>Hordeum vulgare</i>	barleys
<i>Avena sativa</i>	common oat
<i>Avena</i> sp.	oats
<i>Secale cereale</i>	rye
<i>Panicum miliaceum</i>	broomcorn millet
<i>Setaria italica</i>	foxtail millet
<i>Lens culinaris</i>	lentil
<i>Pisum sativum</i>	pea
<i>Vicia faba</i> var. <i>minor</i>	Celtic bean
<i>Vicia ervilia</i>	bitter vetch
<i>Vicia sativa</i>	common vetch
<i>Lathyrus cicera/sativus</i>	chickling vetch/pea
<i>Lupinus albus</i>	white lupin
<i>Linum usitatissimum</i>	flax
<i>Papaver somniferum</i>	opium poppy
<i>Camelina sativa</i>	gold-of-pleasure
<i>Cannabis sativa</i>	hemp

Fig. 5: Correspondence between Latin and English names of plants in the CAs.

einkorn wheat (a secondary wheat in terms of MNI) on the other. Another characteristic feature is the repeated occurrence of millets and bitter vetch; peas and common vetch are included in this group. The north zone is strongly marked by oats and emmer, as well as lentils and flax.

1.1. From the end of the second Iron Age to the Augustan Age (Period 1)

As regards animals, no data was available for zone G (Alsatian plain), and in zone B (English Channel coast) the frequencies were too low (see Appendix 1-3) to reveal any pattern. Together, the first two axes explain 94 % of the total variation. The main contributions were obtained for pigs and cattle (at the same level), followed by caprines (Fig. 7). The southern edge of the zone (Seine River valley) and the Artois region (around Arras) are characterized by a very high proportion of cattle, in contrast to zone K (Champagne-Perthois region), which is rich in pigs, and zones H (Moselle River valley) and C (Somme River valley), which shows the highest caprine rates.

There was no data for carporemaines in zones F, I and J. Axes 1 and 2 explain 77.71 % of the inertia. The highest contributions were related to free-threshing wheats, barley and emmer wheat. Mapping reveals a partition in three groups (Fig. 8): zone E (centre of the Paris Basin) is plotted in the negative values of axis 1, and zones K, H and G (Champagne, Lorraine, Alsace) in the positive values. Axis 2 opposes the east zone (K, H, G), in positive values, and the north zones (A, B, C), in negative. The species relating to the centre of the Paris Basin are free-threshing wheats and Celtic bean. The east zone is characterized by barley on one side and spelt wheat and

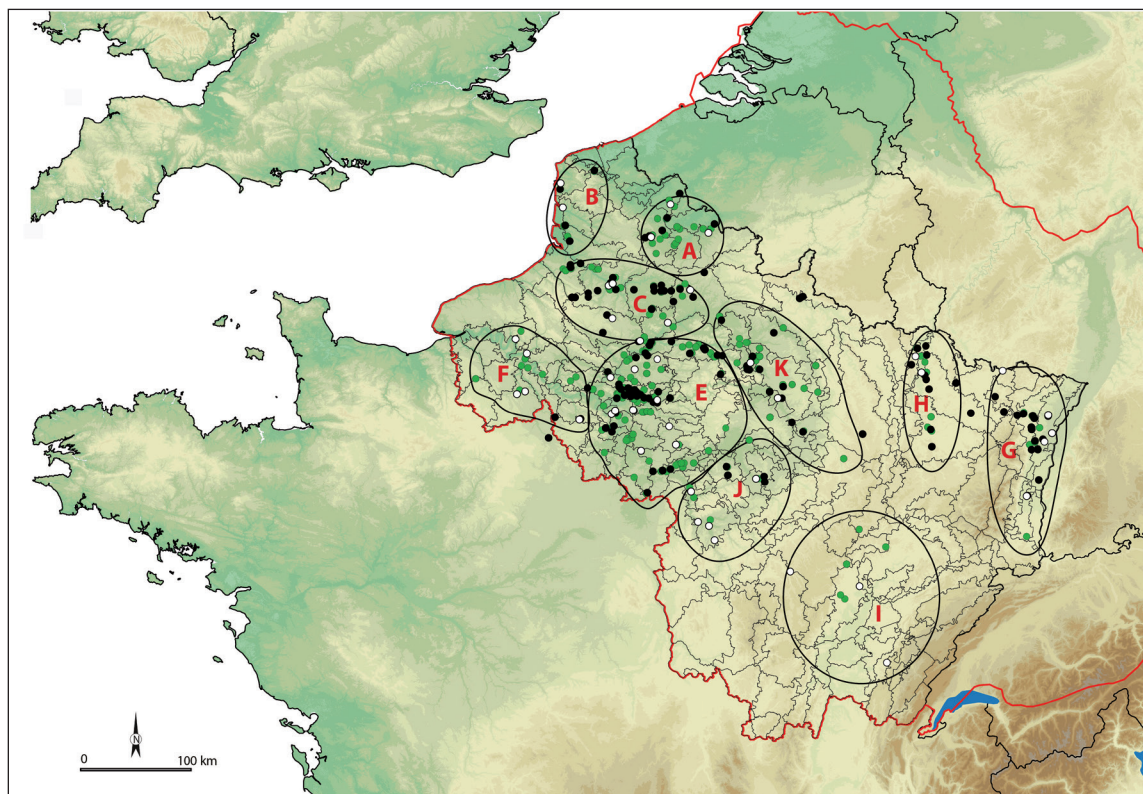


Fig. 6: Workshops defined as part of the analysis and position of the sites. In black, the carpological assemblages; in green, the archaeozoological rural assemblages; in white, the archaeozoological assemblages from an urban context. It should be noted that several sites overlap.

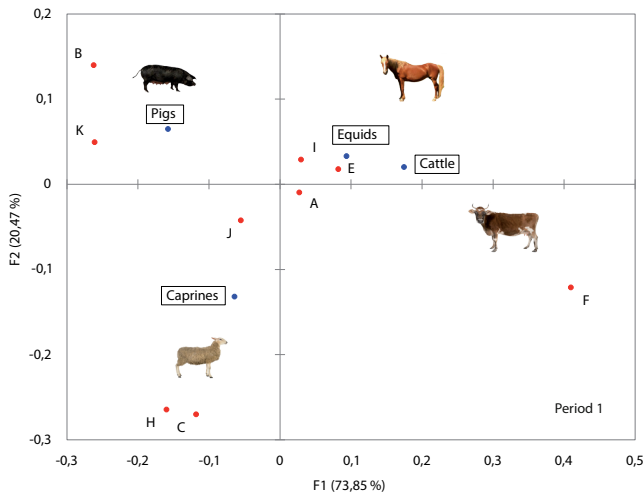


Fig. 7: Correspondence analysis (CA) of archaeozoological data for period 1 (late second Iron Age at the transition LT D2b–Augustan period / early 2nd century BC – 30 BC).

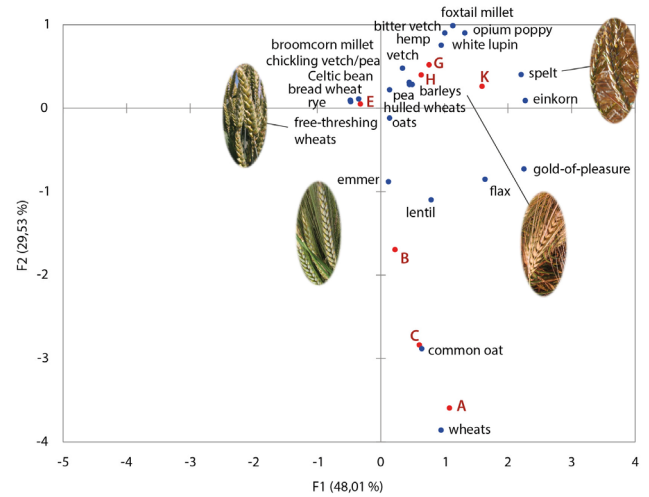


Fig. 8: Correspondence analysis (CA) of carpological data (18 taxa variables) for period 1 (late second Iron Age at the transition LT D2b–Augustan period / early 2nd century BC – 30 BC)

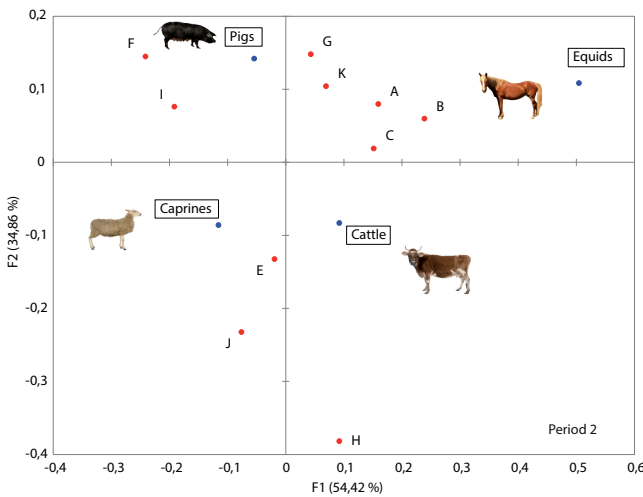


Fig. 9: Correspondence analysis (CA) of archaeozoological data for period 2 (High Empire 30 BC – 275 AD).

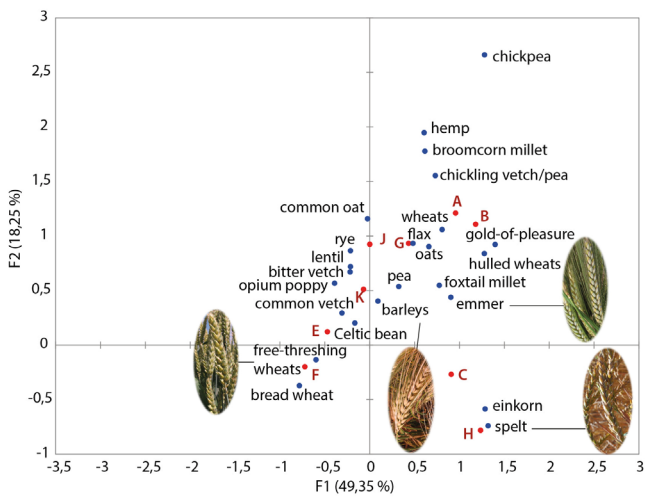


Fig. 10: Correspondence analysis (CA) of carpological data (19 taxa variables) for period 2 (High Empire 30 BC – 275 AD).

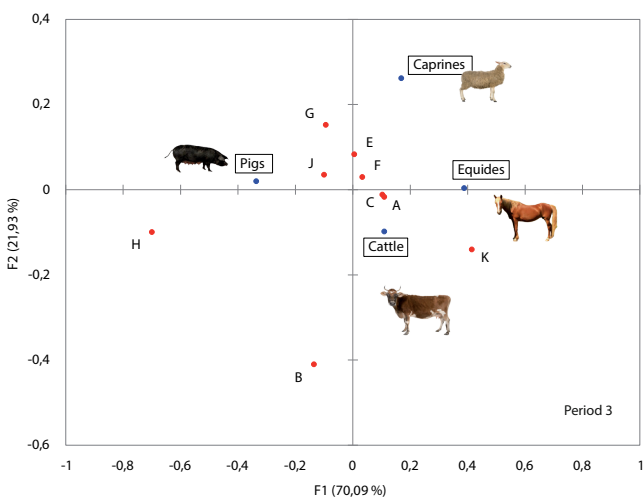


Fig. 11: Correspondence analysis (CA) of archaeozoological data for period 3 (Late Antiquity / last quarter of the 3rd century – 5th century AD).

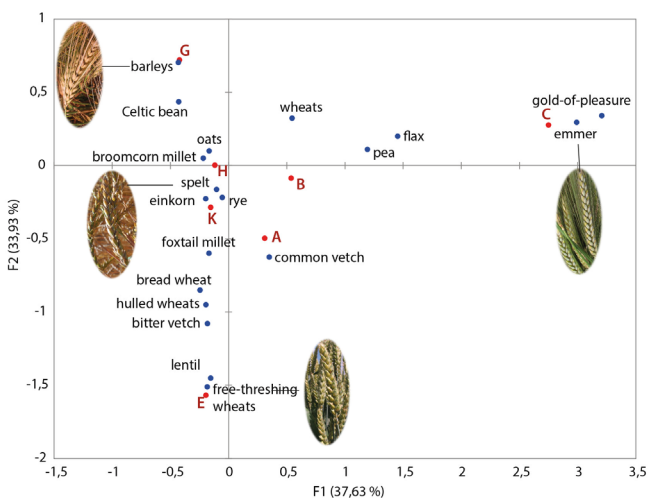


Fig. 12: Correspondence analysis (CA) of carpological data (15 taxa variables) for period 3 (Late Antiquity / last quarter of the 3rd century – 5th century AD).

1.2. High Empire period (Period 2)

For the High Empire period, zooarchaeological analysis enabled reliable distribution across all the zones to be obtained, with the exception of the Moselle River valley (H) which was poorly represented with only 3 sites. Axes 1 and 2 explain 90 % of the inertia. (Fig. 9). The strongest contributions were, in practically equal amounts, those of pigs, cattle and caprines, followed by a much lower value of equids.

The entire north and north-eastern edge, made up of the Artois region, the English Channel coast, the Somme River valley, the Champagne and Perthois regions, and the Alsatian plain (A, B, C, K, G) are clearly characterized by high cattle rates, whereas the southern edge, the Seine River valley and its tributaries, the Saone River valley, the Doubs region and the Dijon region show much smaller numbers. In the middle of this southern band, zones E and J have high numbers of sheep while the two extremities (F and I) are rich in pigs. Analysis also revealed the strong presence of equids in the Flanders region, the Artois region and along the English Channel coast.

For plant remains, only zone I did not produce any data. Axes 1 and 2 explain 67.81 % of the inertia. (Fig. 10). The weight of free-threshing wheats remains a strong explanatory factor in the distribution of variables, followed by barley. However, the third variable that highly contributed to the projection is no longer emmer but spelt. Chronological distribution maps for the latter species clearly show the rise of this glume wheat, which overtook emmer. The two main protohistoric species thus underwent a distinct change of direction: barley maintained its frequencies, but emmer was partially replaced by spelt, a hulled bread wheat, in climates or soils where free-threshing wheats were harder to cultivate. The High Empire period sees a strong opposition persist between the centre of the Paris Basin (zones F, E) as well as the Champagne region (zones K, J), plotted on axis 1 in the negative values, and the other zones in positive values. The first zone is still characterized by free-threshing wheats, combined with a greater variety of pulses: Celtic bean, lentils, bitter vetch, common vetch, and rye, the latter being negligible in terms of remains. Barley positions itself as intermediate between the negative and positive values on axis 1. Although present in every context, and even if its abundance remains the same, barley has been classed among the secondary varieties in Fig. 13, to signify that it does not represent a regional specificity.

On axis 2, the structuration of the zones results from the opposition of spelt and emmer: einkorn wheat linked with spelt as before, and zones H and C differing from G, A and B. Emmer, glume wheats and oats were more numerous in the north zone, following the pattern of the previous period. In the east zone the contributions of barley and spelt remained determinant, while the role of millets was less noticeable hereinafter.

1.3. Late Antiquity (Period 3)

For Late Antiquity, zooarchaeological analysis revealed a reliable distribution across all zones except zone I (Saône River valley, Doubs and the Dijon regions) for which there is no data. Axes 1 and 2 explain 92 % of the total variation. (Fig. 11). The cattle score alone is almost 50 % of the relative weights, but without distinguishing one specific territory in particular. This species dominated all the assemblages of that era (see under 2.2), with pigs and caprines following and then finally equids, though the latter is represented in smaller numbers. Patterns were noted in zone B, rich in bovine animals, and zone H (Moselle River valley), rich in pigs. However, detailed analysis done in the Metz region (Daoulas *et al.* 2017) shows that this phase is dominated by the observed anomaly of the Mondelange site's assemblage. Conversely, the Seine River valley is rich in sheep, and the Champagne region presents higher equid proportions than elsewhere.

As regards vegetal remains, there is no data for zones F, J and I. Axes 1 and 2 explain 71.57 % of the inertia (Fig. 12). The relative abundance of free-threshing wheats diminished as their distribution over the zone reduced. Barley takes the lead in explanatory variables, followed by spelt and free-threshing wheats. Grouping the zones enables a more clearly defined geographic coherence. It is possible that the absence of certain zones in mapping reinforces the partition in distinct entities, as in period 1. In axis 1, zones A-B-C are plotted opposite the others in the positive values, whereas in axis 2 the east entity (zones G and H), in positive, is separated from the centre of the Paris Basin (zone E) in negative. The Champagne region (zone K) is in an intermediate position between these last two groups. The centre of the Paris Basin remains the favoured zone for farming free-threshing wheats and pulses such as bitter vetch and lentils. The east shows a high proportion of barley and spelt, associated with einkorn, and the recurrence of broomcorn millet.

The following table (Fig. 13) sums up the evolutionary trends that appeared from mapping.

	Phase 1								Phase 2								Phase 3													
Zones	B	A	C	E	K	H	G	F	I	J	A	B	G	F	E	K	J	H	C	I	A	B	C	E	K	H	G	D	F	J
Taxa																														
cattle																														
caprines																														
pigs																														
equids																														
free-threshing wheats																														
spelt																														
emmer																														
einkorn																														
hulled wheats																														
wheats																														
barleys																														
common oat																														
oats																														
rye																														
broomcorn millet																														
foxtail millet																														
lentil																														
pea																														
Celtic bean																														
bitter vetch																														
common vetch																														
chickling vetch/pea																														
pulses																														
flax																														

Fig. 13: Entities highlighted by the grouping of zones and synthesis of the principal and secondary species characteristic to each one. Main species in black; secondary species in grey.

The CA integrating both plants and animals corroborated the separate approaches, without providing pertinent additional information. For the three periods, the scores of different zooarchaeological variables revealed that their relative contribution did not have much bearing compared to vegetal species. For the latter, strong crop combinations were perceptible for the main and secondary species. In the centre of the Paris Basin, free-threshing wheats and pulses were a constant pair, even if the species involved may have varied over time or from one site to another. In the east, the link between einkorn and spelt seems constant, to the point where the two species may have been purposefully cultivated in the same field (maslin) or that one was subordinate to the other (the hypothesis that einkorn became a weed may be put forward). Together with barley and spelt, broomcorn millet seems to have been well established. The particularities of the north zone lie in the persistent presence of emmer, and the regular occurrence of oats and flax. The frequencies of other species fluctuate more.

The variables attributed to the major axes also change significantly: spelt replaces emmer between the Iron Age and the Roman period, and free-threshing wheats are relegated behind barley between the High and the Late Antiquity periods.

Comparative analysis revealed plant-animal associations. These are rather diverse during the Iron Age with the centre of the Paris Basin evidencing cattle, free-threshing wheats and pulses. In the east, einkorn and spelt occur with sheep; in the north, emmer is linked with sheep or pigs, or both. A much clearer structuration takes place during the Roman period, when the cultivation of free-threshing wheats spreads out considerably throughout the centre of the Paris Basin. Caprines are clearly associated with zone E. Equids and cattle are found in the north zone, but clearly move towards the Champagne region in Late Antiquity.

We also wondered if more detailed analyses would confirm whether caprines appeared at the same time as the expansion of free-threshing wheats or during the reappearance of pulses (which was at least two centuries after the rise in free-threshing wheats) but, unfortunately, the data did not enable confirmation.

2. Production maps

2.1. Plant production

The second stage of our undertaking consisted in mapping the compared frequencies of hulled barley and glume wheats, free-threshing wheats and pulses. As charred emmer and spelt caryopses may be difficult to differentiate when degraded they were not taken into account if the distinction could not be established on spikelet bases preserved by the grains.

The maps presented in Fig. 14-18 are based solely on plant assemblages that include more than 100 charred remains (MNI) of precisely identified domestic species. Each sectorial graph corresponds to one settlement, whatever the number of contexts sampled (from 1 to more than 50). For each site, the relative percentages of the taxa were based on the average MNI calculated from all the assemblages.

The first findings concern the evolution of hulled barley and emmer, cereals considered as the common basis of La Tène agriculture in northern France (Fig. 14). The relative importance of hulled barley does not seem to decline in notable proportions in the early days of the Roman Empire. On the contrary, its distribution widens to include the territories of the Ambiani, Atrebatres and Nervii people. It is only during the Late Empire period that barley appears to decline in the northern territories. In contrast, emmer becomes less important in the Seine River valley; its highest proportions are recorded in the Somme River valley, especially in plateau contexts (Zech-Matterne 2014, Fig. 4). However, it still remained locally cultivated in the east, although as a secondary species. Emmer cropping seems to collapse during the Roman period, and even becomes marginal during the Late Empire period.

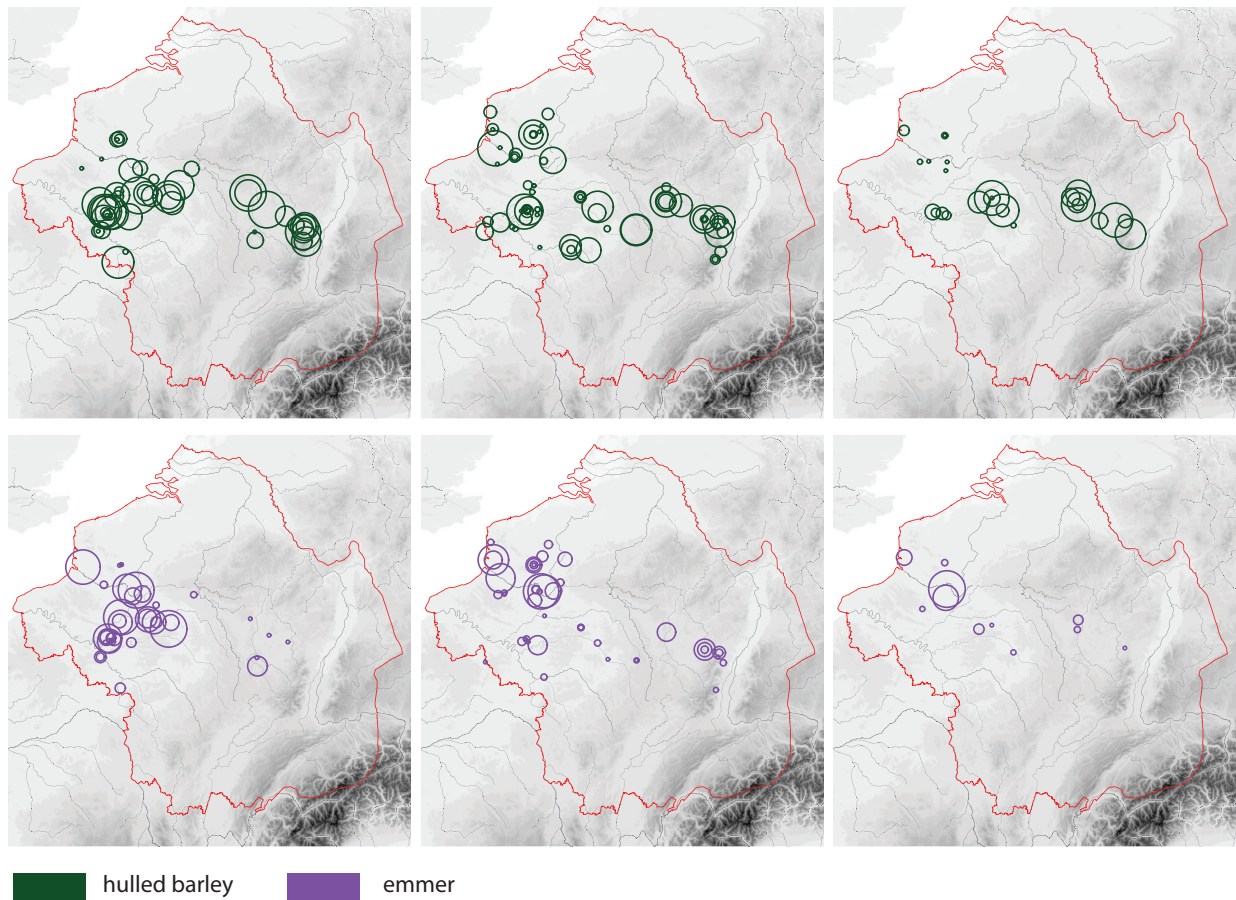


Fig. 14: Evolution of relative proportions of hulled barley (top) and emmer wheat (bottom). MNI averages calculated at the scale of each of the sites for all the structures that delivered carpological remains. Sites with more than 100 domestic species remains, with the exception of indeterminate cereals and pulses. Phase 1: early 2nd century BC – 30 BC; Phase 2: 30 BC – 275 AD; Phase 3: last quarter 3rd century – 5th century AD.

During the Roman period we note increasingly greater proportions of free-threshing wheat and spelt cultivation, which spread out geographically on luvisols (brown washed soils) (Fig. 15). But whilst the free-threshing wheat zone spreads out coherently and then breaks up, the distribution of spelt lacks continuity. The importance of the latter is clearly visible in the north of the study zone, where it accompanies emmer cultivation during phase 2; just like emmer, spelt requires substantial post-harvest processing (Fig. 16). During the Late Antiquity period spelt distribution changed. Evidence for mass storage of spelt is linked to the later phases of vast *villae* (Wiethold & Zech-Matterne 2016).

Spelt certainly represents some of the grains associated with milling and bread making, but it is difficult to evaluate the exact place of bread wheat among the free-threshing wheats, as it is a term which encompasses several species (Toulemonde, in Bernigaud *et al.* 2017). Two types of free-threshing wheats were identified among the rachis internodes and culms: tetraploid species like rivet wheat and/or durum wheat, and hexaploid species like bread wheat, best suited to making leavened bread. The fact that the rachises can be easily separated from the caryopses and other parts during threshing does not favour optimal evidence in living areas. These were probably eliminated at source and were found only in storage areas when the harvest was stored as spikes or sheaves, or alternatively in fuel residue.

The rise in free-threshing wheats in the centre of the Paris Basin began at the end of the Iron Age, probably in correlation with urbanization, and accelerated after the Roman Conquest. The importance of these specialized crops during the Empire period was strongly marked in these regions and can be regarded as an important shift in crop choices. Naked wheats had been cultivated in northern France since the Neolithic period but never reached this importance and extent. In contrast, the marked importance of hulled barley in the east was not new because the species was already largely cultivated during the Iron Age, and even the Bronze Age (De Hingh 2000; De Hingh *et al.* 2016). In some ways, barley asserted its predominance by default, due to the smaller number of free-threshing wheats to the east of the Marne.

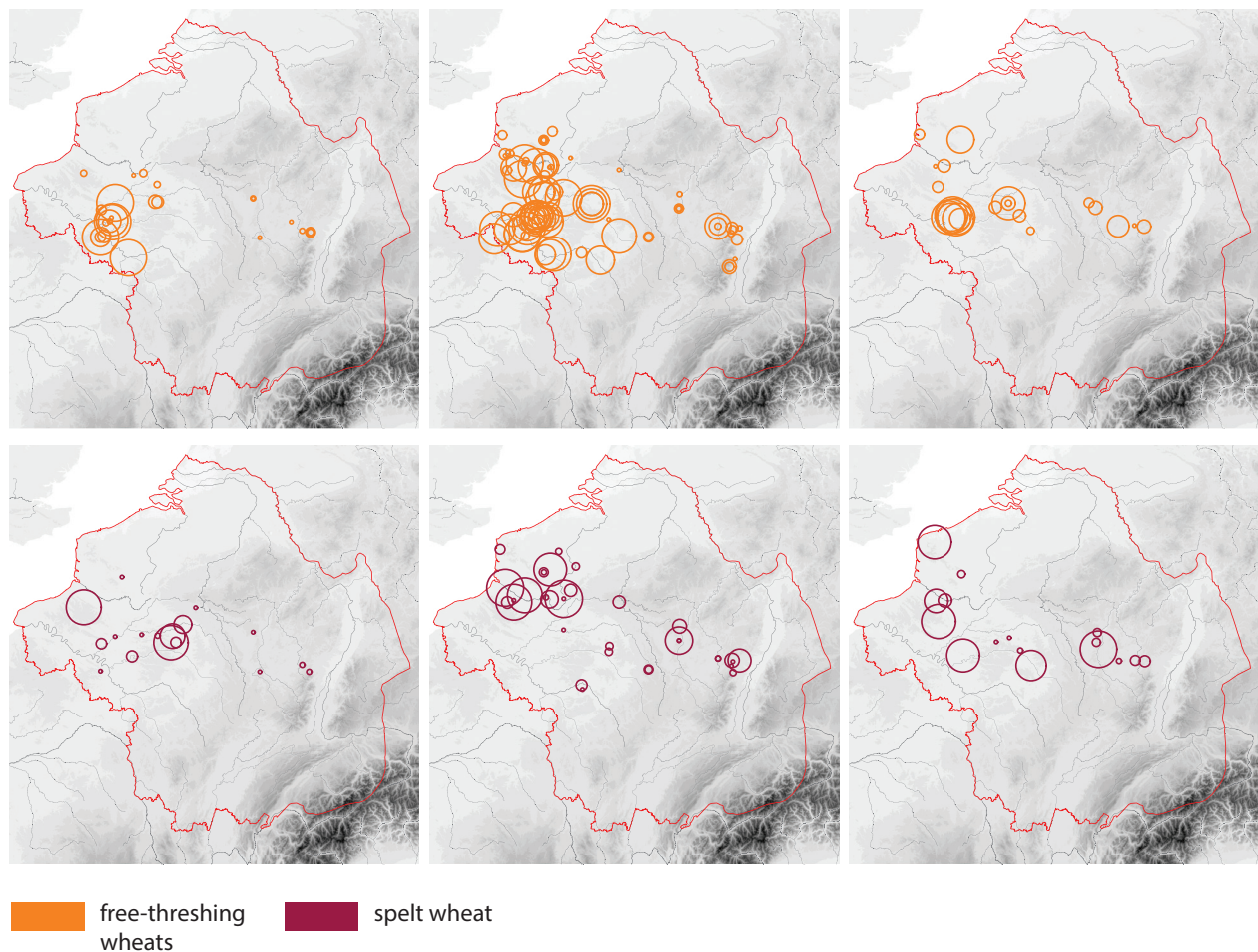


Fig. 15: Evolution of relative proportions of free-threshing wheats (top) and spelt wheat (bottom). MNI averages calculated at the scale of each of the sites for all the structures that delivered carpological remains. Sites with more than 100 domestic species remains, with the exception of indeterminate cereals and pulses. Phase 1: early 2nd century BC – 30 BC; Phase 2: 30 BC – 275 AD; Phase 3: last quarter 3rd century – 5th century AD.

More subtle changes were seen in the northern zones where, in line with the La Tène crop choices, hulled cereals persisted. Although glume wheats kept their ground, spelt tended to strongly counterbalance emmer quantities (Fig. 17). These two species present similar dehusking constraints, but spelt flour is considered more suitable for bread making than emmer. To roughly summarize these two evolution patterns, in the centre of the Paris Basin we see specialized farming appear with the production of free-threshing wheats, to which pulse farming was added from the 2nd century AD, probably to sustain the system already in place (discussed later in the paper) (Fig. 18).

Hulled barley maintained its place in the east and over the whole study zone, along with species of secondary importance, which enabled it to adapt to and exploit a large diversity of soils; these systems were safer bets. Whatever the local edaphic conditions were, the use of barley made the cultivating of lower quality or shallower soils possible. Indeed, the role of species requiring less manure such as oats, rye and einkorn wheat remains faint throughout the Roman period (Zech-Matterne *et al.* 2017a).

In terms of evolution, the dynamics of change began at the end of the La Tène period. It is therefore clear that it was not the Roman Conquest or the stationing of troops at its frontiers that sparked the cultivation of free-threshing wheats in the centre of the Paris Basin (Zech-Matterne *et al.* 2014). This type of specialized farming was, however, reimplemented and amplified throughout the Roman period. It is possible that the change in scale that took place in commercial exchanges during the spread of the Roman Empire may have been the source of commerce development and massive cereal stock circulation. Even if these foodstuffs were not the most profitable, they were nevertheless items of basic necessity, and it is possible that the state or the cities may have wanted to regulate their supply.

The perceptible changes between the High and Late Antiquity periods are more difficult to interpret because the available dataset declines from 77 to 27 instances and their distribution is irregular. It seems that the previously continuous zone of free-threshing wheat farming breaks up into several islands. There are intermediate sites where the recorded percentages of free-threshing wheats are very low, which makes it possible to affirm that the view obtained is not solely dependent on available data.

Spelt farming increases, although less concentrated in the north, but without ever presenting a coherent pattern. Could a reorganization of distribution circuits or a different product circulation system, recentred at a more local scale, explain crop distribution during the Late Antiquity period? However, limited data means we are unable to draw any immediate conclusions.



Fig. 16: Product obtained following the threshing of a spelt crop. At this stage, the grain is still tightly enclosed in its glumes and will require additional dehusking.

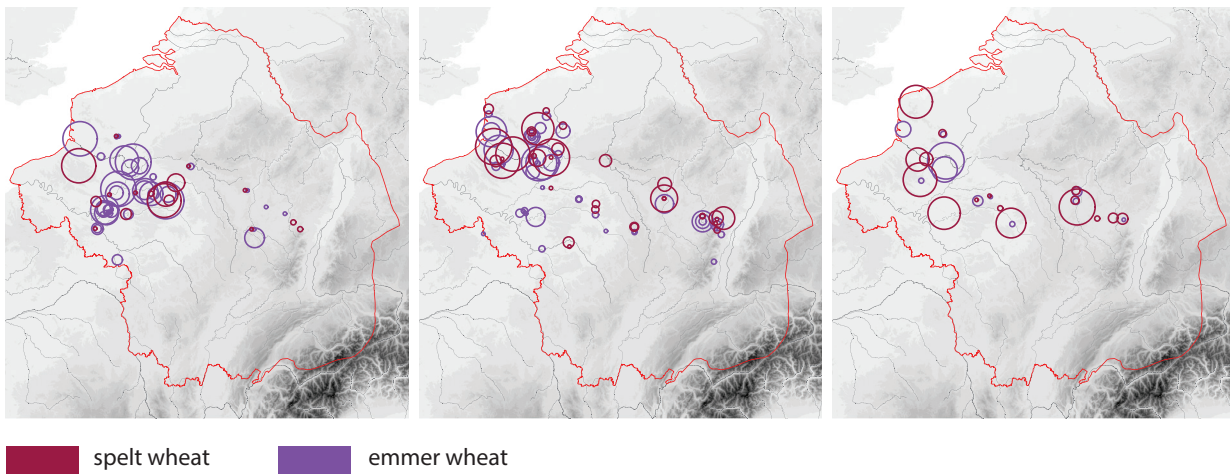


Fig. 17: Evolution of the relative proportions of hulled wheats (emmer and spelt). MNI averages calculated at the scale of each of the sites for all the structures that delivered carpological remains. Sites with more than 100 domestic species remains, with the exception of indeterminate cereals and pulses. Phase 1: early 2nd century BC – 30 BC; Phase 2: 30 BC Phase 3: last quarter 3rd century – 5th century AD. There are significant fluctuations in the distribution of spelt wheat from one phase to another. During phase 2, however, emmer and spelt appear to be associated in the north, as their zonation strongly coincides.

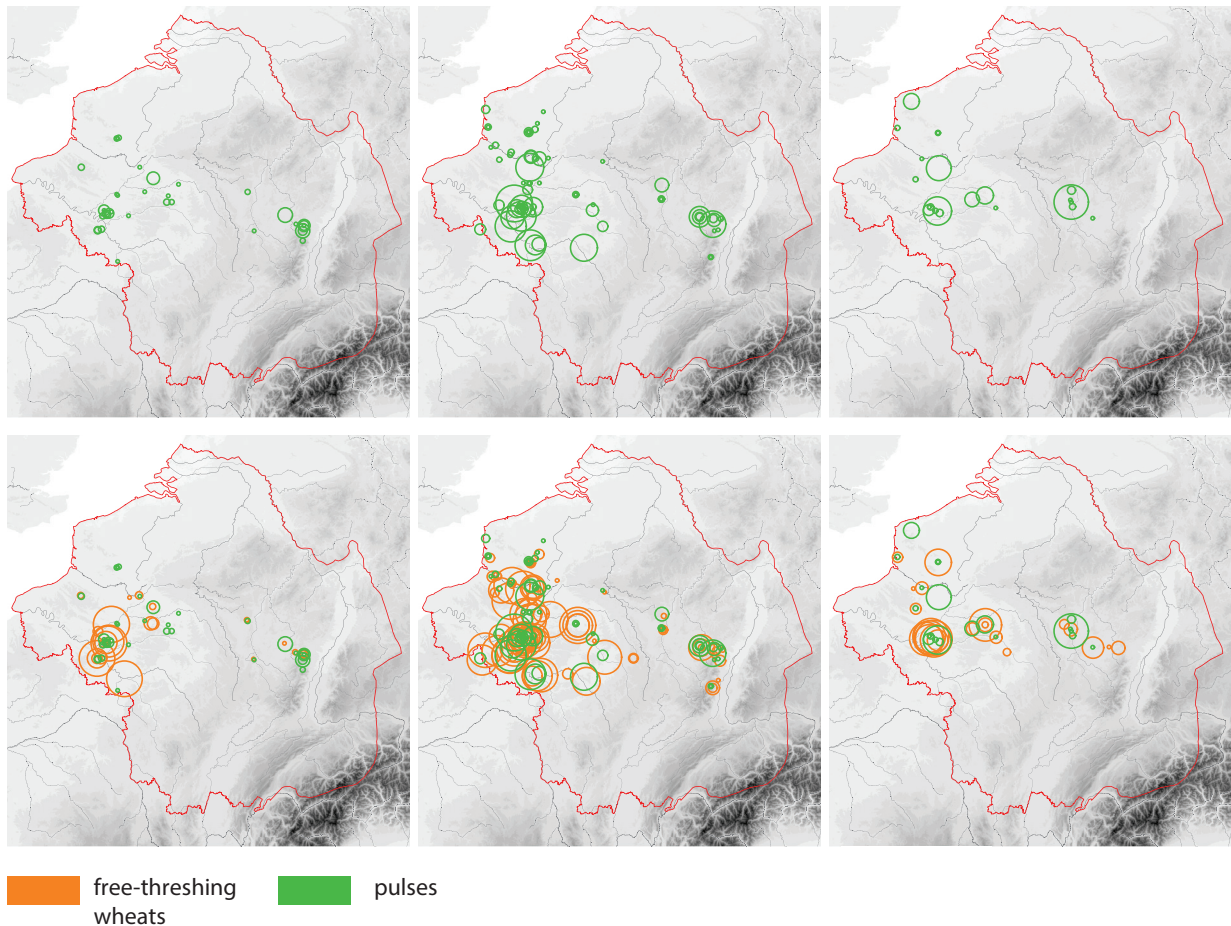


Fig. 18: Evolution of relative proportions of pulses (top) and comparison between distribution of pulses and free-threshing wheats (bottom). MNI averages calculated at the scale of each site for all the structures that delivered carpological remains. Sites with more than 100 domestic species remains, with the exception of indeterminate cereals and pulses. Phase 1: early 2nd century BC – 30 BC; Phase 2: 30 BC – 275 AD; Phase 3: last quarter 3rd century – 5th century AD. A considerable homogeneity and a significant constant was observed, throughout the sequence, when the free-threshing wheats and pulses culture zones were superimposed, with an increase of the pulses during phase 2.

2.2. Livestock

In both a rural context and across the entire study zone (Fig. 19), the analysis of animal remains showed that during the Middle La Tène period sheep were the most numerous (close to 36 %) with pig and cattle remains being present in equal amounts (33 % and 31%). During the Final La Tène period caprines seem to lose importance (23 %) to the benefit of the other two (36 % and 40 %). The numbers increase again during the High Empire period (30 %), but without ever catching up to the other species (36 % and 34 %). It is only during Late Antiquity that one notices a clean break, with cattle becoming the most prevalent animals (over 51 %) and caprines the least (20 %). The analysis of urban domestic contexts confirms the pattern for the Roman period as a larger number of cattle and a lower number of sheep.

On the scale of each defined case study area, the numbers illustrate information revealed through multivariate analyses. They also make it possible to define certain aspects of this zonation by more precisely targeting certain species.

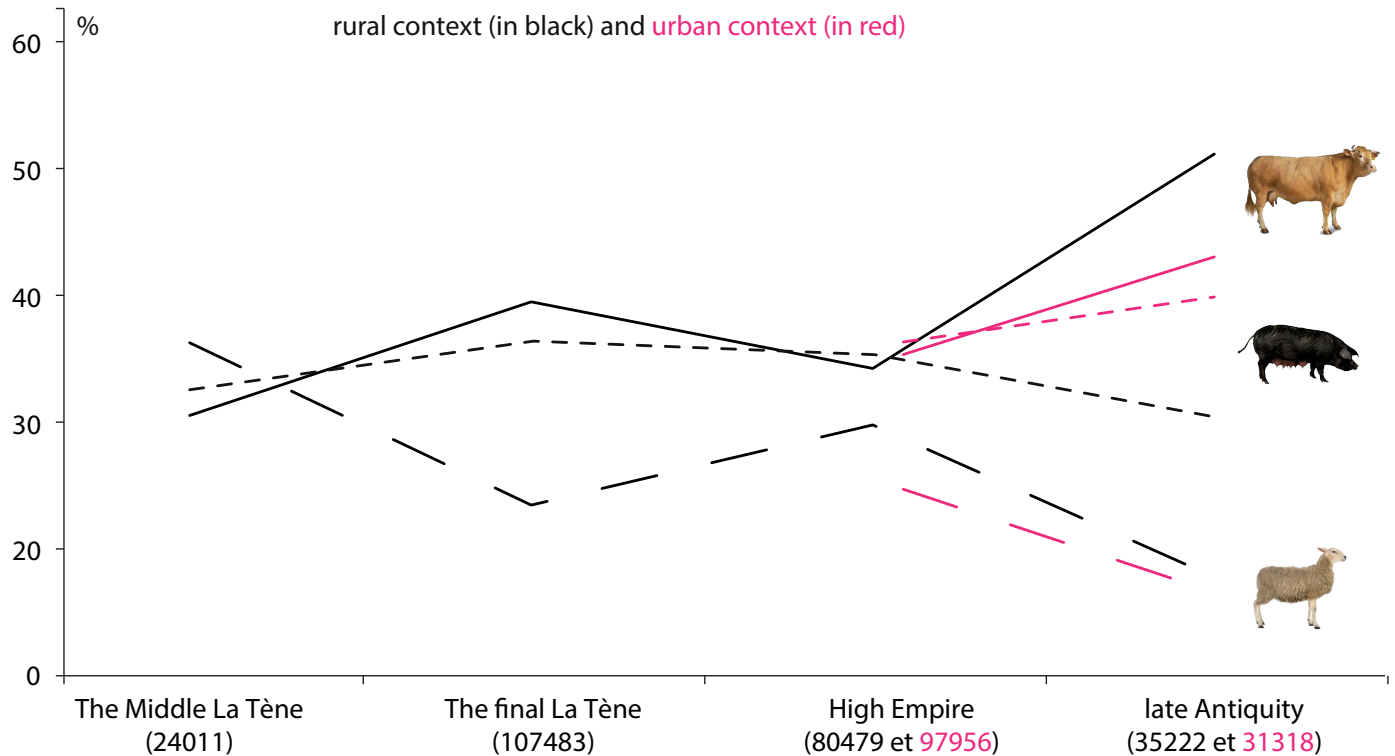


Fig. 19: Evolution of the three main domestic taxa in a rural and urban context. The number of remains is given in parentheses.

Indeed, bone assemblages are sensitive to the settlements' socio-cultural characteristics. This is true for the general patterns (between periods or between contexts) and also within settlements. Such is the case in the countryside, where the differences are observed between contemporaneous waste pits in different areas of the same site, for example between the *pars urbana* and the *pars rustica* of a villa. At the Vitry-sur-Orne site, close to Metz (Daoulas *et al.* 2017), the remains essentially came from the residential zone and are characterized by a high number of pig remains, similar to what was observed in the urban levels of the Metz amphitheatre neighbourhood. These variations were also found for chickens and pigs and are also seen between the urban neighbourhoods. Consequently, because the levels can occasionally be very high in certain contexts, these fluctuations, which are difficult to control, skew the view of choices truly linked to agro-pastoral practices and balance, especially as regards the other two main taxa: caprines and cattle. It is the balance between these two animals that should be studied, as their husbandry influences, and is most influenced by, crop choices (Fig. 20). The Middle La Tène assemblages present a variety of bovine/caprine remains ratios. During the Late La Tène period there were, on the whole, more cattle than sheep; most often the ratio is $\frac{2}{3}$ – $\frac{1}{3}$, except for the Picard plateau, the north of the Champagne region and the Moselle River valley, which have much higher sheep numbers. The pattern evolves during the High Empire period, where the northern regions (Artois, Picardie: zones A, B, C) and eastern regions (Moselle zone H, Alsace zone G) present cattle rates that are clearly more significant than in Ile-de-France, the Seine River valley and the Champagne region (zones E, F, J, I, K), where sheep are the most prevalent. During Late Antiquity these patterns diminish and the results become remarkably homogenous with a strong development of cattle husbandry. The "sheep zones" of the High Empire period diminish. The central Seine River valley stands out with a slightly higher presence of sheep, but cattle rates everywhere are between 70 and 90 %. We must consider the consequences of this apparent drop in sheep husbandry in terms of meat and raw material production. Could a drop in

wool production be considered? If that were the case, then it should have been compensated by massive importation, or by an increase in the cultivation of other textile fibres (e.g. flax, hemp) intended for fabric making. However, we do not see a major change in the number of these species in the carpological remains. Flax seeds are marginal in the assemblages and only really prove grain consumption or the use of oleaginous products (Zech-Matterne *et al.* 2008). Likewise, though hemp is first recorded during the Roman period in northern Gaul (and Early Iron Age in southern Gaul), it is only from the medieval period that certain palynological sequences show high proportions of hemp/hop pollens multiplying (Boulen & Zech-Matterne, forthcoming). As for exotic fibres, cotton is even more rarely identified than silk in fabric fragment analyses for Roman Gaul (Moulhérat, 2017)⁷. But we must keep in mind that it is difficult to think in terms of heads of livestock and that the change in ratio might not have been a major influence on production volume.

In any event, this rise in cattle husbandry helps define the economic changes that occurred at the time and which have been perceived in the various changes in settlement morphology (Kasprzyk 2016). We noticed that plateau sites were

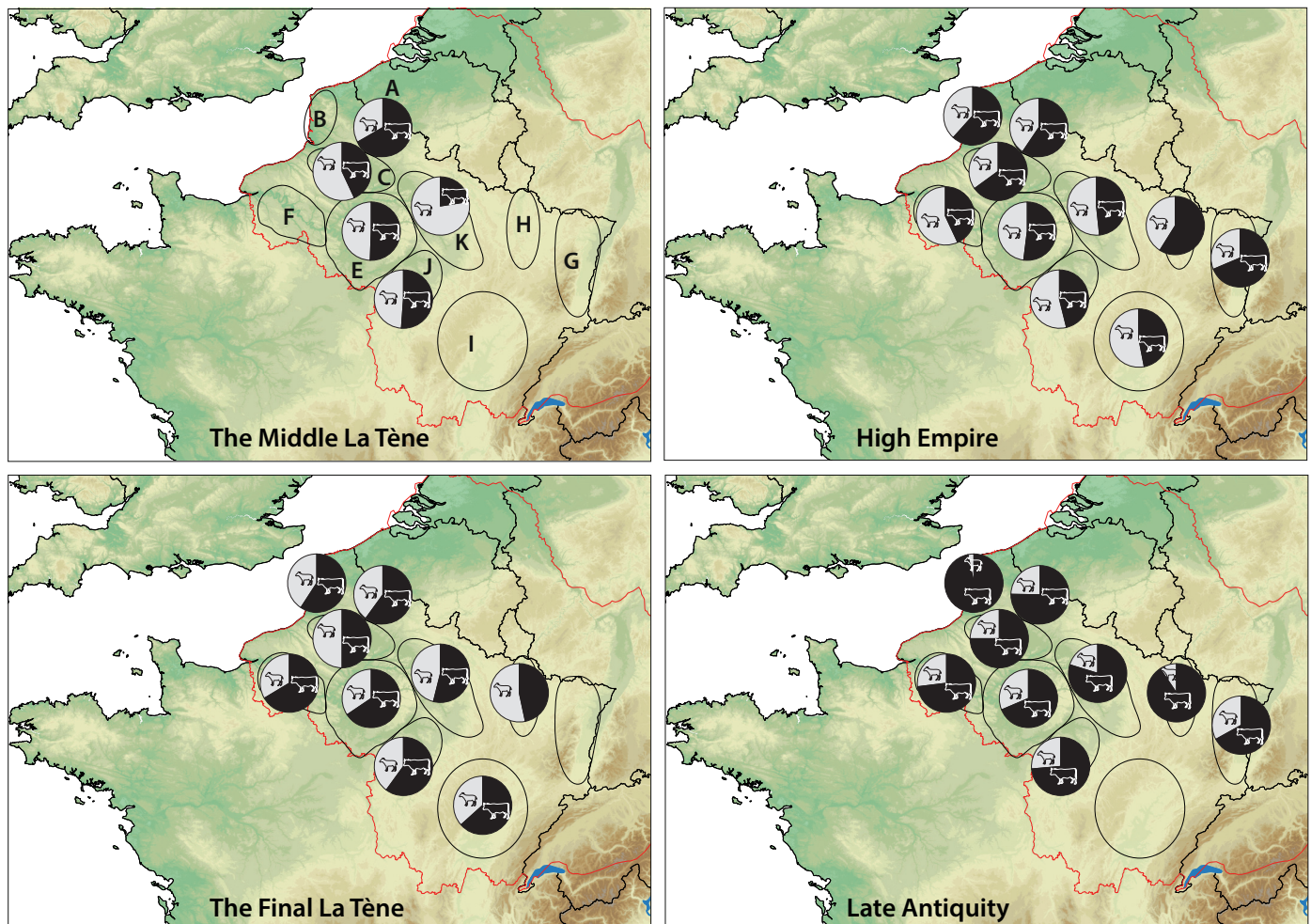


Fig. 20: Proportions of caprines and cattle at rural sites in the study area.

abandoned and valley settlements continued, as well as the disappearance of, or lack of maintenance of, ditch networks which ensured land drainage. Should this be interpreted as a condition for, or a consequence of, the development of cattle husbandry? The explosion in cattle numbers and the decrease in numbers of sheep continued and increased during the 5th and 6th centuries. Research undertaken for the same region by Jouanin & Yvinec (in press) reveals rural cattle rates of around 60 % and sheep rates of 10 %. Pig rates, however, are at their absolute highest in cities. During the High Middle Ages, the global pattern continued for the northern regions of the study zone: the importance of cattle increased but diminished in sheep. However, this shift happened concurrently with a new socio-economic context where new agrarian systems following the Gallo-Roman model were taking hold.

The issue revealed by the analysis of equids is a little different. Indeed, when preservation conditions for bones are not optimal, the species with the strongest and tallest bones are better preserved than those with shorter ones; thus, analyses combining all

7. Chr. Moulhérat, "Le coton dans le monde antique, une fibre d'exception". Oral presentation at the workshop: *Le coton dans l'Ancien monde : domestication, culture, usage et commerce*. Paris, Muséum national d'histoire naturelle, 3-4 May 2017.

the taxa will always favour the taller beasts. We must, therefore, as much as possible, compare species and bones of the same size. The surest way of doing this is to compare the number of equid bones with cattle bones because they stand equal chances of being preserved. The maps in Fig. 21 reveal a constant decrease in the proportion of equids in the assemblages between the Middle La Tène and Late Antiquity (Lepetz & Morand 2017, Fig. 35). Numbers decrease from 18 % to 8 % for the number of equids compared to the number of equids + cattle. During the Middle La Tène, zone K (around the Champagne area) indicates a higher amount of equids than elsewhere (about $\frac{1}{3}$ more than cattle), whereas in the Bourgogne region (zone I) the levels are lower (less than 8 %). During the Late La Tène period, the highest levels were reached in the lower Seine River valley (zone F, with 20 %) and around the Champagne area (K). A change clearly appears during the High Empire period. The three northern zones A, B and K (Nord-Pas-de-Calais and Champagne regions) present rather high equid rates (between 17 % and 21 %), in contrast with the rest of the territory where proportions do not go beyond 12 %. This rate is also found in the neighbouring Picardie region (zone C). For the others the levels are less than 10 %. Therefore, it seems clear that an equine husbandry zone takes shape in the northernmost lands of the study area.

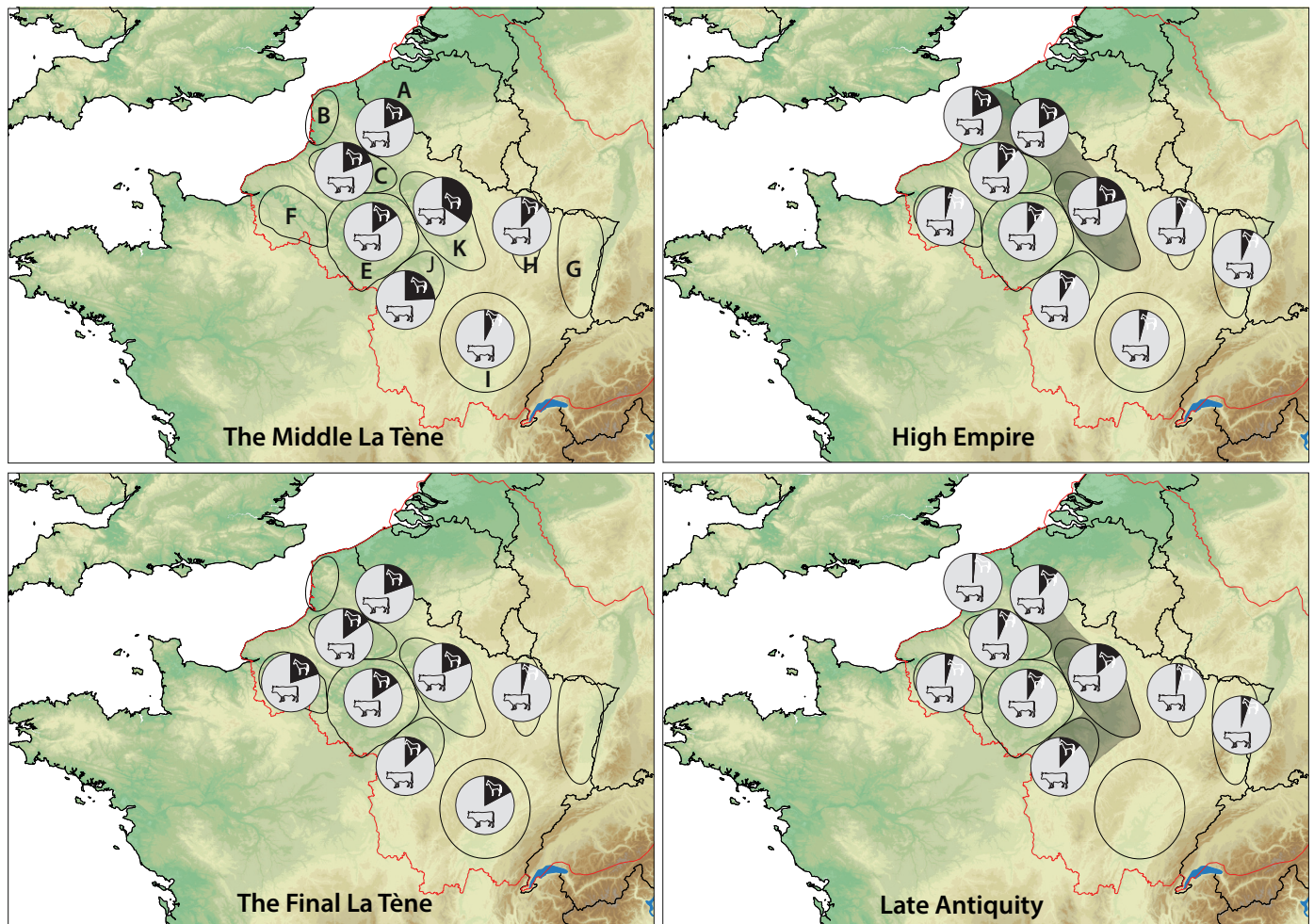


Fig. 21: Proportions of cattle and equids at rural sites in the study area.

During the following period, this zone is maintained and moves slightly to the east. The English Channel coast sees its equid numbers diminish to the slight benefit of the upper Seine River valley. It could be tempting to compare this data with that obtained by M. Groot (2008) at Tiel-Passewaaij (close to Nimègue/Nijmegen), in the Netherlands, where the hypothesis of a site dedicated to equine husbandry during the Roman period was put forward, thus recognizing a privileged area for horse husbandry throughout the northern part of Gallia Belgica. This is probable if we consider the results as well as the data gathered in the Rhine delta by Lauwerier (1988, 163, table 75) on rural settlements, showing high rates of equids (in comparison with the number of equids + cattle) at Heteren (17 % during the 1st century and 24 % during the 2nd century), at Ewijk (26 % during the 2nd century), at Druten (22 % during the 1st century, 16 % during the 2nd century, and 39 % during the 3rd century). Aside from the 4th century levels of Nimègue (26 %), cities or military camps (Kesteren, Meinerswijk, Nijmegen) logically reveal considerably fewer equid remains (between 0.1 % and 9 %) because the animals were rarely eaten and therefore not found in domestic waste pits.

3. Barriers and soil constraints observed in the studied territory

3.1. Soil nature

Investigations carried out here (see also Lepetz & Morand 2017; Zech-Matterne *et al.* 2017a; Zech-Matterne *et al.* forthcoming), showed that the distribution of the main domestic species, especially cereals, sheep and equids, underwent important changes between the La Tène and Roman periods. At the same time, persistent limits raised the question of environmental constraints that Gallo-Roman farmers were not able to circumvent.

In the centre of the Paris Basin free-threshing wheats constituted a common basis for all settlements in the Seine River valley and its tributaries. As of the 2nd century AD, legume crops (lentils, peas, Celtic bean and common vetch) were planted with them.

In the east, crop diversity is more accentuated, but barley is the common base. The importance and role of spelt, however, should not be overlooked, as it remains part of the protohistoric common base encompassing Switzerland, south-west Germany and southern Belgium (Jacomet & Vandorpe 2011; Rösch *et al.* 1992). Despite that, the importance of this wheat in the RurLand programme zone fluctuates between the High Empire period, where it was concentrated north of the Somme, and the Late Empire period, where its distribution was more haphazard.

It is remarkable that this distribution which favours wheats in the centre-north zone and barley in the east zone practically mirrors the current layout of cereal farming basins (Fig. 22). These two staple foods occupy a considerable surface. In 2016, France produced 43.7 million tons (MT) of straw cereals, 29 MT of bread wheat and 10.2 MT of barley, of which 1/3 was for breweries (agreste.agriculture.gouv.fr, 2017).

Why did wheat cultivation essentially develop in the centre of the Paris Basin and surrounding areas? Can the motivations mentioned in the statistical review of the Ministry of Agriculture (agreste.agriculture.gouv.fr, 2017) help us understand the reasons and bring to light natural (geological?) barriers as they surely existed during the Roman period and which would have, at least partially, dictated the systems adopted by the farmers of that period?

Before attempting to find answers, it is important to keep in mind that taphonomic phenomena seriously impact the vision of the productions we are trying to reconstruct. Systematic approaches based on thousands of samples and hundreds of thousands of carpological remains were carried out to determine strong patterns and level disparities. This is the reason why the main crops are mapped at the scale of large regions, whereas in reality our documentation is based on the juxtaposition of micro-local contexts (archaeological settlements). The local environment of these micro-local contexts may have evolved in terms of soil composition between the Roman and contemporary periods, notably due to soil erosion or occasional colluviums. Due to the rarity of archaeopedological analyses that describes the state of soils during Antiquity, this information is rarely accessible. Moreover, even if pedological units remained supposedly similar, these micro-local contexts might be different from the main pedological units shown on the map. That said, the contemporary wheat/barley distribution may be explained by the nature of the substrates and the resulting superficial formations, much more so than by climatic or economic reasons. The parameters indicated as determining factors are water availability, hydromorphy, salinity, slaking (a crust that forms on the soil's surface due to the rain), stoniness and pH.

The soils from the centre of the Paris Basin are, for the most part, luvisolic and degraded luvisols (formerly known as brown soils and washed brown soils). They are deep soils (80–120 cm or more) but heavy to work as they retain water. Due to the leaching of clays to the lower horizon they tend to be sodden during the winter, which may cause seedling asphyxiation; drainage is often necessary to remedy the problem. In surface horizons, the clay content is average (10–20 %). Clay loams, fine aeolian deposits and alluviums give the soil a fine texture; it is cohesive and easy to work, albeit prone to erosion. In the centre of the Paris Basin, luvisols develop from loess and present moderate acidity, or neutrality, which is excellent for cultivating cereals in general. Average altitudes are between 100 and 200 m. Slopes are nil to minimal (Camizuli *et al.* 2015⁸).

The soils found in eastern France are rendzina, cambisol and calcisol. Rendzina soils are shallow, filtrating and saturated in calcium. Cambisols are chalky soils with an average to high pH (7–8); calcisols (calcic brown soils) are soils where the decarbonation process currently operates. The noxious effect of active lime is the most powerful in rendzinas and of lower

8. E. Camizuli, Ch. Petit, P. Ouzoulias, V. Zech-Matterne, "Determining suitable soil quality indicators for Roman agriculture. Mapping at different scales for the RurLand project". Oral presentation, Paris, INHA, 18 March 2015.

importance in calcisols. Generally, all are easy to work but they do not easily retain water. Their arable potential strongly depends on their depth and the amount of coarse elements. Considering that cereal rooting is under 1 m, these constraints affect the RurLand zone unequally, and generally affect those in the east more, along the line between Reims and Sens. Stoniness increases (10–15 % of stones in arable soils) in a quadrangle encompassing Reims, Sens, Langres and Metz.

Depths are average in the chalky Champagne area (40–80 cm), but we also find deep soils in the 'Champagne *humide*' area. A higher clay content in localized areas makes the soils heavy and sodden. Depths are superficial (< 40 cm) between the Meuse and Moselle River valley, reaching limit values for cultivating cereals. They improve on the Lorraine plateau (80–120 cm) to the east of the Moselle River valley, and decrease again farther along (40–80 cm). Beyond the Meuse River valley, the soils have a fine, clayish texture or, on the contrary, are coarse and sandy in the Massif des Vosges area; fine textures are found in the Rhine plain. They are either chemically rich, but poorly aired and difficult to work, compact and heavy in the winter, slowly warming up in springtime and hardening during the dry season, or they lack cohesion and drain abundantly making

them nutrient poor. Average altitudes are between 200 and 400 m, except for the Massif des Vosges. The slope factor must also be taken into account. Today, the Ardennes, Lorraine and Alsace regions have more forests than in the Champagne region and the centre of the Paris Basin. The combined constraints of soil and slope logically explain this devolution.

Cultivating both wheat and barley adapts to all these factors. The deep soils of the centre of the Paris Basin are great for cultivating manure-demanding wheats such as bread wheats. The main benefit of loams lies in their capacity to retain water but they may also be too sodden, which may slow down biological life and increase the risks of anoxia and compaction. Barley crops are sensitive to this, but bread wheat can accommodate these conditions better than winter barley. The most sensitive phase is germination because seedlings may choke. Combined with frosts, too much water is catastrophic as it mechanically destroys the sprouts.

In chalky Champagne (the Reims-Châlons-Troyes region), where soils may be skeletal, the low amount of available water will diminish potential yields. Tiny fractures in the chalk cause the water to descend deeply, far from the cereals' superficial root systems. Gravel formations result from the decomposition of the chalky substrate and feature big nodules. Soils are cold. In the carpological assemblages, barley and spelt, though to a lesser degree, seem favoured, probably due to their greater tolerance for these conditions.

In the Lorraine region the most limiting factors are stoniness (which can be significant), soil depth (which may be shallow) and the amount of clay (which may provoke serious hydromorphy). According to the data gathered for the Roman period, arable crop production seems to have diversified to adapt to this mosaic of local conditions, and barley is constant there as well.

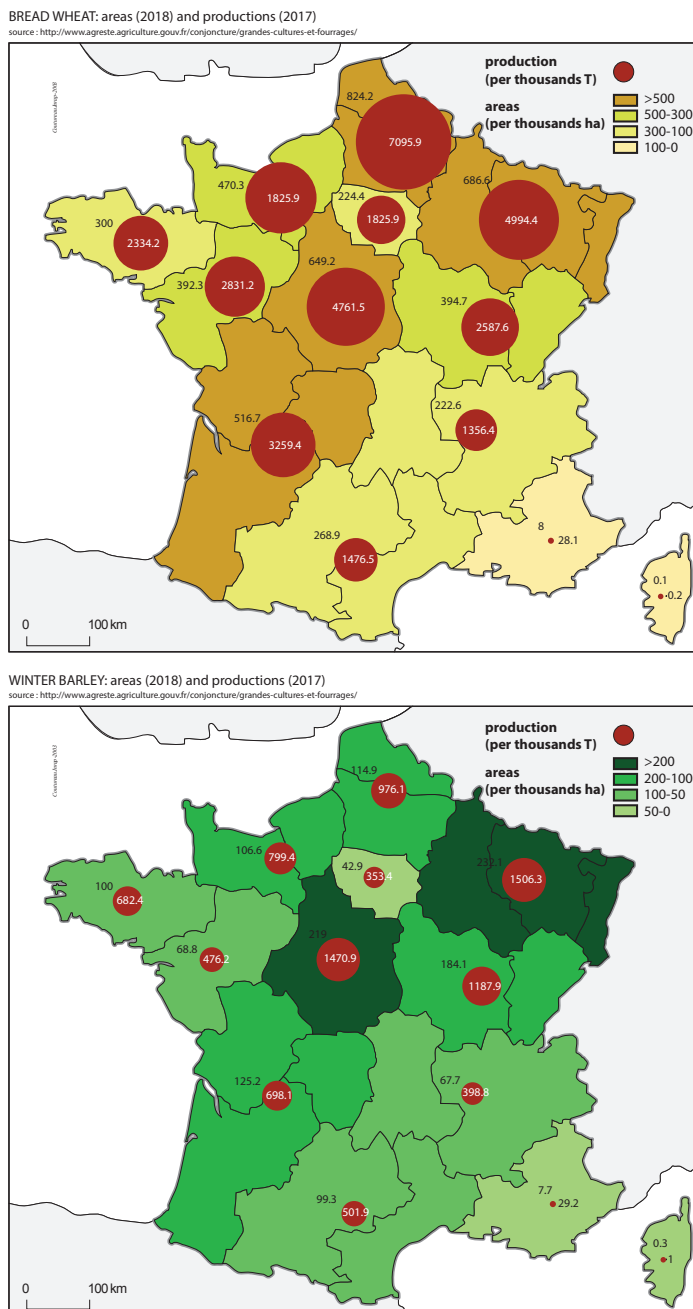


Fig. 22: Areas (per thousand hectares; in black) and production (per thousand tons; in white) of bread wheat (top) and winter barley (bottom) in France, by region. Agreste. Statistique, évaluation et prospective agricole. Ministère de l'agriculture et de l'alimentation. <http://www.agreste.agriculture.gouv.fr/conjoncture/grandes-cultures-et-fourrages/>

If the diversity of pedological conditions influences the choice of crops to cultivate today, it was most certainly the case during Antiquity because certain parameters existed due to the nature of the substrate. It will always be easier to limit the risks of hydromorphy by setting up adequate drainage systems rather than trying to improve water and moisture retention in the soil. This factor is vital for counterbalancing climate effects and irregular rainfall. Coarseness is another factor directly influenced by the nature of the geological layers and how they are likely to degrade to become superficial horizons. During the Roman period, the only way to remedy the problem was by removing stones from the plots by hand, which was an extremely expensive effort in terms of time and labour.

3.2. Crop rotation

The view we have of the main species cultivated during the Roman period does not take into account the dynamics of successively alternating them in the fields. Maslins are no longer evidenced in Roman cereal mass finds. Wheats, barley and pulses were thus cultivated as monocrops; indeed, several crop successions are described by Pliny the Elder and Columella.

After observing the main elements of Roman period farming in the RurLand zone, we propose several possible crop rotation schemes. The benefits of crop rotation are threefold:

- It helps prevent soil nutrient depletion because cultivating the same plant on the same plot continually draws on the same types of nutrients. Certain species deplete soils more than others, whereas pasturelands or legume crops contribute to replenish the soil's nitrogen resources. Lastly, some plants (buckwheat, common flax) produce toxins in their roots making them impossible to plant in the same place two years in a row.
- It reduces the growth of arable weeds which compete with the domestic species sown (Fig. 23). Cover crops that may eventually be ploughed and turned over into the soil as green fertilizers, contribute to limiting the spread of unwanted and persistent species such as thistles. Alternating sowing seasons also helps limit the development of certain types of plants. Before the implementation of industrial agriculture, completely setting aside a plot and ploughing it several times was the most effective way to fight weeds and reduce the need for hoeing.
- It helps to fight diseases and pests which are often dependent on a particular species and will therefore not be as vigorous if the host habitat changes.



Fig. 23: *Fallopia convolvulus* (wild buckwheat) wrapped around a cereal stalk. This weed is difficult to eliminate because of the size of its seeds and the propensity of the plant to use cereals as a stake. Credits F. Toulemonde. Arvalis, July 2017.

But which schemes should be considered? F. Sigaut said that in France, before industrial agriculture, at least four succession planting systems existed; the main ones being two-field or three-field crop rotations (1976). Two-field crop rotation is similar to the single cultivation of winter cereals. After harvesting comes a period where the long stubble is left in place and range pasturing begins as livestock graze the stubble. Then comes the fallow period (with the meaning this term had in pre-contemporary European agriculture) where a succession of spring ploughing prepared the field for fall sowing (*'jachère'* or *'guéret'*). This needs to be at the start of the rotation cycle, as it is this preparatory work that really begins the cultivation cycle (Sigaut 1993). The complete cycle lasts 14 to 16 months, and this fact alone justifies why one cannot sow winter wheat two years in a row in the same plot. This succession, sometimes repeated, may be followed by a certain number of years where the plot is left uncultivated (*'pâtis'*) and used for rough grazing, if there is sufficient land. This system produces one harvest every two years and is more often done on smaller farms.

Three-field rotation is a two-field rotation including a spring cereal (oats, barley) right after the winter wheat harvest. Comparing equal acreage, spring-sown crop yields will be a half, perhaps a third, of fall-sown crop yields, obtaining 1.5 harvests every three years, at best. That considered, it would be inexact to assert that the three-field system is intrinsically more profitable than the two-field system. Moreover, spring-sown cereals are much more susceptible to climatic accidents which put the harvest at risk. The main advantage of this system is that the labour needed for spring cereal farming is done during the off-peak periods of the winter cereals. Three-field crop rotations are not ideal if the territory is densely occupied, due to the difficulty of increasing ploughable surfaces. A succession of two cereals would probably not leave the field clean enough for hoed crops (such as pulses or vegetables) to fix, so that a complete fallow was still necessary afterwards.

According to F. Sigaut, the three-field system is akin to a technological impasse, which supposed to maintain a fallow period and imposed an increase in manure. It may, however, be considered in certain situations: in coastal areas where seaweed serves as fertilizer, in peripheral areas around cities, and in alluvial overflow zones where the transfer of fertility operates naturally by itself.

If the aim is to increase production, then a two-field crop rotation is better than a three-field crop rotation. Two-field rotation is ideal for small farms or in densely populated regions where manure is abundant, as it aims to increase a soil's production capacity. Three-field rotation is better for large farmsteads with lots of land seeking to rather increase labour efficiency.

Contemporary crop rotation is no longer based on the species cultivated during the Roman period. Systems that might inspire us today are implemented within the framework of organic farming, which limits inputs and counts on crop rotation to maintain soil fertility and limit the impact of weeds and pests. In these specific, modern situations the first crop sown is meant to fix a maximal amount of nitrogen in the soil. An improved ley will be sown, incorporating legumes or protein crops for green manure as the greens will be turned over into the soils. Cereal stubble will also be turned over into the soil to increase phosphorus and potassium levels. Leaching may be limited by avoiding bare soil in the winter with grass fallow or autumn sowing. The next crop is a nitrogen-demanding winter cereal such as wheat, followed by cereals that require less nitrogen (barley, oats or rye). During Antiquity, einkorn could have been added as it does not need fertilizer. Barley, a non-choking cereal, is ideal for cover cropping, which clearly associates it cereal with legumes.

In the centre of the Paris Basin, the most notable element is the combination of free-threshing wheat crops and pulses (lentils and bitter vetch); barley is omnipresent, but less important than wheat in terms of remains. This combination can be done in several ways:

- A legume family crop followed by a nitrogen-depleting wheat crop, then leaving the plot fallow as in the two-field rotation system. Statistical analyses based on arable weed life traits show that winter-sown annuals increased at the same rate as the development of free-threshing wheat crops, indicating, for the latter, an autumn-sown regime that will enable higher yields (Zech-Matterne *et al.* 2017b).

- It is also possible that after wheats, another cereal (*"seconde paille"*), like barley, could be cultivated, followed by bare fallow, as in the three-field rotation system. Less nitrogen-demanding cereals such as rye, oats or einkorn could also be used at the end of the crop rotation cycle. They could be sown after one ploughing and without fertilizer. However, rye and oats played only a tiny role in Roman era farming within the RurLand programme zone (Zech-Matterne *et al.* 2017a) and throughout northern France (Ruas & Zech-Matterne 2012). As regards einkorn during the recent protohistoric era, its importance dropped considerably, becoming a rarely sown species, perhaps even a weed. The fact that it is closely linked to spelt in the CA suggests that einkorn became a relict species still present in spelt fields.

These possibilities are combined in the centre of the Paris Basin with animal husbandry mostly geared toward sheep – to graze stubble and pack down the soil – but with some other livestock as well. The two-field system would have been ideal for the

smaller farms of the “Plaine de France”, north of Paris, which also cultivated free-threshing wheats, as well in the regions with a high farm density, a situation is recorded on the archaeological transects that preceded the development of major road and rail axis in the Picardie and Ile-de-France regions (Bayard *et al.* 2014).

-Inter- or mixed-cropping is also worth considering, with pulses sown under cereal cover. This system makes it possible to increase crop yields in comparison with monocropping and limits the spread of weeds, which quickly overwhelm less competitive legume crops. However, these practices may be modern and their inconvenience lies in the fact that pulses have an acidifying effect on already slightly acidic soils (plateau loams). Low differences in pH values could, nevertheless, be counterbalanced by marling, but the extent of this practice has yet to be evaluated for the Roman period. Although clay-limestone outcrops were accessible in the studied zone, the transportation logistics would have been consequential. Plus, there are no carpological assemblages evoking mixed sowing combining barley and pulses.

3.3 Persistent limits

During the High Empire, the Somme River valley seems to mark the northern edge of the expansion zone for growing free-threshing wheats. The wheat types cultivated beyond this limit are hulled wheats, such as emmer and spelt, in line with protohistoric production. These are mostly seen in Ambien, Atrebat and Nervien territories (Derreumaux *et al.* 2008; Clotuche *et al.* 2017) and are paired for the most part with cattle husbandry. The material culture of the sites shows a common cultural sphere that borrows from, without completely espousing, Mediterranean trends.

Several sources were consulted to try to understand if the Somme River valley constituted a natural or a cultural barrier. Dominant soils are not the cause as they are similar to the typical luvisolic soils predominant in the Picardie region (with the exception of the coastal edge): neutral to basic, deep (> 1 m) and with vast available water capacities (150 – 200 mm) (GIS Soil study, Arrouays *et al.* 2002). Precipitation charts show superior values for the zone located north-west of the Somme (1000–1200 mm versus 700–800 mm to the north of the Seine River and 500–600 between the Seine and Loire Rivers (Joly *et al.*, 2010)⁹. This could favour spelt, a wheat that makes the best of cold and humid climates (Sigaut 1989) but the values balance out as soon as one moves inland; therefore, it is not the sole explanation. Likewise, annual average temperatures are similar, around 10°C (Joly *et al.*, 2010)¹⁰.

We also looked at the maps created by P. Ouzoulias¹¹, from M. Demonet's PhD work (Demonet, 1990)¹². It shows the state of agriculture in France, before the mechanization of production means. The distribution maps and yield maps, established for the same cereal, are enlightening (Fig. 24). While bread wheat is still widely cultivated in the zone that corresponds to the RurLand project (upper), only the Artois, Picardie and Ile-de-France regions show high yields (middle). In these regions bread wheat cultivation is strongly associated with improved leys (lower).

According to the same sources, the most superficial chalky soils of the area around Amiens were cultivated as meslin (bread wheat and rye) with average yields, while north of the Somme, in Flanders, in the Perthois-Douais and Hainaut-Cambrais regions, bread wheat was associated with livestock farming. The Somme region did not present two distinct cultivation zones, but the nature of the soils in the Amiens area is not best suited for bread wheat cultivation.

Partitioned agriculture, as observed during the Roman period, was probably not entirely due to natural constraints, which would have still been an issue in the 19th century before the appearance of chemical fertilizers. The hypothesis of diverging dietary choices, linked to two cultural zones with different supply circuits, is very tempting. In the east, barley represents a significant constant, accompanied by a variety of species among which spelt wheat plays an important but fluctuating role. The 1852 Agricultural Study maps are also eloquent (Fig. 25). If it is clear, as in the case of barley, that the best yields are obtained from the best soils (upper), necessity dictates that barley cultivation in the east is dominant (middle), complemented with pastureland and natural grasslands (lower), neither of which play a fertilizing role comparable to improved leys where the species are very carefully selected.

9. <http://journals.openedition.org/cybergeol/23155?lang=en>, see average annual temperature appendix: <http://journals.openedition.org/cybergeol/26864?file=1>.

10. <http://journals.openedition.org/cybergeol/23155?lang=en>, as are annual precipitation rates: <http://journals.openedition.org/cybergeol/26852?file=1>

11. E. Camizuli and P. Ouzoulias, “Potentialités des sols et systèmes agricoles dans les Gaules du Nord et de l’Est”. Oral communication, Workshop #14 of the RurLand Programme, Paris, INHA, 5 April 2016.

12. Based on the book *Statistique de la France: statistique agricole*, Paris, Imprimerie Impériale, first part 1858, second part 1860. This publication resulted from a national enquiry that took place in 1852, using a unique, standardized form, including more than 600 variables (Marin & Marraud 2011).

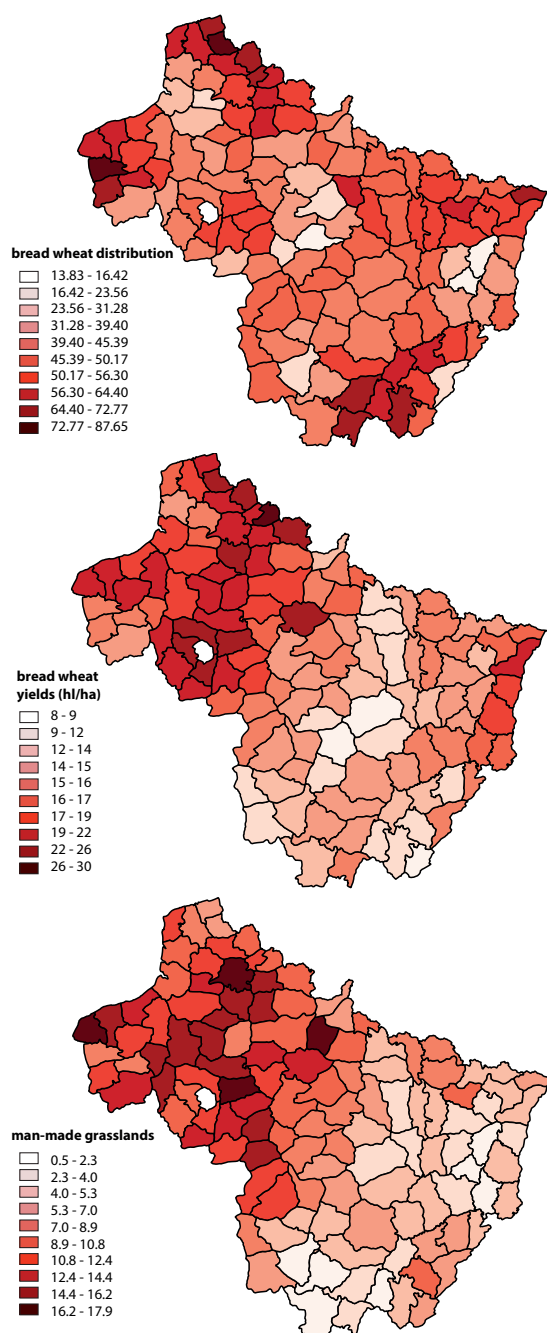


Fig. 24 a-c: Distribution and yield maps of bread wheat crops (A and B) and their association with improved leys (C) in the programme area. Maps : P. Ouzoulias, from the data of M. Demonet, *Tableau de l'agriculture française au milieu du XIX^e siècle : l'enquête de 1852*, eds. École des Hautes Études en Sciences Sociales, Paris, 1990, transcribing the agricultural survey of 1852: *Statistique de la France : statistique agricole*, Paris, Imprimerie Impériale, first part 1858, second part 1860, BN, O.600 (18 and 19).

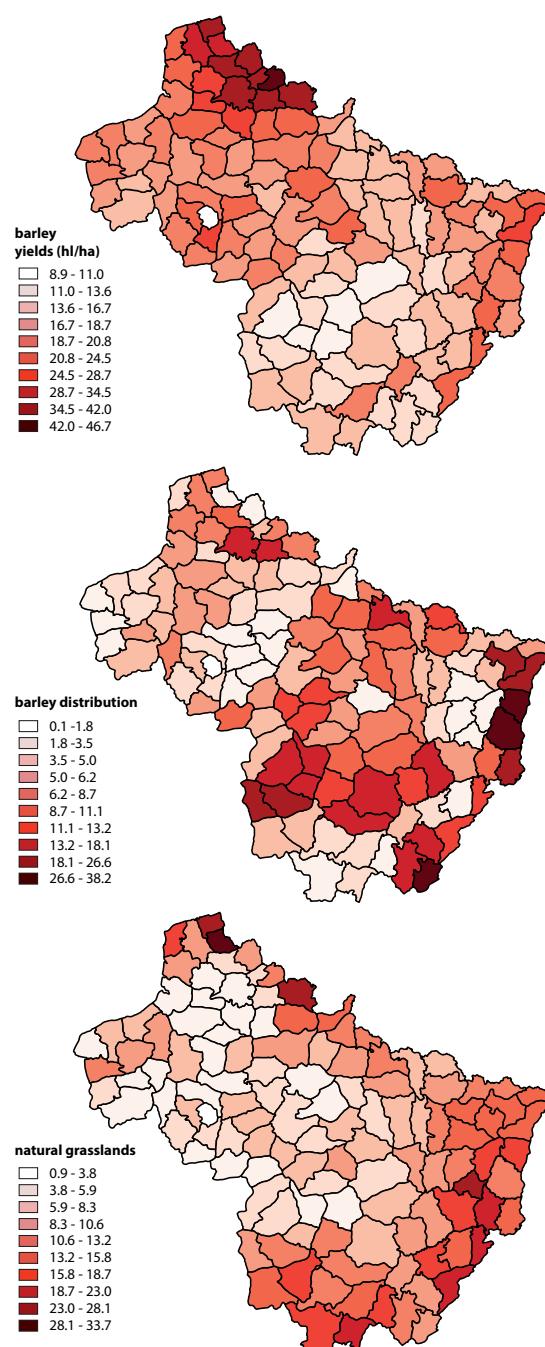


Fig. 25 a-c: Yield maps (A) and distribution maps of barley crops (B), and their association with natural grasslands (C) in the programme area. Maps : P. Ouzoulias, from the data of M. Demonet, *Tableau de l'agriculture française au milieu du XIX^e siècle : l'enquête de 1852*, eds. École des Hautes Études en Sciences Sociales, Paris, 1990, transcribing the agricultural survey of 1852: *Statistique de la France : statistique agricole*, Paris, Imprimerie Impériale, first part 1858, second part 1860, BN, O.600 (18 and 19).

The system currently promoted in the Lorraine region for organic farming includes rotating cereals that are moderately nitrogen demanding and pastures. Spring barley, sown three years after a grass fodder crop, enables the remaining nitrogen to be optimally exploited.

During the Roman era, cattle husbandry was predominant in the Moselle River valley (Daoulas *et al.* 2017). Meadows and grasslands occupied the large areas. For the Roman period we can consider systems where grasslands were starter crops,

followed by moderately fertilizer-demanding cereals like barley or spelt wheat. Locally, emmer and broomcorn millet cultivation endured, but the role of these two secondary species is difficult to determine (catch crops). Alternatively, the starter crops could have been pulses, which during the Roman period are represented in the east in far superior numbers than during the Iron Age. Spelt, which is a primary cereal in several large, late Roman *villae*, was probably locally cultivated, as it was discovered in a zone favoured since the Protohistoric period.

In the chalky Champagne area, hulled barley was the basic component of agriculture, together with spelt. Still, at the beginning of the 19th century, the distribution of rye crops (a cereal that does not need fertilizing) clearly reflects the reduced yield capacity of Champagne area soils before the use of chemical inputs (Fig. 26). The prevalence of barley persisted until the early Middle Ages, when free-threshing wheat cultivation finally began to take hold¹³. So why were free-threshing wheats so widespread during the medieval period yet practically absent during the Roman era? The explanation undoubtedly lies in the new settlement grid and the ensuing waste management. This enabled free-threshing wheats to be cultivated during the Roman period in the countryside around the city of Reims (Toulemonde *et al.* 2017b), whereas farms further away were only able to cultivate barley; therefore, the transfer of fertilizing elements, recuperated or bought into town, is quite probably the cause.

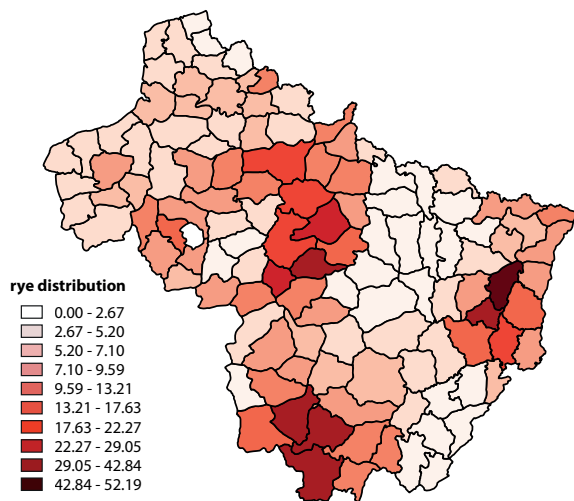


Fig. 26: Distribution maps of rye crops in the programme area. Maps : P. Ouzoulias, from the data of M. Demonet, *Tableau de l'agriculture française au milieu du XIX^e siècle : l'enquête de 1852*, eds. École des Hautes Études en Sciences Sociales, Paris, 1990, p. 304, transcribing the agricultural survey of 1852: *Statistique de la France : statistique agricole*, Paris, Imprimerie Impériale, first part 1858, second part 1860, BN, O.600 (18 and 19).

To summarize these observations, specific crop combinations were perceived in specific area inside the zone covered by the RurLand programme: hulled wheats, oats and flax in the north; free-threshing wheats, lentils and bitter vetch in the centre of the Paris Basin; and barley, spelt wheat and millets in the east. These crop combinations go hand in hand with specific animals. It is interesting to note that the overall evolution in northern France is very different from the pattern seen in Roman Britain (Lodwick & Brindle 2017; Allen and Lodwick 2017). Regarding vegetal species in Roman Britain we note a strong continuity between the La Tène and the Roman period (since AD 43), with a predominance of hulled barley and spelt, whose proportions vary from one territory to the next. Livestock choices are linked to specific species: cattle with spelt wheat and caprines with barley. The presence of free-threshing wheats is low; their proportions rise only slightly and their numbers are stable at 35 % of the assemblages. Regional variations are linked to the nature of the accompanying secondary species. The boost in spelt crops which overtook emmer crops is interpreted as an indicator of the emergence of more extensive farming because spelt wheat was better suited to exploiting average quality soils and was more profitable as a winter crop. From the 3rd century, the production of spelt wheat strengthened in certain regions (West Anglian Plain and Kent, then Wessex) as did the development of crop-processing structures (corn-drying ovens) which made hulling and milling much easier, enabling the products to be taken to market.

Similar events (a military conquest and the attendant reorganization of exchange routes) had very different repercussions in northern France. A natural environment offering contrasted agricultural capacities, another indigenous cultural heritage and opportunities that spawned the emergence of specialized cultivation or animal husbandry lead to more partitioned farming systems with their own evolution rhythms. The importance of meadows and grasslands and their role in crop rotation is, however, difficult to ascertain and differentiate at the level of each zonation. The possibility of alternating cultivation and pasture raises a crucial issue in terms of tools. F. Sigaut (1972) felt that only a tool as strong as the plough would have

13. G. Daoulas, E. Bonnaire, A.-M. Desiderio, S. Preiss, F. Toulemonde, J. Wiethold, V. Zech-Matterne, Les études carpologiques sur les sites d'habitats médiévaux de Champagne-Ardenne : État de la question, Oral presentation, XIIe Rencontres d'Archéobotanique, Perpignan, 07-10 June 2017.

been capable of breaking up turfs and that consequently the advent of fallow grass could not precede the medieval period in France. The variety of ard shares and the technical properties of ards make it possible to consider the existence of field equipment capable of turning over a layer of earth from the Roman era, even if no ploughs existed. (Ferdière 2001; Marbach 2006/07). Indeed, nothing prevents us from considering alternating grasslands and crops in the study zone.

4. Cattle and chickens. Did they really try to improve domestic species?

Size increase in domestic animals at the end of the Iron Age and during the Roman period is one of the emblematic transformations that occurred in the Gallic countryside. Evidence such as different sized bones (depending on the period) were found on the archaeological sites.

4.1. Evolution in animal size

Mean height evolution curves for mammals are well documented for northern France (Fig. 27). For all species, they convey a generalized increase in size, at first moderate and progressive between the 3rd century BC and the 1st century AD (up to 10 %), and then more strongly at the dawn of the new millennium. These evolutions appear to be linked to profound changes in production methods, as well as supply and exchange networks created from at least as early as the 2nd century BC, long before the Roman Conquest. The appearance of *oppida* towards the end of the century in northern France, and the emergence of urban settlements on the plain were undoubtedly the triggers for the rapid evolution in management and distribution of agricultural food resources. The Gallic agro-pastoral system had ample space, structures and farming methods to enable it to keep up with this economic reorganization, and its vitality was expressed through new types of crops and the development of effective tools. The system also produced a surplus making it possible to feed urban populations; this evolution went hand in hand with an increase in the size of cattle, pigs and sheep.

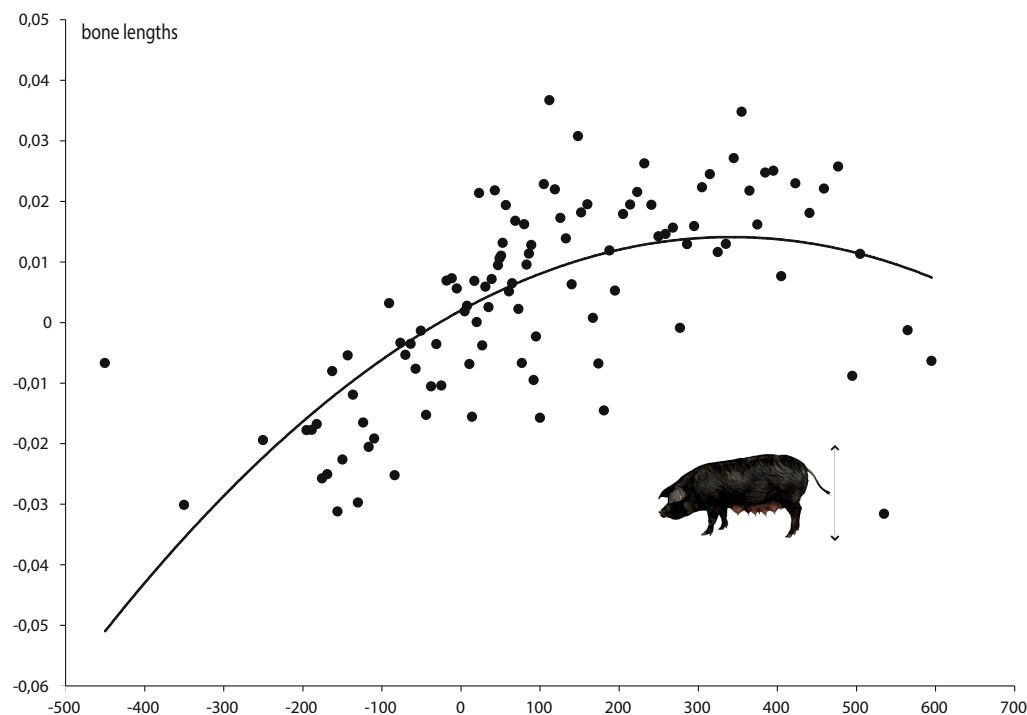


Fig. 27: Evolution of length measurements of Gallic and Roman pig bones. Each point on the graph indicates the average values calculated for a particular site (after Duval *et al.* 2016).

The Roman period thus follows on from a shift which began long before the Roman Conquest, but it is during this period that the observed trend was amplified. If there is a break between the Gallic period and Antiquity, it is more on the level of the sheer size of the recorded progression rather than the appearance of the shift itself, which is clearly much earlier. Along with the profound transformation in production structures – expressed through settlement morphology – trade and relationships with the city and their orientation towards the markets, the growth in animal sizes also accelerated (Fig. 28).

In the 3rd century AD, cattle had an average withers height of 1.32 m, with the largest specimens possibly surpassing 1.60 m, whereas during the La Tène period they were only 1.10 m tall. At the same time, morphological changes can also be seen in certain cattle through the development of the most muscular parts (shoulders and thighs) and a shortening of lower leg bones. The scale of these changes is not the same for all species: cattle increase by about 25 % between the Iron Age and the 3rd century AD, equids only by 13 %, and sheep by about 10%. Optimum heights were reached in the early High Empire period and stabilized during the 4th century. For bovines, the curve even dipped. Sizes then began to decrease throughout the High Middle Ages. Analyses spanning several centuries enables a global view of the history of changes between Antiquity and the 19th century to be observed; it is remarkable to see similarities in the results during the 1st to 3rd centuries and at the beginning of the agricultural revolution, to the point where one could view the mechanisms at work during Antiquity through the lens of what happened more recently. This will be discussed later.

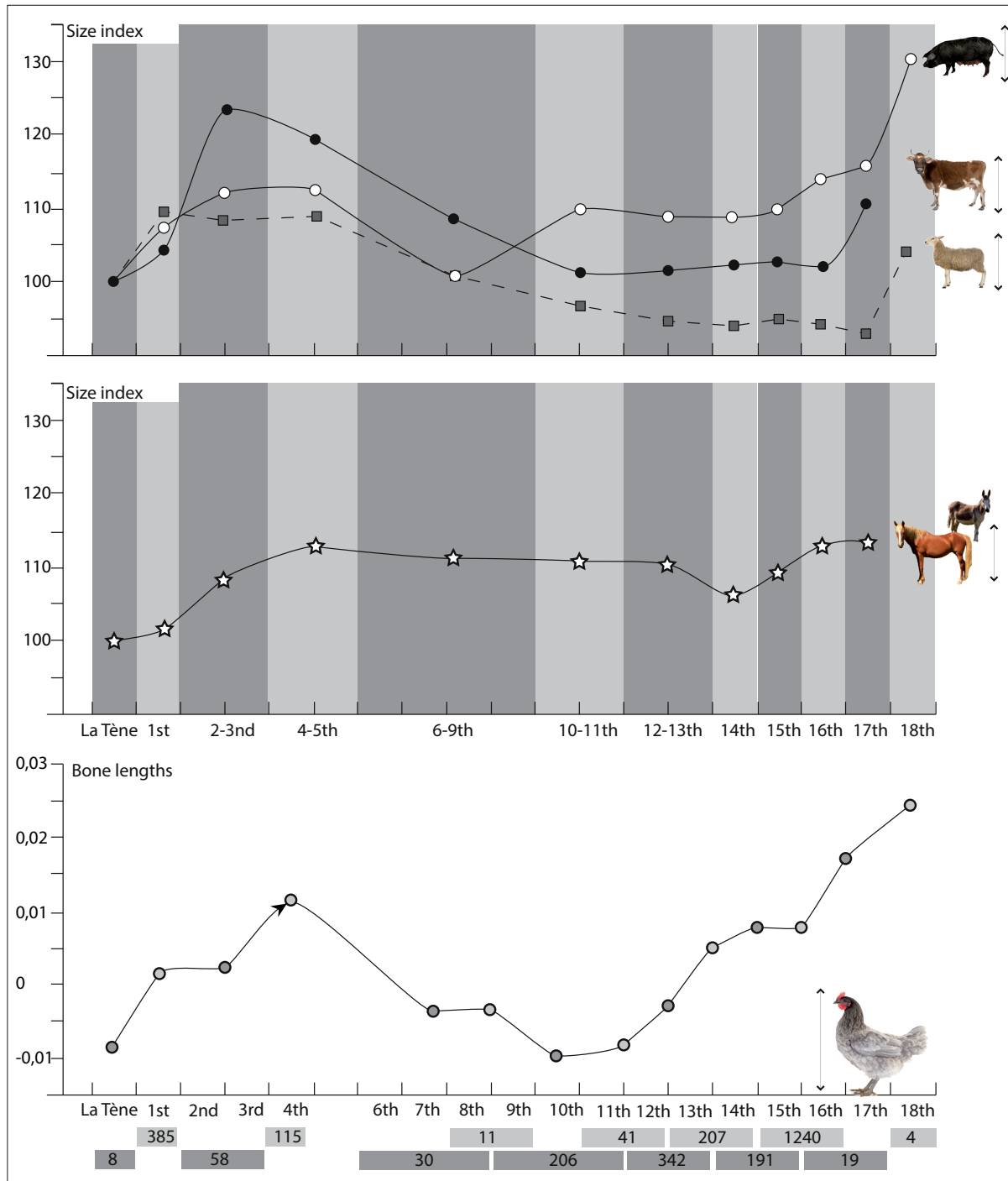


Fig. 28: Size evolution of the three main domestic species between La Tène and the 18th century (after Lepetz 1996 and Clavel & Yvinec 2010), equids (horse and undifferentiated hybrids) and chicken. The figure represents indices (index 100 for the La Tène period). The size evolution of chicken (males were excluded from the calculations) was calculated using the measurements of 2848 bones. The Log Size Index method was used (Meadow 1999 – the reference animal, from which the bone was compared, was a 4th century adult hen skeleton from the Louvres site (S. Lepetz research)). The shaded ranges correspond to the chronological extent envisaged for the data. The numbers correspond to the numbers of hen bones.

This evolution was first brought to light in the 1970s (Boessneck *et al.* 1971), described in more detail by Ménier for northern France (1984) and then further developed by Audoin (see Audoin-Rouzeau 1991, for cattle, or Audoin-Rouzeau 1995, for a comparative approach), who added a geographical aspect by noticing the existence of variations at a western European scale. Subsequently, several other university papers or articles took up the theme and proposed explanations for these modifications (Lepetz 1996 a and b; Forest & Rodet-Belarbi 2002; Duval *et al.* 2012; 2013; 2015). Several hypotheses were put forward: a modification in herd structure which enabled more males to reach adulthood (bigger than females), thus influencing the averages calculated for the assemblages, and large-scale imports from Italy (Audoin-Rouzeau 1995). However, the possibility that the native breed had been improved and that know-how and improvement techniques had also been imported (Lepetz 1996a; Forest & Rodet Belarbi 2002) was clear from the first analyses. Studies on cattle (Duval *et al.* 2012) and then subsequent geometric morphometric analyses on pig teeth (Duval *et al.* 2015) revealed the existence of notable differences between the herds in northern Gaul and those in southern Gaul and Italy. They indicated that morphometric and morphological changes in pigs and cattle essentially resulted from changes specific to northern Gaul and not from large-scale imports, confirming that large-sized animals were actually developed from La Tène breeds.

Of course, the circulation of goods and people undoubtedly facilitated the integration of foreign equids and bovines into the herds, principally those which pulled carts carrying produce to sell or carts accompanying soldiers. Later in the paper we will see that the *Latin Agronomes* broached the issue of purchasing animals from other regions of the Roman Empire, and it seems plausible to assume that what was true for the Italic countryside was also true for the provincial countryside, even if the contribution of this new blood was probably limited. Indeed, the case of the north-eastern Iberian Peninsula illustrates this possibility. Metatarsal measurements and the evolution in the shape of cattle teeth prompted Colominas *et al.* (2014) to consider that the recorded modifications were not only due to an improvement of the native breed, but that they also suggested the introduction of cattle presenting a different phenotype during the Romanisation period. She also remarked that these new types of bovines are mostly recorded in settlements founded during the Roman period.

The studies by Duval *et al.* (2015) also showed that if the trend was observed throughout the western provinces of the Empire and that if larger animals were documented on a good number of sites, then the trend differed depending on the territory: the methods, rhythms and amplitude of these modifications varied. First, the situation is different for southern France because analyses have shown phenotype links between pigs from *Lattara* (Lattes) and those from Rome, in comparison with those from the north. Duval *et al.* also brought to light the similarities in shape between pigs from sites in the centre of Gaul, *Caesardunum* (Tours) and *Argentomagus* (Saint Marcel), and pigs from Narbonne. Next, they noted that the large animals were mainly concentrated in *Gallia Comata* (long-haired Gaul), where our study zone is, stunningly illustrating the existence of a fertile, high-performance production activity far from the Italic Peninsula.

Thirdly, they noted that the northern provinces do not present a homogenous whole that contrasts with the southern ones – the regions, valleys and cities present specific particularities that distinguish them from the other (Duval *et al.* 2013). Such is the case for the Gallic bovine herds during the La Tène D period when, for example, the city of the Andecavi supplied smaller animals than those from neighbouring cities. The bovines from Soissons were similar in size to their counterparts from Sens, but they were more slender.

It is also possible to distinguish territory-specific evolution patterns which show different transformations. We noted, for example, that the Pictone or Ambiani bovines which were small during the Iron Age underwent a period of strong, rapid and linear growth at the turn of the Christian era, becoming much bigger animals during the Roman period. These bovines were smaller than their Remi (Reims) counterparts, yet similar in size to Baiocasse (modern day Normandy) cattle, which had been bigger during the previous period. The various evolutions of Gallic herds, presenting several shapes and heights, created a regional mosaic during the Roman period, which was different to that of the Gallic period (Fig. 29 and 30). The pattern is thus one of a territory that did not react uniformly to the Roman *stimuli*, but whose cities, valleys and biozones each evolved at their own speed and rhythm. We can easily imagine that these changes influenced the structuration of settlements, their morphology and their organization in various ways. (Fig. 31).

4.2. Species selection

After studying size evolution, the research aimed to determine the triggers of these changes (imported animals or new know-how implementation). This issue was of the utmost importance because it was linked to the general reflection of the Romanisation of the Gallic people. But it was based on a presupposition: that the cattle herd had been *improved*. We initially considered that the size reflected, or was the objective of, an improvement which implied a link with new socio-economic conditions, the increase in agricultural product volumes and the development of outlets near or next to areas of production

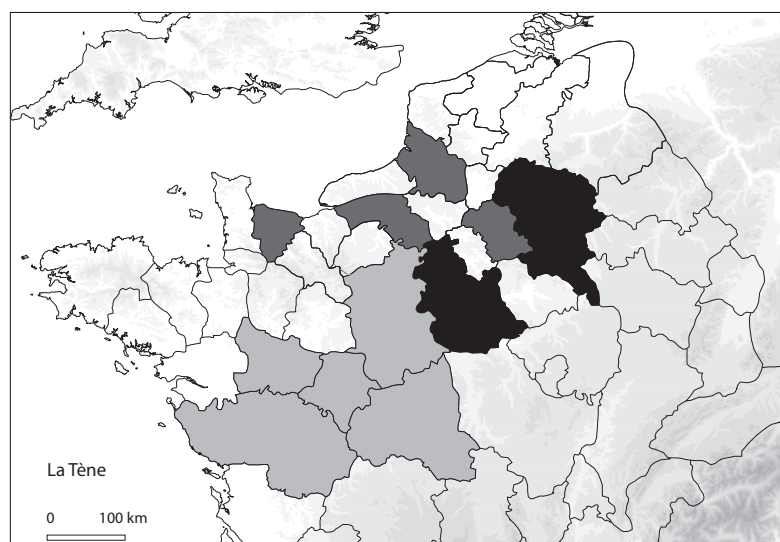


Fig. 29: Representation of the proportion of cattle over 1.20 m in cities during the Gallic period (the darker the shading the higher the proportions) (after Duval *et al.* 2013).

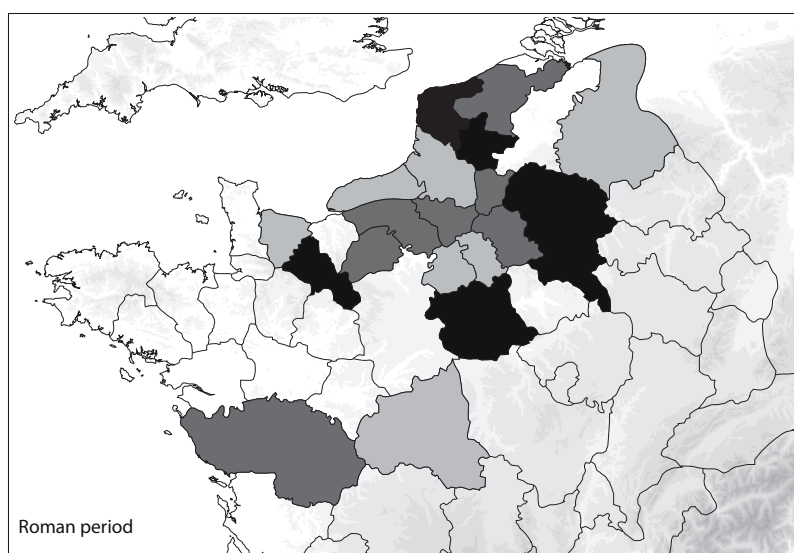


Fig. 30: Representation of the proportion of cattle over 1.20 m in cities during the Roman period (the darker the shading the higher the proportions) (after Duval *et al.* 2013).

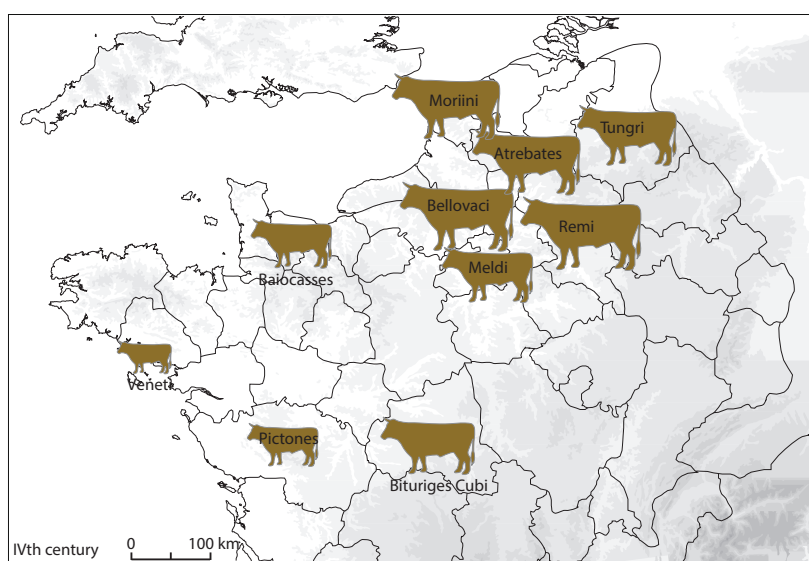


Fig. 31: Schematic representation of the regional diversity of cattle size for the northern half of Gaul in the 4th century.

(cities, urban areas) or farther away (the limes and other regions of the Roman Empire). The subject was thus only approached from the point of view of an “improvement” of the species. The changes implied that a desire to make the animals more efficient had been expressed and that the necessary modifications had been sought. However, the notion of an improved animal is relative, and the notion of size reflecting an improvement is questionable. How would an increase in height constitute an improvement and reflect progress when, in reality, it is just a trait like any other?

It is widely accepted that changes happened early on for Gallic animals; therefore, we have to admit that the changes were due to an evolution in husbandry conditions. If we accept that new know-how was implemented, we can also assume that the farmers had set up a selection strategy beforehand. However, this hypothesis clashes with the realities that Gallic farmers, like Roman farmers, did not face.

Breed improvement is linked to the products it delivers (meat and dairy yields) or to the functional aptitudes that characterize it (reproduction, functional longevity, morphology, resistance and temperament). Selection aims to identify these characteristics in certain individuals of the herd and to favour passing on these characteristics to subsequent generations. But the problem with selection is that it requires identification of the needs and objectives to attain before anything else. Admittedly empirical selection may be undertaken (regarding docility, for example, which is the easiest to consider because it does not influence production), but this happens over a long period of time.

The first essential step in the selection process is to have the capacity to think long term, but this condition is not easily met. Feasibility depends on the animal's fertility and the generational renewal rate¹⁴. That is an important point, hinging on the generation interval for each species (i.e. the age gap between a reproducer and its offspring); this is a small gap in the case of chickens (1 year), longer for pigs (2–3 years) and even longer for bovines (8–10 years) and horses (10–12 years). Clearly it would have been necessary to wait many years before obtaining the (adult) result of previous selection undertaken with livestock reproducers and to analyse the effect of cross-breeding in the new generation (positive, neutral or negative effects), all whilst keeping in mind that the process would have to be repeated and new selections made, without any assurance that the process would work until the characteristics were obtained and fixed.

For chickens, improvements can come from selecting young chicks because their reproduction is rapid, but for bovines, ovines and equids (which are less fertile and who reproduce more slowly) the farmer needs to own males and females that belong to different age groups. This means that generations will overlap, which concretely implies that the farmer has predetermined the capacities of the animals that will become reproducers (choosing one cow rather than another) and that they have rigorous control over their reproducers, that they favour some and eliminate others, or identify the paternal filiation, even if the task remains difficult in extensive or free-range farming.

Secondly, one must be sure of developing specific, sought-after characteristics, without developing unfavourable ones. Indeed, there may be negative correlations for two genetic characteristics, for example increasing milk production may have an impact on fertility. Muscular development may have consequences on egg production for hens, or bone development for mammals. Strictly speaking, sustainable selection implies efforts on reducing the negative characteristics of selection as well.

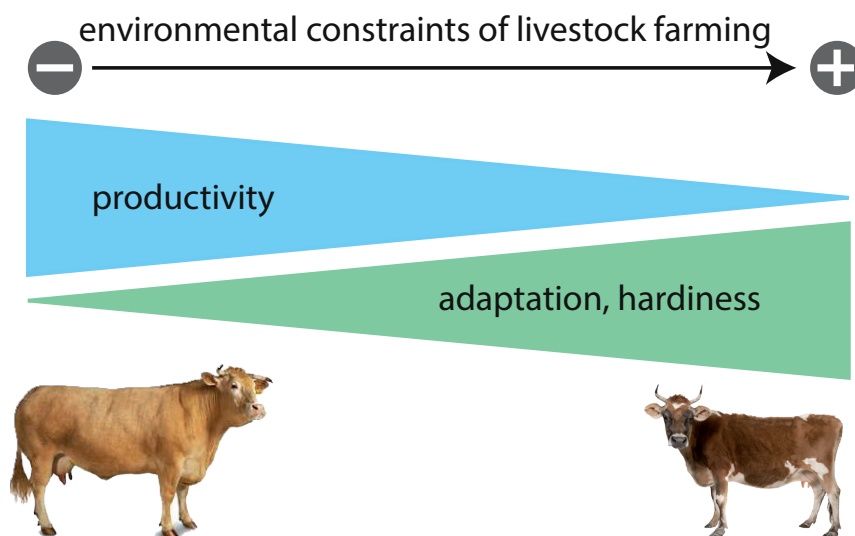


Fig. 32: Inverse relationship between productivity and adaptation, and the hardiness of domestic species according to the environmental constraints of livestock farming (after <https://tice.agroparistech.fr>).

14. Etienne Verrier's work is presented on the pedagogical platform of AgroParis Tech. <https://tice.agroparistech.fr>. It greatly contributed to improvements in this chapter.

Lastly, stock raising conditions and environment constraints must also be taken into account. These constraints may be climatic, linked to parasite loads or food resources. The new specimens will have to optimally combine productivity and resistance depending on the fields they will tread, the pastures they will graze, the cold and the heat they will face; a balance of all these parameters will have to be established over time. In the case of meat production, the farmer may seek to reduce the time between the animal's birth and its slaughter. Early maturity may be sought because an animal which grows faster will naturally be preferred over an animal which matures later and which ends up costing more in food eaten than in meat produced. Improving the diet of young animals enables feeding them for a shorter length of time and increases their profitability (Fig. 32). This means less work for the farmer. The choice to work with early-maturing animals does have its drawbacks, however, because the animals will be more sensitive to the regularity and quality of their fodder, especially if restrictions come into play when they are young, which may compromise their subsequent growth (Hoch 2003). The detrimental effect of poor diet on the profitability of traditional husbandry was studied during the 1950s in farms in the Nivernais province (Boichard 1965). This brings up the issue of the capacity the farm has, or does not have, for pre- and post-season grazing with the appropriate annual crops and the capacity for storing enough high-quality fodder.

Therefore, at the end of the first millennium BC we should thus consider that a prediction process existed in Gaul; a mid- to long-term vision of husbandry guidelines and oriented decisions and, thus, a selection strategy. It would have meant that prescriptive norms determined what was – or what should be – considered a good animal.

This makes us question the possibility that Roman animal selection know-how was imported to Gaul. So what did the Romans really know about herd improvement?

In order to improve a herds' qualities, the farmer had few solutions to modify the individuals they raised: 1) change the husbandry methods or select reproducers from within the herd, or 2) purchase new individuals, change the entire herd or introduce enough new heads of cattle to have an influence through mating. The Roman authors who wrote about agriculture and husbandry did not know about heredity principles and mechanisms, even if they empirically perceived some of their aspects. In certain cases, like for dogs, they undoubtedly favoured a wide diversity of shapes: dwarf dogs, very slender ones or, on the contrary, mastiffs (see Benet and Timm, 2016); they probably also favoured litters presenting the desired format (pets or fighting animals) by targeting the parents; but in the case of farm animals this is not clearly apparent.

The selecting of herd animals is rarely evoked in these early writings, but when it is mentioned it is more about choosing the future terminal sire from rams and goats (those which will not be castrated) in litters where twins are born (Varro II, 2, 18 et II, 3, 4), or only keeping the most robust individual of a twin birth (the other being sold to a merchant) to maintain a herd of goats. Varro also advises making sure that "*the males are of a good breed and to consider their appearance, and that the babies conform to their parent's appearance*" (Varro II, 5, 9). A farmer, an owner whose objective is subsistence farming or speculative farming, will thus want to have the best possible herd; therefore, they will base their activity on the animals they feel are best suited to that end. This truism is clearly seen in the classical *Latin Agronomes* which recommends ewes with abundant wool coats (Varro II, 2, 3), preferably white (Columella VII, 2); cattle with a good constitution and healthy limbs, etc. (Varro, II, 5, 6); pigs with large limbs (Varro II, 4, 3; Columella VII, 9), and nanny goats that produce a lot of milk (Columella VII, 6). But neither Varro nor Columella, or the others for that matter, explain how to implement selection strategies at the scale of the herd or the territories in order to develop sought-after characteristics in the animals (more milk, better conformity or a bigger size). When they recommend looking for these characteristics (and others, including the presence or absence of horns, their size, their colour, the shape of their heads, etc.) they pose these questions in the chapters dedicated to purchasing livestock. Therefore, purchasing new animals is essentially seen as improving the herd (see Varro II, 1, 13 for bovines; II, 2, 5-6 for sheep; II, 3, 5 for goats; and II, 4, 3-4 for pigs). Columella (VI, 1) and Varro (II, 5, 9) indicate that different bovine breeds exist in Italy, that the animals vary in size, character and colour according to their country of origin (Asia, Gaul, Empire) and that it would be good to purchase some. Without going into detail about these breeds and the diversity of possible origins for the herds from which to choose, we should remember that it is essentially through the choice of purchased individuals that the ancient authors considered modifying their herds.

Given that we have shown that the animals' new formats were due to a modification of the native breeds (i.e. there were no large-scale imports of new specimens) and that specific selection was undoubtedly impossible to implement, we should consider that animal size essentially benefited from a strong modification of feeding practices and an increase in the quality and quantity of fodder, all essential factors that directly influence animal size.

4.3. Diet

The importance of diet to explain height evolution during Roman Antiquity has already been addressed by Forest & Rodet-Berlarbi (2002, 295-297). Those who study animal diets in northern Gaul will note the remarkable parallels between the methods used by R. Bakewell and his disciples in Leicester during the 18th century, and the 19th century analyses of the scarcity and slowness of cattle, horses and sheep done in 1841 by L. F. Grogner and J.-H. Magne. Given that the joint intention of multiplying and improving livestock, as proven in Britain and the Netherlands at the time, were not contradictory and could be reconciled, L. F. Grogner and J.-H. Magne described the improvement techniques that the English gentry used for the “*perfecting of agricultural methods resulting in an abundance and superiority of fodder [...]. To achieve (breed improvement), they paid great attention to animal reproduction and early education. It was with the more numerous and more attractive cattle that they obtained more labour and dung, and thus increased fertilization for a more important number of crops*” (Grogner & Magne 1841, 147)¹⁵, creating in some ways a virtuous cycle.

The improvements obtained in Great Britain were rapid: from 1770 onward, over a span of 40 years, the Colling brothers (Charles and Robert) obtained the Durham cattle breed, famous for its great conformity and early fattening ability. This is the breed that was imported to France in 1823 and which were cross-bred with local breeds.

In the mid-19th century, these modifications were perceptible after a few years (Gossin 1858, 279): “*The calf may, through training and diet, take on a different nature than the one it possessed at birth [...]: take young animals of a small variety; feed them better than their fathers were and they will certainly grow bigger and broader. That is how in Champagne and Belgian Ardennes foals became much stronger than their parents. Likewise, the rich Normandy pasturelands transform the young animals brought to them from Brittany, Maine and other poor regions. Diet improvement broadens chests, enlarges muscles and strengthens the body proportionately from head to hoof. [...] If the specimens born from diet-improved animals receive, like their fathers, good feed in abundance, they will be even farther removed from the primitive type.*”¹⁶ Grogner & Magne (1841, xvii) revealed “*that in a few years, the average weight of Bourbonnais cattle increased by seventy-five kilogrammes as a result of cultivated grasslands.*”¹⁷

Lastly we must enquire as to why during the Late Iron Age and, especially at the beginning of the Roman period, one would have voluntarily sought to increase the size of bovine animals. Ultimately, a large cattle is just a small solution in agriculture. Larger animals eat more than small ones, and they barely enrich the field their feed comes from as they only supply a small amount of fertilizer. To pull an ard, a low neck is often better than strong muscle mass. Pliny wrote that “*one should not belittle the species that have a lesser appearance*”, and mentions cows in the Alps that “*give much milk, even though their size is quite small* (Pliny 8, 70). Of course, they supply more meat but this characteristic also raises the issue that the farmer's interests (size, rusticity, increased muscular development, early fattening ability, good milk-producing ability) must also meet the users' and consumers' needs. A large animal must, for example, be adapted to transformation and distribution circuits: from slaughter (butchering, processing great quantities of meat) to consumption (transformation, salting, smoking and avoiding waste). From this point of view, the management of large animals during the Roman period was, as of the 1st century AD, linked to the processing of large quantities of meat in urban zones, through the setting up of butcheries and the development of outlets in urban areas from the Late La Tène period, or for the military presence on the limes thereafter. We may also consider that size increase enables improved by-products such as milk, but that brings us back to the issue of the farmers' capacity to implement selection to that end.

Lastly, another possibility concerns the desire, capacity and necessity to produce large cattle, called *opimi* (Varro II, 20), for public sacrifices. Undoubtedly, some were specifically raised and fattened for that purpose, and one must not underestimate the links between sacrificial practices, ritual precepts, ostentatious practices and the need for big, well-shaped cattle.

The issue concerning the origin of size increase in big animals finds part of its answer in studying the evolution in size of smaller animals. The case for chickens is symptomatic (Fig. 28), and it is rather enlightening to note that the curve for

15. Original quote: “le perfectionnement des méthodes agricoles, d'où est résulté une abondance et une supériorité des fourrages [...]. Pour atteindre (l'amélioration des races), ils ont redoublé de soins à l'égard de la reproduction de l'espèce, et de l'éducation de l'enfance. C'est au moyen de ce bétail (plus nombreux et plus beau) qu'ils ont tiré plus de fumier et de labeurs, qu'ils ont agrandi et fécondé de plus en plus l'agriculture”

16. Original quote: “Le jeune sujet peut, par l'effet de l'éducation et du régime, prendre une nature différente de celle dont il possédait en naissant le principe originel [...] : prenez de jeunes sujets de petite variété; nourrissez les mieux que ne l'ont été leurs pères; ils acquerront certainement plus de taille et d'ampleur. C'est ainsi que les poulains des bruyères de l'Ardenne belge deviennent en Champagne beaucoup plus forts que leurs parents. Les gras pâturages de Normandie transforment de même tous les jeunes animaux qu'on y conduit de la Bretagne, du Maine et d'autres pays pauvres. L'amélioration du régime a surtout pour effet d'élargir le poitrail, de grossir les muscles, de fortifier le corps proportionnellement à la tête et aux extrémités. [...] Si les sujets issus d'animaux améliorés par le régime reçoivent, comme leurs pères, abondance de bons aliments, ils s'éloignent encore davantage du type primitif”

17. Original quote: “qu'en très peu d'années, le poids moyen des bœufs du Bourbonnais a augmenté de soixante-quinze kilogrammes, par suite de la culture des prairies”.

chickens follows that of bovines. In other words, the bird's size increased between the Iron Age and the 4th century, decreased until the 10th century and then increased again up to the contemporary period. It seems scarcely possible that selection was implemented or that birds were imported. In fact, it is probable that the quality of foodstuffs (for humans and animals), their abundance and regularity would have in turn benefited backyard poultry, which makes it possible to confirm that diet is indeed the determining factor in this case, regardless as to whether or not this was the farmer's intention.

Isotopic analyses on chicken remains from Évreux (Clos-au-Duc site, 1st-3rd centuries AD; Herrscher *et al.*, in press) and Amiens (Îlot des Boucheries site, 3rd-5th centuries AD; Mion *et al.*, 2016) revealed that the values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ were the same as those for humans (and dogs), indicating that their diets were similar and contained an important contribution of animal proteins. Chickens and dogs were thus undoubtedly fed with human food scraps.

We may also compare this size increase with the boom in poultry consumption during the Roman period, visible through the large quantities of remains recovered in rural and urban dumps. It seems clear that the Roman period underwent an important development in poultry farming, undoubtedly based on a good quality diet.

Of course, the changes in size for poultry and horses do not have the same impact and we can easily consider that they are not due to the same reasons. Likewise, the stakes for maintaining bigger sizes are not the same. This is something we clearly see during the second part of the Roman period and the High Middle Ages when equid sizes remained stable in comparison to other taxa; therefore they must have benefitted from rearing conditions in line with the intention to continue to raise larger animals. It was better to exchange or buy large horses and care for them by feeding them and their foals, undoubtedly more so than for ovines, or bovines for that matter.

4.4. An improved diet for humans as well?

If changes in animal diets had an effect on animal heights and if we consider the existence of links with human diet, it seems important to look into the eventual changes in human stature for the populations of the territories under consideration. It may seem off topic to address an issue that is not strictly linked with our study material, i.e. vegetal remains or animal bones, by including a paragraph concerning the question of the evolution of human heights during the Gallic and Roman periods, but we believe that one of the future aspects of research will be the comparison of the evolution of agro-pastoral systems with the history of human diet, and the anthropological characteristics of these territories' populations.

L. Heyberger's research (2005) for the Limousin region during the 18th and 19th centuries AD remarkably illustrates the interest of studying human stature within the context of economic history. Anthropometric geography for the generation born in the Limousin region in 1845 highlights the opposition between the north of the region, economically more developed, and the south, economically archaic. Human heights are linked to professional hierarchy in rural Limousin, with important distinctions in height between workers, growers, artisans and owners. The author links the increase in height during the 19th century with better nutrition in this region, itself linked to agricultural changes. Above all, he compares height evolution with average cattle weights between 1814 and 1920, and notes that the heights of conscripts seem to be in correlation with average cattle weights.

For the Antiquity period in northern France, our knowledge of human dietary habits has benefited from isotopic analyses done on human remains from several sites (Mion *et al.* 2016; Herrscher *et al.* in press). Research reveals a diet based on resources, including the meat from herbivores, pigs and poultry (and undoubtedly dairy products and eggs) and cereals. We also see another type of input, either millet (which would have been for human consumption) or, and most probably, shellfish and seafood, which is confirmed by the high number of shells found in waste pits and the fact that millet cultivation sharply decreased after the 5th century BC. Low $\delta^{15}\text{N}$ values indicate a small contribution in animal proteins or a higher legume contribution.

Be it for Évreux or Amiens or other European sites, we see a wide dispersion of isotopic values indicating very varied diets, including within the same site. The people of Évreux seem to have eaten fewer animal products (meat, milk and eggs) and shellfish than their peers in Italy or England, or they possibly ate more legumes. This last point is interesting because in Évreux we observed a chronological evolution: a decrease in animal protein consumption and an increase in legume consumption, which could evoke a modification in dietary habits between the late 1st century and the late 3rd century. However, this information needs to be confirmed by additional studies.

Is it possible to see the effects of changes in dietary habits at the end of the Iron Age and during the Roman period on human heights? Research on this issue for northern Gaul is not readily available, but similar research for other areas is.

For the central territories in Italy (Giannecchini & Moggi-Cecchi 2008), the analyses show a clear decrease in height between the Iron Age (9th century–5th century BC) and the Roman period (5th century BC–5th century AD). Average heights for men went from 1.66 m to 1.64 m; for women they went from 1.54 m to 1.52 m. Another study concerns the evolution of human heights in Sardinia from the Neolithic period to the modern period (Martella *et al.* 2016) where similar results were obtained, characterized by a decrease of about 2.5 cm for males between the Bronze Age and the Roman period (3rd century BC–5th century AD). Heights for women, on the other hand, remained stable or barely increased (1 cm).

Other studies looking at heights in Britain aimed to discuss the impact of Romanisation on the population; these studies also gave similar results. In a synthesis book on the health of the British population, Roberts & Cox (2003) compiled data on heights during the Iron Age (9th century BC–1st century AD) and during the Roman period (mid-1st century AD–first half of the 5th century AD). Here, they noticed a sort of continuity in men's stature (1.68 m to 1.69 m) and a decrease for women (from 1.62 m to 1.59 m). A study from Poundbury Camp in Dorset, with burial sites from both the Iron Age and the Roman period, showed a decrease in stature for both men and women (Molleson 1992, cf. table 1 p. 184). A wider scope synthesis for the same region (Redfern 2005) confirmed the decrease in stature for women but concluded that men's stature remained stable. The average height during the Iron Age (8th century BC–1st century AD) for men was 1.69 m and 1.56 m for women; during the Roman period (1st century–late 4th century AD) it was 1.69 m and 1.53 m, respectively.

This is not the place to consider all the reasons that could explain these variations (especially the differences between men and women), given that they are certainly numerous (Redfern 2005, 318); however, we would have expected an increase in height between the Gallic and the Roman period when taking into account the increase in, and safeguarding of, food stocks. But that is not the case. Heights that top out, or decrease, suggest the existence of deleterious factors at a local or regional scale which have to be identified (access to resources, a decrease in protein consumption, social stresses such as maltreatment and slavery, and environmental conditions) and which counterbalance the visible increase in foodstuff production volume. These characteristics should also be studied for all the social classes in existence at the time.

Another item of information gleaned from these studies is the reversal of the trend during the Middle Ages. In Italy, as well as in Britain, population height increased from the medieval period and it is possible that the human height evolution in our zone of study is similar to what was observed here, but only future analyses will tell. It is, however, clear that for these regions the curves for men and animals differ.

Multiplied to the scale of the sites, the evolution in the size of farm animals must have considerably increased the need for grasslands and fodder plant production. Understanding agricultural systems and evaluating their capacities must therefore take into account the potentially high portion of production set aside for the animals, and a non-negligible amount of land dedicated to pasturing or the production of grass. Through the importance of good-quality fodder crops and the varieties of plant combinations that were created, we can see that agricultural production was oriented to supply enough food to feed these big animals (the increase in size implies an increase in fodder crops of 40 %). In terms of arable and grazing surfaces, transportation and volumes to store, the repercussions of this size increase must have been colossal. That is why we will look more closely at the issue of animal diet in the following paragraphs.

5. The animal foodstuffs issue: a fodder revolution?

5.1. The need for, composition of and importance of fodder

The need to feed animals is felt throughout the year in the organization required to put herds to pasture, to produce feed when there are not enough natural spaces and the proper management of seasonal fodder deficits. In the temperate regions studied, that is an essential and structural issue during the winter and spring-hunger gap when deciduous trees and shrubs are bare, the aerial parts of grasses are absent, and the vegetal growth of evergreen species is nil. This need will be even greater if the animals are kept in buildings or in corrals rather than left outside, free to seek something to feed on.

The quantity and quality of food directly influence an animals' health and weight growth, as well as the demographic growth of the herd. Good quality food also conditions the number of births and the survival rate of offspring at birth and during the nursing period.

Evaluating the food quantities needed to maintain herds is not easy as it depends on the characteristics of the animal species, their relative resistance and the specificities of cultivated and natural fodder. As such, the resistance of ancient species is unknown; it is possible that keeping animals in stables or sheep pens, during the poor season was not an obligation for resistant animals. Protecting them from predators did not by itself justify these precautions. Then again, monitoring

calving and lambing, and then milk production, could eventually require grouping animals in close proximity to dwellings. Archaeological remains of stables and sheep pens exist for the late Protohistoric and Roman periods¹⁸, where the presence of excrement layers containing calcium oxalate have been found (Brochier *et al.* 1992). Likewise, entomology has been conclusive for detecting stable bedding even though the insect spectra are very similar to those found in stocks of hay or fodder (Smith 2008), indicative of the same activity.

In the following paragraphs we will consider the feeding of small and large livestock, but not backyard poultry. Not because they are not interesting, but simply because feeding poultry is not much of a constraint for the farmstead. We do know that poultry benefited from human food scraps and probably from other arable products, which thus fostered an increase in size due to its quality.

Among the domestic animals are herbivores like cattle, sheep, goats, equids and others, like pigs, which can accommodate more varied feed. Ruminant animals, eaters of stems and leaves, have digestive systems adapted to transforming cellulose¹⁹, a glucose polymer that makes up cell walls, which no pluricellular animal is spontaneously capable of doing. Strict herbivores have developed a symbiosis with the bacteria that produce cellulase, an enzyme capable of breaking down cellulose to liberate nutritional elements. In fact, one feeds the cattle's intestinal flora rather than the animal itself. To do so, the ruminant's stomach has several pouches where fermentation occurs, favouring enzymatic action, further reinforced by the fact that the animal regurgitates its food and chews it again. In horses, which are monogastric, this action is done by the large intestine.

This natural capacity to break down fibres does not exist in omnivores like pigs. Therefore, it is not in the best interest of the latter to eat cellulose as they cannot digest it, whereas a herbivore will extract an energetic benefit from it. This benefit nevertheless reveals itself to be unequal for cattle and equids. For cattle, fermentation in the rumen happens at the beginning of the digestive process, whereas with equids breaking down food happens at the end of the process; they must, therefore, eat smaller amounts of food over a longer period of time. However, if a ruminant has a diet that is too rich in fibre, the walls of the rumen will retain a maximum number of large-sized particles which slow down the digestive process to the point of risking the animal's life, as it no longer receives enough energy (Anderson & Ertug-Yaras 1998).

A cellulose-rich diet only slightly nourishes an animal and does not contribute to fattening it up because it is the nitrogen that works to make plant proteins. Nitrogen plays a key role both in the yield and nutritional quality of the plant by favouring the formation of chlorophyll and photosynthesis, which result in the production of amino acids. Plants nourish themselves from mineral nitrogen in the form of nitrates or, in the case of leguminous plants, by fixing aerial nitrogen thanks to a symbiotic relationship with the soil's aerobic bacteria found in the rhizosphere around the roots. They then transfer the nitrogen to the leaves where enzymatic reduction takes place. For the animal, the green parts represent the greatest input of energy. If a complement is to be considered, straw, which has a lot of cellulose, will not be suitable for all animals.

A balanced plant-based diet rests on a wide variety of ingredients in order to respect the balance between energy input, the regulation of the digestive process and available products. Plant fodder including domestic species may benefit from the addition of some of their by-products (straw, stems, green tops, husks and glumes). It is necessary, however, to add high-energy elements that the animal will extract from leguminous plants, hay and cereals. The line between human diet and animal diet is therefore often difficult to see in carpological assemblages.

Several types of fodder may be considered, excepting the particular case of seaweed and the specific seaside environment which has led sheep to adapt to digesting the large quantities of iron and arsenic found in seaweed (Balasse *et al.* 2006; Balasse 2013):

- Forest-sourced fodder: leafy branches and other leaf fodder (Halstead *et al.* 1998), budding branches (Haas *et al.* 1998), acorns, etc.
- Grass-based fodder: hay, grass.
- Arable fodder and its by-products: grasses and legumes such as clover, medicks; domestic pulses and their greens; cereals, straw and other cereal by-products, stubble and arable weeds.

¹⁸ For older periods (Neolithic) see also (Delhon *et al.* 2008); these buildings have been identified with certainty using phosphorus mapping (Fechner 2011; Rouppert *et al.* 2011; Broes *et al.* 2012; 2017).

¹⁹ Cellulose is present in the secondary walls of vascular plants, together with lignin: wood and fibers, as well as straws and cereal glumes.

Fodder may also be classed in two categories:

-Green fodder: grasses and leaves, grazed in the field or cut to be eaten fresh.

-Dry fodder: hay and leaves, harvested and dried to be eaten during hunger gaps. In the latter case, drying produces a product that has lost an important amount of its water. Water content varies strongly between the various types of fodder: from 80 to 85 % (15 to 20% of dry material) for young grass, and from 8 to 15 % (or 85 to 92 % of dry material) for cereals, hay and straw.

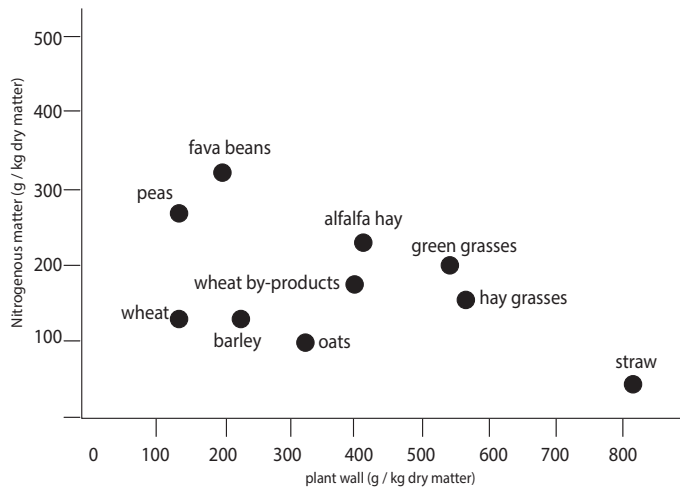


Fig. 33: Relationship between the average nitrogen content and the plant wall content of fodder (modified from Sauvant 2004-2005).

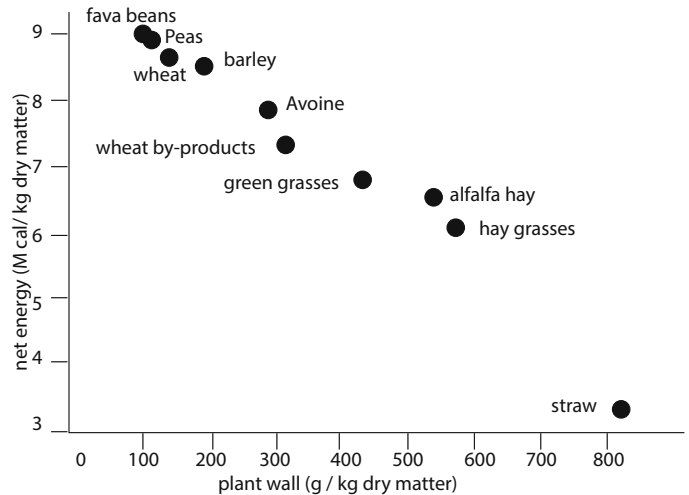


Fig. 34: Negative relationship associated with the energy contents of fodder and plant walls (modified from Sauvant 2004-2005).

It is possible to evaluate the rations needed to cover the nutritional needs of animals, but these proportions vary according to energy, nitrogen, vitamin and mineral values in the available products, as well as the digestibility factor of the feed. It also depends on husbandry methods, the breed (and thus the size and weight of the animal), the age of the animal, what it produces (milk, wool, meat), their living environment, the nutritional value of the fields they live in, and the season when the animals are sent out to grasslands. The nutritional value of feed also varies greatly from one product to another. Moreover, there are as many nutritional elements as there are limiting nutritional factors in the diets; for example, the quantity of nitrogen per kilogram of dry matter varies from 1 to 6 between straw and peas (Fig. 33) and the difference in available energy is 1 for 10 (Fig. 34). If using the international units of fodder per horse, 1 kilo of barley has an energetic value equal to between 1.78 and 2.63 kilos of natural meadow hay and 3.4 kilos of wheat straw (Martin-Rosset 2012). Therefore, we can clearly see that taking into account only available or necessary grass surfaces to feed the herds is not enough to determine the capacities of a system.

Plant products may be selected by picking, cultivating or even by the animals themselves. In the last example they will be eaten directly from the forest undergrowth, pasturelands, high altitude grasslands and natural wet grasslands, which implies direct surveillance (shepherds keeping watch) or indirect watch (by isolating the places to keep animals away from them). Animals tend to pick the most palatable plants in terms of aspect, colour or taste; they usually choose the most tender or youngest plants, as well as the softest parts of plants which have the least amount of cellulose (Anderson & Ertug-Yaras 1998). The use of straw for fodder will provide varying amounts of energy, as previously mentioned, and even if the ruminants can digest cellulose certain animals may show no interest in eating it. Therefore, the nutritional value of fodder is of importance, but it must also be accepted and voluntarily eaten by the animal. Many plants will be picked before maturity (before the plant goes to seed) in order to reduce the amount of ingested lignin; depending on their chemical makeup not all seeds are digested in the same manner. Clearly the taxonomic spectrum recorded in an archaeological context will be limited, to a certain degree. Experiments conducted in England on modern hay harvests tried to determine which taxa had the best chances of subsisting in carpological and palynological recordings (Greig 1984), with the most preoccupying result being the under-representation of Poaceae and *Plantago* in the seed assemblages, two taxa regarded as typical grassland plants.

5.2. The diversity of feeding methods

Attempting to reconstruct the feeding methods of domestic animals during Antiquity must take into account all of the constraints that food production implies. The nature, quantity, supply and surface needed for their maintenance differs greatly according to the contexts under consideration.

5.2.1. Pigs

Pigs are the easiest to feed as they are not very demanding about what they eat, but it is nevertheless necessary to ensure intakes in energy (cereals, roots and tubers), proteins (legumes) and vitamins and minerals. Fodder with a high cellulose content is not adapted to these monogastric animals. They can, however, benefit from cereal by-products that have more nitrogen than grains and, of course, from table (meat and dairy) leftovers, which may be sufficient in the case of a family-operated farm. Therefore, the number of heads of livestock per hectare will vary according to available surfaces, the extent of pasturelands, woods, hedges, orchards, cultivated surfaces, grain residues, the farming type and human population density (urban, suburban zones and open spaces). The surface needed to maintain one pig for one year may exceed two hectares per head, which limits the number of animals that a rural farm could maintain. The data for the 19th century (Grogner & Magne 1841) highlights taking pigs into the forest where they feed on leaves, acorns, roots and insects; but the study also underlines the fact that grasslands abundant in clover are the best adapted terrains.

Legumes and cereals are excellent feed for confined pigs during the fattening stage, and we can consider that certain archaeobotanical assemblages found in the archaeological context may have served this purpose (see 5.2.5). Through the analysis of isotopic signatures on Iron Age pig remains (nitrogen and carbon), the studies by D. Frémondeau (2012; Frémondeau *et al.* 2012) reveal a mainly herbivorous diet enriched with fruits and roots, which seems to support the idea of open air farming. Teeth analyses clearly evidence that there are seasonal variations, with an input of acorns and beechnuts in autumn.

In Amiens, for the 3rd-5th centuries AD (Mion 2016), isotopic analyses confirmed an exclusively plant-based diet with an important input of resources enriched in ¹³C, such as acorns or mushrooms. Studies done for the 1st-3rd centuries AD in Evreux (Herrscher *et al.*, in press) also show isotopic values recorded for pigs that are very similar to those for other herbivores (cattle and sheep); but very different from those of humans and dogs, revealing for the latter a very high animal protein intake. The levels observed for swine are compatible with those recorded for animals raised in the open air in an identical setting to that of sheep and cattle. This information highlights the means of swine production and enables us to re-evaluate the hypotheses concerning the importance of urban husbandry: according to our data, urban rearing was scarce, or it was organized in such a way that pigs would have been exclusively fed with plants rather than table scraps.

5.2.2. Cattle

The amount of feed eaten by one head of cattle varies according to its size, weight, age and sex. The basic ration for a small cow weighing 375 kilos (which corresponds to the mean weight during the La Tène period) is approximately 8 kilos of dry matter per day (or about 9.5 kilos of hay or 53 kilos of fresh grass). For a 615-kilo animal (mean weight for the Roman period) it is 11.5 kilos of dry matter, 14 kilos of hay with a good dry content value (85 %) or about 80 kilos of grass daily (according to the calculations using formulas given by Cuvelier & Dufrasne (2015, 63). This value is close to that given by Chancrin & Dumont (1921) for the early 20th century, indicating that a dairy cow or an ox needs 15 kilos of hay per day.

These evaluations differ slightly for other authors: for example Demarquilly *et al.* (1966) noted 2.1 to 3 kilos of dry matter per 100 kilos of live weight for small format cows, that is to say 12 to 17 kilos of dry matter for a 580-kilo animal. A dairy cow weighing 650 kilos and yielding 20 litres of milk per day will thus need 17 kilos of dry matter (that is to say 113 kilos of grass per day); it is clear that the quantities required can very quickly become massive (Fig. 35). A small farm with just six 600-kilo bovines would have to be able to supply close to 180 tons of grass per year to feed them, which corresponds to about 25 tons of dry matter. Given that the average yield of non-fertilized grasslands is around 5.6 tons of dry matter per hectare (source: INRA 2012 in Doligez 2016), the surfaces needed for maintenance are, at minimum, one hectare per head. Chancrin & Dumont (1921) say 1.5 hectares per head when two cuts are done on a hay meadow.

5.2.3. Horses

For horses, the rations vary from 9 to 11.5 kilos of dry matter per day to feed a 600-kilo animal. For a work horse (1 hour per day) the quantity increases to 11.5-12.5 kilos of dry matter per day (Doligez 2016). Other sources indicate 15 kilos of dry matter per day for a riding horse or 80 kilos of grass (source INRA 2012 or Martin-Rosset 2012). Taking into account the need to harvest hay on half sections of land, to avoid the formation of grazing residuals, one hectare under excellent management

conditions may be enough to maintain one horse; however, more land is undoubtedly necessary in the case of less optimal management.

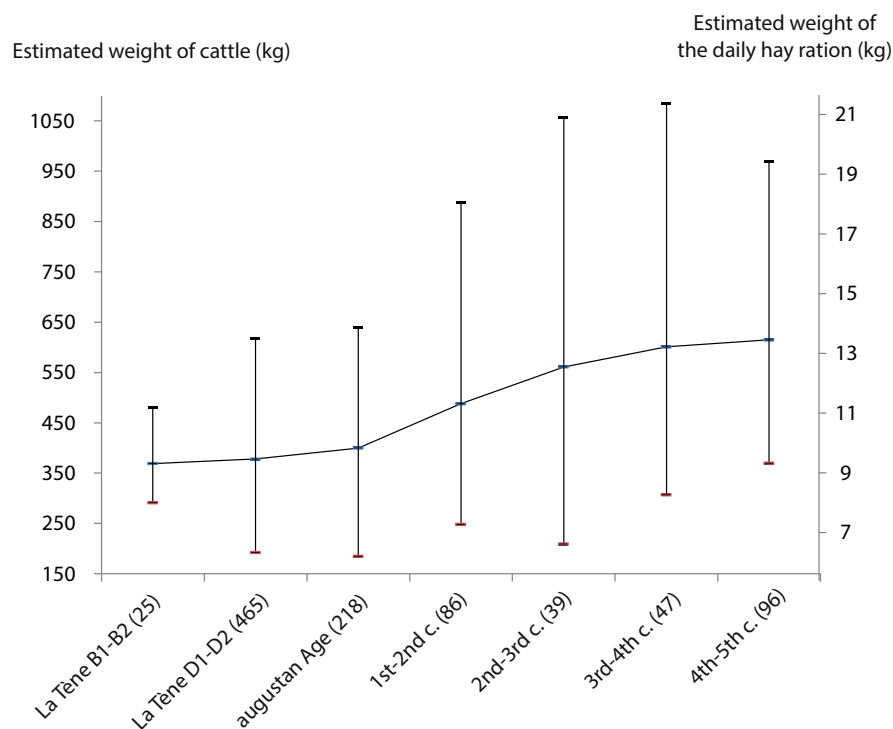


Fig. 35: Evolution of the estimated average weight of cattle between La Tène B and the 5th century (estimated from 976 complete long bones) and the estimated weight of the daily basic hay ration (estimated for the maintenance of a dairy cow, provided by Cuvelier & Dufrasne 2015).

5.2.4. Sheep and goats

For sheep and goats the case is slightly different than for cattle or equids. The amount of feed will depend on their breed, size and condition (maintenance, gestating or lactating). Dry matter rations must be around 2 kilos per head, which makes it possible to consider about 5–6 sheep per hectare (this corresponds to the livestock units (LU) recommended for grass-fed sheep farming).

Along with directly feeding off the ground, plants can also be brought to the pens, which implies adapted storage and transportation means for the volumes needed. Storage capacities required to maintain small animals during the Iron Age have been studied (Malrain 2000, 295). The numbers for one year for one head of livestock were around 45 to 65 m³, (including various feed, hay and straw) and for small livestock were 10 to 15 m³ per individual. It is impossible to admit that period equipment would have sufficed for such volumes, even if the animals were small at that time and if all the buildings of a La Tène period farm were used to store livestock feed.

The issue is even clearer during the Roman period as animal sizes significantly increased. This would mean that animals were fenced in for a good part of the year and that light structures existed (although we find no trace of them in the soil) or that they were housed outdoors. Leaves, branches, grass, straw and agricultural products were stored in haystacks, large-capacity storage pits or above-ground structures (hay lofts or barns). These structures have been studied recently and results show they were distributed mostly in the upper third of France (Ferdrière *et al.* 2017 and map p. 172).

5.2.5. Ancient texts

In their description of supply means and places, ancient sources make a distinction between maintained areas and “natural” areas through the words *pratium*, for improved leys close to the residence, and *saltus*, for natural areas not adapted to farming, far from the habitat, but nonetheless visited by livestock (Ruas 2008). A few areas seem to be more dedicated to feeding animals than others:

- Maintained coppices and hedges which are regularly cut, pruned, trimmed and thinned;
- Uncultivated lands, brush lands and swamp areas (cited by Col., *Rust.*, VII, 9), path borders and abandoned wildland

areas are also frequently visited;

-Lawns, grasslands, meadows and pasturelands differ in their current definitions depending on the point of view: rural, biogeographical or phytosociological (Ruas 2008, tab. 1);

-Improved leys (sown and fertilized), abandoned or temporarily uncultivated fields ("*pâtis*") (mentioned by Palladius for ewes, XII, 13).

The sowing of grasses is explicitly mentioned by Pliny the Elder (18, 57, 6), who indicates that hay fields were planted on the most fertile and best watered fields. Other Latin authors mention several types of fodder plants: barley for sows (Col., *Rust.*, VII, 9), barley flour for calves (Varr., *R.*, II, 5), bran for lambs (Pall., XII, 13), medicks (Plin., 18, 43, 1), clover (Plin., 18, 57, 7), Celtic beans (Plin., 18, 30, 1; 57, 7), vetchs (Plin., 18, 37, 1; 57, 5), bitter vetch (Plin., 18, 38, 1), lupine (Plin. 18, 36, 1 and Cato, *Agr.*, LIV), white lupine and vetch (Pall., I, 6), acorns for pigs (Varr., *R.*, II, 5; and for cattle, Cato, *Agr.*, LIV), hay and straw (Pall., XII, 13), chaff and "laburnum"²⁰ (Col., *Rust.*, V, 12), leaves and ivy (for cattle, Cat., *Agr.*, LIV), grape pomace (for pigs, Varr., *R.*, II, 4; for cattle, Cat., *Agr.*, LIV), wild fruit (Col., *Rust.*, VII, 9) and even orchard product (Col., *Rust.*, VII, 9).

This list is certainly not exhaustive. The authors also regularly evoke harvesting green plants and pasturing in zones that are temporarily uncultivated or even abandoned fields. Some quantities are mentioned, for example for cattle: approximately 6 litres of acorns per head per day with pasturing during the day and 25 pounds of hay at night for each animal (Cat., *Agr.*, LIV). Fodder supply sources are therefore quite varied. But what does archaeobotanical evidence reveal about Gaul, particularly in the north-eastern regions?

5.2.6. Archaeobotanical evidence for the different fodder categories

5.2.6.1. Forest sourced products

In the study zone, evidence of forest foraging essentially pertains to lakeside habitats in the foothills of the Alps dating back to the Neolithic period or the Bronze Age²¹. However there are no settlements preserved in similar conditions for the more recent periods. Layers of manure discovered inside mountain cave sheepfolds have made it possible to document these practices in the Vercors Massif, which is part of the Prealps (Delhon *et al.* 2008; Martin 2014). Ecological anomalies highlighted in the anthracological diagrams for at least eight mountain cave sheepfolds in southern France allows us to posit that certain varieties were specifically selected to feed animals. The use of fodder pollards was not limited to the Alps or the Jura Mountains and probably concerned a larger part of Neolithic Europe (Thiébaud 2005).

Archaeological evidence of pollarding is difficult to take into account. On the one hand because harvesting leaves could have been done by simply stripping the branches leaving them intact, a technique ("*érussage*") documented during the 19th century in western France (Sigaut 1987), and on the other hand because severe cuts (lopping, pruning, trimming) may have been done for sanitary or farm operation reasons that had nothing to do with fodder harvesting (Cardoni 2014). Trimming a tree may aim to shape its contours, to regulate its growth, to stimulate fruit production, or to shape branches to obtain certain products like rods or poles. Nonetheless, leaf fodder was a non-negligible resource. An animal feeding experiment using leafy branches was carried out in 1986 by the Historical-Archaeological Experimental Centre of Lejre in Denmark and described by P. Rasmussen (1988). An ash tree (*Fraxinus excelsior*) and an elm tree (*Ulmus glabra*) were trimmed and yielded 83 and 56 kilos of green leaves, respectively, of which only 42 and 24 kilos of leaves remained after several days (2–7) of drying. The nutritional value of the leaves was calculated and proved to be slightly superior to the nutritional values of clover and hay, which is to say 0.75 FU/kilo of dry matter (Laederich 2003, 31). Based on this experiment and the known nutritional value of leaves, P. Rasmussen (1990) estimated that a Neolithic cow probably ate 4 to 5 kilos of leaves per day, versus 1–2 kilos for a sheep. St. Thiébaud (2005) deduced that taking into account the average 3–4 year intervals between cuts, 72 trees in different growth stages were necessary for the upkeep of one cow over the winter, and a herd of 10 cows would need 3 to 4 hectares of woods at their disposal. L. Laederich (2003, 47), quoting Petrovic (1936) on the use of leafy branches for feed in, what was then, Yugoslavia, indicated that one person needed to work for 3 days to assemble the necessary rations for one cow for one winter (supposing it was fed only with leaves). Storing leaves was done in stacks or silos, after having been allowed to dry (Halstaed 1998; Sigaut 1987).

20. This probably refers to a shrubby legume, though not necessarily *Laburnum anagyroides*

21. Troels-Smith 1984; Robinson & Rasmussen 1989; Rasmussen 1993; Akeret & Rentzel 2001; Laederich 2003; Khün & Hadorn 2004; Bleicher 2016.

For a long time in Europe leaf fodder was the basic food for domestic animals kept in barns or confined in sheep pens, and its harvesting techniques have scarcely evolved. It was not necessarily the sole food for livestock as grasses were also used. A significant change progressively occurred during the Iron Age when grass fodder (hay) was cultivated. While the mineral and nitrogen contents, as well as the energetic values of hay, are inferior to those of leaves, it is a cheaper fodder in terms of quantities to give because hay is almost completely digested (Laederich 2003, 24). Moreover, the decrease in forest surfaces, decimated by agriculture and crafts (ceramic, metal work) between the Neolithic and recent protohistoric periods, would have justified a rebalancing of fodder choices.

The development of the scythe during the La Tène period enabled an unprecedented gain in productivity compared to harvesting grass with a sickle, as the scythe multiplied yield quantities by a factor of 2 to 5 for the same amount of time (Sigaut 1987). This substantial revolution in livestock feeding directly influenced the animals' appearance and their work capacity. F. Sigaut foresaw this when he wrote (1987, 47): *"The animal's work yield depends on how it is fed. Substituting hay with leaves in the fodder made it possible to go beyond an essential stage in the important increase in the use of animal power"*.²² Before attempting to evaluate the consequences of this change, we shall continue describing the main types of fodder under consideration.

5.2.6.2. Grass fodder

The scythe, hay and hay meadows form a whole that is found only in Europe (Sigaut 2003, 282). Here, grasslands are mostly of an anthropic origin; they replaced forest vegetation (Van Zeist 1991). When there is no human intervention, woodlands slowly take over and a closed environment is considered to be the steady state (ecological climax).

Grasslands, meadows and pasture designate dense and continuous or mixed grass formations. There are very subtle distinctions between the ecological, agronomical or vernacular understanding of them. Rather than giving them restrictive definitions, M.-P. Ruas prefers to include the diversity of situations that are hidden in the dynamics that evolve with nature and the intensity of man's use of these environments (Ruas 2008, Fig. 3). We must keep in mind, however, that a hayfield is different from a meadow, in that a hayfield usually designates a delimited space, close to a river or stream, used for growing hay or for pasturing, whereas meadows and grasslands evoke flat land occupied by grasses, with a variety of wildflowers, temporarily or continuously used for grazing. Be it for an improved ley associating 2–3 plant species, or for an unsown hay meadow, the more anthropic pressure there is the more plant diversity decreases. Ruas concludes that *"classifying grass formations into types of meadows or grasslands (without taking into account uncultivated land and pasturelands) is based on three categories of interdependent parameters: the topographic location and the nature of the soil (i.e. wet zones, dry or floodable soils, slope, altitude, plain etc.); the amount of time the land is occupied within the cultivation cycle (i.e. temporary /permanent grassland); the type of management and the degree or absence of human intervention (artificial/ natural grassland)"*.²³ (Ruas 2008, 18).

Scythes considerably increased cut yields; smaller quantities of grass could be cut with a sickle. The length of the blade determines the tool's efficiency and its development enabled more efficient fodder harvesting, which proved crucial for feeding livestock during the colder months in regions subject to snow. Scythes were thus linked to specific climates and regions where sedentary herds were maintained in captivity, at least for part of the year (Sigaut 2003).

Since W. Van Zeist's overview (1991), few papers or studies have addressed the issue of grasslands. For the Rhineland, K.-H. Knörzer (1975) observed that the number of grassland plant taxa recorded in settlements dating back between 800 and -1 BC/+1 AD had doubled in proportion in comparison to those noted on Neolithic sites, even though the number of sites was much smaller for the Iron Age. The presence of wet grassland species added to dry grassland ones seemed to suggest hay harvesting (Knörzer 1973).

A similar approach was pursued on a corpus of sites located in the north-eastern quarter of France, covering the first millennium BC (111 settlements), but a similar evolution was not observed (Toulemonde *et al.* 2017a). The numbers of grassland species and small-seeded Fabaceae were calculated for the eight chronological phases defined, but no manifest increase was perceived (Toulemonde *et al.* 2017a, Fig. 9).

22. Original quote: "Le rendement de l'animal dépend de la manière dont il est nourri. La substitution du foin au feuillard dans les systèmes d'affourrage a permis de franchir une étape essentielle dans l'intensification de l'utilisation de l'énergie animale".

23. Original quote: "Le classement des formations herbeuses en types de prés ou de prairies (sans considérer les friches et les pâtures) s'appuie, en définitive, sur trois catégories de paramètres interdépendants: la localisation topographique et la nature du sol: zones humides, sol sec ou inondable, versant, altitude, plaine, etc.; la durée d'occupation du terrain dans le cycle d'exploitation des parcelles: prairie temporaire/prairie permanente; et la forme de gestion et le degré ou l'absence d'intervention humaine: prairie artificielle/prairie naturelle".

This work was once again taken up for the RurLand programme in two separate areas: the centre of the Paris Basin and the eastern lands (Fig. 36). In the first zone, no evolution in grassland plant diversity or frequency was detected. Nevertheless, the approach should be refined as it first quoted the presence or absence of the said plants but did not take into account the number of remains. In the eastern zone, the only visible inflection was during the High Empire period, but that may be linked to a smaller number of sites, which increases the corrective factor (without weighting, double the amount of sites does not necessarily translate into double the amount of attested species.)

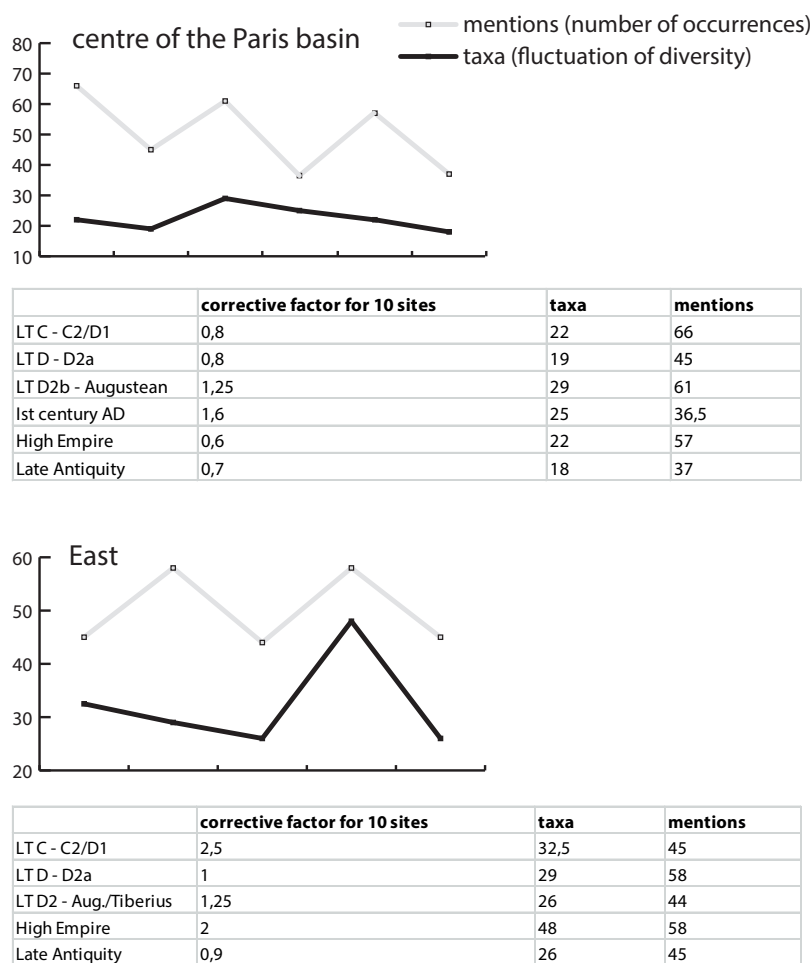


Fig. 36: Diversity of taxa corresponding to grasslands (main or secondary habitat) in carpological assemblages and the evolution of their occurrence by chronological phase and presence/absence. Weighted data for 10 sites/period, considering the fact that the number of settlement analyzed by phase and the duration of the chronological intervals were not constant.

In general, wet grassland species (Molinio-Arrhenatheretea class) are regularly present in carpological assemblages. It is, however, difficult to judge if these numbers reflect hay harvesting or the cutting of plants in the wet zones for litter, fodder, or perhaps even for covering farm buildings.

In Roman Germany, several sites had rich assemblages including grassland plant seeds, especially those from Xanten (Knörzer 1981), Neuss (Knörzer 1970), Welzheim (Körber-Grohne & Piening 1983), Mainhardt (Körber-Grohne & Rösch 1988), Butzbach (Knörzer 1973) and Oberwinterthur (Jacquat 1986) (mentioned by Van Zeist 1991). A burnt stable in the Roman cavalry fort of Dormagen near Cologne yielded an assemblage containing 87 % grassland plants (Knörzer 1979). Hay was also discovered in the Neftenbach villa in Switzerland (Klee & Jacomet 1999). Here, carpological assemblages contained 50 to 80 % grassland and pastureland plants such as Timothy-grass (*Phleum pratense*), rough bluegrass and common meadow grass (*Poa trivialis/pratensis*), self-heal (*Prunella vulgaris*), English plantain (*Plantago lanceolata*), hoary plantain (*P. media*), ox-eye daisy (*Leucanthemum vulgare*), mountain clover (*Trifolium montanum*) and common stitchwort (*Stellaria cf. graminea*).

These assemblages reflect varied ecological conditions and farming practices; therefore, it seems that grasslands which grew in well-watered, nutrient-rich soils were favoured, which could correspond to the environmental conditions of manured meadows, as has been suggested for Welzheim (Körber-Grohne & Piening 1983) and Oberwinterthur (Jacquat 1986). Both grazed and cut grasslands can be reconstructed. At the time, the latter were cut much later in the season than they are now, as the presence of ripe fruit and seeds in the hay reveals (Knörzer 1970, 146). But we could counter this argument with the

fact that an earlier harvest would mean fewer carpological items. The absence of certain species such as *Arrhenatherum elatius* (tall oat grass), *Avenula pubescens* (downy oat-grass) or *Trisetum flavescens* (golden oat-grass) suggests that animals freely grazed in the grasslands at the beginning of the season, before they were kept away in order to allow the grasslands to develop for the subsequent harvest (Knörzer 1970).

In France such assemblages are rare. A carpological spectrum evoking grass fodder was nevertheless reported for the 'La Grande Fosse' site dug by J. Avinain (Inrap) in Épiais-lès-Louvres, in the Val-d'Oise department. Mineralized seed remains were found in a pit alongside a building (structure 3), believed to be a stable, dating from the first half of the 4th century AD (Broes *et al.* 2012). At the bottom of the pit (structure 5107) a greenish layer was observed which yielded 331 mineralized seeds for only 7 charred remains; the latter were interpreted as domestic species. The rest of the spectrum was composed of species growing in fields and grasslands such as *Anagallis arvensis* (scarlet pimpernel), *Anthemis* (corn chamomile), *Ballota nigra* (black horehound), *Chenopodium* (goosefoots), *Daucus carota* (wild carrot), *Eleocharis palustris* (common spike rush), *Glechoma hederacea* (ground ivy), *Linum catharticum* (purging flax), *Myosotis* (forget-me-nots), *Papaver argemone* (prickly poppy), *Papaver rhoeas/dubium* (corn poppies and longheaded poppies), various *Polygonum* (knotweed) and *Poa* (bluegrass), *Prunella vulgaris* (common self-heal), *Ranunculus* (buttercups), *Reseda lutea* (mignonette), *Rumex* (docks), *Stellaria* (stitchwort), *Torilis* (hedge parsleys), and *Urtica dioica* (common nettle). Assuming the pit might have received stable manure, seed mineralization would indicate that the animals had grazed on wild grasses in grasslands, uncultivated, and wildland zones.

Farm equipment yields supplementary information about fodder harvesting. Different tools (sickle, grass hook or scythe) were used for harvesting grasses including long-handled instruments which cut by striking the stems from the side, holding the tool in one or both hands (Sigaut 1985; 2008 unpublished). Pliny the Elder said that the Italian scythe was held in one hand and that the one used in Gaul "cuts grass through the middle [of the stem]"²⁴ (18, 57, 10).

The first grass hooks/scythes ever discovered were found in the Central Alpine area (Switzerland, Austria, Germany, Italy and ex-Yugoslavia), but this area expanded during the Roman period to reach north-eastern France (Sigaut 1985); none have been found on the Atlantic coast (Nillesse & Buchsenschutz 2009). The earliest tool that could correspond to a grass hook/scythe was discovered at the Buchères site in the Aube department; the painted ceramics found in the same layer indicate the tool dates back to the first half of the 5th century BC, as V. Riquier's study shows (Toulemonde *et al.* 2017a). The blade is about 30 cm long but it was not possible to determine the type of shaft. Complete tools of the same type were, however, unearthed at the La Tène site in Switzerland; they have thick blades and short, straight shafts. N. Bernigaud (2013) suggests these tools were perfectly suited to harvesting plants in swampy grasslands. Another blade, a little over 56 cm long, was part of the material culture from a 2nd century BC context from the Acy-Romance site in the Ardennes; these represent the earliest specimens found. For Gaul, A. Ferdière *et al.* recorded 224 items for 115 sites (2009, Fig. 5).

For Britain, the inventory lists more than 50 blades spread over more than 30 sites (Rees 1979) but new discoveries are certainly to be added. Scythe anvils, tools that sharpen blades, and whetstone cases were also recorded. Scythe blades and sharpeners were among the 200 metal pieces found in the cellar of a rural farm in Saint-Clément near Sens, in the Yonne department; the pieces were meant to be recast (Capdeville *et al.* 2015). Pliny the Elder explicitly mentions the use of long-blade scythes in the Gallic provinces (18, 261) among the "*latifundia Galliarum*", as well as for the grain-harvesting machine known as the "Gallic reaper" or *vallus*. He also mentions sharpening stones imported from Crete (18, 57, 9). Technical analyses of archaeological items performed by A. Marbach led him to conclude that they were used to cut grass, without excluding their possible use in cutting straw after the harvest (Marbach 2012).

5.2.6.3. Agricultural products and their derivatives

Identifying fodder composed entirely or partially of domestic grains and seeds is a difficult task because humans and animals may have eaten the same food. Who or what the food was for was not fixed: a crop's end use depended on the annual climate. Moreover, during the post-harvesting handling stage, a single harvest may be divided up; the rich part with grains set aside for humans and the chaff set aside for livestock. The same is true for maslins, where two cereals were grown together in the same field, which may have been separated by grain-winning or sieving – one for humans, the other for animals (Jones 1998).

In order to establish a direct link between the fodder crop and the animal which ate it, various techniques can be used: isotopic analysis of bone collagen or dental enamel (Balasse *et al.* 2015), studying the phytoliths trapped in dental

24. Original quote: "coupe l'herbe par le milieu".

plaque or the micromorphology of enamel surfaces (Mainland 1998). Using a scanning electron microscope to provide high resolution images of contemporary caprine teeth makes it possible to distinguish animals fed mostly with leaves from those fed mostly with hay, and even to distinguish between those which grazed the grass in the field from those which received cut grass. Discriminating analyses also makes it possible to note subtle distinctions in the floral composition of grasslands. Nonetheless, taphonomical problems may make it difficult to apply criteria observed with modern material on archaeological samples. Moreover, chewing causes surface deterioration in such a way that the artefacts only reflect the food eaten by the animal a short time before its death, as previous alteration is often masked (Mainland 1998).

Carpological assemblages that reasonably show the use of cereal by-products for fodder are few and far between. First, we should underline the absence of residues that could indicate a targeted and systematic harvesting of straw. Of course, straw is extremely fragile and burns easily, but in storage contexts it does survive in the form of culm bases. Straw may also be preserved in mineralized form. The rare cereal stocks interpreted as primary deposits were made up of spikelets, not sheaves or ears. One exception for the 2nd century BC was revealed at the Hérouvillette-Ranville site, in the Calvados department, where practically intact ears of emmer were found at the base of a quadrangular pit. The cereals that went into granaries had already undergone threshing, which left the cut stems on the ground, or the stems were left in the fields intact if only the ears had been reaped. Straw's value as a product and its uses are thus very difficult to determine for the periods that the RurLand programme covers. When the stems were preserved in fodder stocks, they are often from bulrushes and sedges which grow in damp zones. Other cereal by-products like glume bases or rachis internodes are more often preserved.

An indigenous type settlement at De Horden in the Netherlands (Lange 1988, mentioned by Van Zeist 1991) yielded mixes of untreated hay and cereals. In the *vicus* of Jouars-Pontchartrain (Yvelines department), the same type of fodder mix, made up of free-threshing wheats, barley and hay, was identified in the filling remains of an Augustan Age pit (Matterne 2001). The assemblage comprised 59 taxa (MNI = 1241) and associated several domestic species, but also several crop weeds, grassland plants and grasses indicating damp soils (plants from stream banks and wet meadows). Certain species that animals easily eat such as common ray-grass, crested dog's tail, vulpia, brome grasses, sedges, medicks and sweet clover seem over represented in the assemblage.

For the same site, analysis was undertaken to determine the diets of some domestic animals, cattle and sheep, using isotopic analyses on collagen (Aguilera et al. 2017²⁵). The high $\delta^{15}\text{N}$ value of an arable plant that benefited from intense manuring is transmitted to those who eat it: a direct relation being clearly established between the $\delta^{15}\text{N}$ of mammal collagen and the animal's food (DeNiro & Epstein, 1981; Minagawa & Wada, 1984); it is widely used for paleo-diet reconstructions (Koch *et al.*, 1994). If the values obtained are higher than those measured on local wild herbivores, then we may suppose the animals pastured on manured lands or were fed with fodder plants rich in ^{15}N .

The values obtained for cattle, for $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$, after applying the corrective factor taking into account the trophic level, are much higher than the values estimated for the $\delta^{15}\text{N}$ of wild plants, which suggests the cattle grazed in natural grasslands partially enriched by their own excrements. Different results were observed for sheep. After weighting the values with the same corrective factor, the carbon and nitrogen isotopic compositions presented much higher values than those of wild plants and tended to be closer to those of cereals (included in the same graph). This could indicate a contribution of wheat or its by-products, like straw, to the food of this site's caprines (Fig. 37).

Litter or fodder residues, made up of cereal stems, caryopses and chaff were found at the Roman site of 'Marais de Dourges' in the Pas-de-Calais department (Derreumaux 2005). The samples come from the soil of what was probably a stable, associated with a Gallo-Roman roadhouse for travellers. The context is very well preserved and dates back to the 3rd-4th centuries AD. Accumulations of charred organic matter evoke a litter level and excrements in which equid hoof prints were still visible.

Other samples came from nearby pits in which carbonized waste was also found. Close to 260,000 carpological remains were identified, spread out over three assemblages. The first sample is made up of 60 % cereal grains, 19 % chaff. Emmer wheat dominates, followed by free-threshing wheats. Barley and einkorn are much less present. The second sample is essentially made up of cereal chaff (67 % from more than 80,000 remains), among which emmer again dominates, with free-threshing wheats also present in the shape of sprouted grains. The third sample contains 171,000 remains and is made up of 98 % cereal chaff, among which emmer represents 81 %; the rest are free-threshing wheats and einkorn. A total of 35 % of the grains show traces of germination.

25. M. Aguilera, M. Balasse, S. Lepetz and V. Zech, Techniques de mise en culture et de bonification des terres en Gaule du Nord. Oral presentation Paris, INHA, 30 November 2015.

The conclusions of the archaeobotanical study are that the animals were kept in the stable on straw bedding and post-harvest by-products, mostly emmer wheat, and that they were fed with fodder essentially made up of the same glume wheat and free-threshing wheat by-products, spikelets and sprouted grains.

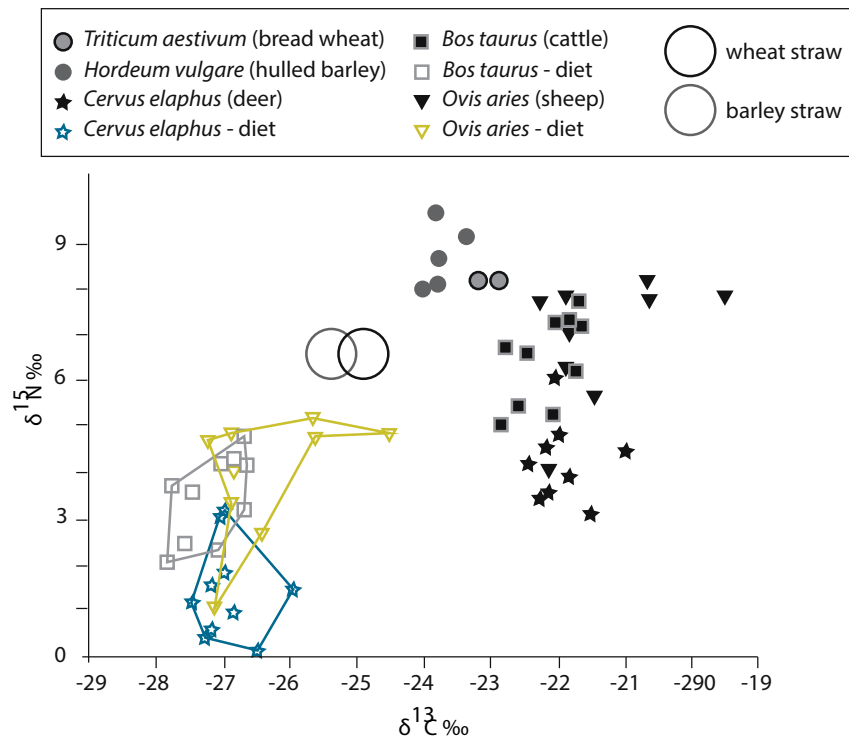


Fig. 37: Values of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ extracted from stock cereal grains and the collagen of deer, cattle and sheep bones from the site of Jouars-Pontchartrain, Yvelines (excavated by O. Blin, Inrap). For animals, a corrective factor was applied to account for the trophic level. The values recorded for sheep tended to be closer to those of cereals, suggesting a possible contribution of wheat or its by-products to the diet of caprines (according to the data of Mònica Aguilera). Credits M. Aguilera, M. Balasse, S. Lepetz, V. Zech (UMR 7209).

A similar mix for horses was found in a Roman fort in Lancaster, as reconstructed from dung containing whole cereals, mixed with processing residues, leguminous plants and hay (Wilson 1979).

It is difficult to prove that livestock were brought to the fields after harvesting so that they could graze on stubble and weeds, or brought to the grassy bands between the fields and paths to graze, but studying excrement residues does shed some light on this matter. Bringing sheep to graze in harvested fields or on grassy bands is particularly appropriate because they can feed on long stubble which, despite its low biomass in the grasslands, perfectly suits them thanks to the presence of easily digested regrowth, which contain a majority of dicotyledons that provide mineral elements during the autumn hunger gap period (Gerbaud *et al.*, 2001).

A few carpological assemblages might be linked to the practice. A silo dated to the La Tène C (structure 4312) at the 'ZAC Tulipes Nord II' site in Gonesse in the Val-d'Oise department yielded 671 mineralized seeds from a total of 1014 samples, or 66 % of the assemblage. The species involved corresponded to crop or fallow land weeds such as *Anagallis arvensis* (scarlet pimpernel), *Chenopodium* gr. *polyspermum* (many-seeded goosefoot), *Eleocharis palustris* (common spike rush), *Fallopia convolvulus* (black bindweed), *Fumaria officinalis* (common fumitory), *Galium* spec. (bedstraws), *Papaver rhoeas/dubium* (corn poppy, long-headed poppy), *Ranunculus* (buttercups), *Rumex* (docks), *Sambucus ebulus* (danewort), *Solanum nigrum* (European black nightshade), *Stachys* (woundworts) and *Urtica urens* (burning nettle). In another part of the same complex (site III), mineralization uniformly affected carpological assemblages from storage pits located behind the residential buildings (structures 313, 314, 334, 340 and 555), but it was not the dominant preservation mode, as the amount of mineralized seeds did not exceed 28 % of the recorded number (328 remains from the richest structure, number 313). However, here as well, it was the arable species that were the most affected, not the domestic species (Zech-Matterne & Derreumaux, 2018).

We will finish by mentioning rich assemblages of brome, a plant that sometimes reaches the proportions of domestic species (especially in the Louvres site in the Val-d'Oise department and the Oroër site in the Oise department), and whose status as a weed or fodder plant has not yet been decided. We cannot exclude the possibility, therefore, that it was intentionally cultivated for fodder.

5.2.6.4. Legume-based mixes

Protein crops are a good source of nitrogen which favours the growth and fattening of calves. In contemporary farms, the species used are sweet peas, fava beans and lupine²⁶. Grass pea, chickling vetch and Spanish vetchling were also used for fodder in Spain and Greece. In the north of Castilla they cultivated mixed-crop *comuña*, which included barley, bitter vetch, cultivated vetch and chickling vetch (Peña-Chocarro & Zapata Peña 1999). Mixing with several types of peas or beans was also discussed by the Latin authors. Pliny the Elder speaks of *ocymum*, a mixed fodder composed of Celtic beans, common vetch, bitter vetch and “Greek” oats, for cattle (18, 42, 1). Varro mentions *farrago*, a seed mix of barley, vetch and other pulses, cut young or mature, which was given to equids and cattle to first purge them and then to fatten them (Varr., *R.*, I, 31).

The first carpological assemblage from the ‘Les Fussis’ site in Limé in the Aisne department could prove the use of pulses to feed cattle. A bulk of seeds found in the contents of a pit from the 3rd century AD yielded a mixed batch with grass peas (17 %), Celtic beans (4 %), common vetch (4 %), bitter vetch (1 %), lentils (1 %), hulled barley (71 %), einkorn wheat (1 %) and oats (1 %), in proportions established for a MNI from 500 remains. This assemblage strongly resembles the high-energy cereal/legume combinations that were given to bovines working in the fields. Such mixes were not found in the concentrations of food waste associated with ovens or burnt storage structures where cereals were the main components.

Another assemblage, dated to the High Empire (n = 9252), from the carbonized stock found in a cellar of the villa ‘La Grange du Mont’ in Mareuil-lès-Meaux (Ph. Bet, INRAP), associates arable plants (free-threshing wheats, emmer wheat, spelt wheat, barley, lentils, peas and flax), immature grains and by-products (spikelet bases and rachis segments) of the same species, with wild species (n = 2605) such as crop weeds, sorrels, clubs, legumes and grassland legume pods (*Lathyrus cf. pratensis*) (Fig. 38).

In relation to comments on the use of legumes, and for the thorough cross comparison of carpological and archaeozoological data, we must state that no consistency was found between livestock-raising zones and oat and pulses farming zones, either for the La Tène or the High Empire period; this is particularly clear in the case of pulses (Fig. 39). Legume-based fodder is generally composed of small-seeded legumes, like clover, trefoil or medicks, which make up artificial grasslands. Carpological evidence of these species is too scarce for us to hope to map them like pulses. As for barley, another potential fodder ingredient, we noted that its zone expanded from the Roman period (Fig. 40). The other zones, where bigger animals were raised, do not present any particular consistency with zones of copious barley cultivation.



Fig. 38: Carpological assemblage discovered in a storage structure of the ‘La Grange du Mont’ villa in Mareuil-lès-Meaux (Ph. Bet, Inrap), indicating a forage mixture. Credits V. Zech.

26. P. Haurez, regional programme “Utilisation des protéagineux en élevage”, coordinated by the Chambre d’agriculture of Midi-Pyrénées.

To summarize, a quick review shows that fodder took on a variety of types and concerned a wide range of products and by-products during the Iron Age and Antiquity, a diversity mentioned by several Latin authors and which is partially reflected in carpological assemblages from the Roman period in north-eastern Gaul. The production, harvest, storing and distribution of these foodstuffs entailed major logistics, at least equivalent to those deployed to satisfy human food needs. We must therefore include them in any reasoning linked to agricultural systems rather than considering cereal cultivation as being done solely for humans.

Although agricultural by-products and wild species were included, pulses and cereals were regularly part of animal fodder, as the many carpological assemblages show. In an attempt to reconstruct the theoretical needs (the amount of fodder required) and surfaces (the area needed to grow this fodder), the great unknown is the manner in which ancient species made it through wintering, which undoubtedly included long periods of snow, making feeding indispensable.

We also saw that the energy value of fodder was extremely variable according to the type and state (green or dry), as well as the composition of the mixes that were used. The animals' needs were also very varied according to the breed and their functions (fieldwork animals, milking cows or ewes, or fattened animals to produce meat).

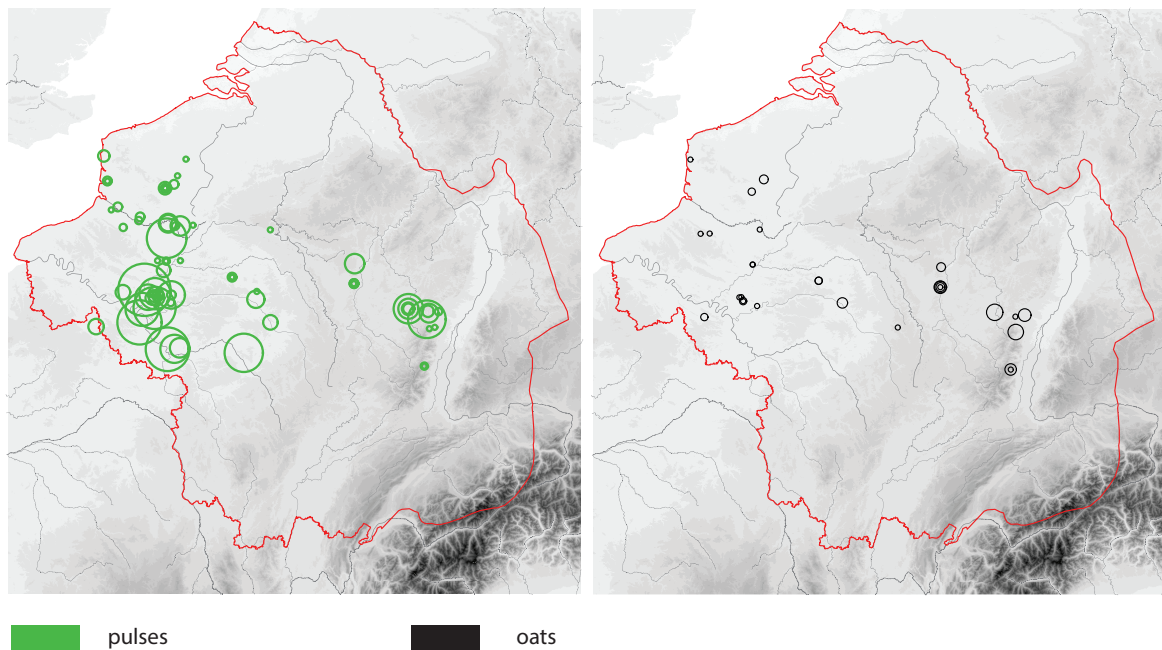


Fig. 39: Frequency of pulses (all species combined) on the left, and oats (*Avena* sp.) on the right; period 2.

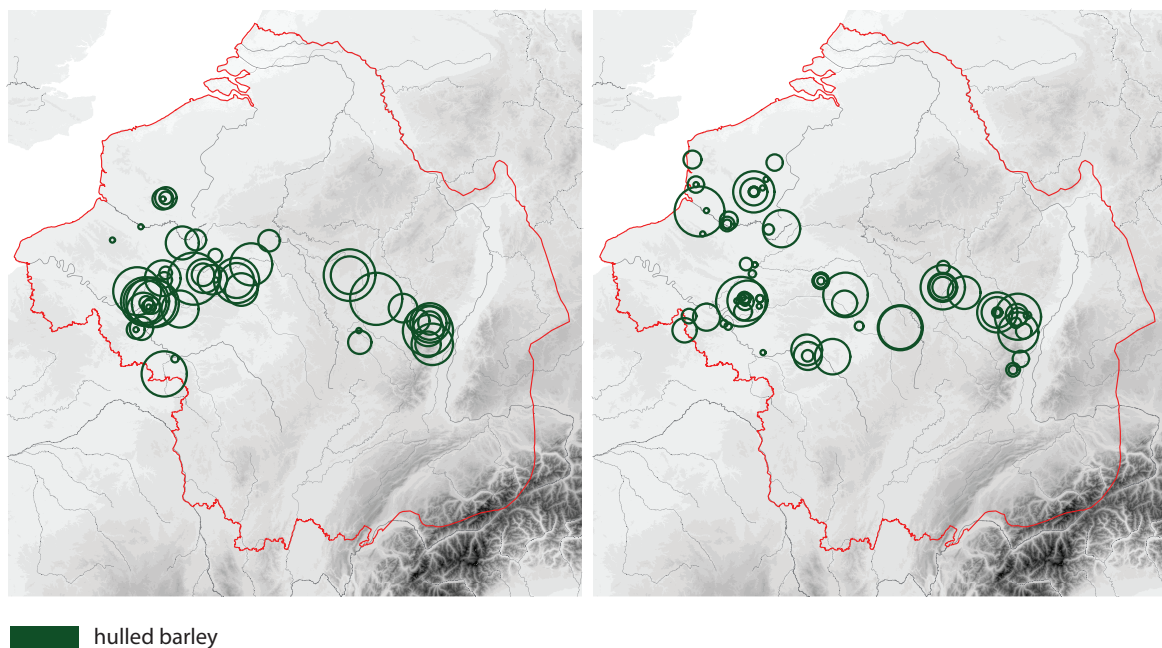


Fig. 40: Frequency of barley; period 1 on the left, and period 2 on the right.

The general improvement of feeding practices had major repercussions on the size of livestock, which in turn needed more fodder, which then required an increase in production yields. The need to produce more, in a more concentrated and intensive manner, naturally leads us to the question of the soils' natural production capacities and limits. Were soil improvement measures set up in order to maintain high yields? Was the balance of the system maintained everywhere or, on the contrary, did it reach a plateau or a threshold beyond which it was no longer possible to go? Adding manure would not solely solve the problem, as F. Sigaut (1998, 2009) reminds us: *"It is not true that the value of a fertilizer or the richness of a soil is due to the proportion of organic content. Also false is the classic notion, or magic formula, that says that the way to increase grain production is to increase the amount of fertilizer, therefore the number of livestock, therefore the number of grasslands and the amount of fodder. Because grasslands and fodder crops also need fertilizers, and where are they to be found, if all are destined to the cereals?"*²⁷. In the following paragraphs we will come back to the question of fertilizers and finish with a few remarks about calculating yields.

6. The role and benefits of amendments on an arable soil's production capacity

Soil is a living and dynamic ecosystem and its agricultural capacity depends on its chemical, physical and biological properties. Soil improvement measures aim to influence the chemistry and structure of a soil in order to improve its performance; these amendments may be organic or mineral.

Different chemical elements play a determining role in plant growth, flower formation and fruit development. The main elements are the major ones: calcium (Ca), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), but the chemical elements also include trace metals such as iron, copper, zinc and manganese, etc.

The major chemical elements generate normal plant growth. Calcium ensures the rigidity of cell walls; nitrogen regulates the plant's metabolism and therefore its growth; phosphorus helps transfer energy and breaks down carbohydrates, and is therefore essential for optimal tillering (the multiplication of stems carrying ears), for flower formation and the development of fruit; potassium plays an essential role by absorbing ions, accumulating proteins and moisture reserves; lastly, magnesium is a component of chlorophyll and therefore affects photosynthesis.

In damp climates, it is necessary to compensate the loss of nutritional salts due to leaching, either by alternating fields to have non-depleted soils, or by regularly adding fertilizing elements (stable dung, street muck, ashes, etc.) to fix nutrients in the fields.

The physical characteristics that participate in the structural stability of a soil are porosity, the texture of the elements that it consists of and the way these interact. These factors determine water circulation and root penetration, the development of soil organisms, the cohesiveness of the superficial layer and its capacity to resist destructive elements like wind, rain, frost and other natural phenomena.

A soil's fauna maintains its porosity, ensures the humification of organic materials and the mineralization of nutrients so that they may then be assimilated²⁸. It also helps to fix atmospheric nitrogen, through the enzymatic reduction of ²N (molecular nitrogen) into NH₃ (ammonia), a process that legumes indirectly do in a mycorrhiza mutualistic relationship between rhizosphere bacteria and the plant's roots.

But the presence of nutritional elements is not enough to ensure optimal growth; the elements need to be regularly available and assimilated. Incorporating organic matter favours cohesion and improves soil structure. Calcium plays a key role in the good functioning of the clay-humus complex (CHC) which designates the association of clays and organic matter known as humus. This role is both structural and metabolic. With the stabilising effect of calcium, the soils positively charged cations – its nutritional elements – pair with the negatively charged clays and form clumps. These aggregates are a sort of element reservoir for the nutrients which, in this shape, are much less likely to get washed away, making them available to crops for a longer period of time. Moreover the formation of clumps improves the soil's structure and its capacity for being worked, as well as supporting a great number of soil organisms and improving soil cohesiveness.

Amending a soil aims to renew or increase the quantity of vital nutrients for the plants by adding decomposed or-

27. Original quote: "Il est faux que la valeur d'un engrais ou que la richesse d'un sol soient en raison de leur proportion de matière organique. Et fausse est la formule classique, ou pour mieux dire magique, selon laquelle le moyen d'accroître la production des grains est d'accroître la masse des engrais, dont le nombre des bestiaux, donc la surface des prairies et des fourrages. Car prairies et fourrages ont aussi besoin d'engrais, et où les prendre, puisqu'ils sont tous destinés aux grains ?"

28. Worms are active down to 70 cm; a height slightly inferior to the one occupied by cereal roots.

ganic matter, to favour the formation of aggregates to absorb nutrients and improve soil structure, and mineral matter such as limestone. Adding limestone improves the structure of plateau silts (altered loess), considered to be very fertile thanks to their significant water retention capacities, but they are prone to slaking and colluviation. In more acidic soils, liming with clay or marl liberates the phosphorous combined with free iron, which becomes soluble and assimilable by the plants.

High alkaline levels are easier to correct than acidic ones²⁹. Slash and burn cultivation may be a solution for the first following year, but soil organisms will be affected. In soils with an important silt cover, the limestone subsoil is much deeper and does not influence the soil. Mineral amendments need to be added, which is usually done by spreading fine lime and marl. These supplies need to be regularly repeated, because under the influence of atmospheric agents decarbonation happens progressively in the superficial layers to a depth that may reach 3 m.

Lime alkalizes the soil more than marl does. However, making lime is a costly operation in terms of fuel because the blocs of lime must be heated in very large, specific ovens to 1000°C before they can be pulverized. Inputs depend on the type of soil and are all the more important if the soils are heavy. The spreading of lime aims to modify the pH and also helps to make the hydromorphic soils more filtering by the aggregation of clays. On sands, spreading is 0.65 t/ha and on clays 2 t/ha, every 3 years. Lime is brought in powder form (0.1-2 mm) and extinguishes itself in the field. It is spread on stubble, before the next sowing; and on meadows it takes place in spring, in order to cleanse them³⁰. Marling requires picking limestone nodules from bands in the hillside and is thus easier to exploit. In organic farming, a massive input of lime suffices: 15 t/ha every 10–20 years or 40 t/ha every 30 years to correct the soil's pH level³¹. Frost will fracture the larger elements after they have been spread out in fields. In soils that present more than 5 % of lime, the natural calcium reserves eliminate the need for this type of amendment.

Too much active lime (smaller than 2 microns) generates a noxious effect that is felt on very thin, rendzina type soils on chalk. It blocks the cationic exchanges and thus limits the absorption of nutritional elements through the root system. It may thus cause a risk of chlorosis: iron is no longer available, yet this element plays a determining role in the formation of chlorophyll and therefore photosynthesis. The plants whiten and become stunted because they are deprived of essential nutrients. Although the addition of lime benefits some soils, it is necessary to carefully calculate its dosage.

Mineral amendments are difficult to determine in an archaeological context because lime dissolves in the soil. The alkalization of deep horizons sometimes preserves traces of an agricultural past. Modifications made to the soils are important enough to influence, on the scale of historic times, the floral richness and the diversity of plant groups that grow back on these plots of land at a later time (Dupouey *et al.* 2002).

6.1. How does one reconstitute soil improvement practices in an archaeological context?

Incorporating various types of organic matter into arable land in order to improve its fertility has been done since the Neolithic period in temperate climate Europe (Bakels 1997). The interest of residual waste and its use in the history of agriculture in France has already been addressed several times (Poirier & Nuninger 2012; Aguilera *et al.* 2017a).

Studying ancient soil improvement measures calls on a great variety of markers very often associated in combined approaches. Soil sciences contribute greatly to the study of soils' agricultural capacities by detecting ploughing practices and organic supplies through archaeopedology and micromorphology (Macphail *et al.* 1990; Gebhardt 2000; Fechner *et al.* 2009; Gebhardt *et al.* 2014). Mapping tossed potsherds, discovered off-site, was also used to locate fertilized fields (Poirier & Nuninger 2012). Bioarchaeological approaches combining plant macroremains (e.g. seeds and fruits, mosses, leaves), archaeoentomology (fly pupa and beetles specialized in faecal matter) and paleoparasitology (intestinal parasite eggs) were deployed by the Environmental Archaeology Unit of the University of York in order to define, with the help of an indicator group, the manure, latrine pit matter and organic waste that subsisted in the archaeological levels. These methods were successfully applied in the context of the ancient city of York (Kenward & Hall 1997, 2012). On-site decomposed straw, probably from added stable manure, provoked an accumulation of phytoliths (microscopic fossils of plant cells) in the soil; several morphological types are specific to cereal stems and distinct from the shapes produced by wild grasses (Vrijdags *et al.* 2007).

Other methods use the molecular signatures of faecal matter (Shilito *et al.* 2011; Baeten *et al.* 2012; Lanceoletti *et al.*

29. Personal communication, B. Brasseur, pedologist, EDYSAN, UPJV, Amiens.

30. Com. Maison Vincent, lime-burner, 58250 Ternant (Bourgogne). In modern ovens, the burning of calcareous stones for agricultural purposes is done with anthracite ; 1 t of anthracite is needed to obtain 7-8 t of lime.

31. Ibid.

2012) to determine which animals excreted them (Linseele *et al.* 2013), thanks to the analyses of specific biomarkers (Bull *et al.* 2002; Birk *et al.* 2012; Lauer *et al.* 2014).

On a smaller scale, micro-stratigraphic observation combined with biogeochemical analyses of anthroposols made it possible to determine the addition of organic matter in garden or vegetable patch areas in urban zones (Borderie *et al.* 2012). Determining the functions of farm buildings, especially livestock stables, was possible through cross studies pairing magnetic susceptibility and phosphorus mapping; these cross studies were done in the Somme department, within the framework of archaeological surveys prior to construction of the Seine-Nord-Europe canal (Hulin *et al.* 2012).

6.2. Exploring the question of soil fertilization

Within the framework of the RurLand programme, several approaches aimed to see if manuring was regularly done to improve soil quality in the great cereal production regions, and to assess if several farming systems (intensive *vs* extensive) could be envisioned for the regions under consideration.

The question came up as to the early emergence and subsequent continuation of a zone specializing in free-threshing wheat cultivation, including bread wheats, demanding cereals in terms of soil preparation and fertilization. Formed during the 2nd century BC, the free-threshing wheat zone progressively expanded in the centre of the Paris Basin, to the Somme River valley in the north and the Champagne region in the east, reaching its peak during the 3rd century AD. At the transition of the 1st to the 2nd century AD, pulses were again grown at a large scale (Fig. 41) and their distribution strongly coincided with that of free-threshing wheats (see above: Fig 18 and the geography of livestock/crop combinations).

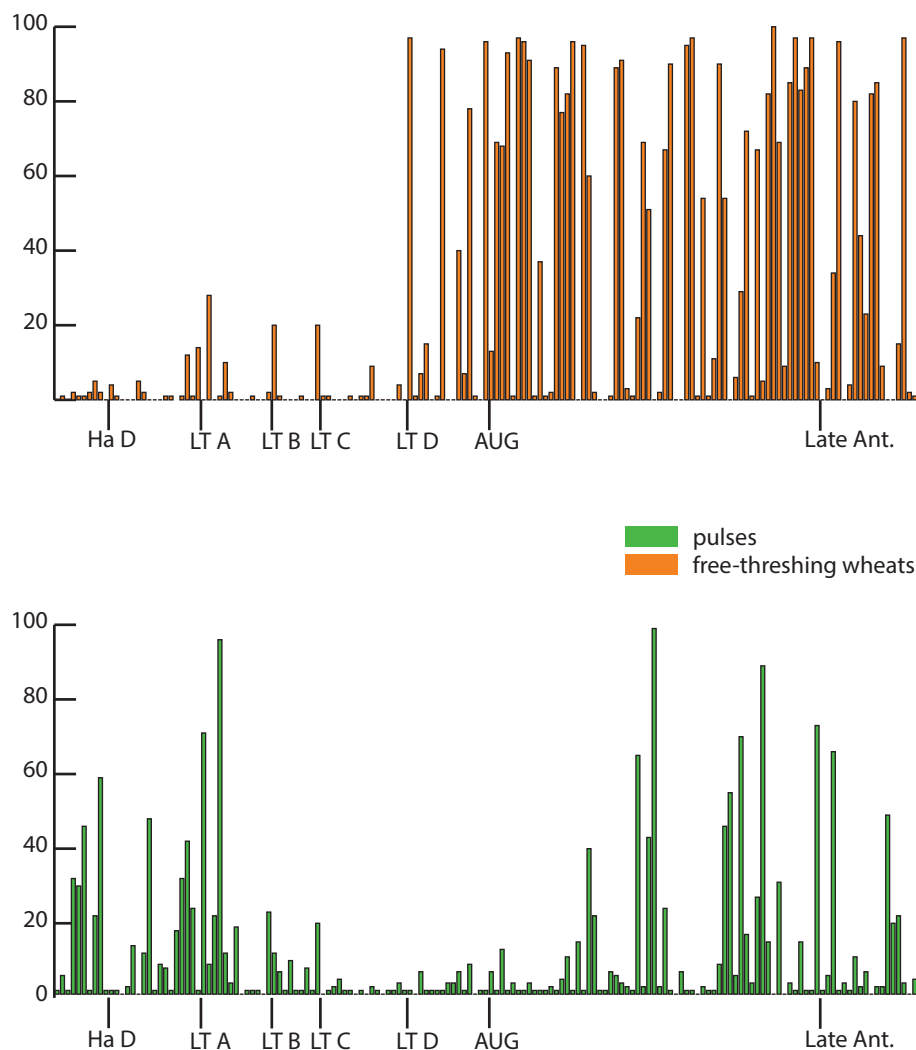


Fig. 41: Evolution of the relative importance of free-threshing wheats (top) and pulses (bottom) from the 6th century BC to the 5th century AD sites of northern France. The upturn of free-threshing wheats during La Tène D is clearly observed, as is the second peak of intensity of pulses crops which occurred from the 1st to 2nd century AD transition.

Interpreting this novel free-threshing wheats/pulses combination should follow several leads:

1. Pulses are spring crops which fit into the winter grains calendar to make the most efficient use of the laborious repeated ploughing associated with complete fallow, in the sense meant by P. Morlon and F. Sigaut (2008). Peas or beans would not have been sown over winter wheat because they would have choked the seedlings already sprouted in autumn or disrupted tillering in spring. Pulses would thus be sown after lightly preparing the soil, preceding an autumn grain, according to the figure 42. (Summer crop system; Fig. 42). This succession does not necessarily provide higher yields than those of systems essentially based on autumn-sown grains (Sigaut 1976). It does, however, present the advantage of better distributing the work over the year and it offers winter wheats a preceding crop that will improve the soil's nitrogen content.

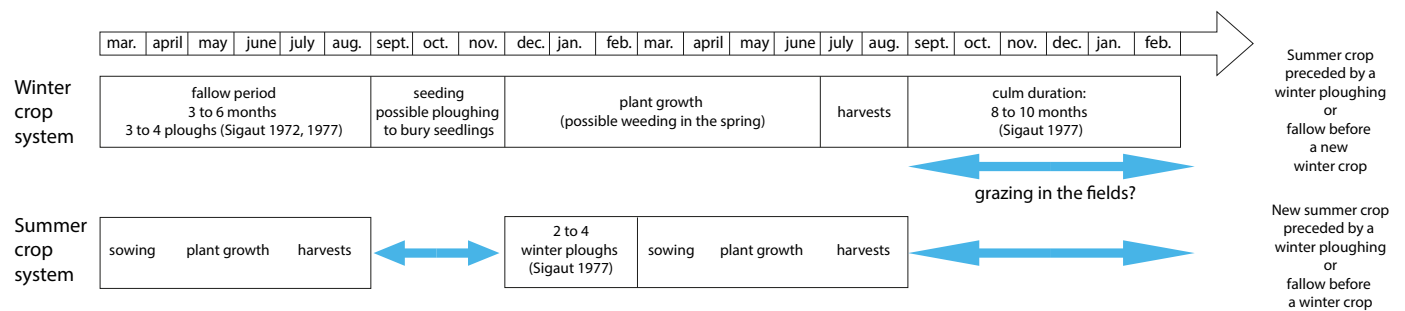


Fig. 42: Schedules of autumn and spring sowing, after Neveu 2017.

2. The loamy topsoils of the Paris Basin plateaus are actually quite thick and present excellent arable potential. However, this production capacity needs to be maintained through repeated fertilization which brings different essential elements to the plants that grow in it. Nitrogen input (N) is a determining factor for the plants' amino acid synthesis as it favours their growth and development. The mineralization processes followed by lixiviation (leaching) regularly depletes nitrogen reserves, which means it must be added again several times a year. However, legumes use aeolian nitrogen (^{2}N) through mycorrhizal symbiosis (association between the bacteria and fungi found at the plants roots) and therefore contribute to slowing down nutritional resource depletion; they also clean and enrich the soil. The following crops benefitted from these effects which were empirically known by the "*Latin Agronomes*".

3. Are legume crops just green fertilizer? This is something we cannot yet confirm. If it were the case, they would have to be turned into the soil before complete maturation. It is important to highlight that several pulses are involved and that these species are different from one period to another. For the High Empire, during which the association of free-threshing wheats and pulses was the closest, the species involved were lentils and bitter vetch and, to a lesser degree, common vetch and Celtic beans (see Figures 10 and 13). Lentils are omnipresent in storage contexts, ovens and food waste, as are Celtic beans, a great number of which were found in a cellar on the Villiers-le-Sec site. These two pulses were quite realistically used as food. Bitter vetch and common vetch could have been used for human food but also as fodder or green manure. Both are classed as a species which, when eaten in abundance, may cause a lathyrism syndrome due to the presence of neurotoxic amino acids in the teguments (testa) of their seeds, but they may nonetheless be given to livestock (Enneking 1995; Enneking & Miller 2014). Given that they are less frequent than the alimentary species, the hypothesis of a bitter or common vetch crop grown as a green fertilizer remains possible; however, all the pulses recorded in the carpological assemblages could not have been used for that sole purpose.

4. And what about the issue of improved leys made up of small-seeded legumes? Such husbandry practices, beginning as early as the Iron Age, have been documented for southern France (Bouby & Ruas 2005). Wild vetches and wild grasspeas, medicks, melilots, clovers and trefoils are regularly evidenced in the programme's sites, although in low numbers, and their representation does not seem to increase over time. For the 14 taxa recorded for the *Lathyrus*, *Lotus*, *Medicago*, *Trifolium* and *Vicia* genera, 60 occurrences from 48 sites are listed for period 1 (data from F. Toulemonde, J. Wiethold and V. Zech); 40 samples from 36 sites for period 2, and 19 samples from 22 sites for period 3. The randomness of preserved remains is due to taphonomic factors and makes it rather difficult to precisely judge the role of these species; there are no charred assemblages that can indicate the possible composition of these improved leys.

5. Does the emergence of pulse cultivation signal soil depletion?

An alternative hypothesis to the rise in pulse cultivation and especially their reincorporation in free-threshing wheat cultivation, with a chronological lag of at least two centuries, would be that in the zone where free-threshing wheats are a form of specialization within farming systems, the continual cultivation of nutrient-depleting crops would have caused, in the long term, a deficit in certain chemical elements in the soils. The detailed study of wildflowers (arable weeds and ruderals) that grew alongside crops at these sites seems to corroborate that thought, as it indicates that soil quality varied from the end of the Iron Age and throughout the Roman period, especially in terms of nutrient resources (Zech-Matterne *et al.* 2017b).

The multivariate analyses performed (Canonical Correspondence Analyses - CCA), made it possible to exploit, at the same time and in the same projection, both the taxonomic diversity of weeds in cultivated fields and their physiological features or life-traits. According to Julve 1998, we listed the species in 5 classes, depending on their sensitivity to the presence of nitrates, due to nitrogen input: oligotrophic (indexes 1-4), mesotrophic (5), mesoeutrophic (6), nitrophilous (7), eutrophic (8-9). These indexes determine 4 categories: poor soils (1-4); average soils (5-6); rich soils (7); very rich soils (8-9). According to the physiological characteristics of the weeds recorded (most of which were nitrophilic) in the Early Iron Age and Early La Tène sites their inhabitants must have exploited soils that were very rich in nitrogen, naturally or thanks to regular input. The sites for the following periods also had rich soils, as well as average and poor soils. Roman period sites revealed less favourable situations: there were no longer any sites with very rich soils, a small number of sites had rich soils, but there was an increase in average or poor soils (Zech-Matterne *et al.* 2017b). These results could be interpreted in two ways: 1) the continually evolving pattern could perhaps indicate soil depletion over the long term, not compensated by manuring, or 2) a change in soil improvement practices induced by new farmstead configurations or modifications in access to fields. The result was an increase in more extensive farming which then exploited all available fields and plots, without seeking to artificially improve soil quality (Zech-Matterne & Brun 2016).

In order to further define these regional patterns at a more local scale, analyses were undertaken on stock residues in order to compare fertilization practices at the scale of the sites, using another angle of approach and a new tool: stable isotope analysis.

To that end, the isotopic analyses of collagen found in carbonized animal bones and cereal caryopses were carried out in order to measure the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values of these components. In France³² this type of approach is not yet well developed. Within the framework of a post-doctoral contract³³ the first steps were taken with the analysis of 12 sites/19 settlement phases (Aguilera *et al.* 2017b). The atomic elements covered by these analyses were carbon and nitrogen, for which we noted the ratio between the respective quantities of stable isotopes $^{12}\text{C}/^{13}\text{C}$ and $^{14}\text{N}/^{15}\text{N}$.

The fertilization of cultivated soils using manure or faecal waste translated into a change in the ratio between ^{15}N and ^{14}N , expressed by the value of $\delta^{15}\text{N}$. Manure has a relatively high value of $\delta^{15}\text{N}$ in comparison with the values generally measured in soils, due to the preferential loss of the light isotope ^{14}N in volatile ammonia. Residual ammonia, enriched in ^{15}N , is then converted into nitrates, which represent an essential source of nitrogen for the synthesis of amino acids by the plants. This results in a manifest enrichment of the plants in ^{15}N . The exploitation of this principle, as seen in archaeological charred seeds or rachises, is possible to the extent that charring affects the signal in known proportions (in the range of 1 ‰; Fraser *et al.* 2011). Applied to a large range of cereals and pulses: einkorn, emmer, spelt, bread wheat, hulled and naked two-row barley, peas and Celtic beans, experiments of *in vivo* cultivation in the short and long term, in fertilized fields for which the quantity (variable) of manure was measured and in unfertilized control fields, have shown that all cereal species showed significant growth, measured on 200 to 300 grains, with values of ^{15}N in the range of 4, 5.5 or 9 ‰ depending on the cultivation stations. The increase is not as pronounced (+ 0.2, 0.3 or 0.7 ‰) for pulses which are capable of fixing atmospheric nitrogen through mycorrhizal symbiosis. Fertilization – even intense – does not affect this process. For cereals, the values increase as of the first year of fertilizer input, and the gap widens progressively when fertilization intensifies or continues over time (Bogaard *et al.* 2007; Fraser *et al.* 2011a).

We therefore have direct archaeological evidence of fertilization practices, but we would have to be able to evaluate the baseline of the non-fertilized soils for the periods under consideration. The weeds accompanying cultivated fields gen-

32. These approaches are still poorly applied in France, in contrast with the UK and Spain who promoted them much earlier and remain leaders in their development

33. Post-doctoral contract at the EPHE, within the framework of RurLand: Soils fertilization through manuring and the potential role of cereals in the foddering of animal stocks: contribution of stable isotope analysis of archaeobotanical and archaeozoological remains (May 2014-October 2015), Monica Aguilera-Delgado, under the supervision of M. Balasse, V. Zech-Matterne, S. Lepetz.

erally only reflect ambient growth conditions. In order to determine the interval values of $\delta^{15}\text{N}$ for non-fertilized plants, the collagen of deer bones from the same archaeological sites as those that had delivered the seed mass-finds were used, and a corrective factor was applied in order to take into account the herbivores' higher trophic level. Without completely excluding the fact that these animals may have on occasion pilfered some food from the fields, most of their diet was based on unfertilized wild plants.

The questions relating to fertilizing practices, which also took into consideration the archaeological context and the plant species under consideration, were numerous and regarded the specificities of crop systems recognized by previous carpological studies. As previously mentioned, we performed isotopic analyses linked to the emergence of pulses in the free-threshing wheat zone. These free-threshing wheats were the result of increasingly specialized cultivation zones, observed since the Late Iron Age. Throughout the La Tène period in north-eastern Gaul, crop production was dominated by emmer and spelt, together with hulled six-row barley (*Hordeum vulgare* ssp. *vulgare*). As of the 2nd century BC, and in conjunction with the development of urbanization, free-threshing wheat crops emerged, first in a small area in the middle of the Seine River valley which later expanded into a vast zone where most sites produced these wheats (Zech-Matterne *et al.* 2014). A few rare contexts also delivered post-harvesting by-products next to the grains, which made it possible to establish the presence of tetraploid sub-species (*Triticum turgidum* ssp. *durum*: macaroni wheat or more likely *Triticum turgidum* ssp. *turgidum*: rivet wheat for climatic reasons) and hexaploid *Triticum aestivum* types (*Triticum aestivum* ssp. *aestivum*: bread wheat; ssp. *compactum*: club wheat).

Bread wheats and durum wheats in the wider sense were thus cultivated. The farmsteads of Palaiseau (Essonne department), Tremblay-en-France (Seine-Saint-Denis department), Mareuil-lès-Meaux (Seine-et-Marne department), Houdan (Yvelines department), and Marcelcave (Somme department), delivered diagnostic rachis segments that proved either a mix of both 4n and 6n types, without it being possible to establish if they were grown together, or the presence of bread wheat alone (Toulemonde F., in Bernigaud *et al.* 2017, 423-424). Naked wheats produced the highest yields, but they were also among the most nutrient-depleting species. Following the protohistoric practices, glume wheats persisted on the outskirts of the production zone which was established in the north as of the 3rd century AD, on the Somme River valley and which continued east towards the Champagne region. Spelt and hulled barley continued to play a major role in these zones (Zech-Matterne *et al.* 2014).

At the time of the transition between the 1st and 2nd centuries AD, pulses were re-introduced in zones where free-threshing wheat cultivation was predominant. Was the aim to counterbalance soil depletion due to the continual cultivation of free-threshing wheats by favouring nitrogen fixation in the soils? We had hoped that the direct measurements applied to archaeological grain stocks would be able to tell us more about the fertility levels of the soils and their eventual improvement through the use of manure.

We also hoped to better understand how very poor soils could be exploited. Was there massive recourse to manure and for which species? These issues were particularly interesting in the case of the chalky Champagne area for which the analysis of ancient soils (Fechner *et al.* 2009) showed that the very superficial topsoils had already been considerably eroded by farm work. Consequently, the Gallo-Roman farmers sought out the sinkholes where colluviums were trapped to avoid cultivating directly into the chalky subsoil. Although today the Champagne region is one of the most productive, thanks to the massive recourse to chemical fertilizers, it was certainly not the case during the Roman period, when farmers were confronted with skeletal soils in which free-threshing wheat crops were clearly not able to adapt (Boulen *et al.* 2012).

The results of geochemical analyses appear conclusive (Aguilera *et al.* 2017b), although at this stage they cannot be generalized to the scale of both regions. They do, however, show marked contrasts in the centre of the Paris Basin, where the soils are of good quality, on the whole, but where the degrees of fertilization can vary widely from one site to the next: from a total absence of improvement measures (Bonneuil) to intense and prolonged manuring (Jouars-Pontchartrain). One can repeatedly observe for the same site high fertilization levels throughout its chronological sequence (three centuries for Palaiseau) or, on the contrary, more contrasted situations from one phase to another like at Épiais-lès-Louvres. For the Champagne region, the three assemblages analysed showed a total absence of organic amendment. However, the soils that naturally possessed the best arable capacities were reserved for spelt wheat rather than barley (most notably in Acy-Romance).

The persistence of favourable situations or at least very diverse situations for the entire middle zone of the Paris Basin does counter the hypothesis of generalized soil depletion. This leads us to be utterly convinced that we are looking at a diversification of manuring practices and a cohabitation of intensive and extensive farming systems. It remains to be determined which species enabled the exploitation of the poorest soils without necessarily needing to fertilize them. The occurrences of rye tend to group in the free-threshing wheat crop zone, but the species' proportions go beyond 1 % of the MNI remains in just two sites. The other possible candidates, oats, scarcely have a role in Roman agriculture (Ruas & Zech-Matterne 2012;

Zech-Matterne *et al.* 2017a). Lastly, einkorn may also grow in poor soils, but its distribution is very clearly linked to that of spelt, to such a degree that we wonder if the species became a weed in spelt fields. The species that most likely adapted to all types of soils is barley, omnipresent yet locally replaced by glume wheats, spelt and emmer, which persisted and were sometimes extensively cultivated.

It would be very interesting to pursue these analyses and include parameters such as farmstead status (are the more intensive systems specific to smaller family-run farmsteads or large *villae* ?) and the topographic localization of these farms. Likewise, we could study how manuring practices influence crop soils over time, which in turn could have impacted the sites' longevity and their cycles of rebuilding, extension and enrichment. To do so, we would need to have many more assemblages to analyse, as well as a tighter timeframe and a better understanding of the social rank of the associated farms.

It is clear that all the plots or fields that make up a farmstead cannot benefit from organic amendment. The limiting factors are on the one hand, the quantities of manure produced, and on the other hand, the difficulties raised by the transportation of said manure to the fields.

6.3. Manure

The amount of manure produced by a farm will vary considerably and will depend on: 1) the number of heads of livestock, 2) herd conformation (the ratio of bovines, equids, ovines and poultry), 3) the composition of the manure (generally straw, moisture content), and 4) its level of maturity, degradation and composting. It is clear that for the ancient periods we have no control over any of these factors.

The estimated data we have for present-day animal faeces have largely been studied within the framework of modern agriculture. The density of cattle dung varies from 500 kilos per m³ (fresh manure with lots of straw) to 1000 kilos/m³ (older manure with less straw, or scraped manure). Fresh dung, without straw, presents a density of 1 tons/m³. For horses, the average is around 171 kilos/m³ (but values vary between 14 to 418 kilos/m³).

The amount of manure produced by the animals depends on their size: a 600-kilo dry cow produces around 30 kilos of dung per day; a lactating cow of the same weight will produce a little under 50 kilos; a 450-kilo horse produces about 21 kilos; a 50- to 80-kilo pig produces about 5 kilos, and an adult sheep between 2 and 3 kilos³⁴.

Using the low values, we estimate that a 600-kilo bovine will produce 11 tons of dung per year, a horse 8 tons of droppings, a pig 1,800 kilos and a sheep 900 kilos. Of course this amount of dung will be mixed with straw, will lose water (bovine dung contains an average of 83 % water, and sheep droppings contain around 70 %) and it will vary depending on the farming system, stabling means and the period of the year. Today, a dairy cow kept on straw bedding with four months of pasturing will produce 10 tons of manure per year or more, depending on its size³⁵. Chancrin & Dumont (1921) state 15 tons of manure can be expected from a 500-kilo cow in one year.

We also have difficulties assessing the amount of droppings the animals leave in the soil when they graze – which benefits the grasslands – and the amount of manure coming from barns, stables and pigsties, which varies depending on the amount of time the animal spent in pens or stalls (unknown), that will benefit crops. The variables are numerous, but the ideal solution would have been to have the animals graze by day and send them to enrich crop fields at night. The quantity of manure spread depends on the quantity available and the number of fields to fertilize. Today, manuring is about 10 tons per hectare (light spreading) to 40 t/ha or even 50 t/ha (thick spreading). The usual levels are around 30 t/ha, which makes it possible to optimally cover the cereals' requirements of potassium and phosphorus, but we also understand that these values vary greatly according to the type of production, the types of soils and resource availability. Consequently, we are surprised by the manuring levels calculated for the Roman period using data supplied by Columella and Pliny the Elder (Ouzoulias 2006; Poirier & Nuninger 2012): between 15 and 47 t/ha. If the low values correspond to a moderately dense manuring (according to modern criteria), the high values correspond to the maximal values currently in use.

34. Data from Institut de recherche et de développement en agroenvironnement du Québec.

35. Cultivation technical data sheet 'Fiche technique agricole' from <http://www.riviere-viaur.com/fr/>.

Whether or not these figures are accurate, they enable two estimates:

The first is that if we take into account the production of 10 tons of manure per bovine, we must consider that the manuring of one hectare would require the droppings of between 1 and 4 bovines (depending on the desired concentration). We may easily calculate the equivalent numbers for sheep: roughly 10 to 40 sheep per hectare.

The second is about transporting these quantities to the places they were to be spread. This transportation could have been done by hand using woven branch stretchers (as seen on the mosaic of Saint-Romain-en-Gal) or by using hitched carts, hand carts or *travois*. When the manure is transported in a two-mule cart that can pull about 500 kilos (Rapsaet 2002), a one hectare fertilized field will require anywhere from 30 trips (15 t/ha) to 100 trips (47 t/ha). If it is a pair of oxen hitched to a heavy cart, the towed load is twice as important (one ton) and the number of trips is likewise divided. We can see that the amount of work and the amount of time these trips take (loading, transporting, unloading) are compatible only with relatively short distances between the manure storage sites and the fields. It must also be said that manuring must be staggered over time because the nitrates are slowly drawn deep into the soil by water (leaching). Ideally, manuring will be done several times a year.

To complement insufficient quantities of manure, green fertilizers might also have been cultivated and ploughed under before the grains reach maturity. Pulses such as lupines, fava beans, vetches and grass peas could have been used for this purpose. The Latin authors mention them (Cato, *Économie rurale*, 37) along with cereal stubble and chaff.

6.4. Is domestic waste a solution in the surroundings of big cities?

In the countryside, all the waste that could have been used for fertilizer was quite probably gathered. Mapping phosphorus has, in certain cases, made it possible to show the existence of manure pits and to determine where they were located (Broes *et al.* 2012, Fig. 7: example of pit 1117 and building 1 at Saint-Brice-sous-Forêt, Val-d'Oise). The quality of manure depends on the amount of slurry; unfortunately, not all of the pits were built with masonry, which would have enabled storage. The absence of cesspits and latrines at most of the rural sites suggests that human faeces were not part of the rational management of waste.

In urban contexts, however, the concentration of waste was clearly much more organized and procuring residues susceptible for use in fields much easier (Bouet 2009, 169-171). Latrine residues, called *stercus*, constituted a precious raw material that estate owners sold for a profit (Cordier 2003). Nevertheless, here too, the factor that could limit the amplitude of waste reuse in arable fields was a logistical one, like distance. If cultivated areas existed in town, transportation was easier and faster. If, on the contrary, the food belt was in the suburbs, the distance from the production spots of wastes became crucial.

In the 18th century a type of “gilded belt” was found around towns where sludge, sewage and other waste nourished vegetable patches. However, the surfaces concerned were very limited as traditional fertilizers were almost all heavy products and transporting them by land, beyond 5 to 10 km, was out of the question (Sigaut 2013). On the scale of Gaul, areas fertilized by sludge were therefore not very vast; on the scale of towns and their surrounding countryside, their role was bigger. It is, therefore, necessary to make this distinction between a general situation and particular cases.

One example is given for the city of Reims (*Durocortorum*) and its peripheral farms (Toulemonde *et al.* 2017b). Car-pological studies were performed for the centre of the city, the suburbs and the surrounding countryside. Because the chalky Champagne region has mostly rendzina type soils, which are by nature thin, dry and barely fertile (Boulen *et al.* 2012), local crops remained static and mostly favoured the long-term growth of barley, in order to remedy the soil's constraints (Boulen *et al.* 2012). The limited isotopic analyses that have been done confirm that the soils were not fertilized (Aguilera *et al.* 2017b).

However, fruit trees may have represented alternative crops to cereals, as at least seven orchards have been identified in the city and its suburbs (Achard-Corompt *et al.* 2017). Cultivating these fruit trees in the clay soils of Champagne required manuring, which was perhaps just reserved for them? Adding fertilizers during the planting phase was demonstrated for ancient contexts in southern Gaul through the presence of charcoal and shards, coupled with profile reading (Jung *et al.* 2009).

The cereal stocks discovered at *Durocortorum* are mostly made up of free-threshing wheats and spelt. Other rare discoveries were also made such as the Pompeian millstone in rue Cernay (Fig. 43) or the *in situ* carbonization of loaves of bread or dough, found in the cellar of an urban *domus* which burned down at the beginning of the 3rd century AD in rue Saint Symphorien (Fig. 44).

Analysis of microscopic elements susceptible at identifying the composition of flours by A. Heiss (Austrian Academy of Sciences, Vienna)³⁶ revealed the presence of wheat cells and the use of carefully sieved flour, almost entirely free of glume and epidermis fragments. The crumb was analysed using RX microtomography at the National Museum of Natural History, Paris, and revealed a very alveolate structure (Fig. 45).

If spelt was cultivated locally, the rural farms seemed more likely to have produced barley, which may be the reason behind the idea that the stocks of free-threshing wheats had been imported (Mathelart *et al.* 2014). Free-threshing wheats only progressed in the region from the medieval period (Daoulas *et al.* oral communication 2017)³⁷. Nevertheless, we see that stocks of free-threshing wheats were also identified at farms in Bezannes, in the suburbs of the city. It would thus be pertinent to believe that local free-threshing wheat crops were possible thanks to city-countryside transportation (Toulemonde *et al.* 2017b). This situation was, in all likelihood, repeated regularly, but had gone unnoticed elsewhere because cereal stocks produced in the countryside do not offer as much of a contrast as those discovered in urban areas. The contents of an urban granary that burnt down in Amiens during the 2nd century AD delivered a layer of spelt spikelets (Matterne *et al.* 1998), coherent with the productions north of the Somme, essentially dominated by spelt and emmer (Zech-Matterne *et al.* 2017a).

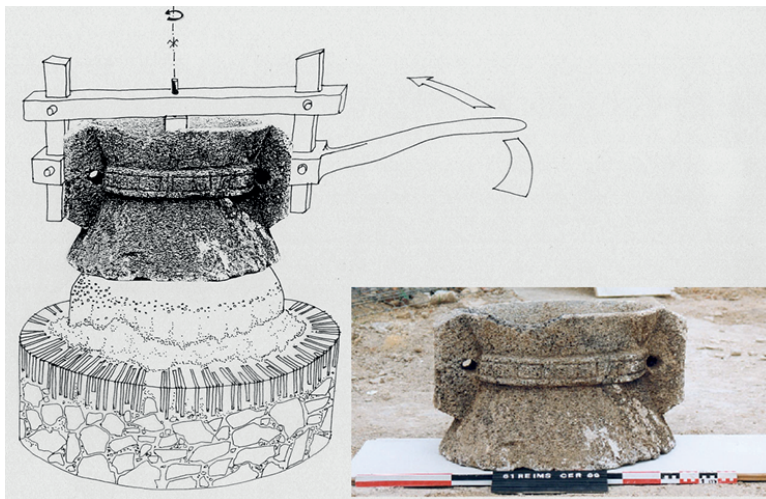


Fig. 43: Contextualization of the cereal mill remnant discovered in Reims, rue Cernay. Credits M. Poirier; Ph. Rollet, Inrap.



Fig. 44: Charred bread or dough discovered *in situ* on the floor of a cellar burned down at the end of the 2nd or the beginning of the 3rd century AD, rue Saint Symphorien, Reims, Marne (left). View of the wooden tray and breads it supported, *in situ* on the cellar floor (right).

36. In the framework of a PEPS programme CNRS/INEE Panexplore, dir. V. Zech, 2016.

37. G. Daoulas, E. Bonnaire, A.-M. Desiderio, S. Preiss, F. Toulemonde, J. Wiethold, V. Zech-Matterne, Les études carpologiques sur les sites d'habitats médiévaux de Champagne-Ardenne : État de la question, Oral presentation, XII^e Rencontres d'Archaeobotanical, Perpignan, 07-10 June 2017.

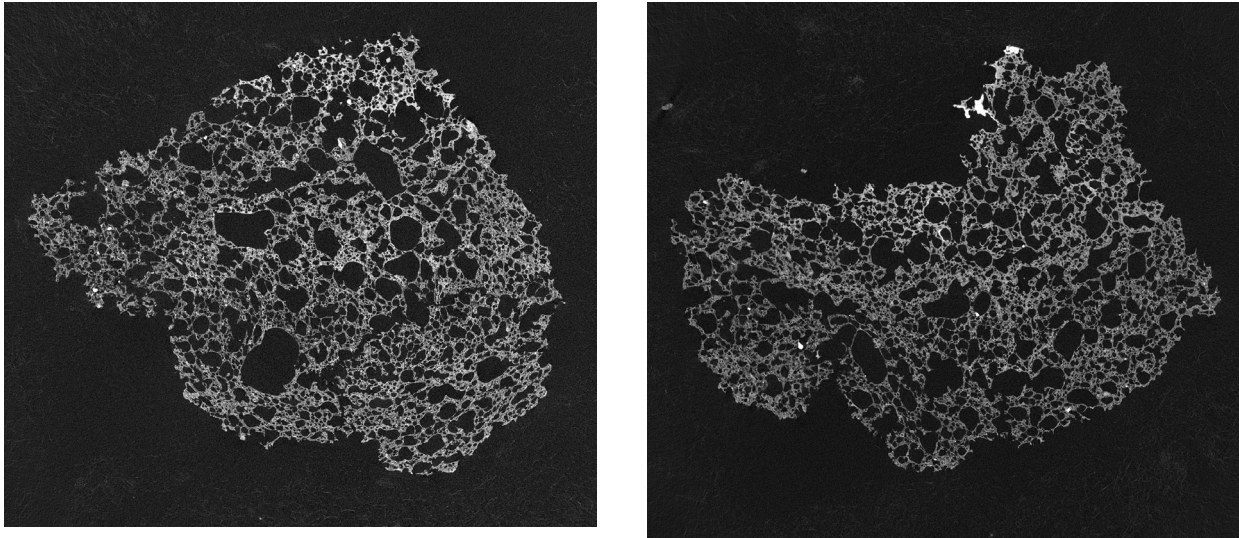


Fig. 45 : a and b: Reconstituted section of two pieces of bread or dough discovered at rue Saint-Symphorien with a resolution of 10 microns. Acquisition and processing of scans Patricia Wils, MNHN. Fig. 1: Diversity of the plant species mentioned

6.5. How to evaluate the yields

Several calculation methods were and still are in use. Those that calculate the harvest yield in terms of surface units are relatively recent, but they are only reliable when they associate the volume of grains with their state, hulled or dehusked, and their density relating to the moisture content recorded in the caryopses. This production surface yield should take into account the total amount of land needed to maintain crop fertility and the duration of rotation cycles, as a harvest is not obtained every year in each field/plot (Sigaut 1992).

Seed yield evaluation was used more often during the Roman period. This designates a size ratio between the amount of sown seeds and the amount of grains harvested. Data from ancient sources strongly varies: Varro (*R.*, I, 44, 2) or Pliny the Elder (18, 21) estimated that certain regions of Sicily, Italy or Egypt yielded 100 grains for one sown. Columella (*Rust.*, III, 3, 4) gives a much lower ratio for Italy: four harvested for one sown.

But as Fr. Sigaut remarks (1992), the ratio only makes sense if we know the sowing density, and therefore the sowing technique used, in order to evaluate surface yield. Several sowing techniques were used during Antiquity. In the vast Italian domains, broadcast sowing seems to have been favoured, as passages in Columella (II, 8, 4) and Pliny the Elder (18, 173) affirm; but what clues do we have to prove which techniques were indeed used for the various types of farms in Gaul?

This question is a vital one and represents a genuine hurdle to addressing the answer because the sowing technique tells us both about production capacities and labour costs. Sigaut (1988, 26) rightly insists on the fact that “*in non-mechanized farming, sowing and labour are completely linked, one cannot do one without the other*”³⁸.

Hand dibbling or row planting requires the immediate burying of small quantities of seeds to keep them from being eaten by birds or rodents, or from being blown towards an environment that would not be good for their development. Broadcast sowing wastes a lot of seeds, even when an expert hand distributes them on the surface of the soil, as burying (most often with a harrow) happens later when some of the seeds may have already been removed by predators. Choosing to broadcast sow implies that the amounts of seeds previously produced are sufficiently abundant to bear the waste; therefore, that farm must regularly produce a surplus or have sufficient stocks in storage. Conversely, a less wasteful sowing technique will be favoured in smaller farms that need to economize seeds: a saving of half the amount needed for broadcast sowing (Sigaut 1992, 402).

38. Original quote: “dans les agricultures non mécanisées, en fait, semence et main-d'œuvre sont largement substituables. On ne peut épargner l'une qu'en prodiguant l'autre”.

Another corollary is linked to the sowing technique. A sower can broadcast sow 4 ha/day (Moslan s. d. [circa 1880-1890], 35; quoted by Sigaut 1992), whereas an adult man and three helpers can only hand dibble 0.2 ha/day³⁹. Broadcast sowing would thus be a distinguishing feature of extensive farming which would cost less in terms of labour. Conversely, hand dibbling or even row planting is time consuming, and requires the help of several people. The entire family was usually enlisted in order to save on both the cost (and availability) of seeds and labour.

The question of expensive (or inexpensive) labour is a major factor to take into account when looking at the choices made. Switching from one technique to another also must be thought out not only in terms of profitability and yield, but also in terms of human labour. Cheap labour may, however, be found in both vast farmsteads (serf labour) and very small farms (family members who accepted to be paid little or nothing at all in the interest of the group's survival). For the Roman period, this parameter is difficult to calibrate.

Another parameter is the availability of seeds: are they abundant or scarce, and do they generate a surplus? Indeed, were Iron Age and Roman period farms sufficiently productive to regularly generate surpluses and therefore be able to use wasteful sowing techniques?

One very clear and singular example of generating an important surplus in Gallic farms is based on the carpological study of a cluster of granaries at the Entrammes site in the Mayenne department, as studied by B. Pradat (Guillier *et al.* 2015). A battery of 82 granaries among which 7 are dated to LT C2 (1st half of the 2nd century BC) and 75 to LT D1a (2nd half of the 2nd century BC) was recorded. Practically all delivered carpological remains; a total of 212 samples from the post holes of 60 granaries were analysed. Research showed that each of the granaries essentially contained emmer wheat (in 44 contexts the proportion exceeded 80 %) and that species represented 81.5 % of the 75,484 crop remains. It just does not seem plausible that the granaries were the stocks of individual families or that they were assembled in one area in order to protect them, especially when we take into account that one single species predominates in all the stocks and that the contexts are attributed to two distinct chronological phases. The idea that these stocks met a specific demand or that they were perhaps a compulsory contribution seems more plausible. The study's author concludes that they represented "*a voluntary mass storage before redistribution*" (Pradat 2015, 253).

This idea is reinforced by the fact that the study of cereal crops accompanying plants reveals that they were not locally produced. The wild plants included a large number of arable weeds that specifically grow in calcareous soils, whereas the array of granaries were set up on acidic soils, like those evidenced on almost all the exploited land in the Armorican Massif. Small calcareous zones nevertheless exist in the neighbouring area, about 15 to 30 km. In terms of transportation, "*managing such resources requires great organisation and proves a pooling of means and great power*" (Pradat 2015, 252). The quantities were massive, which implies that the production techniques gave the capacity to produce surpluses, and that farmers had the means to transport them.

A second similar example results from the carpological assemblages of the 'Les Errants' site in Val-de-Reuil, studied by L. Herveux (Moreau *et al.* 2015). Harvests with a majority of hulled barley and some emmer wheat, were stored in a battery of granaries dating back to the 2nd century BC (LT C2-D1), with some 40 structures set up along the edge of a paleochannel of the Eure River, before being transported by boat. The grains of these two hulled wheats had been completely dehusked, which made them unfit for long-term storage; this confirms both the transitory nature of the storage and the fact that the grains were "ready to eat". Here too, the specialized characteristic of these two species and the volumes involved, show that large amounts could be extracted and set aside from the harvests for commercial purposes and/or large-scale supply.

39. Columella II, 12.

7. Discussion, summary and perspectives

La Tène societies strove to increase yields and stabilize cereal production; the question of whether these crops were capable of generating important surpluses, especially cereal surpluses, has been raised in Britain by studying the great batteries of storage structures discovered on hill forts, especially at Danebury. The debate of “producing sites” versus “consumer sites” and determining the related production scales has long stirred the community of archaeobotanists and archaeologists working on the Iron Age⁴⁰. The model elaborated by M. Jones (1985) was based on the relative proportions of grain, straw and weed components. It was analyzed and enriched to reach the conclusion that the assemblages which were rich in grains were the result of accidents that could have happened as much in producing sites as in consumer sites. Van der Veen & Jones (2007) suggested associating these stock residues destroyed by fire with a production scale that generated important surpluses. They were more frequent in harvest-centralizing sites, whether the stocks were destined for local consumption or for “exportation”. The authors also put forward the hypothesis that the increase in grain-rich deposits was proof of a change in production scale (Van der Veen & Jones 2007, 426).

This argument is not easily transposed to France because granaries became more prevalent at the end of the Iron Age, practically replacing storage pits (Gransar 2000; Zech-Matterne *et al.* forthcoming). Although fire can affect the contents of a granary, a silo pit does not burn. The frequency of burnt stores consequently depends on, at least in part, storage means – concentrated or dispersed – and on the nature of the structures sheltering the crops. This indicator is thus also biased. We came to the conclusion that evaluating production scale must be based on a regional scope which would smooth out conservation variations on all the sites. To that end, the implementation of specialized crops based on free-threshing wheats at the scale of the Paris Basin and the fact that the development of these crops began a century and a half before the Roman Conquest constitutes is, in our opinion, a good indicator of the high degree of expertise reached by La Tène period farms and farmsteads. Other indicators of their success are the batteries of granaries where a single cereal makes up the entire stock, indicating that important levies were done on collective crops, as seen at the Entrammes or the Val-de-Reuil sites (see section 6.5 on yields).

Likewise, livestock farming and the great cattle bone pits proved the existence of large butcheries at the *oppidum* in Villeneuve-Saint-Germain, Titelberg and the Acy-Romance site; these clearly illustrate the countryside's capacity to generate a surplus with which to feed the towns, which in turn needed to organize live animal markets, their slaughtering and butchering, and the subsequent distribution as foodstuffs.

At the end of the second Iron Age, and even more so during the Roman period, farmers sought to increase productivity rather than production capacities. In other words, the objective was no longer to ensure surplus crops or animals, which were included in distribution circuits, but rather in optimizing the labour to produce said surpluses by opting for a better distribution of tasks throughout the entire agricultural calendar. Production means changed, as seen with the introduction of crop rotation for certain species like oats, a spring crop which was sown after just one ploughing and which fits into the off-peak times of the winter grain calendar; or inventions like the rotating mill, which divided grinding times by ten; the scythe, which enabled profitable fodder harvesting (Nillesse & Buchsenschutz 2007); and the *vallus* “machine”, used to harvest cereals in the larger farmsteads in north-eastern Gaul (Ferdère 1997; Raepsaet & Lambeau 2000).

Because the generation of surplus crops and the setting up of a distribution system (controlled by the ruling elite), as well as the subsequent needs to supply developing towns, had already highlighted the need to reinforce and improve tool performance, iron was readily used everywhere. Consequently, one observes the rise in plateau farming where arid ploughing could tackle heavier soils and the exploitation of previously unused soils in marginal situations (Malrain 2013; Malrain *et al.* 2015). Another way of increasing productivity was to increase the use of bovine or horse strength, already used for transportation. Here too, Gallic and Roman innovations in terms of means of communication and transportation, carts, coupling and harnessing, should be mentioned (Marbach 2004; Buchsenschutz 2009; Raepsaet 2013; David 2015). Indeed, heavy products were transported on rivers (Pals & Hakbijl 1992; Moreau *et al.* 2015; Pasquini & Petit 2015), but one still had to get them to the loading area.

In order to improve and ease herd maintenance, particular attention was paid to their feed. Tree fodder, a bigger volume to store and, due to its lower digestibility, with a lower nutritive interest than hay, was gradually reduced to the benefit of other fodder products, especially since the tools for cutting branches had not significantly evolved (Sigaut 1987). Progressively, grass fodder took over, especially when the scythe replaced the sickle for grass harvesting and multiplied cut yields by 2 to 5.

40 Dennell 1976; Hillman 1981; 1984; Gent 1983; Jones M. 1984; 1985; 1996; Jones G. 1987; Van der Veen 1991; 1992; Bakels 1996; Campbell 2000; Stevens 2003; Van der Veen & Jones 2006; 2007.

Inventing and developing such a complex tool involved much trial and error before fulfilling a very specific function; scythes were thus only to be handled by specialists (Sigaut 1988, 22).

This quest for new techniques or tools, that would enable a reduced work time or the number of labourers while continuing to increase yields, spurred evolutions that would have some unexpected repercussions, almost like a small agricultural revolution. *“By multiplying human labour yields in fodder harvesting, the straw scythe enabled European societies to use animal strength much more intensively than anywhere else in the world”*⁴¹ (Sigaut 1988, 22). But as they were better fed, the animals that made up this work force would see their morphologies evolve to impressive proportions.

Obtaining big and stocky animals was not always an advantage or is an indicator of progress. Moreover, the selection process was very long for bovines and equids and presupposed that the farmers had a predetermined and very precise idea of the size and build they wanted to obtain. This line of thinking is not borne out in the written sources, and the approach was conceptually distant from people's knowledge during that period; indeed, they knew nothing about the genetic mechanisms at work. Achieving big animals was not influenced by market demands but would have been a collateral result of improved diet, perhaps intended to sustain work animals, which resulted in an increase in the amount of meat produced *per capita*, the sub-system of distribution and the adaptation of consumption (with the development of markets) to reflect this change of scale.

The generalized increase in size quite probably caused the need to produce up to 40 % more fodder, which in turn increased energy and surface needs. Here as well, the creation of paths and roads and the use of animal strength facilitated the new operating systems, but the fodder, harvest processing and field fertilization (e.g. manure, clay, marl) product quantities to transport must have been gigantic. A simple evaluation of possibilities shows that certain systems should be reassessed, as the labour means they necessitated were incomparable with the hoped-for return. We are thus under the impression that the system had gone out of control during the High Empire and reached its limit in regions where access to land began to be more and more difficult, or in places where labour was not available in sufficient quantity. People leaving the countryside to live in urban areas as well as the variety of jobs that many former farm labourers took up undoubtedly reinforced these effects⁴².

Thenceforth, to the extent that it is not a question of selection, but rather one of feed which provoked the increase in size, how can one interpret the generalized decrease in size during the High Middle Ages? The current explanation of a loss of know-how in terms of zootechnics is not really an option because selecting animals through genetic manipulation does not seem to have concerned these populations for conceptual reasons. Should we not just see a sort of readjustment to a system that had expanded out of control and a return to animal and crop resource management that was better adapted to the territories' potential and workforce? The reorganization of distribution circuits favoured a clustering of economies in more regional spheres.

But in a similar way to what happened at the end of the Iron Age, if the increase may not have been desired, it can be assumed that the decrease was also an unintended consequence of new breeding practices. The decline in food quality may have been due to a reduction in feeding during the lean winter season, grazing on land of lower quality, the higher stocking density. This was to be expected since there was an explosion in the number of cattle heads, resulting in less food, as well as the abandonment of the use of protein fodder. An increase in stock density can lead to deleterious parasitism which can quickly influence the stature of animals (Andrey P. 2008) and is also potentially linked to poor herd maintenance. The age of females at first calving and inbreeding can also play an important and rapid role. Work on the reconstituted aurochs shows that the resulting drop in stature can be very rapid, about 10 cm high at the withers in 30 years (Guintard, Blond and Lepetz, submitted). But it is also quite possible that this decrease in size, perhaps due to feed, could be consciously supported and controlled. Whether the increase in size due to changes in diet was an involuntary side effect (?) accepted or not (?), we cannot affirm this, but once the result was taken into account obtaining the opposite pattern probably did not result from an unconscious effort. It is also symptomatic to observe that equidae underwent only a slight inflection of height, but were maintained at these larger sizes. In other words, breeders were able to implement what it took to maintain these taller horses.

This change in point of view begs us to revisit and reinterpret the carpological and archaeozoological data for Late Antiquity and the early medieval period, a cross-study endeavour that has yet to be undertaken. Indeed, if the corpus of studies for carpology exists, the collective work to gather and compare the data with an aim to providing a comprehensive overview has not yet been done, but it will constitute one of the next priorities for this research field.

41 Original quote: “En accroissant plusieurs fois le rendement du travail humain dans la récolte du fourrage, la faux à foin a permis aux sociétés européennes d'utiliser le travail animal bien plus intensivement que nulle part ailleurs dans le monde.”

42. See Malrain 2018

Without having resolved the several equations that govern the functioning of an agrarian system, as some parameters are beyond our archaeological reach, it is an overview of the limits that frame these systems that we have tried to address in this collective work; the outcome being the need for comparative research, as livestock husbandry and crop cultivation are so closely linked and interdependent. Concluding with such a commonplace remark would not be interesting if it was not accompanied by an absolute certitude: bones and seeds will continue to enlighten us about this complementarity, and the reflections they will generate go far beyond the sphere of bioarchaeology.



«Sheep grazing in a wheat field - 13th June 2007» - © Jean Bienvenu

La Tène - Augustan Age	A	B	C	E	F	G	H	I	J	K
<i>Sus scrofa domesticus</i>	1834	62	1890	24689	331		845	3140	1511	11072
<i>Bos taurus</i>	2002	38	1696	30943	1135		743	3427	1427	6013
<i>Caprinae</i>	1359	26	2254	17335	568		922	2080	1131	6020
<i>Equus</i> sp.	506		405	5416	288		34	719	275	1559
<i>Avena sativa</i>		28	4	1						5
<i>Avena spec.</i>	13	63	43	1244		66	2			284
<i>Hordeum vulgare</i> (tous taxons)	122	2	103	50182		8560	1251			20766
<i>Panicum miliaceum</i>			1	196		88	132			5
<i>Setaria italica</i>				13		130				2
<i>Triticum aestivum</i> (rachis)			4	1552						
<i>Triticum dicoccum</i>	10	470	6454	24942		10	82			4305
<i>Triticum monococcum</i>			252	1		13	2			3388
<i>Triticum spelta</i>	2		151	643		17	3			11438
<i>blés vêtus indét.</i>				25		2				6
<i>Triticum</i> sp.	163		2063	394		107	9			359
<i>Triticum aestivum/turgidum</i>		1	19	168162		33	13			12
<i>Lens culinaris</i>	14		3	42			1			26
<i>Pisum sativum</i>	1		2	172		65	1			58
<i>Vicia ervilia</i>				5		485				94
<i>Vicia sativa</i>			1	7		10				
<i>Vicia faba</i>			1	490		9				18
<i>Linum usitatissimum</i>	5		1	4		5				16
<i>Cannabis sativa</i>						1				
<i>Papaver somniferum</i>						2				
<i>Lupinus albus</i>							2			
<i>Camelina sativa</i>	1									5
<i>Lathyrus cicera/sativus</i>				5						
<i>Secale cereale</i>				5						

Appendix 1 : Number of archaeozoological and carpological remains in each of the workshop areas (La Tène - Augustan period)

High Empire	A	B	C	E	F	G	H	I	J	K
<i>Sus scrofa domesticus</i>	5184	255	3050	7603	1464	271	65	6466	223	2656
<i>Bos taurus</i>	5087	280	3576	9670	805	245	188	4461	321	2030
<i>Caprinae</i>	3448	173	1967	8846	1063	111	130	5036	373	2120
<i>Equus</i> sp.	1041	65	490	926	35	17	12	198	31	534
<i>Avena spec.</i>	248	8	62	116	84	124	122		4	24
<i>Hordeum vulgare</i> (tous taxons)	1095	202	2018	5443	4662	3042	2883		712	5258
<i>Panicum miliaceum</i>	5		1	4		84	5			2
<i>Setaria italica</i>			28	6		25	2			1
<i>Secale cereale</i>	1			116	2	10	4		2	259
<i>Triticum aestivum</i> (rachis)		1	124	9	1823	55	1		3	1
<i>Triticum dicoccum</i>	1237	943	5738	1648	17	1223	215			93
<i>Triticum monococcum</i>	54		255			42	336		3	53
<i>Triticum spelta</i>	904	75	15128	46		193	6966		34	335
<i>blés vêtus indét.</i>	863	590	1795	10		61	6			9
<i>Triticum</i> sp.	3133	2	2510	1427	9	389	88		99	396
<i>Triticum aestivum/turgidum</i>	595	50	8035	29625	47278	320	253		137	3068
<i>Lathyrus cicera/sativus</i>		2	3	1		12				
<i>Lens culinaris</i>	53	13	136	1016	220	219	19		304	56
<i>Pisum sativum</i>	78	65	230	405		63	13		2	17
<i>Vicia ervilia</i>			14	77	3	3			22	59
<i>Vicia sativa</i>	22	1	247	1436	55	22	12		129	6
<i>Vicia faba</i>	9		574	1983	5	149	3			38
<i>Linum usitatissimum</i>	1		2	1	1	3				
<i>Papaver somniferum</i>	2			14						
<i>Camelina sativa</i>		1	1							
<i>Cannabis sativa</i>			1			25				
<i>Cicer arietinum</i>	1									
<i>Avena sativa</i>				4		4				

Appendix 2 : Number of archaeozoological and carpological remains in each of the workshop areas (High Empire)

Zone	A	B	C	E	F	G	H	I	J	K
<i>Sus scrofa domesticus</i> - Porc	1000	615	869	3558	500	922	1289		1201	404
<i>Bos taurus</i> - Bœuf	2061	1223	1943	5451	959	1179	713		1504	2081
<i>Caprinae</i> - Caprinés	668	39	647	2264	351	578	72		535	523
<i>Equus</i> sp. - Équidés	244	19	136	581	44	61	25		180	342
<i>Avena spec.</i>			17	25		460	3059			40
<i>Hordeum vulgare</i> (tous taxons)	18	63	39	295		29917	3672			1898
<i>Panicum miliaceum</i>			1	23		64	177			
<i>Secale cereale</i>			4	7		4	52			46
<i>Triticum dicoccum</i>	15	145	5511	30		5	78			142
<i>Triticum monococcum</i>	6			8		120	202			1308
<i>Triticum spelta</i>	23	503	413	1946		2440	8159			3722
<i>blés vêtus indét.</i>	2			52		6	41			
<i>Triticum sp.</i>	235	281	754	14		1311	622			263
<i>Triticum aestivum/turgidum</i>	181	66	136	12482		442	1078			1713
<i>Lens culinaris</i>	7		7	370			63			60
<i>Pisum sativum</i>	3	8	487	19		8	699			2
<i>Vicia ervilia</i>	1			13			1			13
<i>Vicia sativa</i>		130	4	63		1	11			9
<i>Linum usitatissimum</i>			12			1	12			
<i>Vicia faba</i>				1		7				1
<i>Camelina sativa</i>			2							
<i>Triticum aestivum (rachis)</i>				3		1				3
<i>Setaria italica</i>				2			4			1

Appendix 3 : Number of archaeozoological and carpological remains in each of the workshop areas (Late Antiquity)

References

- COLUMELLE. *De Re Rustica*. On Agriculture, The Loeb Classical Library edition. 3 Vol., 1941, 1954 and 1955.
- CATON. *De l'Agriculture*. Texte établi et traduit par R. Goujard, première publicat. 1975, Les Belles Lettres, Collection des universités de France série latine, Paris.
- PALLADIUS. *Traité d'agriculture*. Tome I : livres I et II. Texte établi et traduit par R.F. Martin, première publicat. 1976, Les Belles Lettres, Collection des universités de France série latine, Paris.
- PALLADIUS. *Traité d'agriculture*. Tome II : livres III à V. Texte établi et traduit par C. Guiraud et R. Martin, 2010, Les Belles Lettres, Collection des universités de France série latine, Paris.
- PLINE. *Histoire Naturelle*. Livre XXVIII, De l'agriculture. Texte établi et traduit par H. Le Bonniec, avec la contribution d'A. Le Boeuffe, première publicat. 1972, Les Belles Lettres, Collection des universités de France série latine, Paris.
- VARRON. *Economie rurale*. Tome I : livres I. Texte établi et traduit par J. Heurgon, première publicat. 1978, Les Belles Lettres, Collection des universités de France série latine, Paris.
- VARRON. *Economie rurale*. Tome II : livres II. Texte établi et traduit par C. Guiraud, première publicat. 1985, Les Belles Lettres, Collection des universités de France série latine, Paris.
- Achard-Corompt N., Audebert A., Dessaint M., Durost R., Le Quellec V. (2017) : "Les modes d'occupation du sol chez les Rèmes", in : Reddé dir. 2017, chapitre 11, 495-554.
- Agreste (2003) : L'utilisation du territoire en 2002. Agreste n° 148 : Chiffres et Données Agriculture, 55-65.
- Agreste.agriculture.gouv.fr (2017) – Accessed on line december 8 2017: /<http://agreste.agriculture.gouv.fr/donnees-de-synthese/statistique-agricole-annuelle-saa/>
- Aguilera, M., M. Balasse, S. Lepetz, V. Zech-Matterne (2017a) : "Amender les sols cultivés avec des fumiers et déchets domestiques : une origine multimillénaire pour un enjeu majeur du développement durable", in : Balasse & Dillmann 2017, 51-71.
- Aguilera, M., V. Zech-Matterne, M. Balasse, S. Lepetz (2017b) : "Crop fertility conditions in north-eastern Gaul during the La Tène and Roman periods : A combined stable isotope analysis of archaeobotanical and archaeozoological remains", *Environmental Archaeology*, 1-15 (online), mis en ligne en Janvier 2017, consulté le 27 Octobre 2017. URL : <http://dx.doi.org/10.1080/14614103.2017.1291563>
- Akeret, Ö., P. Rentzel (2001) : "Micromorphology and plant macrofossil analysis of cattle dung from the Neolithic lake shore settlement of Arbon Bleiche 3", *Geoarchaeology*, 16, 6, 687-700.
- Akeret, Ö., M. Kühn, L. Wick (2016) : "The meadow of Onoldswil (Switzerland) in the summer of AD 1295 - an example of a palaeobiocoenosis", Abstract book of the 17th IWGP conference, Paris, 4-9 Juillet 2016, 1.
- Allen, M. (2016) : "Pastoral farming", in : Allen et al., éd. 2016, 85-138.
- Allen, M., L. Lodwick (2017) : "Agricultural strategies in Roman Britain", in : Allen et al., éd. 2017, 142-177.
- Allen, M., L. Lodwick, T. Brindle, M. Fulford A. Smith, ed. (2017) : *The rural economy of Roman Britain, New visions of the countryside of Roman Britain*, volume 2, *Britannia Monograph Series*, 30, London.
- Anderson, P.C., dir. (1992) : *Préhistoire de l'agriculture. Nouvelles approches expérimentales et ethnographiques*, Monographies du C.R.A., 6, Paris.
- Anderson, S., F. Ertug-Yaras (1998) : "Fuel fodder and faeces : A, ethnographic and botanical study of dung fuel use in Central Anatolia", in : Charles et al. 1998, 99-110.
- Anderson, P. C., C. Cheval, A. Durand, dir. (2013) : *Regards croisés sur les outils liés au travail des végétaux. An interdisciplinary focus on plant-working tools*, Actes des XXXIII^e Rencontres Internationales d'Archéologie et d'Histoire d'Antibes, Antibes, 23-25 Octobre 2012, Antibes.
- Andrey P., (2008) : *La race bovine Aurochs-reconstitué (code race 30) : importance du parasitisme digestif et actualisation des mesures biométriques. Etude expérimentale dans cinq élevages types*, Thèse de Doctorat vétérinaire, Nantes.
- Audoin-Rouzeau, F. (1991) : *La taille du bœuf domestique en Europe de l'antiquité aux temps modernes*, *Fiches d'ostéologie animale pour l'archéologie. Série B : Mammifères*. 2, APDCA, Juan-les-Pins.
- Audoin-Rouzeau, F. (1995) : *La taille des animaux d'élevage à l'époque romaine et leur exportation*, *Homme et animal dans l'antiquité romaine* n° hors série, Tours.
- Baeten, J., E. Marinova, V. De Laet, P. Degryse, D. De Vos, M. Waelkens (2012) : "Faecal biomarker and archaeobotanical analyses of sediments from a public latrine shed new light on ruralisation in Sagalassos, Turkey", *Journal of Archaeological Science*, 39, 4, 1143-1159.
- Bakels C.C. (1996) : "Growing grain for others or how to detect surplus production?", *Journal of European Archaeology*, 4, 329-336.
- Bakels C.C., (1997) : "The beginnings of manuring in western Europe", *Antiquity*, 71, 442-445.
- Balasse, M. (2013) : "L'élevage au Néolithique : l'éclairage des analyses isotopiques", in Thiébault & Depaepe, dir., 2013, 77-88.

- Balasse, M., A. Tresset, S.H. Ambrose (2006): "First evidence for seaweed foddering in the Neolithic of Scotland", *Journal of Zoology*, 270, 170-176.
- Balasse, M., Dillmann, Ph., ed. (2017): *Regards croisés : quand les sciences archéologiques rencontrent l'innovation*, Collection Sciences Archéologiques, Paris.
- Balasse, M., J.-Ph. Brugal, Y. Dauphin, E.-M. Geigl, Ch. Oberlin, I. Reiche (2015): *Message d'os. Archéométrie du squelette humain et animal*. Collection Sciences Archéologiques, Paris.
- Ballet, P., P. Cordier, N. Dieudonné-Glad, dir. (2003): *La ville et ses déchets dans le monde romain : rebuts et recyclages*, Actes du colloque de Poitiers, 19-21 septembre 2002, Archéologie et histoire romaine, 10, Montagnac.
- Barker G., C. Gamble, ed. (1985): *Beyond Domestication in Prehistoric Europe*, London.
- Bayard, D. et J.-L. Collart, éd. (1996) : *De la ferme indigène à la villa gallo-romaine*, *Revue Archéologique de Picardie* n° spécial 11, Amiens.
- Bayard, D., N. Buchez, P. De Paepe, dir. (2014): *Quinze ans d'archéologie préventive sur les grands tracés linéaires en Picardie. Seconde Partie*, *Revue Archéologique de Picardie*, 3-4, Amiens.
- Becker, C., H. Manhart et J. Schibler (1999): *Historia animalium ex ossibus : Beiträge zur Paläoanatomie, Archäologie, Ägyptologie, Ethnologie und Geschichte der Tiermedizin : Festschrift für Angela von den Driesch zum 65. Geburtstag*, Internationale Archäologie : Studia honoraria ; Bd. 8.
- Bernigaud, N. (2013): "Systèmes agro-pastoraux et utilisation de la faux en Dauphiné depuis le second âge du Fer ", in : Anderson et al., dir. 2013, 37-47.
- Bernigaud, N., A. Berga, J. Blanchard, O. Blin, M. Boulen, L. Boulenger, M. Derreumaux, S. Lepetz, F. Toulemonde, V. Zech-Matterne (2017): "L'Île de France", in : Reddé, dir 2017, chapitre 10, 389-494.
- Bertrand, I., A. Duval, J. Gomez De Soto, P. Maguer, dir. (2009): *Habitats et paysages ruraux en Gaule et regards sur d'autres régions du monde celtique*, Actes du XXXIe colloque international de l'AFEAF, 17-20 mai 2007, Chauvigny, 85-92.
- Birk, J. J., M. Dippold, G. L. B. Wiesenberger, B. Glaser (2012): "Combined quantification of faecal sterols, stanols, stanones and bile acids in soils and terrestrial sediment by gas chromatography-mass spectrometry", *Journal of Chromatography A*, 1242, 1-10, (En ligne], mis en ligne le 15 Juin 2012, consulté le 27 Octobre 2017. URL : <https://doi.org/10.1016/j.chroma.2012.04.027>
- Blancquaert, G., F. Malrain, ed. (2016): *Évolution des sociétés gauloises du Second âge du Fer, entre mutations internes et influences externes*, Amiens, *Revue Archéologique de Picardie*, n° sp. 30, Amiens.
- Bleicher, N. (2016): "Pastoralism, landscape and woodland use in the Late Neolithic in southern Germany", in : Retamero et al. 2016, 239-252.
- Boessneck, J., A. Von den Driesch, A. Meyer, U. Lempennau, E. Wechsler von Ohlen (1971): *Die Tierknochenfunde aus dem Oppidum von Manching von Boessneck, Joach, Römisch-Germanische Kommission des deutschen archäologischen Instituts zu Frankfurt am Main, Wiesbaden*.
- Bogaard, A., T.H.E. Heaton, P. Poulton, I. Merbach (2007): "The impact of manuring on nitrogen isotope ratios in cereals : archaeological implications for reconstruction of diet and crop management practices", *Journal of Archaeological Sciences*, 34, 335-343.
- Boichard, J. (1965): "L'élevage du bœuf et la production de la viande en Nivernais", *Revue de Géographie de Lyon*, 40, 1, 47-75.
- Borderie, Q., M. Fondrillon, C. Nicosia, Y. Devos, R. I. Macphail (2015): "Bilan des recherches et nouveaux éclairages sur les terres noires : des processus complexes de stratification aux modalités d'occupation des espaces urbains", in : Lorans & Rodier 2015, 235-261.
- Bouby L., M.-P. Ruas (2005): "Prairies et fourrages : réflexions autour de deux exemples carpologiques de l'Age du Fer et des Temps Modernes en Languedoc. *Anthropozoologica*, Publications scientifiques du Muséum, 40, 1, 109-145.
- Bouet, A. (2009): *Les latrines dans les provinces gauloises, germaniques et alpines*, Supplément à Gallia, 60, Paris.
- Boulen, M., V. Zech-Matterne (accepted) : *Témoins archéologiques et archéobotaniques de chanvre (Cannabis sativa L.) dans les sites de France septentrionale: l'ambiguïté des sources*. In : *De cordes et de toiles. Le chanvre et le lin à la mer. Cultures, usages et innovations, des origines à demain*, Actes du colloque international tenu à Lorient – Douarnenez en Juin 2012, Presses Universitaires de Rennes.
- Boulen, M., Y. Creteur, K. Fechner, S. Loicq, V. Zech-Matterne, with the collaboration of E. Bonnaire, D. Bossut, V. Clavel, O. Decocq, F. Deligne, R. Peuchot, J.-L. Slachmuylder, F. Toulemonde (2012): "Environnement et exploitation des sols autour des sites protohistoriques champenois. Première confrontation des résultats archéobotaniques, malacologiques et pédologiques", in : Schönfelder & Sievers, dir. 2012, 41-76.
- Brochier, J. E., P. Villa, M. Giacomarra (1992): "Shepherds and sediments : geo-ethnoarchaeology of pastoral sites", *Journal of Anthropological Archaeology*, 11, 47-102.

- Broes, F., V. Clavel, W. Declerc, K. Fechner, V. Rouppert, J. Vanmoerkerke (2012): "À la recherche des espaces de stabulations : Étude pluridisciplinaire d'habitats du Néolithique au Moyen Âge dans le Nord de la France", *Archéopages*, 35, Vivre avec les bêtes, 6-17.
- Brumont, F., dir. (2008): *Prés et pâtures en Europe occidentale. Actes des XXVIII^e Journées Internationales d'Histoire de L'Abbaye de Flaran*, 15-16 Septembre 2006, Flaran, 28, Toulouse.
- Brun, J.-P., Ph. Jockey, dir. (2001): *Techniques et sociétés en Méditerranée, Hommages à M.-C. Amouretti*, Travaux du Centre C. Jullian, Aix-en-Provence.
- Buchsenschutz, O. (2009): "Chars, charrettes et transport dans l'agriculture celtique", in : Bertrand, Duval, Gomez De Soto, Maguer, dir. 2009, 85-92.
- Bull, D., M. J. Lockheart, M.M. Elhmmali, D.J. Roberts, R.P. Evershed (2002): "The origin of faeces by means of biomarker detection. *Environment International*", 27, 647-654.
- Campbell, G. (2000): "Plant utilization: the evidence from charred plant remains", in Cunliffe dir. 2000, 45-59.
- Capdeville, C., S. Chevrier, B. Fort, N. Tisserand (2015): "Saint-Clément, Yonne, Bourgogne. Les objets métalliques de la cave de Saint-Clément : un corpus exceptionnel dans le monde romain", *Dossier scientifique, Inrap GES*, 47 p. (consultable au SRA Bourgogne).
- Cardoni L. (2014): *Méthode d'étude des stigmates anatomiques d'émondage : perspectives anthracologiques*, Mémoire de M1 en Evolution, Patrimoine naturel et Sociétés, spécialité Quaternaire et Préhistoire, Muséum national d'Histoire naturelle.
- Champion, T.C., J.R. Collis, ed. (1996): *The Iron Age in Britain and Ireland. Recent Trends*, Sheffield.
- Chancrin, R., C. Dumont (1921): *Larousse agricole*, Paris.
- Chapelot, J., éd. (2010): *Trente ans d'archéologie médiévale en France : un bilan pour un avenir / IX^e congrès international de la Société d'archéologie médiévale*, Vincennes, 16-18 juin 2006.
- Charles, M., Halstead, P., Jones, G., ed. (1998): *Fodder : archaeological, historical and ethnographic studies*, *Environmental Archaeology*, 1, Oxford.
- Clavel, B., J.-H. Yvinec (2010): "L'archéozoologie du Moyen Âge au début de la période moderne dans la moitié nord de la France", in : *Trente ans d'archéologie médiévale en France*, Publication du CRAHM, 2010, 7187.
- Clotuche, R., M. Derreumaux, F. Pigièrre, G. Jouanin, S. Preiss, J.-H. Yvinec (2017): "Les campagnes en territoire Nervien : approches croisées", in : Reddé dir. 2017, chapitre 5, 179-210.
- Colominas, L., A. Schlumbaum, M. Saña (2014): "The impact of the Roman Empire on animal husbandry practices : study of the changes in cattle morphology in the north-east of the Iberian Peninsula through osteometric and ancient DNA analyses", *Archaeological and Anthropological Sciences*, 6, 1, 116.
- Comet, G., ed. (2003): *L'outillage agricole médiéval et moderne et son histoire*, Actes des XXIII^e Journées internationales d'Histoire de l'Abbaye de Flaran, 7-9 Septembre 2001, Toulouse.
- Cordier, P. (2003): "Le destin urbain du stercus et de l'urine", in : Ballet et al., dir. 2003, 51-60.
- Costamagno, S., dir. (2014): *Histoire de l'alimentation humaine : entre choix et contraintes*, Actes du 138^e congrès du C.T.H.S., Se nourrir : pratiques et stratégies alimentaires, Rennes, 22-27 Avril 2013, Actes des congrès nationaux des Sociétés Historiques et Scientifiques (éditions électronique), Paris, (En ligne], consulté le 02 Novembre 2017, URL : <http://cths.fr/ed/edition.php?id=6848>.
- Cunliffe B. (2000): *The Danebury Environs Programme. The Prehistory of a Wessex Landscape*, ol. I: Introduction, Committee for Archaeology Monograph 48, London.
- Cunliffe, B., D. Miles, ed. (1984) : *Aspects of the Iron Age in Central Southern Britain*, Oxford University Committee for Archaeology Monograph, 2, Oxford.
- Cuvelier, C., I. Dufrasne (2015): *L'alimentation de la vache laitière. Aliments, calculs de ration, indicateurs d'évaluation des déséquilibres de la ration et pathologies d'origine nutritionnelle*, Livret d'Agriculture, Liège.
- Danielisova, A., M. Fernandez-Götz, ed. (2015): *Persistent economic ways of living. Production, distribution, and consumption in late prehistory and early history*, Proceedings of the 19th EAA annual meeting held in Pilsen, Septembre 2013, *Archaeolingua*, 35, Budapest.
- Daoulas, G., G. Jouanin, G. Auxiette, J.-H. Yvinec, J. Wiethold (2017): "Productions végétales, alimentation et élevage dans la vallée de la Moselle entre Metz et Thionville et dans les environs de la cite de Metz : l'apport des données carpologiques et archéozoologiques", in : Lepetz & Zech-Matterne, dir. 2017, 103-110.
- David, F. (2015): "Les harnais des attelages gallo-romains", *Hist. & Sociétés Rurales*, 43, 1 (juillet), 7-44.
- De Hingh, A. (2000): *Food production and food procurement in the Bronze age and Early Iron Age (2000-500 BC). The organi-*

sation of a diversified and intensified agrarian system in the Meuse-Demer-Scheldt region (The Netherlands and Belgium) and the region of the river Moselle (Luxemburg and France), Archaeological Studies Leiden University, 7, Leiden.

De Hingh, A., V. Matterné, J. Wiethold (2016): "Agriculture, alimentation végétale et paléoenvironnement", in Koenig, dir. 2016, chap. 2, 31-92.

Delhon, C., L. Martin, J. Argant, S. Thiébault (2008): "Shepherds and plants in the Alps : multi-proxy archaeobotanical analysis of neolithic dung from 'La Grande Rivoire' (Isère, France)", *Journal of Archaeological Science*, 35, 11, 2937-2952.

Demarquilly, C., M.-C. Engrand, J.-F. Cristofini, Y. Manis, B. Marquis (1966): "Valeur alimentaire de l'herbe des prairies temporaires aux stades d'exploitation pour le pâturage. II. - Quantité intégrée par les vaches laitières", *Annales de Zootechnie*, 147-169.

Demonet, M. (1990): "Tableau de l'agriculture française au milieu du XIXe siècle. L'enquête de 1852". Paris, EHESS, 304 p.

Dennell, R.W. (1976) : "The economic importance of plant resources represented on archaeological sites", *Journal of Archaeological Science*, 3, 229-247.

DeNiro, M.J., S. Epstein (1981): "Influence of diet on the distribution of nitrogen isotopes in animals", *Geochimica et Cosmochimica Acta*, 45, 341-351.

Derreumaux, M. (2005): "How to detect fodder and litter ? A case study from the Roman site 'Le Marais de Dourges', France", *Vegetation History and Archaeobotany*, 14, 373-385.

Derreumaux, M. (2012): *Du terrain au terroir : appréhender les systèmes agraires grâce aux grands décapages : trois études carpologiques en territoires ménapien et arébate, de La Tène ancienne au Haut Moyen-âge*, Thèse de doctorat en Archéologie de la Gaule romaine, Paris 1 Panthéon-Sorbonne.

Derreumaux, M., S. Lepetz (2008): "Food supply at two successive military settlements in Arras (France): an archaeobotanical and archaeozoological approach", in : Stallibrass & Thomas 2008, 52-68.

Deru, X., R. Gonzalez-Villaescusa, dir. (2014): *Consommer dans les campagnes de la Gaule romaine*. Actes du X^e colloque AGER, Lille, 4-6 Avril 2012, *Revue du Nord*, hors- série, Art et Archéologie, 21, Villeneuve d'Ascq.

Devroey, J.-P., J.-J. van Mol, dir. (1989): *L'épeautre (Triticum spelta)*. Histoire et ethnologie. L'homme et son terroir, Treignes.

Doligez, P. (2016): "Alimenter les chevaux avec de l'herbe et des fourrages", Ressource en ligne : consulté le 8 décembre 2017. http://www.ifce.fr/wp-content/uploads/2016/10/DIFF-Webconf-PDO-alimentation_herbe_fourrages.pdf.

Dupouey, J.-L., E. Dambrine, J.-D. Laffite, C. Moares (2002): "Irreversible impact of past land use on forest soils and biodiversity", *Ecology*, 83, 11, 2978-2984.

Duval, C., S. Lepetz, M.-P. Horard-Herbin (2012): "Diversité des cheptels et diversification des morphotypes bovins dans le tiers Nord-Ouest des gaules entre la fin de l'Âge du fer et la période romaine", *Gallia*, 692, 79114.

Duval, C., M.-P. Horard, S. Lepetz (2013): "Morphological evolution of bovines in Gaul, from the 2nd century BC to the Vth century AD : diversity of herds in the Seine valley (France) and Northern Gaul", *Journal of Archaeological Sciences*, 40, 39773990.

Duval, C., S. Lepetz, M.-P. Horard-Herbin, T. Cucchi (2015): "Did Romanization impact Gallic pig morphology ? New insights from molar geometric morphometrics", *Journal of Archaeological Science*, 57, 345354.

Duval, C., D. Frémondeau, S. Lepetz, M.-P. Horard-Herbin (2016): "L'élevage du porc : un savoir faire gaulois ? Apport croisé des études isotopiques et ostéométriques des os de cochon", in : Blancquaert & Malrain, éd. 2016.

Echt, R., B. Birkenhagen, F. Sărățeanu-Müller, ed. (2016): *Monumente der Macht. Die gallo-römischen Großvillen vom längsaxialen Typ*. Internationale Tagung, Archäologiepark Römische Villa Borg, 26-28 Mars 2009, Saarbrücker Beiträge zur Altertumskunde, 90, Bonn.

Enneking D. (1995): "The toxicity of Vicia species and their utilization as grain legumes", Centre for Legumes in Mediterranean Agriculture (CLIMA), Occasional Publication, 6, Nedlands W.A.

Enneking, D., N.F. Miller (2014): "Bitter vetch Vicia ervilia: ancient medicinal crop and farmers favorite for feeding livestock", in : Minnis 2014, 254-268.

Fechner, K. (2011): "Case studies of phosphorus mapping in Late La Tène to Roman enclosures and ponds between Rhine and Seine", in : Fechner et al., dir. 2011, 29-64.

Fechner, K., Y. Devos, M. Léopold, et J. Völkel, dir. (2011): *Archaeology, soil- and life sciences applied to enclosures and fields*. Proceedings of the 12th Annual Meeting of the European Association of Archaeologists, Krakow, 19-24 Septembre 2006, BAR International Series, 2222, Oxford.

Fechner, K., J.-L. Slachmuylder, with the collaboration of M. Boulén, O. Decocq, F. Deligne, Y. Devos, H. Doutrelepont, I. Figueiral, A. Gebhardt, D. Harmand, J. Hus, R. Langohr, V. Matterné, H.G. Naton, R. Peuchot, M. Saurel, D. Sordoillet, W. Tegel, J. Vanmoerkerke (2009): "Les 'sols noirs' en relation avec l'homme sur le tracé champenois du TGV-Est. Compréhension pédologique et malacologique, approche statistique et essai d'interprétation archéologique", in : Van Moerkerke, dir. 2009, 45-56.

- Ferdière, A. (1997): "Le vallus et la faux, l'épeautre et le bœuf : fable", Bulletin AGER, 7, 3-9.
- Ferdière, A. (2001): "La charrue gauloise : histoire d'un mythe", in : Brun & Jockey, dir. 2001, 169-190.
- Ferdière, A., with the collaboration of H. Bender, P. Lemaire (2009): "Recherche sur les contextes de découverte d'outillage agricole et objets liés au travail et à la production rurale en Gaule romaine", in : Leveau, Raynaud, Sablayrolles, Trément, dir. 2009, 81-107.
- Ferdière, A., F. Malrain, V. Matterné, P. Méniel, A. Nissen-Jaubert, with the collaboration of B. Pradat (2006): Histoire de l'agriculture en Gaule. 500 avant J.-C. -1000 apr. J.-C., Paris.
- Floret, Ch., G. Serpantié, dir. (1993): La jachère en Afrique de l'Ouest, Actes de l'atelier international, Montpellier, 2-5 Décembre 1991, Colloques et Séminaires, Paris.
- Forest, V., I. Rodet-Belarbi (2002): "À propos de la corpulence des bovins en France durant les périodes historiques", Gallia, 59, 1, 273-306.
- Fraser, R. A., A. Bogaard, T.H.E. Heaton, M. Charles, G. Jones, B. T. Christensen, P. Halstead, I. Merbach, P. R. Poulton, D. Sparkes, A. K. Styring (2011): "Manuring and stable nitrogen isotope ratios in cereals and pulses : towards a new archaeobotanical approach to the inference of land use and dietary practices ". Journal of Archaeological Sciences, 38, 2790-2804.
- Frémondeau D. (2012): Rythmes saisonniers des élevages porcins archéologiques : propositions pour un protocole d'analyse isotopique, Thèse de doctorat, Muséum national d'Histoire naturelle, Paris.
- Frémondeau, D., T. Cucchi, F. Casabianca, J. Ughetto-Monfrin, M.-P. Horard-Herbin, M. Balasse (2012): "Seasonality of birth and diet of pigs from stable isotope analyses of tooth enamel ($\delta^{18}O$, $\delta^{13}C$): a modern reference data set from Corsica, France", Journal of Archaeological Science, 39, 7, 2023-2035.
- Gebhardt, A. (2000): "[Anthropisation, agricultures anciennes et formation des paysages ruraux : le rôle de la micromorphologie des sols](#)", Études rurales, 153/154, 139-149.
- Gebhardt, A., S. Occhietti, K. Fechner (2014): "Grandes phases de pédogenèse, d'érosion et d'anthropisation des sols au cours de la seconde moitié de l'Holocène en Lorraine (France)", ArchéoSciences, revue d'archéométrie, 38, 7-29.
- Gent, H. (1983): "Centralized storage in later prehistoric Britain", Proceedings of the Prehistoric Society, 49, 243-267.
- Gerbaud, E., T. Dutoit, A. Barrois (2001): "Rôles du pâturage des chaumes (estoubes) dans le système de parcours ovin d'une exploitation agricole du parc naturel régional du Lubéron : un argument pragmatique pour la conservation des messicoles", Courrier scientifique du Parc naturel régional du Lubéron, 5, 90-101.
- Giannecchini, M., J. Moggi-Cecchi (2008): "Stature in archeological samples from central Italy: Methodological issues and diachronic changes", American Journal of Physical Anthropology, 135, 3, 284-292.
- Giligny, F., Z. Tsirtsoni Z., dir. (2015): Dossier : Environnement et sociétés, Les Nouvelles de l'Arch., 142, Paris.
- Gossin, L. (1858): L'agriculture française : principes d'agriculture appliqués aux diverses parties de la France , Paris.
- Gransar, F. (2000): "Le stockage alimentaire sur les établissements ruraux de l'âge du Fer en France septentrionale: complémentarité des structures et tendances évolutives", in : Marion & Blancquaert, 2000, 277-297.
- Greig, J. (1984): "The palaeoecology of some British hay meadow types", in : Van Zeist & Casparie 1984, 213-226.
- Grogner, L.-F., J.-H. Magne (1841): Cours de multiplication et de perfectionnement des principaux animaux domestiques, Bouchard-Huzar, Paris.
- Groot, M. (2008): Animals in Ritual and Economy in a Roman Frontier Community : Excavations in Tiel-Passewaaij, Amsterdam.
- Guillier, G., A. Levillayer, B. Pradat, V. Deloze, P. Forré (2015) : "Des poteaux, des greniers et des graines. Une zone de stockage de masse à La Tène C2/D1a au 'Clos des Primevères' à Entrammes (Mayenne)", Revue Archéologique de l'Ouest, 32, 177-260.
- Guintard C., Q. Blond, S. Lepetz (submitted): Évolution de la taille de l'aurochs-reconstitué depuis 30 ans : conséquences pour l'élevage et pour la connaissance des processus impliqués dans l'évolution de la stature des bovins aux périodes anciennes in : Environnement : temps, territoires, sociétés. Mélanges en l'honneur de Corinne Beck, Presses Universitaires de Valenciennes.
- Haas, N., S. Karg, P. Rasmussen (1998): "Beech leaves and twigs used in winter fodder : Exemples from historic and prehistoric times", in : Charles et al., dir. 1998, 81-86.
- Halstaed, P., J. Tierney (1998): "Leafy hay : An ethnoarchaeological study in NW Greece", in : Charles et al., dir. 1998, 71-80.
- Haselgrove, C., T. Moore, ed. (2007): The later Iron Age in Britain and beyond, Oxford.
- Herrscher, E., S. Pluton-Kliesh, C. Bémilli, S. Lepetz (in press): "Normes alimentaires et déterminants socio-culturels dans le nord de la Gaule romaine : Apport de l'analyse isotopique d'ossements humains et animaux du site du Clos au Duc à Evreux (27)", in : Nouvelles approches de l'archéologie funéraire, 6e rencontre du groupe d'anthropologie et d'archéologie funéraire.

- Heyberger, L. (2005): "Stature et niveau de vie biologique, Abstract", *Histoire & Sociétés Rurales*, 24, 2, 83-104.
- Hillman, G. (1981): "Reconstructing crop husbandry practices from charred remains of crops", in : Mercer 1981, 123-162.
- Hillman, G. (1984): " Interpretation of archaeological plant remains: the application of ethnographic models from Turkey", in : Van Zeist & Casparie 1984, 1-41.
- Hoch, T., G. Begon, I. Cassar-Malek, B. Picard, I. Savary-Auzeloux (2003): "Mécanismes et conséquences de la croissance compensatrice chez les ruminants", *INRA Productions Animales*, 16 (1), 12003, 49-59.
- Honneger, M., D. Ramseyer, G. Kaenel, B. Arnold, M.-A. Kaeser, dir. (2009): *Le site de La Tène : bilan des connaissances – état de la question*, Actes de la Table ronde internationale de Neuchâtel, Neuchâtel, 1-3 Novembre 2007, Archéologie neuchâteloise, 43, Neuchâtel.
- Hulin, G., F. Broes, K. Fechner (2012): "Caractérisation de phénomènes anthropiques par la mesure de paramètres magnétiques sur surface décapée : Premiers résultats sur le projet Canal Seine-Nord Europe", *ArchéoSciences*, revue d'archéométrie, 36, 61-70.
- Institut de recherche et de développement en agroenvironnement. Accessible online, 8 december 2017 : (https://www.irda.qc.ca/assets/documents/Publications/documents/irda-mapaq-aiaq-2012_fiches_dejections_animales.pdf).
- Jacomet, S., U. Leuzinger, J. Schibler, ed. (2004): *Die jungsteinzeitliche Seeufersiedlung Arbon Bleiche 3*, Veröffentlichungen des Amtes für Archäologie des Kantons Thurgau, 12.
- Jacomet, S., P. Vandonne (2011): "Plantes anciennes et nouvelles. La région du Rhin supérieur et l'Allemagne du Sud-Ouest", in : Reddé et al., dir. 2011, 345-360.
- Jacquat, Ch. (1986): *Römerzeitliche Pflanzenfunde aus Oberwinterthur (Kanton Zürich, Schweiz). Beiträge zum römischen Vitodurum-Oberwinterthur 2*, Berichte der Zürcher Denkmalpflege : Archäologische Monographien, 7, Zurich.
- Jaubert, J., N. Fourment, P. Depaepe, ed. (s. d.): *Transitions, ruptures et continuité en préhistoire*, Volume 1 : Evolution des techniques - Comportement funéraires - Néolithique ancien. XXVIIe congrès préhistorique de France.
- Jones, G. (1987): "A statistical approach to the archaeological identification of crop processing", *Journal of Archaeological Science*, 14, 311-323.
- Jones, G. (1998): "Distinguishing food from fodder in archaeological records", in : Charles et al., dir. 1998, 95-98.
- Jones, M. (1984): "Regional patterns in crop production", in : Cunliffe & Miles 1984, 120-125.
- Jones, M. (1985): "Archaeobotany beyond subsistence reconstruction", in : Barker & Gamble 1985, 107-128.
- Jones, M. (1996): "Plant Exploitation", in : Champion & Collis 1996, 29-40.
- Jones, R.L.C., ed. (2012): *Manure Matters*, Farnham/Ashgate.
- Jouanin, G., J.-H. Yvinec (in press): "Changes in faunal spectra in northern France during the Late Antiquity", in : *Food production and land use at the transition from Antiquity to the Middle Ages in the Roman world*, Quaternary International.
- Jung, C., M. Compan, I. Figueiral (2009): "Les cultures et les pratiques agricoles antiques dans la cité de Béziers : L'exemple de la viticulture et de l'arboriculture sur l'autoroute A75 (Pézenas-Béziers, Hérault)", in : *Viticulture et arboriculture antique sur le tracé de l'autoroute A75 Béziers-Pézenas. Résultats préliminaires*, Nov. 2008, Girona, 85-97, *Studies on the rural world in the Roman period*. <hal-00598794>
- Kasprzyk, M. (2016): "Établissements ruraux, occupation du sol et systèmes agraires de l'Antiquité tardive dans le nord de la Gaule : quelques remarques", in : Reddé 2016, 261-276.
- Kenward, H., A. Hall (1997): "Enhancing bioarchaeological interpretation using indicator groups : stable manure as a paradigm", *Journal of Archaeological Science*, 24, 663-673.
- Kenward, H., A. Hall (2012): "Dung and stable manure on waterlogged archaeological occupation sites : some ruminations on the evidence from plant and invertebrate remains", in : Jones 2012, 79 - 95.
- Klee, M. S. Jacomet (1999): "Ackerbau und Grünlandwirtschaft : Ergebnisse der archäobotanischen Untersuchungen", in : Rychener 1999, 464-472.
- Knörzer, K.-H. (1970): "Römerzeitliche Pflanzenfunde aus Neuss". *Novaesium 4*, Limesforschungen, 10, Mann/Berlin.
- Knörzer, K.-H. (1973): "Römerzeitliche Pflanzenfunde aus einem Brunnen in Butzbach (Hessen)", *Saalebürg-Jahrbuch*, 30, 71-114.
- Knörzer, K.-H. (1975): "Mittelalterliche und jüngere Pflanzenfunde aus Neuss am Rhein", *Zeitschrift für Archäologie des Mittelalters*, 3, 129-181.
- Knörzer, K.-H. (1979): "Verkohlte Reste von Viehfutter aus einem Stall des römischen Reiterlagers von Dormagen", *Rheinische*

Ausgrabungen, 20, 130-137.

Knörzer, K.-H. (1981): "Römerzeitliche Pflanzenfunde aus Xanten", *Archaeo-Physika*, 11, 3-176.

Koch, P. L., M.L. Fogel, N. Tuross (1994): "Tracing the diets of fossil animals using stable isotopes" : in : Latjtha & Michener 1994, 63-92.

Koenig, M.-P., dir. (2012): *Le gisement de Crévéchamps (Lorraine). Du Néolithique à l'Époque romaine dans la vallée de la Moselle*, Documents d'Archéologie Française, 110, Paris.

Körber-Grohne, U., U. Piening (1983): "Die Pflanzenreste aus dem Ostkastell von Welzheim mit besonderer Berücksichtigung der Graslandpflanzen", in : Körber-Grhne et al. 1983, 307-323.

Körber-Grhne, U., M. Kokabi, U. Piening, D. Planck, ed. (1983): *Flora und Fauna im Ostkastell von Welzheim*, Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg, 13, Stuttgart.

Körber-Grohne, U., M. Rösch (1988): "Römerzeitliche Brunnenfüllung im Vicus von Mainhardt, Kreis Schwäbisch Hall", *Fundberichte aus Baden-Württemberg*, 13, 307 – 323.

Kühn, M., P. Hadorn (2004): "Pflanzliche Makro- und Mikroreste aus Dung von Wiederkäuern", in : Jacomet et al. 2004, 327-357.

Laederich, L. (2003): *Apport des végétaux par l'homme pour la nourriture du troupeau au Néolithique. Données archéologiques (Sud-Est de la France et plateaux suisses) et ethnologiques, mémoire de maîtrise, université de Paris 1, Panthéon-Sorbonne.*

Lancelotti, C., M. Madella (2012): "The 'invisible' product : developing markers for identifying dung in archaeological contexts", *Journal of Archaeological Science*, 39, 953-963.

Lange, A.-G. (1988): *Plants remains from a native settlement at the Roman frontier : De Horden near Wijk bij Duurstede. A numerical approach*, thèse de doctorat, université de Groningen.

Latjtha, K., R.H. Michener, ed. (1994): *Stable isotopes in Ecology and environmental science*. Oxford.

Lauer, F., K. Prost, R. Gerlach, S. Patzold, M. Wolf, S. Urmersbach, E. Lehdorff, E. Eckmeier, W. Amelung (2014) : "Organic fertilization and sufficient nutrient status in prehistoric agriculture ? Indications from multi-proxy analyses of archaeological topsoil relicts". *Plos One*, 9, 9, [On line], mis en ligne le 02 septembre 2014, consulté le 02 novembre 2017. URL : <https://doi.org/10.1371/journal.pone.0106244.t001>.

Lauwerier, R.C.G.M. (1988) : *Animals in Roman Times in the Dutch Eastern River Area*, Amersfoort.

Lepetz, S. (1996a): "Effets de la romanisation sur l'élevage et la diète carnée dans les établissements ruraux du nord de la Gaule. L'exemple de l'augmentation de la stature des animaux domestiques", in : Bayard & Collart, éd. 1996, 317-324.

Lepetz S. (1996b): *L'animal dans la société gallo-romaine de la France du Nord*, Amiens.

Lepetz, S., V. Matherne (2003): "Elevage et agriculture dans le nord de la Gaule durant l'époque gallo-romaine : une confrontation des données archéozoologiques et carpologiques", in : Lepetz & Matherne, éd. 2003, 233-235.

Lepetz, S., V. Matherne, ed. (2003): *Cultivateurs, éleveurs et artisans à l'époque romaine en Gaule*, *Revue Archéologique de Picardie*, 1 / 2, Amiens.

Lepetz, S., V. Zech-Matterne, ed. (2017): *Productions agro-pastorales, pratiques culturelles et élevage dans le nord de la Gaule du deuxième siècle avant J.-C. à la fin de la période romaine*, Actes de la table-ronde internationale, Paris, 8-9 Mars 2016, *Archéologie des Plantes et des Animaux*, 5, Montagnac.

Lepetz, S., N. Morand (2017): "Archéozoologie des territoires du nord-est de la France du second Âge du Fer à l'Antiquité tardive : banque de données et éléments de synthèse", in : *Archéozoologie des territoires du nord-est de la France du second Âge du Fer à l'Antiquité tardive : banque de données et éléments de synthèse 2017*, 11-42.

Lepetz, S., V. Matherne, M.-P. Ruas, J.-H. Yvinec (2002): "Culture et élevage en France septentrionale de l'âge du Fer à l'an mil. Approches archéozoologique et carpologique.", in : *Association d'Histoire des Sociétés rurales*, éd. 2002, 77-108.

Leveau, Ph., C. Raynaud, R. Sablayrolles, F. Trément, dir. (2009): *Les formes de l'habitat rural galloromain. Terminologies et typologies à l'épreuve des réalités archéologiques*, Actes Colloque AGER VIII, Toulouse, 2007, Aquitania, Suppl. 17, Bordeaux.

Linseele, V., H. Riemer, J. Baeten, D. De Vos, E. Marinova, C. Ottoni (2013): "Species identification of archaeological dung remains : A critical review of potential methods", *Environmental Archaeology*, 18, 5-17.

Lodwik, L., T. Brindle (2017): "Arable farming, plant foods and resources", in : Allen et al., éd. 2017, 11-84.

Lorans, E., X. Rodier, ed. (2015): *Archéologie de l'espace urbain*, Paris.

Macphail, R.I., M.A. Courty, A. Gebhardt (1990): "Soil micromorphological evidence of early agriculture in North West Europe", *World Archaeology*, 22, 1, 53-69.

- Madella, M., D. Zucchi, ed. (2007): *Plants, people and places. Recent studies in phytolith analysis*, Oxford.
- Mainland, I. (1998): "The lamb's last supper : The role of dental microwear analysis in reconstructing livestock diet in the past", in : Charles et al., dir. 1998, 55-62.
- Malrain, F. (2000): *Fonctionnement et hiérarchie des fermes dans la société gauloise du III^e siècle à la période romaine : l'apport des sites de la moyenne vallée de l'Oise*, thèse de doctorat, université de Paris I, Panthéon-Sorbonne.
- Malrain, F., V. Matterné, P. Ménéel (2002): *Les paysans gaulois*, Collection des Hespérides, Paris.
- Malrain, F., G. Blancquaert, Th. Lorho, dir. (2013): *L'habitat rural du second âge du Fer. Rythmes de création et d'abandon au nord de la Loire*, Recherches Archéologiques, 7, Paris.
- Malrain, F., V. Zech-Matterné, G. Blancquaert, with the collaboration of G. Auxiette, Ch. Leroyer, T. Lorho, P. Ménéel (2015): "Apprehending Continuity and Discontinuity in Iron Age Soil Occupation and Rural Landscape through a Collective Database", in : Danielisova & Fernandez-Götz 2015, 137-144.
- Marbach, A. (2004): *Recherches sur les instruments aratoires et le travail du sol en Gaule Belgique*, British Archaeological Reports, International Series, 1235, Oxford.
- Marbach, A. (2006/07): "Essai de classement et de reconstitution des araires en Gaule romaine en fonction des pièces métalliques découvertes", *Revue Archéologique du Centre de la France*, 45-46, en ligne : <http://racf.revues.org/index758.html>.
- Marbach, A. (2012): [Catalogue et étude des faux et outils agricoles de coupe à lame et à manche entiers en Gaule](#), British Archaeological Reports, International Series, 2376, Oxford.
- Marcigny, C., V. Carpentier, dir. (2012): *Des hommes aux champs. Pour une archéologie des espaces ruraux dans le Nord de la France, du Néolithique au Moyen Âge*, Actes de la table-ronde internationale, Caen, 8-9 Octobre 2008, Rennes.
- Marion, S., G. Blancquaert, ed. (2000): *Les Installations Agricoles de l'Âge du Fer en France Septentrionale*, Études d'Histoire et d'Archéologie, 6, Paris.
- Marion, S., S. Defressigne, J. Kaurin, G. Bataille (2017): *Production et proto-industrialisation aux âges du Fer*, Actes du XXXIX^e colloque international de l'AFEAF, Nancy, 14-17 Mai 2015, Mémoire, 47, Bordeaux.
- Martella, P., M. Brizzi, E. Sanna (2016) : "Is the evaluation of millennial changes in stature reliable? A study in southern Europe from the Neolithic to the Middle Ages", *Archaeological and Anthropological Sciences*. <https://doi.org/10.1007/s12520-016-0374-4>.
- Martin, L. (2014): *Premiers Paysans des Alpes. Alimentation et agriculture au Néolithique*, Tables des hommes, Rennes/Tours.
- Martin-Rosset, W., ed. (2012): *Nutrition et alimentation des chevaux: nouvelles recommandations alimentaires de l'Inra*, Collection Savoir-faire, Éd. Quae, Versailles.
- Matterné, V. (2001): *Agriculture et alimentation végétale durant l'âge du Fer et l'époque gallo-romaine en France septentrionale*, Archéologie des Plantes et des Animaux, 1, Montagnac.
- Mathelart, P., V. Zech-Matterné, G. Auxiette, A. Bandelli, with the collaboration of X. Deru, G. Florent, C. Pagnoux, Ph. Rollet, S. Sindonino (2014): "Cuisiner et manger dans la capitale des Rèmes de l'époque augustéenne au IV^e siècle de notre ère. Approche croisée des données céramologiques, archéozoologiques et carpologiques", in : Costamagno, dir. 2014, 287-312.
- Matterné, V., J.-H. Yvinec, D. Gemehl, with the collaboration of C. Riquier (1998): "Stockage des plantes alimentaires et infestation par les insectes dans un grenier incendié de la fin du II^e siècle après J.C. à Amiens (Somme)", *Revue Archéologique de Picardie*, 3/4, 93-122.
- Meadow, R.H. (1999): "The Use of Size Index Scaling Techniques for Research on Archaeozoological Collections from the Middle East", in : Becker et al., éd. 1999, 285-300.
- Ménéel, P. (1984): *Contribution à l'histoire de l'élevage en Picardie du Néolithique à l'Age du Fer*, n° spécial de la *Revue Archéologique de Picardie*, Amiens.
- Ménéel P. (2005): "Porc et sanglier en Gaule septentrionale, entre archéozoologie et imaginaire collectif", *Munibe (Anthropologia - Arkeologia)*, 57, 463-468.
- Ménéel, P., G. Auxiette, D. Germinet, A. Baudry, M.-P. Horard Herbin (2009): "Une base de données sur les études de faunes des établissements ruraux en Gaule", in : *Habitats et paysages ruraux en Gaule et regards sur d'autres régions du monde celtique*, Actes du XXXI^e colloque international de l'Association Française pour l'Étude de l'Âge du Fer Tome II. 2009, 412-442.
- Mercer R., ed. (1981): *Farming Practice in British Prehistory*, Edinburgh.
- Mignot, P., G. Raepsaet (1998): *Le sol et l'araire dans l'Antiquité*, Actes du colloque tenu à Jemelle, Malagne la Gallo-romaine, Avril 1997.
- Milles, A., D. Williams, N. Gardner, ed. (1989): *The beginnings of agriculture*, Symposia of the Association for Environmental Archaeology 8, BAR, International Series, 496, Oxford.

- Minagawa, M., E. Wada (1984): "Stepwise enrichment of $\delta^{15}\text{N}$ along food chains: further evidence and the relation between $\delta^{15}\text{N}$ and animal age", *Geochimica et Cosmochimica Acta*, 48, 1135–1140.
- Minnis P.E., ed. (2014): *New lives of ancient and extinct crops*, Tuscon.
- Mion, L., E. Herrscher, J. Blondiaux, E. Binet, G. Andre (2016): "Comportements alimentaires en Gaule du Nord : étude isotopique du site de l'Îlot de la Boucherie (Ille–v e siècles apr. J.-C.) à Amiens", *Bulletins et Mémoires de la Société d'Anthropologie de Paris*, 28, 3-4, 155-175.
- Molleson, T. (1992): "The anthropological evidence for change through Romanisation of the Poundbury population", *Anthropologischer Anzeiger*, 179–189.
- Moreau C., F. Granier, E. Dubreucq, with the collaboration of L. Herveux (2015): "Stockage et transport fluvial des céréales au Second âge du Fer : l'exemple de Val-de-Reuil (Eure)", in : Olmer & Roure 2015, 539-568.
- Morlon P., Sigaut F., (2008): "La Jachère, d'une signification à l'autre. La jachère retrouvée (Éléments pour une histoire du mot jachère)", *Pour la Science*, décembre, 374 : 94-99.
- Nillesse, O., O. Buchsenschutz (2009): "Les faux et la datation de l'outillage agricole des dépôts de l'Âge du fer", in : Honneger et al., dir. 2009, 157-166.
- Olmer F., R. Roure, ed. (2015): *Les Gaulois au fil de l'eau*, Actes du XXXVII^e colloque de l'AFEAF, Montpellier, 8-11 mai 2013, *Mémoires* ; 39/1 et 2, Bordeaux.
- Ouzoulias, P. (2006): *L'économie agraire de la Gaule : aperçus historiographiques et perspectives archéologiques*, Doctorat, Université de Franche-Comté École doctorale Langues, espaces, temps, sociétés, Besançon.
- Pals, J.P., T. Hakbijl (1992): "Weed and insect infestation of a grain cargo in a ship at the Roman fort of Laurium in Woerden (Province of Zuid-Holland)", in : Pals, Buurman, Van der Veen 1992, 287-300.
- Pals, J.-P., J. Buurman, M. van der Veen, ed. (1992): *Festschrift for Professor van Zeist, Review of Palaeobotany and Palynology*, 73, Amsterdam.
- Pasquini, B., Ch. Petit (2015): "Le portage entre la Saône et la Moselle dans l'Antiquité (I^{er}-IV^e siècles). Recherches d'itinéraires", in : Giligny & Tsirtsoni dir. 2015, 27-32.
- Peña-Chocarro, L., L. Zapata Peña (1999): "History and traditional cultivation of *Lathyrus sativus* L. and *Lathyrus cicera* L. in the Iberian peninsula", *Vegetation History and Archaeobotany*, 8, 49-52.
- Pigière, F. (2009): *Evolution de l'économie alimentaire et des pratiques d'élevage de l'antiquité au haut moyen âge en Gaul du nord: une étude régionale sur la zone limoneuse de la moyenne Belgique et du sud des Pays-Bas*, BAR international series 2035, Oxford.
- Poirier, N., L. Nuninger (2012): "Techniques d'amendement agraire et témoins matériels. Pour une approche archéologique des espaces agraires anciens", *Histoire & Sociétés Rurales*, 38, 11-50.
- Raepsaet, G. (2002): *Attelages et techniques de transport dans le monde gréco-romain*, Bruxelles.
- Raepsaet G. (2013): *Attelages et techniques de transport dans le monde gréco-romain*, in : *Inventions et techniques chez les grecs et les Romains*, *Archéothéma*, 28 (mai) : 18-21.
- Raepsaet, G., F. Lambeau, ed. (2000): *La moissonneuse gallo-romaine*, Journées d'études de l'ULB, Bruxelles.
- Rasmussen P. (1990): "Leaf foddering in the earliest Neolithic agriculture, Evidence from switzerland and Denmark", *Acta Archaeologica*, 60, 71-86.
- Rasmussen, D. (1993): "Analysis of sheep/goat faeces from Egolzwil 3, Switzerland : evidence of branch and twig foddering of livestock Neolithic", *Journal of Archaeological Science*, 20, 479-502.
- Reddé, M., dir. (2016): *Méthodes d'analyse des différents paysages ruraux dans le nord-est de la Gaule romaine*. France. 2016. [hal-01253470](#).
- Reddé, M., dir. (2017): *Gallia Rustica. Les campagnes du nord-est de la Gaule, de la fin de l'Âge du fer à l'Antiquité tardive*, T1 : études régionales. *Mémoires* 49, Bordeaux.
- Reddé, M., Ph. Barral, F. Favory, J.-P. Guillaumet, M. Joly, J.-Y. Marc, P. Nouvel, L. Nuninger, Ch. Petit, dir. (2011): *Aspects de la romanisation dans l'Est de la Gaule 1, Bibracte*, 21, Glux-en-Glenne.
- Redfern, R.C. (2005): *A gendered analysis of health from the Iron Age to the end of the Romano-British period in Dorset, England (mid to late 8th century B.C. to the end of the 4th century A.D.)*, Ph. D. Thesis, University of Birmingham.
- Rees, S.E., (1979): *Agricultural implements in Prehistoric and Roman Britain*, *British Archaeological Reports*, British Series, 69, Oxford.

- Renfrew, J.M., ed. (1991): *New Light on Early Farming. Recent Developments in Palaeoethnobotany*, Edinburgh.
- Retamero, F., I. Schjellerup, A. Davies, ed. (2012): *Agricultural and pastoral landscapes in Pre-industrial society. Choices, stability and change, Earth 3- Early Agricultural Remnants and Technical Heritage* ; 8,000 years of resilience and innovation, Oxford.
- Roberts, C.A., M. Cox (2003) : *Health and disease in Britain : from prehistory to the present day*, Gloucester.
- Robinson, D., P. Rasmussen (1989): "Botanical investigations at the Neolithic lake village at Weir, north east Switzerland : leaf hay and cereals as animal fodder", in : Milles et al. 1989, 149-163.
- Rösch, M., S. Jacomet, S. Karg (1992): "The history of cereals in the region of the former Duchy of Swabia (Herzogtum Schwaben) from the Roman to the Post-medieval period: results of archaeobotanical research", *Vegetation History and Archaeobotany*, 1, 193-231.
- Rouppert, V., J.-Y. Dufour, K. Fechner (2011): "An example of a fruitful discussion between a pedologist and an archaeologist. A 1st-4th century AD agricultural enclosure with a stable and a manure pit at 'Chapelle Saint-Nicolas' in Saint-Brice-sous-Forêt (Val d'Oise, France)", in : Fechner et al. 2011, 133-142.
- Ruas, M.-P. (2008): "Pré, prairies, pâturages: éclairages archéobotaniques", in : Brumont 2008, 13-43.
- Ruas, M.-P., V. Zech-Matterne, with the collaboration of M.-F. Dietsch-Sellami, B. Pradat, S. Preiss (2012): "Les avoines dans les productions agro-pastorales du nord-ouest de la France : données carpologiques et indications textuelles", in : Marcigny & Carpentier, dir. 2012, 327-365.
- Rychener, J., ed. (1999): *Der römische Gutshof in Neftenbach. Monographien der Kantonsarchäologie Zürich*, 31, 1, Zurich.
- Sauvant D. (2004-2005) : *Principe généraux de l'alimentation animale*, Institut national agronomique Paris-Grignon, document électronique consulté le 8 décembre 2017 : <http://www.ladocumentationcaprine.net/plan/alimentation/art/F-0040.pdf>
- Schönfelder, M., S. Sievers, dir. (2012): *Die Eisenzeit zwischen Champagne und Rheintal*, Actes du XXXIVe colloque international de l'AFEAF, Aschaffenburg (Allemagne), 13-16 Mai 2010, Mayence.
- Shillito, L.M., I.D. Bull, W. Matthews, M. J. Almond, J.M. Williams, R. P. Evershed (2011): "Biomolecular and micromorphological analysis of suspected faecal deposits at Neolithic Çatalhöyük, Turkey", *Journal of Archaeological Science*, 38, 8, 1868-1877.
- Sigaut, F. (1972): "Les conditions d'apparition de la charrue". *Journal d'Agriculture Tropicale et de Botanique Appliquée (JAT-BA)*, 19, 10-11, 442-478.
- Sigaut, F. (1976): "Pour une cartographie des assolements en France au début du XIX^e s.", *Annales. Economies, Sociétés, Civilisations*, 3, 631-643.
- Sigaut, F. (1985): "Moisson et fenaison", *Les Nouvelles de l'Archéologie*, 19, 28-38.
- Sigaut, F. (1987): "L'arbre fourrager en Europe : rôle et évolution des techniques", in : *La forêt et l'élevage en région méditerranéenne française*, éd. AFPE, CNRA, Versailles, 47-54.
- Sigaut F. (1988): "L'évolution technique des agricultures européennes avant l'époque industrielle", *Revue Archéologique du Centre de la France*, 27, 1, 8-41.
- Sigaut, F. (1989): "Les spécificités de l'épeautre et l'évolution des techniques", in : Devroey & van Mol, dir. 1989, 29-51.
- Sigaut, F. (1992): "Rendements, semis et fertilité : signification analytique des rendements", in : Anderson, dir. 1992, 395-403.
- Sigaut, F. (1993): "La jachère dans les agricultures pré-contemporaines de l'Europe", in : Floret & Serpantié, dir. 1993, 113-123.
- Sigaut, F. (2003): "La faux, un outil emblématique de l'agriculture européenne", in : Comet 2003, 281-295.
- Sigaut, F. (s. d.): "Les "révolutions" de l'histoire et de la préhistoire : Apparences ou réalités ?", in : Jaubert et al., éd. s. d., 121-126.
- Smith, D. (1998): "Beyond the barn beetles: Difficulties in using some Coleoptera as indicators of stored fodder", in Charles et al., dir. 1998, 63-70.
- Stallibrass, S., R. Thomas, ed. (2008): *Feeding the Roman army. The archaeology of production and supply in NW Europe*, Oxford.
- Stevens, C.J. (2003): "An investigation of agricultural consumption and production: models for prehistoric and Roman Britain", *Environmental Archaeology*, 8, 1, 61-76.
- Thiébaud, S. (2005): "L'apport du fourrage d'arbre dans l'élevage depuis le Néolithique", *Anthropozoologica*, 40, 1, 95-108.
- Thiébaud, S., P. Depaepe, dir. (2013): *L'archéologie au laboratoire*, Paris.
- tice.agroparistech.fr (2017): Ressource en ligne : consulté le 8 décembre 2017 : <https://tice.agroparistech.fr/>
- Toulemonde, F., V. Zech-Matterne, J. Wiethold, C. Brun, F. Malrain, V. Riquier, with the collaboration of F. Durand (2017a):

“Évolution des modes de production agricole au cours du 1^{er} millénaire av. n. e. dans l'est de la France : propositions d'après l'analyse carpologique des adventices”, in : Marion et al. 2015, 29-50.

Toulemonde, F., V. Zech-Matterne, A. Bandelli, with the collaboration of G. Auxiette, J. Wiethold, E. Bonnaire, G. Daoulas (2017b): “Diversité des productions végétales et animales dans les campagnes champenoises et leur capitale de cité : études archéobotaniques et archéozoologiques récentes à et autour de Reims/Durocortorum”, in : Lepetz & Zech-Matterne, dir. 2017, 91-102.

Touquet Laporte-Cassagne, dir., (in press): Les sites ruraux du second âge du Fer du Bassin versant du Crould en Val d'Oise et ses marges, Revue archéologique d'Île-de-France, Supplément 3.

Troels-Smith, J. (1984): “Stall-feeding and field-manuring in Switzerland about 6000 years ago”, *Tools and tillage*, 5, 1, 13-25.

Van der Veen, M. (1991): “Consumption or production? Agriculture in the Cambridgeshire Fens”, in : Renfrew 1991, 349-361.

Van der Veen, M. (1992): *Crop Husbandry Regimes. An Archaeobotanical Study of Farming in Northern England, 1000 BC–AD 500*, Sheffield Archaeological Monograph, 3, chapitre 7, Sheffield.

Van der Veen, M., G. Jones (2006): “A re-analysis of agricultural production and consumption: implications for understanding the British Iron Age”, *Vegetation History and Archaeobotany*, 15, 3, 217-228.

Van der Veen, M., G. Jones (2007): “The production and consumption of cereals: a question of scale”, in : Haselgrove & Moore 2007, 419-429.

Van Ossel, P., A. Defgnée, dir. (2001): *Champion, Hamois. Une villa romaine chez les Conduses*, Etudes et Documents, Archéologie 7, Namur.

Van Moerkerke, J., dir. (2009): *Le Bassin de la Vesle du Bronze final au Moyen Age, à travers les fouilles du TGV est*, Bulletin de la Société archéologique champenoise, 102, 2, Châlons-en-Champagne.

Van Zeist, W., (1991): “Economic aspects”, in van Zeist et al. 1991, 109-130.

Van Zeist, W., W.A. Casparie, ed. (1984): *Plants and Ancient Man. Studies in Palaeoethnobotany. Proceedings of the VIth symposium of the IWGP, Groningen, 30 May-3 June 1983*, Rotterdam/Boston.

Van Zeist, W., K. Wasylikowa, K.-E. Behre, ed. (1991): *Progress in Old World Palaeoethnobotany, A Retrospective View on the Occasion of 20 Years of the International Workgroup for Palaeoethnobotany*, Rotterdam/Boston.

Vrydaghs, L., Y. Devos, K. Fechner, A. Degraeve (2007): “Phytolith analysis of ploughed land thin sections. Contribution to the early medieval town development of Brussels (Treurenberg site, Belgium)”, in : Madella & Zucchi 2007, 13-27.

Wiethold, J., V. Zech-Matterne (2016): “Ergebnisse zu Landwirtschaft und pflanzlicher Ernährung aus römischen Axialvillenanlagen im östlichen Gallien”, in : Echt et al. 2016, 397-417.

Wilson, D.G. (1979): “Horse dung from Roman Lancaster: a botanical report”, *Archaeo-Physika*, 8, 331-350.

Zech-Matterne, V. (2014): “Bilan des études carpologiques réalisées dans le cadre des Grands Tracés, en région Picardie”, in : Bayard et al., dir. 2014, 309-324.

Zech-Matterne, V., M. Derreumaux, S. Preiss (2008) : “Production et utilisation des plantes “techniques” de l'âge du Bronze à l'époque médiévale en France du Nord. Quelques indices carpologiques”, in : Zech-Matterne, Derreumaux, Preiss 2008, 9-17.

Zech-Matterne, V., M. Derreumaux, S. Preiss, ed. (2008): *Archéologie des textiles et teintures végétales. Les Nouvelles de l'Archéologie*, 114, Paris.

Zech-Matterne, V., J. Wiethold, B. Pradat, with the collaboration of F. Toulemonde (2014): “L'essor des blés nus en France septentrionale : systèmes de culture et commerce céréalier autour de la conquête césarienne et dans les siècles qui suivent”, in : Deru et al. 2014, 23-50.

Zech-Matterne, V., E. Bonnaire, G. Daoulas, M. Derreumaux, F. Durand, O. Rousselet, C. Schaal, F. Toulemonde, J. Wiethold (2017a): “Diversité et évolution des productions céréalières et fruitières dans le quart nord-est de la France (IIe s. a.C.-Ve s. p.C.), d'après les données carpologiques”, in : Lepetz & Zech-Matterne 2017, 43-62.

Zech-Matterne, V., C. Brun, F. Toulemonde, J. Wiethold (2017b): “Essai d'approche du mode d'exploitation des terres et des pratiques agricoles dans le nord-est de la France, à partir de l'évolution des flores adventices (IIe s. a.C.-Ve s. p.C.)”, in : Lepetz & Zech-Matterne 2017, 63-74.

Zech-Matterne, V., M. Derreumaux (to be published): “Les restes végétaux”, in : Touquet Laporte-Cassagne, dir. à paraître.

Zech-Matterne V., Malrain F., Bossard S., Lorho T., Derreumaux M., Neveu E., Toulemonde F. (forthcoming): “Formes, durabilités et productions des fermes à l'âge du Fer : divergences et convergences”, in : Annual conference of the Iron Age Study Group (AG Eisenzeit), 18th–21st September 2016, Münster, Allemagne.