

IRREVERSIBLE IMPACT OF PAST LAND USE ON FOREST SOILS AND BIODIVERSITY

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Abstract. In western Europe, forest area has been expanding rapidly since the 19th century, mainly on former agricultural land. Previous studies show that plant diversity differs between these recent forests and ancient forests that were already forested at the time of first national cadastral surveys, around 1800. Here, we investigated the duration of such agricultural aftereffects. In northeastern France, large areas were deforested during the Roman occupation and thereafter abandoned to forest. In one such forest that was farmed during the period AD 50–250, we show that species richness and plant communities vary according to the intensity of former agriculture. These variations are linked to long-term changes of chemical and structural soil properties. Hence, we suggest that such effects of past agricultural land use on forest biodiversity may be irreversible on an historical time scale.

Key words: archaeology; biodiversity; forest; forest soils; Lorraine limestone plateau, France; past land use; phosphorus; plant diversity.

INTRODUCTION

Numerous traces of ancient agricultural use from different historical periods have been identified in contemporary agricultural landscapes. In contrast, due to forest cover, presently forested areas have been poorly investigated despite archaeological and palaeoecological data that suggest these areas have often gone through unforested states during the Holocene (Segerström et al. 1994, Jackson 1997, Spek 1998). Agriculture results in the differentiation of landscape units in which soils are modified according to the type of land use. Plant communities that develop after afforestation of abandoned lands differ from ancient forests in relation to the modification of soil properties (Glatzel 1991, Compton and Boone 2000) and to the relative colonization rates of species into new forests (Brunet and Oheimb 1998). These aftereffects have been shown to control vegetation diversity in forests (Foster 1992, Hermy 1994, Koerner et al. 1997) even 300 yr after afforestation, and it has been suggested that they could persist indefinitely (Peterken and Game 1984). The assumption that forest plant communities modified by agriculture revert to their former state has been seldom tested. Archaeological remnants of occupation during the Roman period are very common in northeastern French forests (Petry 1977, Peltre and Bruant 1991). Using this opportunity, we tested the hypothesis that the impact of ancient agricultural land use may last for millennia.

SITE AND METHODS

In an oak–beech forest on the Lorraine limestone plateau, a Roman agricultural occupation covering ~20 ha of flat area along a previously known Roman way has been identified from surface stone-wall remnants and excavations. These structures were dated to the first to third century AD based on coins and ceramics identification. More recent artifacts were not found. The ownership of the land by the Abbey of Saint Mansuy, founded in the tenth century, was later transferred to the nearby village of Thuilley-aux-Groseilles after the French Revolution (1789). The first local map of some accuracy (1:30 000) was drawn up in 1730 by Naudin and displays continuous forest cover. Available historical documents do not mention any cultivation since the Middle Ages. The current silvicultural regime is coppice with standards, a two-story management system in which, among regularly cut hornbeam trees or “coppice,” some oak and beech trees called “standards” are left to grow to larger size timber. This regime has been homogeneously applied over the entire site for the last century at least, according to local cutting records. But this regime is probably far more ancient, because it expanded in western Europe during the medieval period (Peterken 1996) and has been the prevailing oak woodland management system in France since this time. Soils are rendzic leptosols (FAO classification), characterized by a dark red-brown, homogeneous layer of silty clay to clay texture, shallow in depth (17 cm on the average), overlying the partially altered Bajocian parent limestone with a clear, irregular boundary.

Based on the density and spatial distribution of walls,

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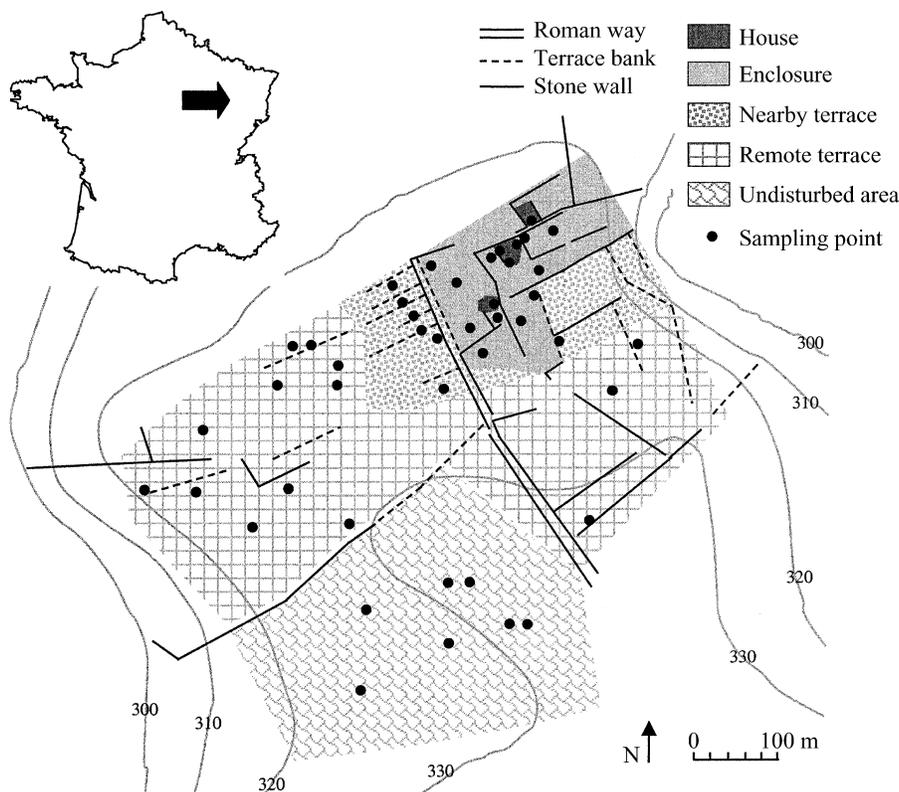


FIG. 1. Map of the site with indications of former land use intensity according to archaeological investigations.

and the abundance of potteries and tiles, five levels of decreasing land use intensity were defined and then mapped: (1) ancient houses, (2) surrounding areas enclosed by walls, hereafter called enclosures, (3) nearby terraces delimited by stony embankments, (4) remote terraces with few stone piles and walls, and (5) apparently undisturbed areas (Fig. 1).

Following this former land use map, a stratified sample of 43 plots was established. Plots were 20×20 m in remote terraces and undisturbed areas, but between 100 and 200 m² on the average in houses, enclosures, and nearby terraces, because of their limited surface area. In each plot, the complete list of phanerogams and terricolous mosses was drawn up. At five locations randomly selected within the plot, a 0–10 cm topsoil layer was sampled in pits. The subsurface layer, in contact with the underlying parent limestone, was not sampled. An additional pit was dug in the center of the plot down to the bedrock and described. Soil subsamples from the five pits were mixed, air dried, sieved (2 mm), and analyzed for pH, C, N, plant-available P, $\delta^{15}\text{N}$, and texture. At two plots (one enclosure and one undisturbed site), thin sections were made from the 0–10 cm soil layer and observed under an optical microscope for organic matter characterization. Oak leaf samples were collected in mid-August from the upper

crown of 31 standard oaks chosen in order to represent the previous land use classes and analyzed for N and P.

Vegetation composition was analyzed by factorial correspondence analysis. The ecological meaning of vegetation differences between the plots was partly interpreted using Ellenberg's indicator values for nitrogen, acidity, and humidity. Based on field observations and, to a lesser extent, on laboratory tests, Ellenberg et al. (1991) assigned scores to Central European plants along an arbitrary nine-point scale, according to their ecological requirements for various ecological factors. Low values of nitrogen, acidity, and humidity scores indicate preferences for nitrogen-poor, acid, and dry conditions, respectively. Differences in soil and leaf measurements, mean Ellenberg's values, and position of plots along the first factorial axis were tested by a one-way analysis of variance with past land use (five levels) as fixed effect. In order to meet the normality assumption, soil and leaf phosphorus contents were log transformed before analysis.

RESULTS AND DISCUSSION

Soil phosphorus content matched the spatial distribution of archaeological artifacts (Craddock et al. 1985, Bethell and Máté 1989), with high values near the houses, intermediate in nearby terraces, and equally low in remote terraces and undisturbed areas (Fig. 2).

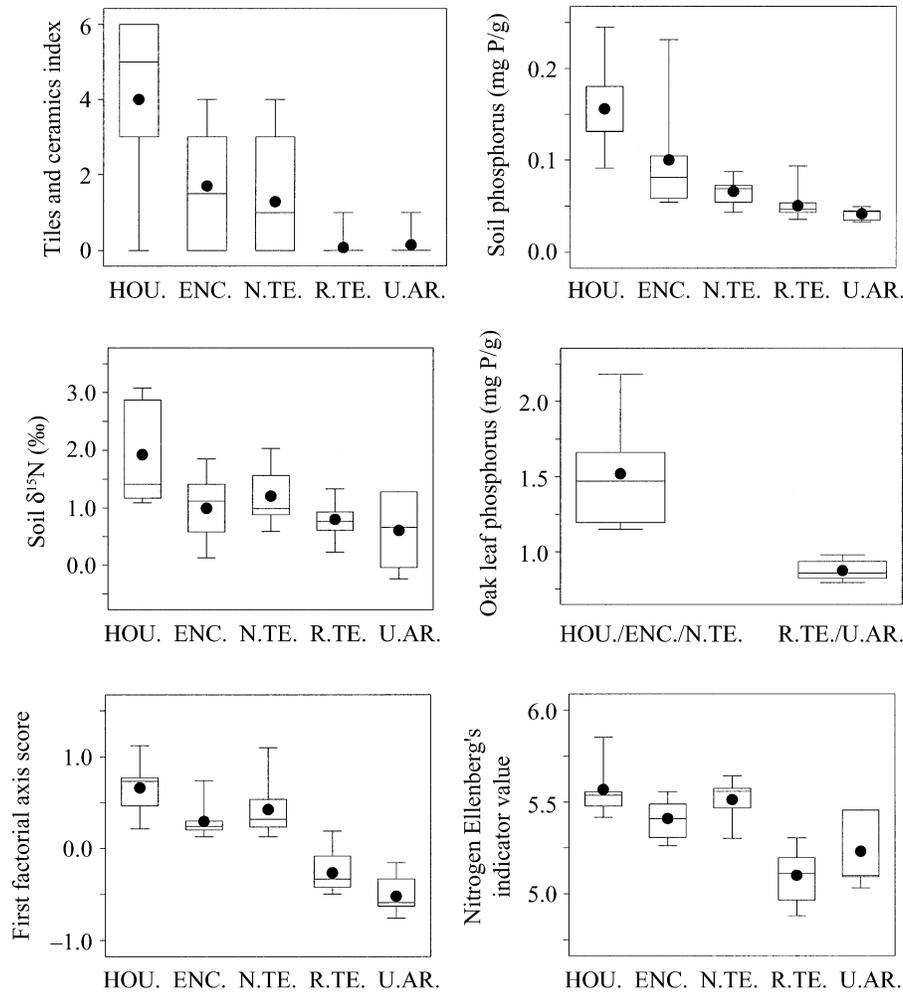


FIG. 2. Box plot diagrams showing the variability of main soil and vegetation characteristics according to ancient land use. Abbreviations are: HOU. = houses, ENC. = enclosures, N.TE. = nearby terraces, R.TE. = remote terraces, and U.AR. = undisturbed areas. Tile and ceramics abundances were combined by addition into a single variable, ranging from 0 to 6. See also footnotes in Tables 1 and 2.

TABLE 1. Average soil properties in relation to ancient land use in northeastern France.

Ancient land use (no. sites)	Depth†	Tile content	Ceramics content	Phos- phorus (mg P/g)	Clay (%)	Silt (%)	pH	C (%)	N (%)	C:N	Soil $\delta^{15}\text{N}$ (‰)
Houses (5)	17.4	1.6	2.40	0.16	35	55	7.1	7.7	0.59	13.0	1.92
Enclosures (10)	16.9	0.6	1.10	0.10	44	50	7.1	8.2	0.63	13.3	0.99
Nearby terraces (7)	22.1	1.0	0.29	0.07	52	42	7.2	7.1	0.54	13.2	1.20
Remote terraces (14)	15.3	0	0.14	0.05	55	38	6.7	7.1	0.50	14.2	0.80
Undisturbed areas (7)	14.4	0	0.07	0.04	55	39	6.9	6.8	0.48	14.1	0.61
Total (43)											
<i>F</i>	1.6 NS	4.2**	8.6***	15.7***	12.0***	12.4***	9.2***	3.1*	6.2***	2.9*	5.0**

Notes: All data except depth to the altered limestone bedrock refer to the 0–10 cm layer. Abundance of tiles and ceramics was evaluated after soil sieving, along a scale from 0 to 3. Values of *F* for the test of ancient land use effect in a one-way analysis of variance are presented with their associated probability.

* $P < 0.5$; ** $P < 0.01$; *** $P < 0.001$; NS, nonsignificant.

† Depth to altered bedrock.

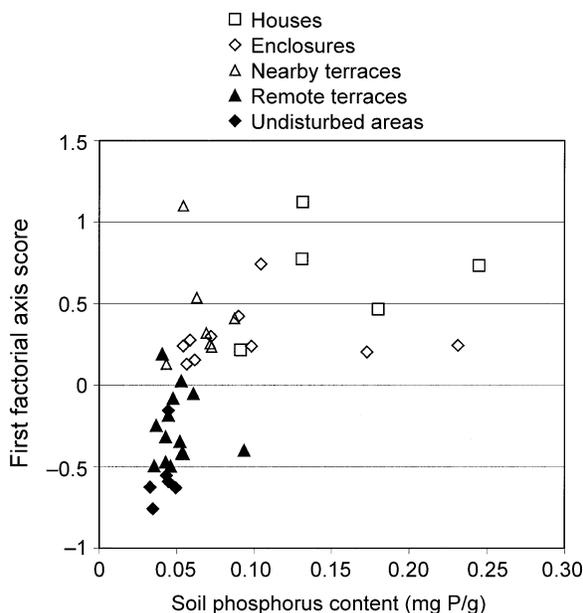


FIG. 3. Position along the first axis of a factorial correspondence analysis of vegetation data vs. soil phosphorus content.

Soil pH, carbon and nitrogen content, and $\delta^{15}\text{N}$ increased and C:N ratio decreased with increased land use intensity (Table 1). Soils were homogeneously shallow all over the site, but richer in silt and darker in houses, enclosures, and nearby terraces compared with remote terraces and undisturbed areas (modal color 7.5YR32 vs. 7.5YR43 according to the Munsell soil and plant tissue color chart). Thin sections showed a much higher concentration of fine sand and silt-size charcoal fragments in the enclosure compared with the undisturbed area, which explains part of the difference in silt content.

Present oak leaf levels of phosphorus indicate adequate phosphorus supply in former enclosure and nearby terraces, and deficient supply in remote terraces and undisturbed areas (Fig. 2, threshold value of 1 mg/g,

Stefan et al. 1997). No difference in leaf nitrogen content was found.

Plant and animal macroremains and assemblages of pollen grains found in other sites of Lorrain (Willame et al. 1993), and written sources (Columella 1961, written ~AD 60–65) give an insight into agricultural practices which may have been used by Roman farmers. Club wheat (*Triticum compactum* Host) was the most common cereal, accompanied by barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), and rye (*Secale cereale* L.). Latin authors repeatedly mentioned the need for regular fertilization, using ashes, animal, or green manure (Columella 1961: II. 13–15). Both for this reason and for food, legumes (*Pisum sativum* L., *Lens esculenta*, and *Vicia* sp.) were intensively cultivated. Animal bones indicate significant sheep rearing, together with goat, horse, and cattle.

The spatial variation of soil and leaf properties reflects these ancient agricultural practices. Stones from enclosures and nearby terraces were removed and heaped into surrounding walls before plowing, thereby increasing soil water-holding capacity. Fragmentation and dispersion of limestone gravels by cultivation raised soil pH, which may have favored organic matter accumulation. Near the houses, ash dispersion increased fine-size charcoal content. Manuring decreased soil C:N ratio, which in turn favored N mineralization, and increased $\delta^{15}\text{N}$ (Koerner et al. 1999, Jussy et al. 2002) and soil phosphorus in enclosures and nearby terraces. The similarity of soil properties between remote terraces and undisturbed areas suggest a lower intensity of agricultural use of these zones, possibly devoted to herd grazing in the former and forest in the latter.

Present understory vegetation differs widely among the categories of ancient land uses. The factorial correspondence analysis of plant communities reveals a gradient of plant species composition closely related to the intensity of ancient land use (Fig. 3), with a marked difference between undisturbed areas and remote terraces on the one hand and nearby terraces,

TABLE 2. Vegetation characteristics in relation to ancient land use.

Ancient land use	Number of species not found in undisturbed areas	Total species richness	Position along the first axis of correspondence analysis of vegetation data	Ellenberg's indicator values			Oak leaf P (mg P/g)
				Nitrogen	Humidity	Light	
Houses	24	70	0.66	5.57	4.93	4.48	1.53
Enclosures	22	78	0.30	5.41	4.93	4.43	1.57
Nearby terraces	20	70	0.43	5.51	4.96	4.52	1.19
Remote terraces	15	80	-0.27	5.10	4.82	4.70	0.89
Undisturbed areas	...	72	-0.52	5.23	4.85	4.61	0.87
Total		116					
<i>F</i>			30.4***	17.4***	7.1***	3.9**	35.1***

Note: Because of unbalanced tree-sampling design, analysis of variance for leaf P was done after grouping land use into two levels (houses, enclosure, and nearby terraces on the one hand, remote terraces and undisturbed areas on the other hand).

** $P < 0.01$; *** $P < 0.001$.



PLATE 1. (Left) *Ribes uva-crispa* L., a typical but infrequent species of ancient human settlements. (Right) *Vinca minor* L., a widespread species commonly associated with ancient human settlements. Photographs by J. F. Picard.

enclosures, and houses on the other hand. This gradient is significantly correlated with the Ellenberg's indicator values for nitrogen ($r = 0.77$, $P < 0.001$, $n = 43$) and humidity ($r = 0.62$, $P < 0.001$, $n = 43$). This increasing

water and nitrogen availability indicated by vegetation is not related to light differences, since light indicator values vary in an opposite direction (Table 2). An increasing number of species not found in the undisturbed

TABLE 3. Frequency of some indicator species according to ancient land use.

Species	Frequency		Probability
	Houses, enclosures, and nearby terraces (% in 22 plots)	Remote terraces and undisturbed areas (% in 21 plots)	
Species with their optimum in the less disturbed areas			
<i>Thuidium tamariscinum</i>	27	100	<0.001
<i>Potentilla sterilis</i>	23	95	<0.001
<i>Carex digitata</i>	27	90	<0.001
<i>Convallaria maialis</i>	18	81	<0.001
<i>Carex montana</i>	5	67	<0.001
<i>Hordelymus europaeus</i>	5	48	0.001
<i>Epipactis helleborine</i>	0	33	0.004
<i>Neotia nidus-avis</i>	9	48	0.007
<i>Ornithogalum pyrenaicum</i>	5	38	0.009
Species with their optimum in the most disturbed areas			
<i>Cardamine pratensis</i>	41	14	0.09
<i>Arum maculatum</i>	32	5	0.05
<i>Euphorbia cyparissias</i>	27	0	0.02
<i>Taraxacum officinale</i>	45	10	0.02
<i>Ranunculus auricomus</i>	100	52	<0.001
<i>Plagiominium undulatum</i>	77	24	<0.001
<i>Galium odoratum</i>	91	29	<0.001
<i>Milium effusum</i>	100	29	<0.001
<i>Vinca minor</i>	100	24	<0.001

Notes: Nomenclature is according to Tutin et al. (1968–1993). Test of the frequency difference between the two past land use categories is according to a Fisher's exact two-tail test.

areas appears along the gradient of previous land use intensity (Table 2). Of a total of 116 species, 29 are only present in the houses, enclosures, and nearby terraces, whereas 15 species are only present in remote terraces and undisturbed areas, despite a higher cumulative sampling area in the latter sites. Thus, ancient cultivation adds a significant amount of diversity to the present forest.

Most of the species characteristic of the disturbed sites (e.g., *Taraxacum officinale*, *Cardamine pratensis*, *Euphorbia cyparissias*) have their ecological optimum in meadows (Table 3). As indicated by their Ellenberg's indicator value for nitrogen, these species are nitrogen demanding (Table 2), and have a ruderal life strategy. Some are well-known anthropophilous species, such as *Vinca minor* or *Ribes uva-crispa*, whose presence on Roman ruins has already been reported (Ghestem et al. 1997; see Plate 1). These species may be favored by high phosphorus availability. Some of these could have been introduced as medicinal or food plants (Vogel-lehner 1984). In contrast, ancient woodland species (Hermý 1994), such as *Convallaria maialis* and the orchid *Epipactis helleborine*, are only present or are more frequent in remote areas, those least modified by ancient agricultural practices. These species cannot re-occupy previously cultivated zones due to their low colonizing ability, the lack of suitable microhabitats, or competitive disadvantage with ruderal species. As such, they have a higher conservation value (Honnay et al. 1999).

We cannot entirely dismiss the role of pre-existing differences in habitat conditions among plots. However, the strength of the relationship between ancient land use and present plant diversity patterns makes it difficult to find any other explanatory factor. Site conditions (topography, parent material, soil depth) were remarkably homogeneous all over the area. The lower clay content in the most intensively cultivated areas may suggest a preferential selection of silty areas by local Roman farmers. However, this difference cannot explain the observed variations in plant composition and soil properties. On limestone plateaus of northeastern France, silt deposits are usually associated with more acid soils and less diverse and nitrophilous plant communities (Becker 1979), an opposite trend to the one we are reporting here. Moreover, the major textural jump occurs between enclosures and nearby terraces (Table 1), while the plant community discontinuity is between nearby and remote terraces (Table 2). The lack of any artifacts from the Middle Ages, the long monastic ownership, and the earliest available map all point to a continuous woodland history after Roman abandonment.

In conclusion, 200 yr of farming during Roman times induced gradients in soil nutrient availability and plant diversity that are still measurable almost 2000 yr later. Modifications of soil physical properties, conservation by biogeochemical cycling of changes in soil chemistry

induced by cultivation, and the very low colonizing potential/competitive ability of some ancient forest species are the most likely mechanisms responsible for this long-term impact. We currently lack replication of this combined historical/ecological pattern in other sites. However, the anthropogenic influence on present forest ecology and biodiversity may have been underestimated, given the large areas cultivated in ancient times and now supporting forests in several parts of France.

In many regions of the world, successive episodes of woodland clearance and cultivation led to impoverishment of soil fertility by erosion, leaching of nutrients, and acidification, usually associated with loss of biodiversity in reforested areas compared with native vegetation. In our study area, agriculture had two opposite long-term impacts on plant diversity: an increase in the frequency of ruderal species, invasion of which was favored by higher nutrient availability, and a concomitant decrease in the frequency of species strictly restricted to undisturbed areas. Considering the high level of disturbance induced by modern agricultural practices, the restoration of plant communities typical of undisturbed forests in presently abandoned agricultural areas of northeastern France should not be expected on an historical time scale. Finally, the analysis of plant communities provides a powerful tool for landscape archaeology, which could help decipher the ancient spatial distribution of land use.

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