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THE FORCHTENBERG PROJECT. AN INTERDISCIPLINARY EXPERIMENTAL APPROACH TOWARDS NEOLITHIC AGRICULTURE

Abstract - Which agricultural practices were used in the Late Neolithic period is still a matter of debate. In order to test the slash-and-burn hypothesis, an experimental archaeological approach is followed near Forchtenberg in SW-Germany. There, a mixed deciduous forest area was dedicated to an interdisciplinary working group for a period of 20 years by the state authorities. Experiments include felling the stems with stone axes, burning by a fire roll, winter wheat as major crop and an animal component. Emphasis in this paper is on the soil related topics. The results revealed pests (mice) as major constraint in the first cropping period after burning and weeds become dominant in the second. Only if these problems can be solved nutrients, especially N and P, limit yield from the second cropping period onwards. Burning has a strong influence on the site properties. It changes morphological, physical, chemical and biological properties of the topsoil. Extreme is the change in the top centimetres. Overall, the experiments support the hypothesis of slash-and-burn agriculture in the Late Neolithic for the Pre-alpine lowlands. The experiments will be continued with emphasis on nutrient cycling and ergonomic aspects.

Key words - Agriculture, Neolithic, experimental archaeology, slash-and-burn, soil analyses, Germany.

Riassunto - *Il Progetto Forchtenberg. Un approccio sperimentale interdisciplinare all'agricoltura del Neolitico.* È ancora oggetto di dibattito quali siano state le tecniche agricole del tardo Neolitico. Un metodo legato all'archeologia sperimentale è stato utilizzato a Forchtenberg in Germania sud-occidentale, per verificare la tecnica del taglia-e-brucia. In questa località, un'area di foresta mista a caducifoglie è stata concessa dallo Stato ad un gruppo interdisciplinare di ricerca per un periodo di 20 anni. Gli esperimenti includono il taglio dei tronchi con asce in pietra, l'incendio a raso, il grano tenero come coltura principale ed una certa influenza animale. I risultati hanno posto in evidenza che i parassiti (topi) sono il principale fattore limitante nel primo raccolto dopo la combustione, mentre le piante infestanti divengono il più importante per il secondo raccolto. Soltanto se questi problemi vengono risolti la disponibilità di nutrienti, in particolare P e N, diviene fondamentale dal secondo raccolto in avanti. Il fuoco ha una forte influenza sulle proprietà del sito, modificando le proprietà morfologiche, fisiche chimiche e biologiche dell'orizzonte superficiale. Le modificazioni sono estreme nei centimetri più superficiali. In generale, questi esperimenti confortano l'ipotesi della pratica del taglia-e-brucia nell'agricoltura tardo neolitica delle pianure prealpine. Gli esperimenti continueranno, soprattutto con attenzione al ciclo dei nutrienti ed agli aspetti ergonomici.

Parole chiave - Agricoltura, Neolitico, archeologia sperimentale, taglia-e-brucia, analisi del suolo, Germania.

Introduction

The interpretation of archaeobotanical data from the Northern Pre-alpine lowlands in the Late Neolithic period (4300-3500 cal. BC) is still controversial (Rösch *et al.*, 2002a). Whether permanent agriculture or shifting cultivation prevailed is still an open question. In order to test different hypotheses an interdisciplinary cross-institutional working group has been established. Involved disciplines are so far soil science (University of Hohenheim), physical geography and archaeology (University of Würzburg), botany (University of Freiburg), archaeobotany (LDA Hemmenhofen), forestry (Forest Department Tübingen) and fire ecology (MPI Freiburg). The paradigm of this working group is that an experimental approach towards Neolithic agriculture can elucidate which management systems had been possible.
One major hypothesis underlying the experimental design is that settlements in that period started at forest sites with slash-and-burn activities. Arguments for this hypothesis are elevated charcoal content, low amount of non-tree pollen but increasing share of pioneer tree vegetation in lake sediments, and scarcity of typical weed remains in settlements (Rösch *et al.*, 2002b).
Consequently, we sought as an appropriate model a potentially fertile loess site with mixed deciduous forest. In 1997 the Forest Department of Baden-Württemberg offered an area (approximately 4 ha) for a time span of 20 years. The first slash-and-burn activities started in 1998. Here, mainly the soil related results are presented.

Site evaluation

The major test site is situated in Northern Württemberg (SW-Germany) near the city of Forchtenberg, north of the river Kocher (Gauss-Krüger coordinates: R 3541 H 5462) on a slightly inclined Triassic limestone (Upper Muschelkalk) plateau. Fine Triassic sandstone and sandy claystone (Lower Keuper) and Pleistocene loess are overlying the limestone in variable thickness. The elevation is 320 m a.s.l. and the climate is mild with a temperature of 9°C and 850 mm rainfall as an annual average. The vegetation is a species-rich mixed deciduous forest. Though field terraces in the eastern part indicate former agricultural use, historical documents prove the existence of a forest for at least the last 200 years (Schulz, 1999).

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The major soil type is Luvisol (according to the World Reference Base of Soil Resources, FAO 1998, a soil with marked clay illuviation in the subsoil) with stagnic properties (stagnant meteoric water for some time of the year resulting in hydromorphic features like mottling), where the underlying claystone comes closer to the surface. Also transitions to Cambisol (Fe-oxide and clay formation as dominant soil forming process) and Planosol (leached topsoil) occur towards the fringes of the experimental area. Especially the mentioned field terraces have only a weak loess cover. There the subsoil developed from Triassic claystone (soils classified as Vertic Cambisols with strong polyhedric structure development in the subsoil).
First major task was the evaluation of site properties in comparison to the assumed typical soil conditions for the Late Neolithic period. Therefore, a complete analytical dataset was produced, including physical, chemical and mineralogical information. Details with respect to soil genesis are discussed by Herrmann (2005). For analytical procedures and approach see Schlichting *et al*. (1995).
With respect to physical properties the evaluated profiles show no severe limitation in the main rooting zone due to aggregation, skeleton content or bulk density (Tab. 1). Only the rooting depth is restricted in the Stagnic Luvisol due to subsoil compaction. The available field capacity (representing the potential plant available water) is high. The silty topsoil texture leads to a good workability but also to a potential high erosion risk, which is actually moderate due to the weak slope gradient.
In general, the physical site characteristics are near optimum conditions for agriculture and match the assumed soil conditions in the Late Neolithic with the exception of stagnic properties in some subsoils.
With respect to the nutrient reserves, conditions are typical for the major parent rock, loess. Potassium, calcium and magnesium content is generally high to very high and does not constrain agricultural production. Nitrogen storage is medium to high. At the soil surface thin litter layers indicate good conditions for organic matter and also nitrogen turnover. Although the soils have low pH in the topsoil (around 4) the good litter quality by the deciduous trees guarantees high mineralisation rates, also reflected by the low C/N ratios (12-13) in the topsoil.
With respect to the nutrient reserves, phosphorus is the limiting element. Though it can be assumed that nowadays data reflect some phosphorus leaching during soil development (compare Wilke, 1979), the loess material in this part of Europe is generally poor with respect to this nutrient (0.04-0.13 wt-%, Sommer *et al*., 2003).
The status of available nutrients is more difficult to compare. First of all, these are highly dynamic in time, depending on different soil, weather and land use characteristics. Secondly, the situation in the Late Neolithic is not well known and depends on assumptions of organic matter accumulation, soil-pH etc. (for more details see Herrmann, 2005). Today's values indicate generally low availability of major nutrients. Related to the parent material, again phosphorus is the major limiting nutrient. We have to be careful with the interpretation of these ratings because the rating scales were developed during the last decades for nowadays annual crops with a high yield potential. Comparing recent cereal varieties with those of the early 20th century, we can also assume that the varieties of the Late Neolithic had a much lower yield potential (due to a lower grain/straw-ratio) and a higher adaptation to the site (due to natural selection at the site). Under this view, the evaluation should shift towards better ratings. Also we have to consider that slash and burn activities significantly change nutrient turnover rates and might be more decisive for the site than the «natural» nutrient availability.
In total, neither soil physics nor nutrient reserves seem to be decisively different from assumed Late Neolithic conditions. The comparison of available nutrients contains a great speculative component. But since slash-and-burn significantly changes site conditions the site can be accepted as a model for Late Neolithic agriculture.

Tab. 1 - Evaluation of site characteristics for major soil types (Haplic Luvisol: HL, Stagnic Luvisol: SL) at Forchtenberg.

			very low		low		medium		high		very high
	rooting depth	cm		15		30		60 sL		100	hL
root zone	limitation eff. BD	kg/dm³		1.2		1.4 sL	hL	1.75		1.95	
root zone	limitation erodibility (k-factor)			0.10		0.25		0.50	hL sL	0.75	
root zone	limitation skeleton	%	hL sL	1		10		30		50	
	available field capacity	l/m²		50		90		140 sL	hL	200	
	field capacity	l/m²		130		260	hL	390 sL		520	
	available bases	mmol(+)/m²	sL	5	hL	20		60		200	
	available N	g/m²		0.1	sL	2 hL		4.5		12	
	available P (lactate)	g/m²	hL sL	10		25		40		60	
	available K (lactate)	g/m²	sL	8	hL	24		48		80	
	N-storage (total)	g/m²		100		250	sL	500	hL	1000	
	P-storage (hot HCl)	g/m²		25 sL	hL	125		250		500	
	K-storage (hot HCl)	g/m²		100		500		1500	sL	3000	hL
	Ca-storage (hot HCl)	g/m²		50		250		500	sL	1000	hL
	Mg-storage (hot HCl)	g/m²		50		250	sL	500		1000	hL

Influence of slash-and-burn on site characteristics

With respect to burning techniques it was assumed that the tree stems were used as building material and as fire wood. In our experiment only the arm-strong branches and finer material was left, formed to a roll, set on fire and drawn across the experimental site. The advantage of this technique is that a relative regular burning pattern is produced. The temperature in the topsoil reaches approx. 200°C for several minutes (Fig. 1). Already in 5 cm depth only 35°C are reached. So the fire intensity is not very high and major changes are expected in the top centimetres only.
The remnants of the fire are to different shares wood ash and charcoal. For analytical purposes these materials were mixed and analysed as one sample.
The C/N-ratio (Tab. 2) of the total material hints towards a great share of charcoal, since it is in the range of woody materials. The pH is alkaline due to water solu-

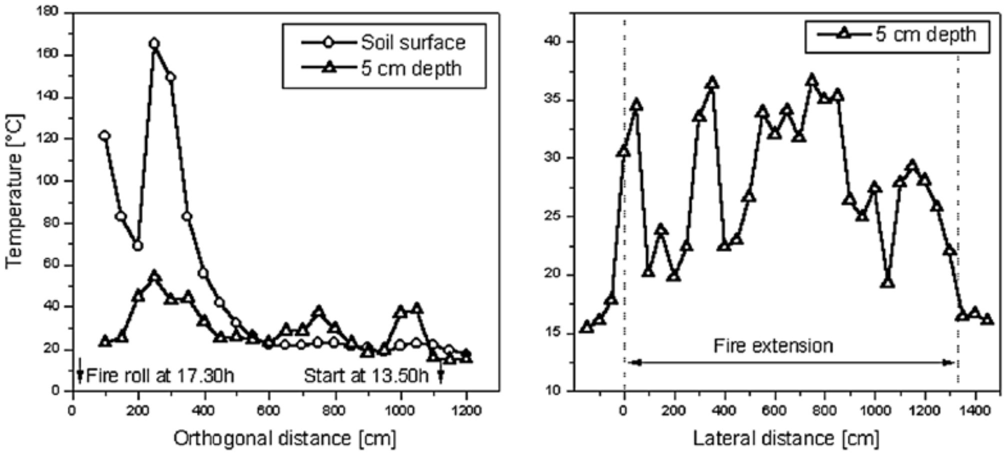

Fig. 1 - Vertical, lateral and orthogonal temperature profiles during a fire event at the site Forchtenberg.

Tab. 2 - Element concentration in burnt residues (n = 2), included nutrient amounts (at application rate of 2t residues ha^{-1}) and resulting potential yields for wheat at the major experimental site Forchtenberg. Analytical procedures: LECO CN2000 (C, N), Wösthoff Carmograph 12 (Carbonate), XRF Siemens SRS (Ca, Mg, K, P).

Analysis	**C %**	**N %**	**C/N**	**PH (H_2O)**	**Carbonate %**
	53	0.9	61	9.1	8.8
Element	**Ca %**	**Mg %**	**K %**	**P %**	**N %**
	3.1	1.1	2.9	0.4	0.9
Added by burnt residues (kg ha^{-1})	62.3	22.6	57.9	8.8	17.4
Available in soil (kg ha^{-1})	529.3	117.7	11.0	9.0	19.0
Atmospheric deposition (kg ha^{-1})					20.0 (estim.)
Sum (kg ha^{-1})	591.6	140.3	68.9	17.8	56.4
Demand kg ha^{-1} t^{-1} (grain + straw)*	4	2	13	5	30
Potential grain yield (t ha^{-1})	unlimited	unlimited	5.4	3.4	1.9

* According to: Verlagsunion Agrar, Faustzahlen für Landwirtschaft und Gartenbau (1983).

ble hydro-carbonate salts. The carbonate concentration is relatively high (8.8 wt %).

Taking into account nutrient delivery by the burnt residues, available nutrients from the soil, and estimated atmospheric contributions, potentially 1.9 t ha^{-1} wheat grain yield can be produced at the site, with nitrogen being the limiting factor. This calculation shows that burning changes the nutrient status of a site. But it must be stated that enhanced mineralisation of the organic matter in the topsoil as additional nutrient source could not be quantified so far.

In our experiment the burnt residues were left on the surface. No tillage was practised except seeding with a stick. So the natural soil structure remains. The release of plant nutrients from the burnt residues depends on the subsequent rains.

The wood ash contains a high share of water soluble readily available nutrients. Nutrient release from the charcoal also depends on mineralisation and transformation processes. Especially with the first rains high amounts of sulphur, phosphorus and potassium are leached into the soil. But P and K could not be detected in subsoil solutions (Herrmann, 2005). They are fixed already in the topsoil. For potassium the process is clear. It is fixed in expanded clays like vermiculite and intergrades, which represent a high share (up to 60%) of the clay mineral composition. For phosphorus the mechanism is not yet clear. One hypothesis is that it is intermediately fixed by the growing micro-organism population. Therefore P in the microbial biomass (Pmic) was analysed with high temporal resolution.

The results for the first centimetre of the topsoil (Fig. 2)

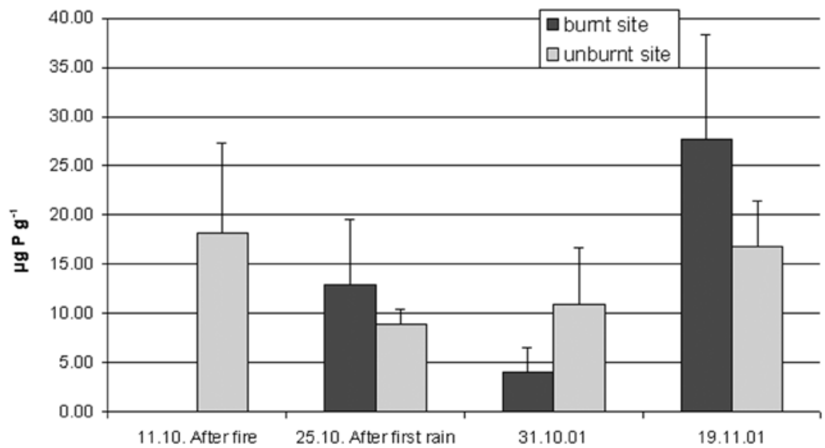

Fig. 2 - Temporal development of phosphorus in the microbial biomass of a burnt and a control plot in Forchtenberg (n = 4, analytical methods according to Schinner *et al.*, 1993).

show a temporal variation of phosphorus in the microbial biomass. The variation in the control plot is mainly due to fluctuations of the water content. In comparison, the fire plot shows higher fluctuations. Immediately after the fire no Pmic could be detected. We explain this fact with the high temperatures in the topsoil which are lethal for the living microorganisms. With the first rains after the fire an immediate recovery follows. The Pmic average in the fire plot even reaches higher average concentrations than in the control. Our explanation for this fact is that dormant cells might have survived the fire. Due to the readily available nutrients provided by the burnt residues and the dead microbe bodies a flush of microbial biomass occurs. This phenomenon is known as cryptic growth (Postgate, 1967). Due to the changed edaphic conditions (higher pH etc.) and weather phenomena the community collapses, giving room for the development of a more adapted species composition. Our hypothesis is that the community structure changes from a more fungi to a more bacteria dominated one. In order to test this hypothesis PFLA-analysis will be carried out in the near future.

In general, the hypothesis that a large amount of P provided by the burnt residues is intermittently fixed in the growing microbial biomass could not be confirmed. So it is either chemically fixed or leached to the deeper soil (several centimetres).

The fire does not only have an influence on the microbial biomass but also on the meso- and macrofauna. As an example the earthworm population is highlighted.

Figure 3 compares an overall burnt plot with a cleared but not burnt control plot. The effect of the fire is obvious for epigeic (living and feeding very close to the surface) species. They vanish with the fire and need approximately 2 years to recover. This is possible by lateral invasion only if the burnt plots are not too large. Marnissen & Van den Bosch (1992) report an earthworm spreading of 6-10 m yr^{-1}.

After 3 years the biomass is even higher than on the control plot. This might be explained by the better litter quality provided by the post-clearing vegetation. Parallel investigations (Ehrmann & Rösch, 2002) on plots with a mosaic burning pattern (burnt and non-burnt patches) revealed a much more rapid recovery of the earthworm population.

The effect of the reduced earthworm population is a reduced nutrient cycling especially for nitrogen and a reduced bioturbation. The latter explains the stable surface conditions at the burnt sites, which were otherwise immediately changed.

Finally, also the water regime is changed by the clearing activities. Figure 4 compares the forest control plot with the fire plot and a cleared but non-burnt site in the shadow of the forest. It shows the temporal development of the water tensions in the soil. The water tension gives information about the water content and availability in the soil. The higher the tension is, the lower the water content.

The control plot under adult mixed deciduous forest (50-60 years old) suffers from dry conditions in August and September due to high transpirative demand of the trees. On the other hand, deforestation leads to conditions near water saturation, because transpiration and interception are reduced to a minimum (fire plot central, 15 m distance to forest boundary). The cleared plot was so close to the forest (1.5 m apart from the forest boundary) that interception and tree root water uptake occurred. These mechanisms explain the reaction similar to the forest control plot.

As a conclusion, the water balance components of the forest and fire site are drastically different. Especially transpiration and interception is reduced at the fire site, whereas evaporation is enhanced by direct insolation. However, the evaporation component can be influenced by the management *i.e.* tillage. Since dry spells were not a major production constraint so far, tillage as a

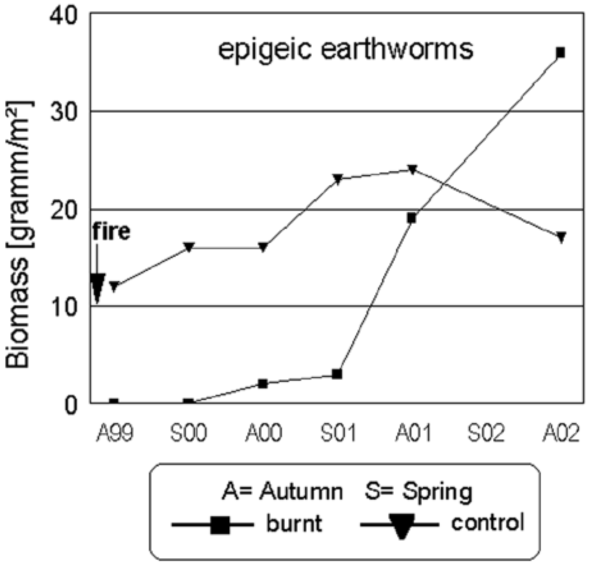

Fig. 3 - Temporal development of the epigaeic (a) and endogaeic (b) earthworm biomass (gm^{-2}) at a burnt plot in Forchtenberg.

regulating measure for the water balance is not followed up.

Draft summary of further interdisciplinary research results

Before clearing, the seed bank in the topsoil of the forest site had been investigated (Kury, 2003). The results revealed only species from clearing and herbaceous forest vegetation but no crop weeds. *Juncus*, *Hypericum* and *Rubus* seeds were the most common.
As preparation for the cultivation different clearing practices were tested. One was peeling of the bark in order to disrupt phloem transport. This measure failed as potential general management concept because the tree species reacted in different manners and time spans. In addition it resulted in lower timber quality for construction. Felling the trees with stone axes revealed a time consumption exponentially increasing with stem diameter.
Cropping was focussed on winter wheat, so far, using old land races since Neolithic ones are not available. Seeding is practised with a stick and no further tillage. At the burnt sites a high yield potential (up to 3 t ha^{-1} grain) is observable. No nutrient disorders could be detected there in the first year of cultivation. In contrast the cleared but non-burnt sites suffered from malnutrition and competition with secondary vegetation.
Major cropping restriction at the fire site in the first cropping season were pests (mice/birds) invading from the forest and feeding on the grains. In the second cropping season, without repeated burning, competition with forest regrowth and pioneer vegetation became problematic. Weeding was the most time consuming

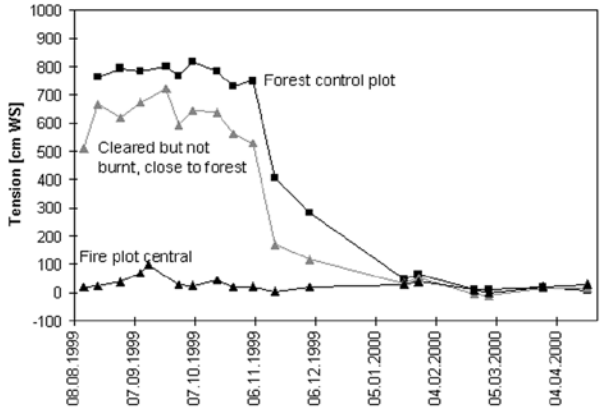

Fig. 4 - Temporal development of water tension at a forest control plot, a cleared but not burnt plot very close to the forest stand and a burnt plot (fire plot central) at Forchtenberg.

practice then. Also nutrient disorders, probably N and P, appeared. Therefore, continuous crop production needs repeated burning. This is only possible if fire wood is imported from the surrounding areas. An alternative could be the use of the plot for alternative crops like berries (*Rubus spec.*) and other products, since *Rubus* species are a dominant component in the regrowth.
Another alternative for weeding is grazing with sheep, goats or pigs. First experiments reveal that goats are effective in reducing tree and *Rubus* species and that grazing influences the subsequent species composition on the plot.

Conclusions and perspectives

Though there are some uncertainties with respect to nutrient cycling, the chosen site near Forchtenberg can be accepted as a model for Neolithic site conditions, since physical and geo-chemical characteristics are close to general assumptions about soils used in the Late Neolithic period. Potentially the most limiting soil factors for cropping are available nitrogen and phosphorus. While phosphorus can be supplied in sufficient amounts by burning practices, nitrogen cannot. Burning induces sound changes of soil characteristics including shift of pH and nutrient availability. Easily available water soluble nutrient fractions are supplied, which are partly fixed in the topsoil (P and K) and partly leached (Ca and Mg). So far insufficient information is available on the nitrogen cycling. Therefore emphasis will be on this topic in the future.
However, nutrients do not seem to be the most important constraints for production. These are in the first cropping season pests, especially mice and birds and in the second weeds. When these problems are solved, nutrients become decisive. An important question at this point is, whether the Late Neolithic farmer tended towards more intensive cropping on a smaller surface,

making intense weeding and nutrient concentration necessary, or whether he decided for slash-and-burn cultivation which implies large spatial extension.

Looking at today's production systems on subsistence level (mainly in the tropics), intensity of cropping depends on the distance to the settlement. Near the settlement vegetables and orchards are grown and fertilised by the waste from the settlement. The intensity of cropping on the arable fields depends on the integration of the livestock component (Schlecht & Hülsebusch, 2000). If livestock is not included in the cropping system for fertilisation purposes, cropping tends towards low intensity with one to three years cropping and long fallow periods (10-20 years). Probably in future more emphasis should be on the role of livestock in the Late Neolithic system.

Permanent cropping at one site needs constant nutrient import. One probable option is «wood ash» fertilisation. It should lead to high charcoal concentrations at the cropped site. Though a share of it will be decomposed in time, another share should accumulate. If so, around former settlements certain areas with very high and others with relative low charcoal concentrations should be found. Former findings should be checked with respect to this question.

The effect of burning depends on the technique used. Potential options are concentration of fire wood and localised burning, overall burning, or the «fire roll» as it was used in this project. The fire roll has the best effect with respect to spatial coverage and complete «weed» destruction. On the other hand it leads to fauna eradication at least in the top centimetres of the soil. This is an important note also for present day management.

Overall, the experiments support the hypothesis that slash and burn agriculture is a viable option for Late Neolithic agriculture in the Pre-alpine lowlands. So far no arguments are known which could finally lead to a rejection of this hypothesis.

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