Centralisation and long-term change in farming regimes: Comparing agricultural practices in Neolithic and Iron Age south-west Germany

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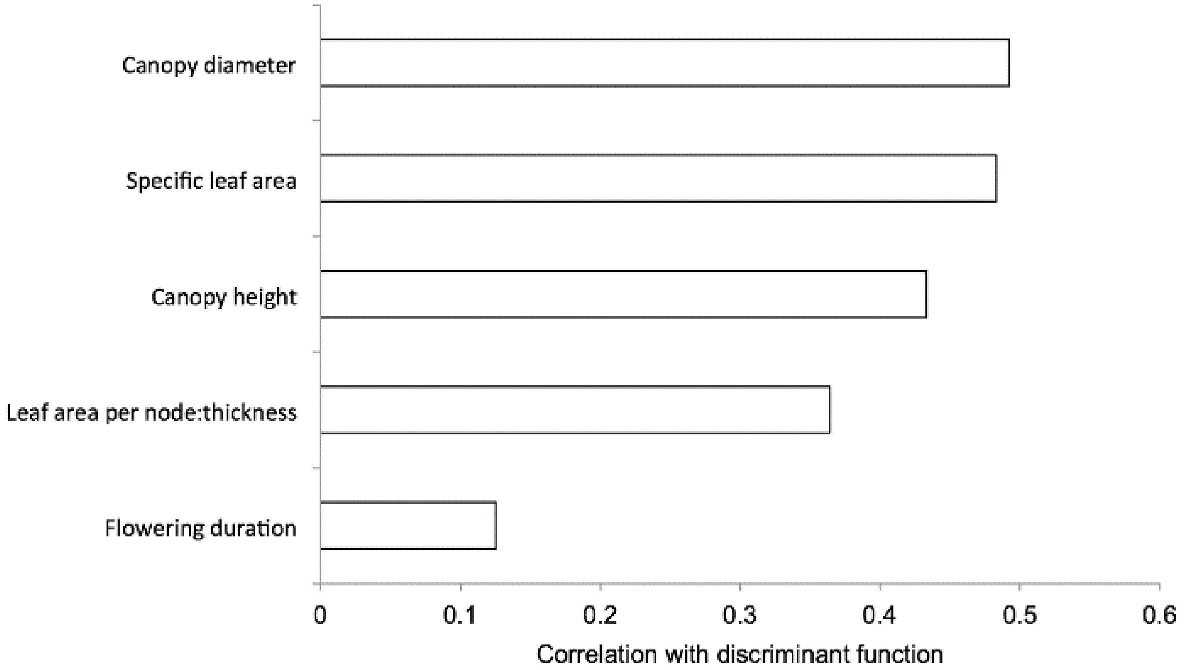
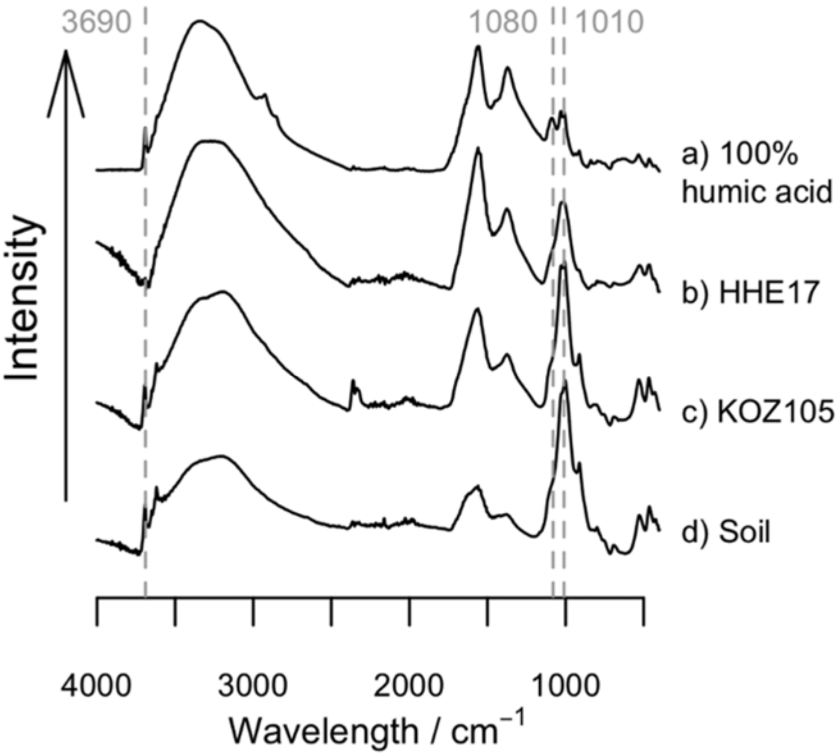
SUPPLEMENTARY MATERIAL
APPENDICES S1–S4; S7–8

APPENDIX S.1. CORRELATIONS BETWEEN THE FUNCTIONAL ATTRIBUTE SCORES USED AS DISCRIMINATING VARIABLES AND THE DISCRIMINANT FUNCTION BASED ON SEMI-QUANTITATIVE (PRESENCE-ABSENCE) DATA

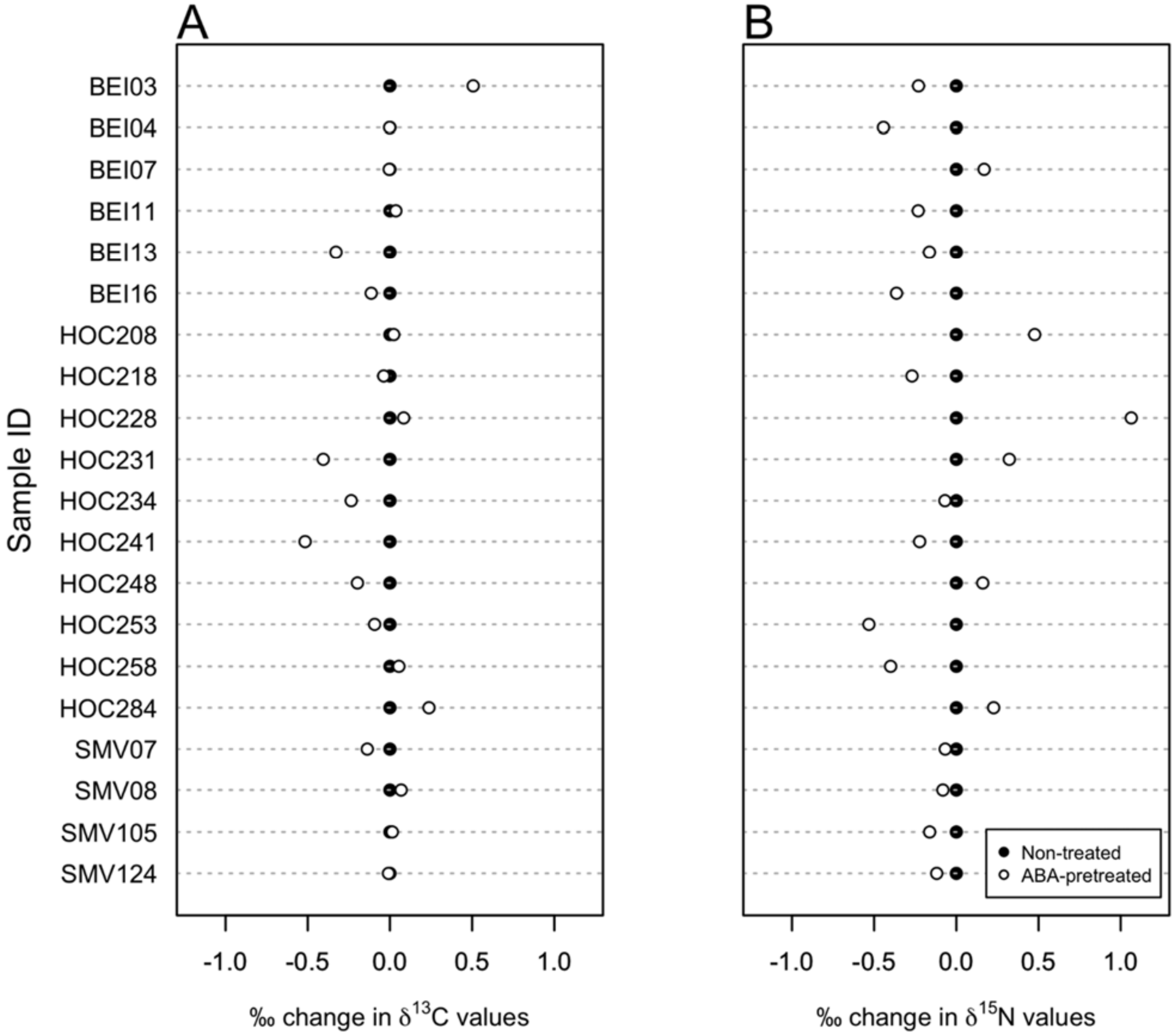


APPENDIX S.2. FOURIER TRANSFORM INFRARED SPECTRA



a) a commercially purchased humic acid sodium salt; b) archaeological spelt wheat grains from the Heuneburg (HHE17); c) archaeological hulled barley grains from Ipf-Zaunäcker (KOZ105); and d) soil adhering to hulled barley grains from Ipf-Zaunäcker. Peaks at wavelengths of 3690 cm^{-1}, 1080 cm^{-1}, and 1010 cm^{-1} are characteristic of humic acids found in soil and are therefore indicative of potential contamination.

APPENDIX S.3. A DOT PLOT COMPARING A) THE δ^{13}C AND B) δ^{15}N VALUES OF UNTREATED AND ACID-BASE-ACID (ABA) PRETREATED ARCHAEOBOTANICAL SAMPLES



APPENDIX S.4. TESTING FOR CONTAMINATION OF CARBONISED CROP REMAINS.

For the carbonised crop remains investigated in previous isotope studies, details of the protocols used to test for and remove contamination are given in Fraser *et al.* (2013b) for Vaihingen an der Enz and Styring *et al.* (2016a) for Hornstaad-Hörnle IA and Sipplingen. For the carbonised crop remains newly investigated in this study, 26 samples (*c.* 10% of the total number), representing the range of visible 'dirtiness' (from pure black charcoal to grains with visible soil inclusions), were scraped clean, crushed and analysed using Fourier transform infrared spectroscopy (FTIR) to look for the presence of carbonate, nitrate and/or humic contamination (cf. Vaiglova *et al.* 2014). Around half of the samples exhibited a peak at 1010 cm^{-1}, a similar wavelength to peaks observed in a commercially purchased humic acid sodium salt, which chemically resembles humic substances that are the major organic constituents of soil (Appx S2). It was therefore decided to test whether acid-base-acid (ABA) pretreatment, a procedure commonly used to remove carbonate and humic contamination from charcoal and charred plant remains prior to radiocarbon and stable isotope analysis, made a significant difference to the determined δ^{13}C and δ^{15}N values.

Twenty samples, comprising between six and ten grains/seeds each, were crushed and then half of each sample was subjected to ABA pretreatment. This three-step procedure consists of: 1) treatment with 10 ml of 0.5 M hydrochloric acid at 70°C for 30–60 minutes, or until any effervescing ceases, then rinsing in distilled water three times; 2) treatment with 10 ml of 0.1 M sodium hydroxide at 70°C for 60 minutes, followed by rinsing in distilled water until the solution is clear and the pH neutral, using a minimum of three rinses; 3) treatment with 10 ml of 0.5 M hydrochloric acid at 70°C for 30–60 minutes, followed by three rinses in distilled water and final freeze drying. Dried pretreated and untreated samples were weighed into tin capsules before stable isotope analysis.

A paired t test showed no significant difference in the δ^{13}C values of non-treated and ABA-pretreated aliquots ($t(19) = -1.059$, $p = 0.303$). The largest difference in δ^{13}C was 0.51‰ (Appx S3A). A paired t test also showed no significant difference in the δ^{15}N values of non-treated and ABA-pretreated aliquots ($t(19) = -0.566$, $p = 0.578$). The largest difference in δ^{15}N was 1.06‰ (Appx S3B). Since the ABA-pretreatment resulted in no significant change in isotope values, it was decided not to ABA-pretreat the remaining samples for the sake of time and because pretreatment may in fact remove a portion of the grain itself (Vaiglova *et al.* 2014).

Among the samples from Ipf-Zaunäcker, four of the 22 samples exhibited FTIR spectra that were unlike any of the carbonised crop remains observed before, with particularly large peaks at 3690 cm^{-1} and 1010 cm^{-1} (Appx S2c). These were also the most visibly dirty samples. Soil found attached to one of the samples was analysed by FTIR and exhibited the same FTIR spectrum (Appx S2d). It was therefore decided to discard these samples from the isotope analysis, since even when ABA-pretreated these samples had the same peaks as the soil in their FTIR spectra, suggesting that the ABA-pretreatment did not remove all of the soil. It is recommended that FTIR is carried out on any visibly dirty samples (with significant soil inclusions) in future studies in order to identify potential contamination.

The δ^{13}C values of carbonised crop remains provide an additional test for potential carbon-containing contamination. According to modern studies, wheat grown in the same watering conditions as barley is expected to have δ^{13}C values c. 1-2‰ higher than barley (eg, Wallace *et al.* 2013). Since south-west Germany has a temperate climate, it is unlikely that any of the crops would have been irrigated and therefore this difference in δ^{13}C values of wheat and barley grains should be observed in the carbonised crop remains. Figure 3 shows the δ^{13}C values of the carbonised crop remains and demonstrates that the trend is indeed as expected (a linear mixed-effects model shows that the δ^{13}C values of barley grains are 0.8‰ lower than wheat grains; Table 2: 27). In addition, the three millet samples from early Iron Age Viesenhäuser Hof have δ^{13}C values between -12 and -10‰ (Appx S5), which is expected for C_4 crops.

BIBLIOGRAPHY

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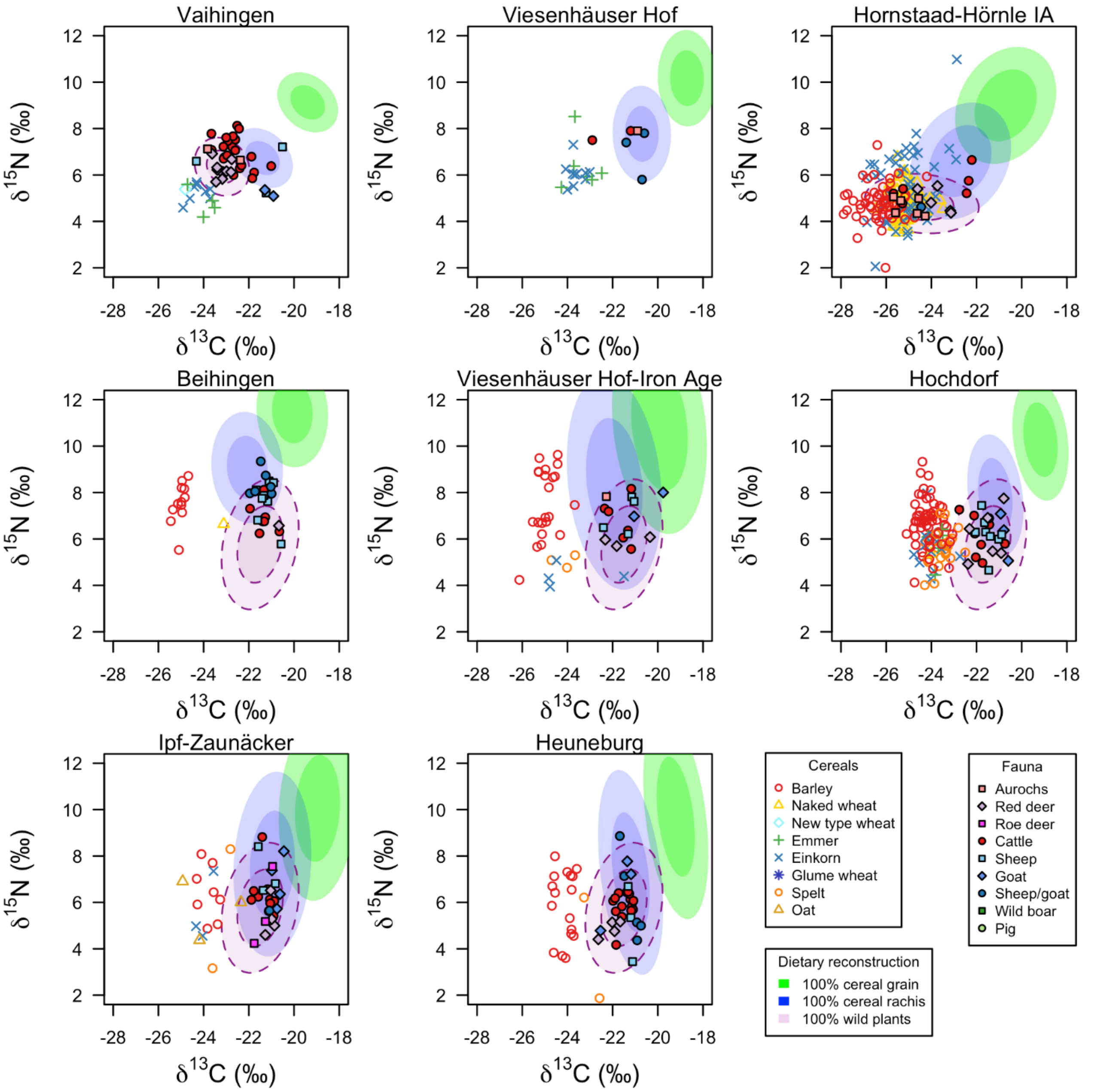
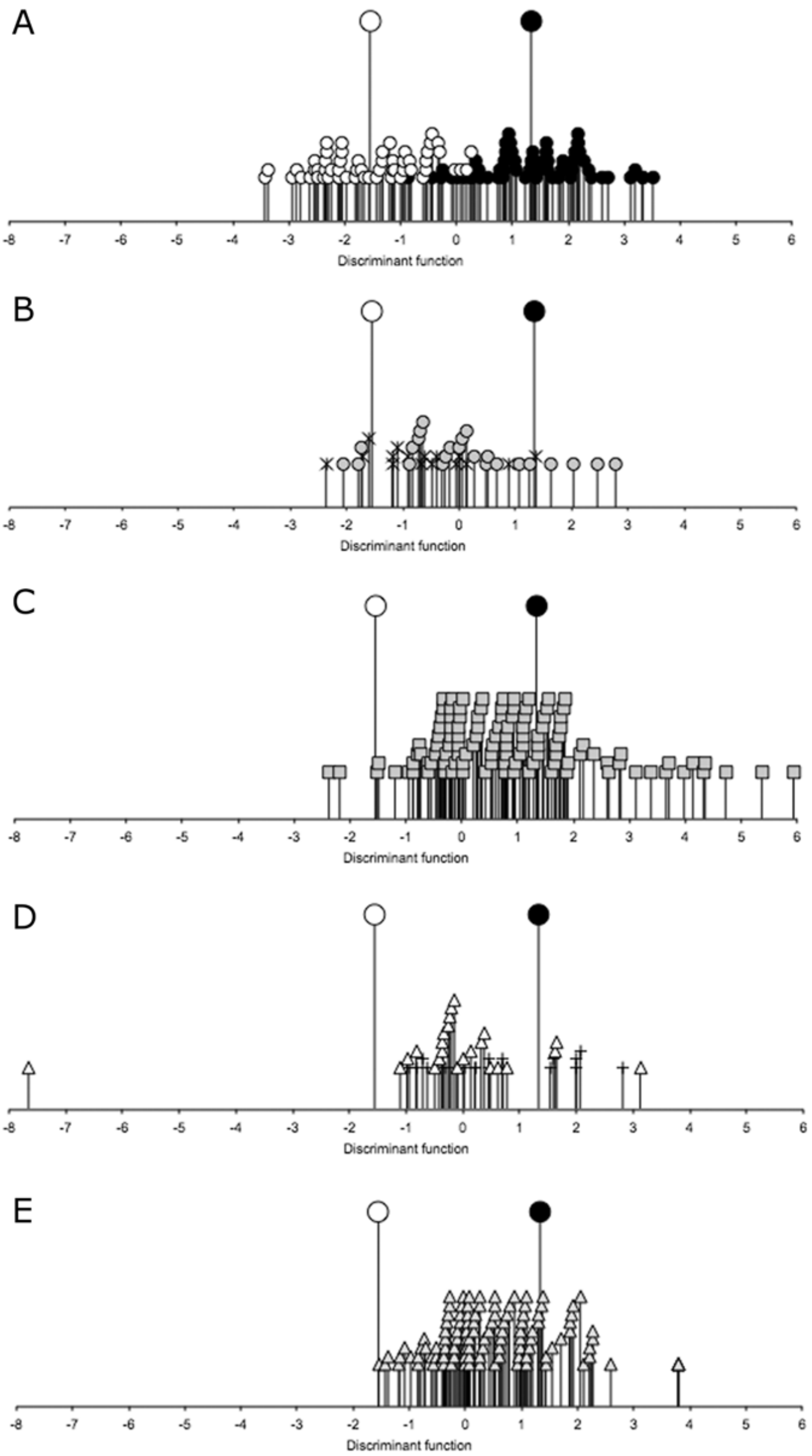
APPENDIX S.7. FAUNAL BONE COLLAGEN AND CROP δ^{13}C AND δ^{15}N VALUES PLOTTED IN RELATION TO ELLIPSES REPRESENTING THE EXPECTED DISTRIBUTION (MEAN ± 1 & 2 STANDARD DEVIATIONS) OF δ^{13}C AND δ^{15}N VALUES OF HERBIVORES CONSUMING DIETS OF WILD PLANTS, CEREAL RACHIS OR CEREAL GRAIN



The expected δ^{13}C and δ^{15}N value distribution of herbivores consuming 100% cereal grains are estimated by adding consumer-diet offsets of 4.8‰ (Fernandes *et al*. 2012) and 4‰ (Steele & Daniel 1978), respectively, to the determined cereal grain δ^{13}C and δ^{15}N values. The expected δ^{13}C and δ^{15}N value distribution of herbivores consuming 100% cereal rachis was estimated by subtracting 2‰ (Wallace *et al.* 2013) and 2.4‰ (Fraser *et al.* 2011), respectively, from the expected cereal grain consumer δ^{13}C and δ^{15}N values, to account for differences in the isotope values of cereal grains and rachis. The expected δ^{13}C and δ^{15}N value distribution of herbivores consuming 100% wild plants is estimated to be the same as the distribution of wild herbivore δ^{13}C and δ^{15}N values. Since there is no significant difference in wild herbivore δ^{13}C and δ^{15}N values between the Iron Age sites (Table 2: 14 & 15), the expected distribution of herbivores consuming 100% wild plants is represented by the mean ± one and two standard deviations of wild herbivore δ^{13}C and δ^{15}N values from all Iron Age sites.

APPENDIX S.8. THE RELATIONSHIP OF SAMPLES



a) present-day traditionally managed plots in Provence, France (open circles, *n* = 56) and Asturias, Spain (filled circles, *n* = 65); b) Early Iron Age Beihingen (crosses, *n* = 16) and Viesenhäuser Hof (grey circles, *n* = 24); c) Early Iron Age Hochdorf (*n* = 113); d) Early Iron Age Ipf-Zaunäcker (vertical crosses, *n* = 19) and Heuneburg (open triangles, *n* = 24); and e) Neolithic sites in south-west Germany (*n* = 141) to the discriminant function extracted to distinguish between intensive and extensive agricultural regimes on the basis of canopy height and size *only*. Larger symbols indicate centroids for intensive (black) and extensive (white) regimes.