Where have all the sickles gone? An experimental investigation of alternative harvesting tools during the Michelsberg period in North-Western Europe

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Author: Marc-Philipp Häg
Supervisor: Prof. dr. Annelou van Gijn
Material Culture Studies, Faculty of Archaeology, Leiden University
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CHAPTER 1 – INTRODUCTION

Neolithic harvesting tools have been of interest to archaeologists since the late 19th century (Spurrell, 1892). Since then, many articles have been written about these instruments, their shape, use, yields and impact on population development all over Europe (Bogaard, 2004; Juel Jensen, 1994; Schlichtherle, 1992; Shennan, 2018; Steensberg, 1943). In addition, many archaeological experiments have been made to reconstruct the reaping technology of the Neolithic and link these results to use-wear traces seen on actual archaeological material (Frank, 1985; Ibáñez et al., 2008; Mazzucco et al., 2022; Pétrequin et al., 2006). But the research focus has been so far exclusively based on flint-tools. Whereas for the Early Neolithic Linear Bandkeramik (LBK) flint sickles are a very common occurrence, for the Michelsberg period, archaeologists are faced with a period of 900 years and a surface of the entire North-Western Europe, where almost no flint-based harvesting tools have been excavated, although cereals were clearly collected (Bakels, 2009, p.73; Bakels & van Gijn, 2015, p. 111). How can this difference be explained when the only material considered in research for reaping is flint (e.g., sickles)?

This exclusive focus on flint tools is understandable. Stone tools used for harvesting are believed to be easily recognisable even with the naked eye due to their characteristic "*sickle gloss*". This shiny surface of flint blades is believed to originate from the cutting of cereals stems (Steensberg, 1943, p.10). In the late 20th century, this particular perception of gloss, has changed considerably with the introduction of use-wear analysis. With that method, on the one hand, plant reaping traces were detected on flint tools without any macroscopically visible sickle gloss. On the other hand, sickle gloss-like traces were discovered as resulting from different use, like sod cutting (van Gijn 1988, p.214; 1990, p.48).

This "*unique*" connection between flint tools and cereal harvesting is unfortunately not always valid. Several prehistoric periods and locations in Europe show an absence of flint reaping implements, despite a presence of collected cereals. This archaeological gap not only existed during the Michelsberg period of North-Western Europe, on which this paper mainly focuses, but also during the early Neolithic in North-Africa (Rodríguez-Rodríguez et al., 2014, p.768), Northern Spain (Ibáñez et al., 2008, p. 191) and Central France (Ibáñez et al., 2001, p.24). Also, in late Neolithic coastal Vlaardingen settlements in the Netherlands and in alpine Horgen sites flint-based harvesting tools are scarce, but cereals were consumed (Schlichtherle, 1992, p. 33; van Gijn & Bakker, 2005, p. 295).

This, in turn, has led many authors to believe that if harvesting was done, it was done manually or with perishable tools (Bakels, 2009, p. 73; Bakels & van Gijn, 2015, p. 111; Ibáñez et al., 2001, p. 33; Vermeersch & Burnez-Lanotte, 1998, p. 51). But so far, no author has tried to recreate, test, and analyse harvesting tools made from alternative materials such as shells, wood, or bone on a large scale. Why is that so?

This could be linked to the absence of such organic materials in many archaeological sites especially of the Michelsberg period. This absence might have stopped researchers to look further into tools made from shells, bone, or wood. However, some tools made from such organic materials have already been archaeologically recorded, such as early neolithic oak wood sickles in Spain (Bosch Lloret et al., 2006, p. 28) or deer mandibles used for harvesting in historic USA (Brown,1964, p. 382). Even harvesting tools made from shells have been archaeologically and ethnographically confirmed (Pétrequin et al., 2006, p. 115; Watanabe, 1973, p. 41). In addition, such alternative materials can easily be sourced in North-Western Europe. People lived close by the sea or rivers to source oysters or freshwater mussels. They were surrounded by forest to cut oak timber and were able to hunt deer. It appears thus obvious, to apply experimental archaeology on tools made from these materials. Can this archaeological gap be closed, and the proposed harvesting techniques (manual or with sickles made of perishable materials) be a suitable alternative?

Next to closing this gap, the aim of this paper is to find out more about the actions of people living 6,000 years ago. People living in North-Western Europe during the Michelsberg period have, for reasons unknown to us, not used flint-based sickles. But they have been consuming four different types of cereals, more than during previous periods of the Neolithic (Bakels & van Gijn, 2015, p. 110). If flint as cutting material was not used, then other materials must have been chosen. If this theory could be proven, this could show the ingenuity of past populations in solving food supply issues through creative thinking, technical adaptation, or cultural choices.

This creative thinking would also be suitable to modern-day archaeologists. As mentioned, flint based harvesting tools have been analysed in depth. However, reaping tools made from alternative materials have rarely been investigated although some archaeological samples made of shell, wood, or mandible, have been found. (Brown, 1964, p. 382; Pétrequin et al., 2006, p. 115; Terradas et al., 2017, p. 209), Or, as the saying goes.

„*Absence of evidence is not evidence of absence*".

Maybe it is about time to actively look for harvesting tools made from these alternative materials and stop focussing on the well-known flint tools?

This project is thus about reconstructing harvesting tools out of shells, wood and bone and examining their functionality. To this end, a series of reaping tools have been designed and produced with these organic materials. These have then been tested in the field by collecting four different cereal types as *Triticum monococcum* or einkorn wheat, *Triticum dicoccum* or emmer wheat, *Hordeum vulgare* or barley and *Triticum aestivum* or naked wheat. The most efficient instruments were then determined, based on three quantitative measures. These were harvested surface, reaping speed, and grain yield. Equally, a qualitative assessment was undertaken, to understand how suitable each of these materials are at cropping cereals. These qualitative measures included the type of harvesting methods, use-wear traces, and tool shape post-harvest. Finally, the tools used during that experiment have been made part of the reference collection at the Laboratory for Material Culture Studies at the Faculty of Archaeology at Leiden University. This collection can enable future researchers to compare these experimental tools to actual archaeological material and confirm that organic materials were used for harvesting in the past. This would not only explain how people in the Middle Neolithic reaped cereals, but also confirm people's ingenuity and creativity in their tool production.

To summarise, the research questions for this thesis are as follows.

1) Can tools, whose cutting edges are made from shells, bone, or wood, be used to harvest cereal plants?

2) What kind of use-wear traces are visible on such tools after reaping cereals and how can they be recognised archaeologically?

3) What reaped surface, grain yield and harvesting speed can be obtained with such tools in comparison to tools with flint inserts?

4) Can enough grain be collected with these tools to cover one or a group of people's grain needs for the year?

5) Why do sickles or harvesting knives made with flint inserts disappear in the Michelsberg period?

These questions will, within the following chapters, be answered. Chapter 2 will focus on the history of harvesting tools during the Neolithic. In chapter 3 the Michelsberg period will be highlighted and in chapter 4 the focus will be on agricultural techniques of that period. The methodology applied to this experiment will be presented in chapter 5, followed by an assessment of the quantitative results in chapter 6. The qualitative and use-wear trace results are shown in chapter 7. The discussion in chapter 8 focuses on four points: the potential use of these tools, the reaping results versus other experiments done, how these items can be discovered archaeologically, and the reasons alternative materials were used. The conclusion is presented in chapter 9 and an outlook is given in chapter 10 how future studies in this field could develop.

CHAPTER 2 - HARVESTING TOOLS

This chapter introduces the different types of harvesting tools of the Neolithic discovered during excavations. It starts by presenting the typology of various tools, be it sickles or harvesting knives including non-flint tools like handheld wood, shell or bone implements. Also, the historic research on harvesting tools starting from 1868 is highlighted. Finally, the regional spread of these tools starting from the Near East is shown. This work focuses mainly on an area which today comprises the countries of the Southern Netherlands, Belgium, Northern France, and Northern Germany. Other sites in Europe, North Africa and the Middle East are also cited as examples. All dates mentioned in this thesis are based on cal BC.

2.1. Typology of harvesting tools

2.1.1. Harvesting by hand

The hand is believed to be the first tool used by humans to collect plant resources (Groman-Yaroslavski et al., 2016, p. 1; Lucarini, 2008, p. 443; Sigaut, 1978, p. 149). There are four ways known to researchers on how to reap by hand.

The first one is uprooting. There, the harvester pulls out, by hand, the entire cereal plant from the soil. Its advantage is that the entire plant can be used, including its stem and roots. A disadvantage is that, through uprooting, much earth is collected with the roots, which needs to be shaken or cut off later (Ibáñez et al., 2001, p. 26). Also, not only the stems but also weeds and grass are collected and must be separated afterwards. For that method to work, the soil must be sufficient friable (Anderson & Sigaut, 2015, p. 86), which in most cases would be a very sandy or volcanic soil. Otherwise, the cereal stems cannot be uprooted, but must be plucked instead (see Chapter 6.1.5.).

For the second alternative, plucking, the stems are broken off their base one by one like a flower. The advantage of this method is, again, the use of almost entire stems, without the need to pull out the roots. But this method is very slow, as each stem must be plucked one by one. However, for organically planted fields, where cereals are growing mixed with grass and weeds, this might be the only way to collect cereals. This method is also suitable for reaping cereals on sparsely planted fields (Anderson & Sigaut, 2015, p. 86).

The third way is to snap off cereal ears by hand. For that, only the ears or a short part of the stem just below are broken off and collected. The remaining stems stay on the field and can serve as animal feed or fertiliser (Ibáñez et al., 2001, p. 32). Some cereal types like *Triticum monococcum* (einkorn wheat) and *Triticum dicoccum (*emmer wheat) are easily harvested that way since their stems have a breaking point. This point is located just below the ears and allows to snap them off easily even without any cutting tool (Anderson & Sigaut, 2015, p. 89). The ears must be simply twisted backwards, and they then cleanly break off (M.-P. Häg, personal experience, 11th July 2022).

Finally, beating is another technique known from ethnographic research, where ripe ears are gathered into a basket with a wooden paddle. For that the ears are beaten with such a paddle and the ripe ears or grains fall into that basket (Lucarini, 2008, p. 446). The advantage of this method is the collection of only ripe cereals. The disadvantage is that several passes over the field are needed to collect all available grain (Anderson & Sigaut, 2015, p. 88).

These hand harvesting techniques are still seen today in places like the Near East, the Spanish island of Lanzarote and Morocco (Anderson & Peña Chocarro, 2015, pp. 95-96). Unfortunately, it is not possible to prove that the above-mentioned techniques have been used in Prehistory. But current ethnographic, geographic, and botanical indications do hint to a potential use of these techniques in the past.

Ethnographic proof come from Syria, where, close to the town of Aleppo, the harvest was done, until recently, by hand. Farmers were squatting in front of a cereal field and uprooted handfuls of *T. aestivum* (wheat) or *H. vulgare* (barley). Once uprooted, these were put aside, bundled, and collected (Anderson & Peña Chocarro, 2015, p. 94). *H. vulgare* is still collected that way on the island of Lanzarote, Spain. The volcanic soil there is very loose and enables an easy uprooting of the plants (Ibáñez et al., 2001, p. 26). In Morocco *T. monococcum (*einkorn wheat) is also reaped that way. The stems are used for roofing and through uprooting, the entire length of the plant can be used (Anderson & Peña Chocarro, 2015, p. 96).

Geographic proof can also be found for a harvest by hand. In certain regions, cereal grains have been excavated in an archaeological context, but harvesting tools or sickle flint inserts are absent. This is the case for the early Neolithic in Cantabria, Northern Spain (Ibáñez et al., 2008, p. 191), Central France (Ibáñez et al., 2001, p. 24) and in North Africa (Rodríguez- Rodríguez et al., 2012, p. 768). Also, for the Michelsberg period, (4,200 to 3,500 cal BC) traces of cereals have been found, but flint sickles are mostly absent (Bakels & van Gijn, 2015, p. 111). However, these plants could also have been collected with tools made from other, organic materials, like shells, wood, or bone, of which no traces have yet been discovered.

Botanically, harvesting by hand can also be assumed. Remains of cereal roots unearthed at excavations, are a strong indicator that the plant was reaped entirely (Anderson & Peña Chocarro, 2015, p. 97).

In short, harvesting by hand appears to have been practiced during Prehistory, but apparently only under certain conditions:

a) the need to use the entire stem of the plant for construction (e.g., roofing) as seen in Morocco (Anderson & Peña Chocarro, 2015, p. 96).
b) the cereal plants growing in soft and loose earth like the volcanic soil in Lanzarote, where it can be easily uprooted (Anderson & Sigaut, 2015, p. 86; Ibáñez et al., 2001, p. 26).
c) the plants are short like *H. vulgare*, where bending forward to cut with a sickle is very tiring and uprooting them is easier (Ibáñez et al., 2001, p. 26).
d) the plants having breaking points just below the ears like *T. monococcum* (einkorn wheat) and *T. dicoccum* (emmer wheat) which do allow for an easy knapping of just the ears (Peña Chocarro, 2015, p. 103).

2.1.2. Sickles

In most European countries, the sickle is defined as a tool having a handle to cut cereals with.

> *One of the most ancient of harvesting tools, consisting of a metal blade, usually curved, attached to a short wooden handle. The short handle forces the user to harvest in a stooped or squatting position. The longer handled scythe, the user of which remains upright, evolved from the sickle. Harvesting with a sickle is very slow, but because of its simplicity and low cost, it is still widely used over the world, especially to reap cereals such as wheat and rice and also as a gardening tool*. (Britannica, 2009)

In Germany the definition of a sickle is more explicit, where a sickle is defined as "*wenn Schneide und Biegung des Schaftes in der gleichen Ebene liegen*" (Schlichtherle, 1992, p. 27). H. Schlichtherle (1992) determined thus a sickle, when the cutting edge and curvature of the shaft are on the same level (p. 27). According to this definition, tools with a cutting edge not on the same axis as the curvature are harvesting knives. But among researchers from other countries such as France, Spain, Italy, Benelux, or the UK this distinction is not seen as sharp (Astruc, 2012; Bar-Yosef, 1998; Bosch Lloret et al., 2000; Ibáñez et al., 2016; Unger-Hamilton, 1989). Therefore, to avoid confusion, in this thesis, the above definition from Britannica will be used. All cutting tools with a straight or curved haft and with multiple cutting inserts will be seen as sickles. Short tools with only one inserts will be classified as harvesting knives. The next section gives an overview of different neolithic sickle types and reaping knives discovered in archaeological context.

2.1.2.1. Curved sickle with oblique inserts

This type consists of a curved haft made of wood, antler, or bone. In the curved inner part of that haft, a long groove has been cut and silex blades or flakes were inserted. These inserts, intentionally broken from larger blades, are around 2-3 cm long and 1 cm wide (Gibaja et al., 2015, p. 112). They are placed in the haft at a 45°angle and show a dented profile (see fig. 2.1). These inserts are fixed into the groove with bitumen, birch, or spruce tar (Schlichtherle, 1992, p. 26). Since the blades are inserted at an angle, use wear traces, such as sickle gloss, are seen diagonally to the blade. These sickles are called composite sickles as they are made from different materials (Cauvin, 1983, p. 65; Schlichtherle, 1992, p. 27). Archaeological experiments with these have proven that they are very effective in collecting cereals, as they not only cut, but also rip through stems. As the inserts are positioned at an angle to each other, the sickle in a way „*jumps*" from insert to insert while cutting and increases the cutting strength. But through that „*jumping*", the individual blades are getting rounded much faster and tend to also fall out faster than if positioned parallel to the haft. (Frank, 1985, p. 20).

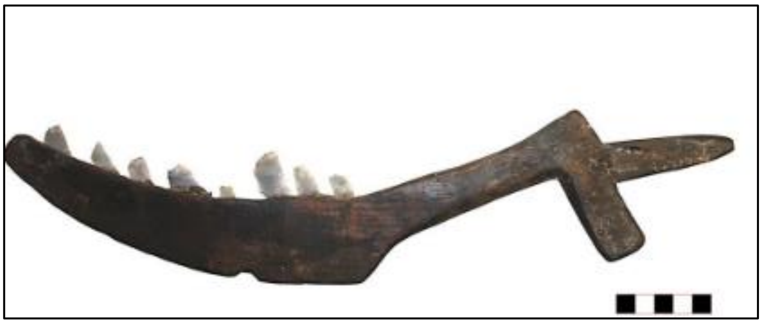


Figure 2.1. Composite sickle from La Marmotta, Italy (Mazzucco et al., 2022, p. 4).

2.1.2.2. Curved sickle with parallel inserts

The haft of this type of sickle has the same shape as the above-mentioned composite sickle, but with the difference that the inserts are not placed at an angle but parallel next to each other. This means that the inserts are either rather small, as they must follow the curved shape of the haft or consist of only one large blade. This placing of several small inserts one next to the other one enables a continuous cutting edge. The single, large insert (see fig. 2.2) is placed in the curved part of the haft and covers with its blade the entire cutting edge (Schlichtherle, 1992, p. 27).

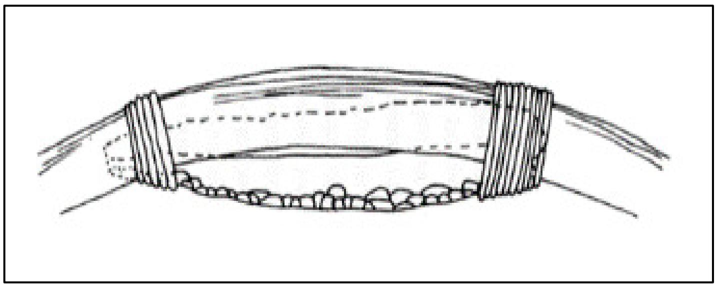


Figure 2.2. Reconstruction of a flint blade inserted in a bended shaft (Ibáñez et al., 2008, p. 187).

2.1.2.3. Angled sickle with single blade in parallel insertion

This L-shaped tool is divided into three parts. The bottom part is the handle. The middle part is the cutting section with one or several grooves cut out parallel or slightly angled from the shaft. In these grooves, one or several flint blades 5 to 10 cm in length were inserted parallel to the shaft. The upper part is bent at a 90° angle to the left, to catch the stems (see fig. 2.3). The entire tool measures between 20-30 cm from the tip to the base. It is frequently made from hard wood as oak or juniper, showcased by examples from the early Neolithic found at the site of La Draga in Spain (Bosch Lloret et al., 2006, p. 49). The stems of the cereal are gathered with the upper part and pulled towards the harvester. These are then held together with one hand. The sickle is then turned by 90° inwards for the flint blades to point towards the stems and the tip to the soil. The stems are then cut. As the tip points to the soil, the cutting height above ground is at least as high as the length of the sickle tip (Gibaja et al., 2015, p. 114). This method avoids cutting close to the ground and thus prevents the flint blades to get damaged by touching the soil. But this use assumes a purely right-handed handling. Indeed, if the tool was used by a left-handed harvester, the tip of the sickle would be turned upwards, and the entire plant could be cut closer to the soil. Gibaja in his article (Gibaja et al., 2015, p. 114) notes that certain blades of that sickle type have strong use-wear traces, which he believes could only happen if in contact with the soil. He thus proposes the theory that these

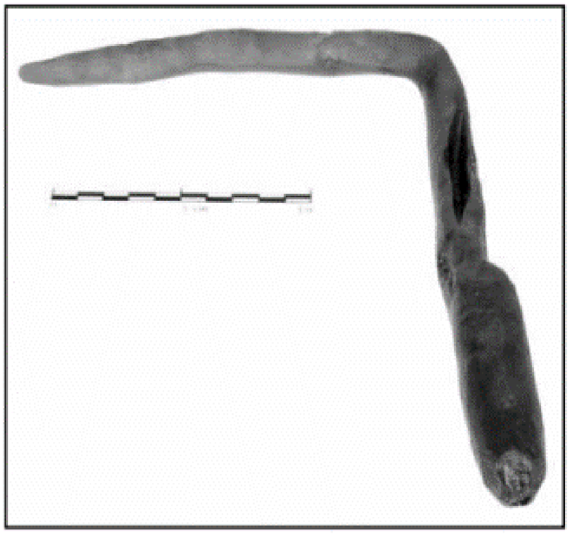


Figure 2.3. Sickle with branch and flint insert (Bosch Lloret et al., 2005, p. 288).

blades have been recycled for other tasks once the harvest was over and have touched the soil during these tasks. But it could also be assumed that some left-handed farmers in this community have used the sickles as described above and therefore generated these strongly developed use-wear traces by cutting close to the soil (Häg, 2021, p. 13).

2.1.2.4. Angled sickle with oblique flint insert

These tools are a variation of the above-mentioned angled sickle. They have the same shape with a handle at the base, the flint inserts for cutting in the middle and the top slanted at 90°. But instead of having one or several parallel blades inserted, they have only one large flint blade placed at a 45° angle to the shaft. Two archaeological examples have so far been discovered (see fig. 2.4). The wooden example is made from a branch of an elder tree with a section jutting out at a 90° angle serving as the tip. In the middle of the haft a large flint blade (1.7 cm wide x 0.2 cm thick) has been fixed with birch tar (Bosch Lloret, 2006, p. 29). The precise length of that blade could be between 5 to 8 cm but cannot be reconstructed as it was recovered broken (Gibaja et al., 2015, p. 115). The antler sample has been encountered in an early neolithic cereal storage in Costamar, Spain and has a length of 37 cm with also a branch jutting out at a 90° angle. Traces of sickle gloss show its use as a harvesting tool. In the middle of the antler piece, a deep groove suggested that a large flint blade was inserted and used for cutting cereals (Flors et al., 2012, p. 2). The blade itself was missing, but the author nevertheless assumed the insert to be a flint blade.

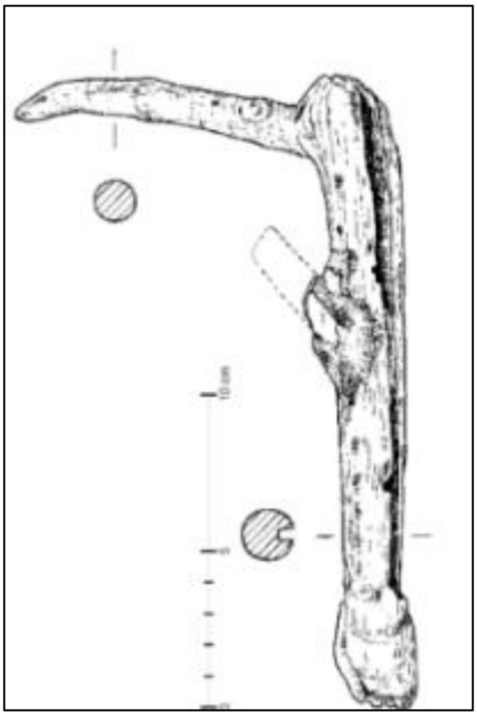


Figure 2.4. Elder wood sickle haft with oblique flint insert (Bosch Lloret et al., 2006, p. 29).

These tools were used in the same way as the angled sickles with single blade in parallel insertion, except for the cutting. Here, the stems were cut with the exterior side of the flint blade instead of the interior part (Gibaja et al., 2014, p. 656; Flors et al., 2012, p. 2). Also, right-handed farmers could only cut the stems up to the height of the tip, whereas left-handed one's could cut the stems closer to the soil.

A variation of these sickles has been identified in Switzerland at the Middle Neolithic site of Egolzwil 3, where 10 almost complete wooden tools with oblique flint inserts have been discovered. Different to the Spanish type, these have a straight and sharpened tip instead of one jutting out at a 90° angle (see fig. 2.5.). It is believed that it served to collect stems in a densely planted field before cutting them with the oblique flint blade (Gibaja et al., 2017a, p. 218).

Figure 2.5. Sickle from the Egolzwil 3 site, Switzerland (Gibaja et al., 2017a, p. 220).

<u>2.1.2.5. Multiple flint blades with straight haft</u>

These tools consist of a straight, long haft made of bone, wood or antler and several smaller flint blades serving as cutting agent. These tools are believed to be the oldest harvesting tools discovered so far (Unger-Hamilton, 1989, p. 90). They date back to the Near Eastern, early Neolithic Natufian period (10th millennium cal BC) (see fig. 2.6.).

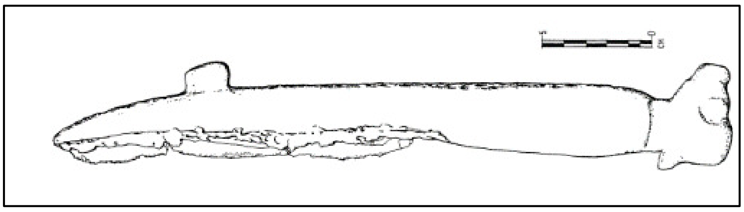


Figure 2.6. Natufian bone sickle from Kebara B, Israel (Unger-Hamilton, 1989, p. 90).

2.1.3. Harvesting knives

This word combination does not appear in British dictionaries such as Merriam Webster or Britannica. It is a combination of harvest *„to gather in (a crop) especially for food*" (Merriam Webster, n.d.) and knife *„a cutting instrument consisting of a sharp blade fastened to a handle "*(Merriam Webster, n.d.) In German, this tool is known as „*eine sehr kurze (5cm) Stein- oder Metallklinge, deren Rückseite in eine Holzfassung eingesetzt oder in Stoff gewickelt ist*" (Sigaut, 1989, p. 520). F. Sigaut (1989) sees harvesting knifes as a very short (5 cm) stone or metal blade whose back is inserted in a wooden frame or wrapped in textile (p. 520). This creates a distinction between a sickle with a long shaft and a straight or curved cutting edge, and a harvesting knife with a short shaft and a straight cutting edge.

But this distinction of sickles and harvesting knives is not very strong in English- Spanish- Catalan- or French-literature. Frequently, both types are used indistinctively in scientific articles as „*sickles, faucilles, falçs or hoces*" (Astruc, 2012; Bar-Yosef, 1998; Bosch Lloret et al., 2000; Ibáñez et al., 2016; Unger-Hamilton ,1989). Here some types of reaping knives used in the Neolithic.

2.1.3.1. Single flint blade with wooden haft

These are rather short, straight flint blades (about 5 cm) inserted with tar or pitch into a wooden frame (see fig. 2.7.). As the cereal polish on the exposed flint blade shows, these have been used to collect cereals. They date to the 4th millennium cal BC (Schlichtherle,1992, p. 26).

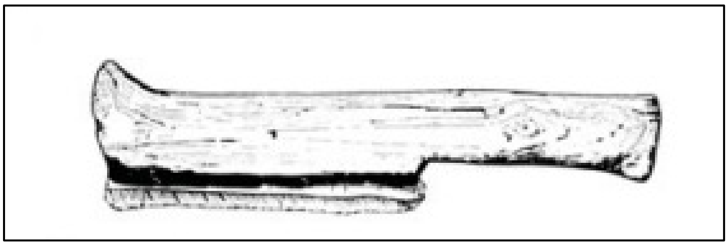


Figure 2.7. Reaping knife, Auvernier-Port, Switzerland (Mazzucco et al., 2017, p. 4).

2.1.3.2. Single flint blade

Single flint blades have also been used as reaping tools. These have on one side, a cutting edge and, on the other side remains of tar. These tar traces are not believed to be part of a hafting in a long-gone wooden sickle handle. But it is assumed that this tar was covered with textile or bark and meant to protect the hand while reaping (see fig. 2.8.). Due to its polish on the cutting edge these tools are believed to have been used to collect cereals. These harvesting knives are dated to the alpine Horgener period (3,350 – 2,800 cal BC) (Schlichtherle, 1992, p. 36).

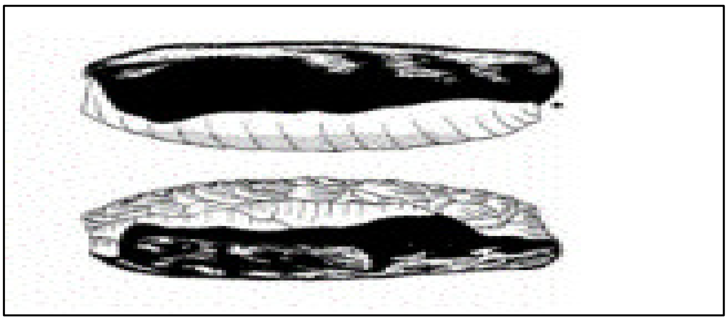


Figure 2.8. Horgener knives with birch tar handle from Sipplingen-Ost, Germany (Schlichtherle, 1992, p. 36).

2.1.4. Other types of harvesting tools

2.1.4.1. Wooden harvesting tools

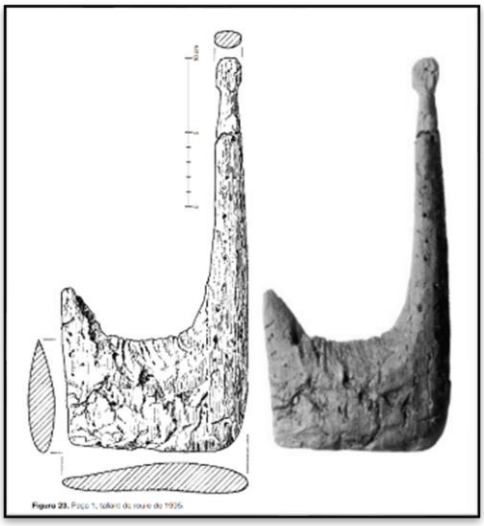


Figure 2.9. Oak wood sickle (Bosch Lloret et al., 2006, p. 27).

Next to the many flint-blade based harvesting tools, instruments made of other materials have also been recovered. In 1985, a wooden sickle has been discovered at the early neolithic lake-site village of La Draga, Spain. This tool is entirely made of oak, has no flint cutting edge, nor any groove to insert a flint blade. It is 29 cm long, 14.5 cm wide and 2 cm thick (Bosch Lloret et al., 2006, p. 27). It dates to the 6th millennium cal BC and is assumed to have been used for cutting reeds or cereals (Terradas et al., 2017, p. 209). It is so far the only wooden tool believed to have cut cereal plants (see fig. 2.9.).

2.1.4.2. Harvesting tools made of bone

In the early part of the 20th century, several deer mandibles were detected during archaeological excavations in the state of Illinois, USA. Traces of not only *"high polish on the sides but also other distinctive characteristics, such as polished anterior ends, polished teeth and binding marks at the base of the ramus"* (Brown, 1964, p. 382) point towards the fact that these have been used by native American to collect plants. Not only do these mandibles show a strong polish, but they also lack their front teeth and have a strong rounding of the front bone (Brown, 1964, p. 382). This is seen as an indication that reaping was done close to the soil or that plant stems have been dug out with these front teeth (see fig. 2.10.). In the 1960's experiments were done with such mandibles to cut grass. It has been confirmed that the traces made on these tools are like the archaeological ones (Brown, 1964, p. 383). Other than these mandibles, boar tusks are also believed to have been used as harvesting tools. Some archaeological objects found in Vlaardingen and Hekelingen in the Netherlands show polish on the cutting edge of the tusks, which has been interpreted as sickle gloss (Maarleveld, 1985, p. 88). But so far, no experimental research has been done to confirm this theory.

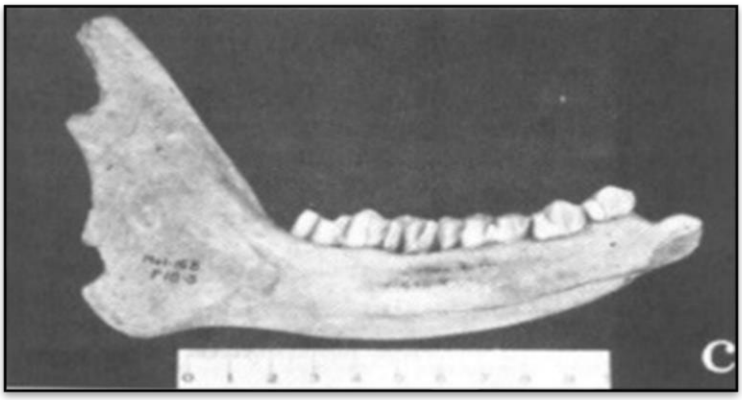


Figure 2.10. Deer mandible used as sickle (Brown, 1964, p. 382).

2.1.4.3. Mesorias or plucking clamps

These harvesting tools consist of two 50 cm long, wooden sticks attached together with a short string at one end (see fig. 2.11.). During harvest, the stems of especially *T. monococcum* or *T. dicoccum* plants are being placed between these sticks and the mesorias is pulled upwards. The ears cleanly break off the stems due to their "*rachis semi-fragility*" and can be transferred into a basket (Peña Chocarro, 2015, p. 103). The advantage of this method is that the ears can be collected without any weed and that the stems are left standing on the field to be used as animal feed or fertilizer. The disadvantage is that this method is rather slow, especially compared to a sickle. These wooden tools are still in use today not only in Spain, but also in Nepal and the Caucasus (Ibáñez et al., 2001, p. 25). Unfortunately, archaeological remains of these mesorias have not been found yet, making their use during the Neolithic a hypothesis, albeit an interesting one.

Figure 2.11. Mesorias sticks (Anderson, 2013, p. 90).

2.1.4.4. Ceramic harvesting blades

In the Near East, another material has been used to reap cereals, namely clay. In the Ubaid (4,500 to 3,900 cal BC) and Uruk period (3,900 to 3,100 cal BC) of Southern Mesopotamia, flint was believed to be scarce, and clay was thus used to produce tools. These were mass produced as the handle, cutting edge and tip were made together in one shallow mould and fired in pottery kilns. Once burned, they could be used as they were (see fig. 2.12.). These were not only used to collect cereals, but also to cut reeds or to work on other plant materials (Benco, 1992, p. 121; Vandiver & Horrocks, 2017, p. 1825). They became so popular, that in many sites of the Ubai period "*they outnumbered all other non-pottery artifacts considered altogether*" (Benco, 1992, p. 120).

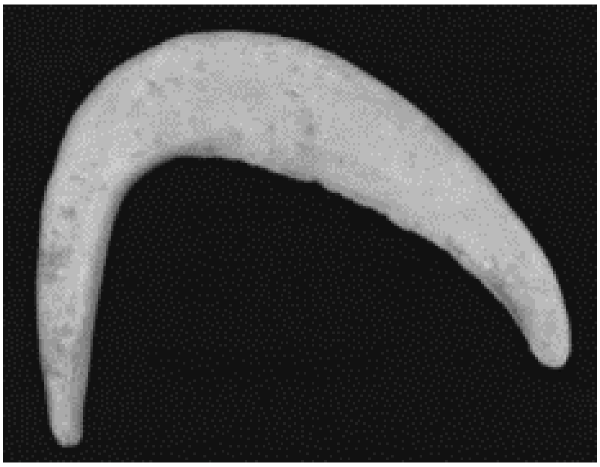


Figure 2.12. Ubaid period clay sickle (Vandiver & Horrocks, 2017, p. 1814).

2.1.4.5. Harvesting tools made from shells

Archaeological finds of shell-based harvesting tools are rare. One example was encountered at the lake-site village of Chalain, Jura, France and is dated to the late Neolithic (2,850 to 2,750 cal BC). This tool was made from *Unio crassus,* or freshwater mussel. It was initially believed to be an ornament (see fig. 2.13) but then reclassified as a potential harvesting tool and published as such (Maréchal et al., 1998, pp. 161-162). Due to its dented cutting edge and perforation in the shell, it was later classified as a harvesting knife (Pétrequin et al., 2006, p. 115). It is believed that through this perforation, a string was passed, which kept the tool attached to the wrist of the harvester (see fig. 2.14). This example of an erroneous classification of a tool could indicate, that other archaeological shell remains are waiting to be properly analysed. Could an analysis of their use-wear traces, yield potential cereal harvesting marks?

In ethnographic research, shell-based reaping tools have also been recorded for the Japanese Ainu people (Watanabe, 1973, p. 41).

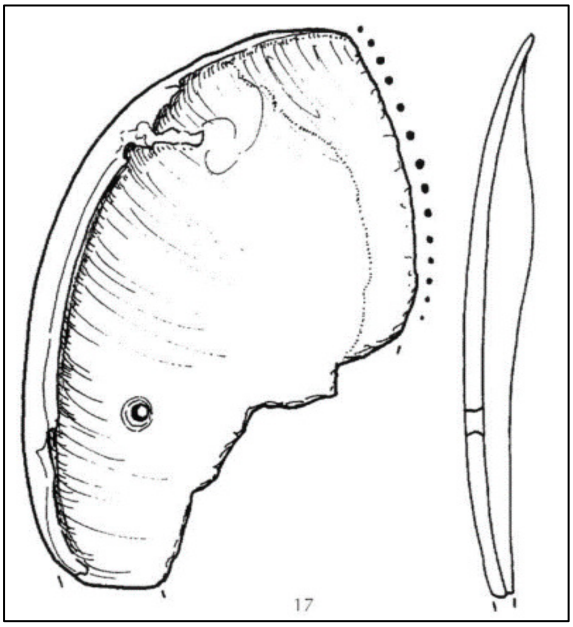


Figure 2.13. Freshwater mussel shell with dented edge (Maréchal et al., 1998, p. 195).

Figure 2.14. Freshwater mussel with two holes and dented edge and harvesting knife, type Clairvaux. (Pétrequin et al., 2006, p. 115).

2.2. Research history

The first archaeological sickles have been identified in 1868 in Spain. M. de Góngora y Martínez describes in his book „*Antigüedades prehistóricas de Andalucía*" the discovery of a cave called the „*Cueva de los Murciélago*s" in Albuñol, Granada, where he encountered human remains, traces of basketry and some ceramics (Góngora y Martínez, 1868, p. 32). In addition, a complete sickle, including its flint inserts and wooden hafting, appears to have been discovered. This find was not mentioned in his book initially but was included much later as a drawing in an article from A. Vayson de Pradenne in 1920 (see fig. 2.15.). This example of the oldest discovered sickle has unfortunately disappeared (Gassin et al., 2008, p. 4; Ibáñez et al., 2008, p. 185). However, F.C.J. Spurrell recognised similar instruments as harvesting tools as early as 1892 in his book „*Notes on early sickles*" (Spurrell, 1892, p. 58). Earlier authors were classifying these only as primitive saws. However, Spurrell not only defined these as reaping tools, but also detected shiny traces on some of the flint inserts, which he deducted must come from harvesting cereals. To confirm his hypothesis he reconstructed these tools, cut straw, and proved his theory right. He in a way practiced an early form of experimental archaeology (Spurrell, 1892, p. 58). In 1920, A. Vayson presented in his article „*Faucille préhistorique*"

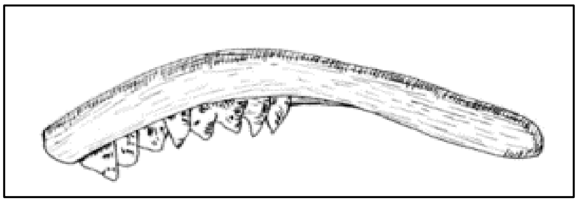


Figure 2.15. Sickle from Murciélagos de Albuñol, Spain (Ibáñez, 2008, p. 185).

additional finds, and, among them, a sickle from Solferino, Italy (see fig. 2.16.). It was discovered close to the Lake Garda and is believed to be one of the oldest complete composite sickles uncovered in Italy (Mercier & Seguin, 1940, p. 213). In contrast to Spurrell, Vayson believed that the gloss on sickles was due to the treatment of wood and not cereal gathering. He therefore believed these items to be primitive saws, like many authors before Spurrell (Steensberg, 1943, p. 2). In 1930, E. C. Curwen initiated further archaeological experiments on sickles and could confirm that the gloss on these tools is due to reaping cereals. Research around flint sickles was done in the Near East during the 1920s and 1930s, where fragments of flint blades were uncovered on excavations and described as part of sickle implements. (Steensberg, 1943, p. 5).

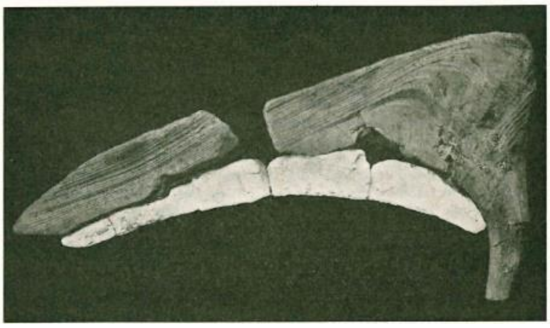


Figure 2.16. The Solferino sickle, Italy (Steenberg, 1943, p. 136).

Further finds of harvesting tool fragments detected in lake-site settlements in Switzerland, France and Germany appeared in publications such as Rudolf Ströbel's: „*Die Feuersteingeräte der Pfahlbaukultur*" in 1936 (Schlichtherle, 1992, p. 24). In the same year, first neolithic sickles were also unearthed in Bulgaria in the eponymous site of Karanovo (see fig. 2.17.). These sickles are of the composite type with oblique inserts (see Chapter 2.1.2.1). This type was not only identified in Bulgaria, but all over central and Southern Europe indicating a technological continuity (Gibaja et al., 2017a, p. 212). In Spain, after the first finds in the 19th century, more discoveries have been made recently. Specifically, the discovery of the early neolithic lake-site settlement of La Draga with their well-preserved wooden industry, changed the understanding of harvesting tools in Spain (Terradas et al., 2017, p. 211). There, other types of sickles than the denticulated version were discovered, including an entirely wooden tool. At the same time, at the lakeshore village of La Marmotta, in Lazio, central Italy, additional, complete, and well-preserved composite sickles of the early Neolithic were unearthed (Mazzucco et al., 2022).

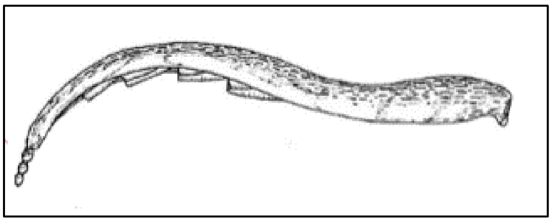


Figure 2.17. Antler sickle from Karanovo, Bulgaria (Mazzucco et al., 2018a, p. 513).

2.3. Near Eastern origins

Before looking more deeply into alternative harvesting tools in North-Western Europe, it is of interest to understand how reaping tools developed from the early Neolithic to the Michelsberg period. Particularly the dating of these tools, the type of plants collected, the materials these were made of and their evolution over time can give us precious information on how sickles and harvesting knives have been used in the past.

The oldest tools used for cereal harvesting have been discovered in the Near East and are dated to about 12,000 cal BC. They were discovered in settlements of the Natufian period (see fig. 2.6) and amount up to 5% of all identified flint artefacts (Bar-Yosef, 1998, p. 164; Goodale et al., 2010, p. 1193). But more recent research has identified flint blades with reaping traces dating already back to 20,500 cal BC at the site of Ohalo II in actual Israel. These might have been used to cut green stems of wild grass. Thus, the inhabitants of Ohalo II, believed to be hunters-gatherers, already collected the wild predecessors of *T. monococcum* (einkorn wheat) and *T. dicoccum* (emmer wheat) and, transformed their grains into food. But these tools appear to have been rarely used as only 0.01% of all flint implements detected, could be related to cereal harvesting (Groman-Yaroslavski et al., 2016, p. 15).

An issue with cereal reaping at such an early period, was the ripeness of these wild grasses. The moment they became ripe, the grains fell to the ground and could not be collected. This is due to "*the component of the ear of a cereal plant to which the spikelets are attached prior to dehiscence*" called rachis (Brown et al., 2009, p. 103). Therefore, it is assumed that the harvest was done earlier, when the grains were still green and could be cut while still on their stems and not shattering to the soil (Groman-Yaroslavski et al., 2016, p. 14). This theory has been verified through experimental archaeology, but also through use-wear analysis on archaeological sickle blades. Both confirmed that the archaeological use-wear traces are matching the experimental traces and that, indeed, the early harvests were done mostly on green cereals (Ibáñez et al., 2014, p. 101; 2016, p. 68). For subsequent periods of the region like the Pre-Pottery Neolithic A and B (10,000 to 8,000 cal BC) the first curved sickles have been unearthed (Astruc, 2012, p.

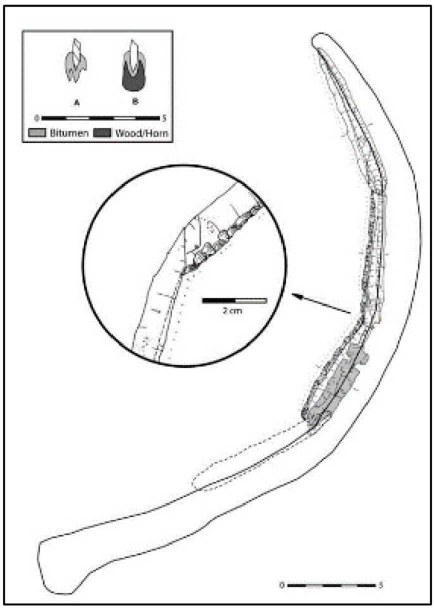


Figure 2.18. Reconstruction of a PPNB sickle with parallel set inserts from Tell Halula, Syria (Borrell & Molist, 2007, p. 65).

685). With these tools, not only wild grasses but also early domesticated cereals were collected (see fig. 2.18). At the end of the Pre-Pottery Neolithic B or PPNB, another technical change occurred on sickles. The inserts were placed at a 45° angle to the shaft. The sickles thus, had a saw-like cutting edge. This edge provides a larger cutting surface and cereals could be cut easier from their stems (Astruc, 2012, p. 685).

The speed of transformation from wild grasses gathered occasionally, to the purposefully planting of domesticated crops has been strongly debated in archaeology. Researchers such as Hillman and Davies have seen the speed of transition from wild grass to a domesticated version of cereals as very fast. In only a few hundred years, this change should have been taking place (Hillman & Davies, 1990, p. 189). The main difference between the wild and domesticated types is that, once ripe, the domesticated grains are of a non-shattering type. This means that they do not fall to the ground, but stay on the stems, waiting to be collected (Nalam et al., 2006, p. 373). According to Hillman and Davies, this rapid change in plant morphology is due to the use of harvesting tools. They believe that these tools have been used to cut cereal plants while the grains were still on their stems. Other cereals, where the grains have already fallen off or, upon touching, have fallen off, have not been gathered. Therefore, the plants which have been harvested were used for food, but also for planting during the next season and their genetic change (grain stays on the ears) is therefore passed on to future plant generations (Hillman & Davies, 1990, p. 172). This approach is seen differently today with a more plant-based approach (Fuller et al., 2010, p. 17). Early harvesting tools have been used already during the Natufian period or even earlier to gather wild grasses, but it took 2,000 to 2,500 years from the Natufian to the PPNB period until this grass changed to a domesticated cereal (Brown et al., 2009, p. 106). Therefore, harvesting tools appear not to have influenced the genetic changes in cereals. But a gradual selection of cereal plants having their grains staying on the plant has, over time, created domesticated cereal types as *T. monococcum* or *T. dicoccum* with a stable ear or "*tough*" rachis (Brown et al., 2009, p. 108; Maeda et al., 2016, p. 228).

How were these cereals reaped? Cutting the plant close to the soil enables the use of the entire stem to be used for roofing. A cut just below the ears enables to collect only the ears and avoid reaping weeds. The remaining stems can then be used as animal feed or burned to the ground and used as fertiliser (Ibáñez et al., 2001, p. 32). Use-wear analysis of flint blades from the period of the PPNB shows that the sickle gloss is frequently covered with striations. These striations are believed to have been produced through the contact with the soil. This in turn is seen as an indication that the tools were used to cut a plant close to the soil (Unger-Hamilton, 1985, p. 122; 1989, p. 100). Also, the limited finds of sickle blades in the Near East (up to 5% of all flint tools) (Goodale et al., 2010, p. 1193) has been interpreted as a long-term use of these implements and that sickles were an important part of the harvester's tool kit (Goodale et al., 2010, p. 1199). This links with the discovery of sickles in individual houses of Tell Halula. It has been interpreted as belonging to a single domestic unit and not a collective unit (Borrell, 2008, p. 68). Some sickles are even decorated like the one from the 7th millennium cal BC discovered in the cave of Nahal Heimar. It has a zigzag pattern (Astruc 2012 p. 674; Bar-Yosef, 1987, p. 161) and indicates that sickles were important to people of that time.

2.4. Geographic distribution

The oldest harvesting tools have been discovered in the Near East. They are believed to have developed at the same time as the domestication of cereal plants. Starting from this region, the knowledge of making these tools spread rapidly in several directions with archaeological traces detected along different routes. One route led to the North-West into today's Greece, the Balkan and along the Danube River into Central Europe. Another route lead South into Egypt and possibly along the southern Mediterranean coast. A further route led East further into Asia with early archaeological traces encountered in today's Pakistan and Azerbaijan. Finally, one route led towards the West along the Northern Mediterranean coast into the Italian Peninsula, Southern France, and Spain.

2.4.1. The Danube route

Dating around 8,000 cal BC, first sickles with a dented cutting edge have been unearthed in the Levant and in Mesopotamia (Astruc, 2012, p. 674). Later, the same type of sickle has been discovered in Bulgaria in the settlement of Karanovo. During excavations in the 1930s and 1950s, in total four such sickles were uncovered at that site. They have a haft made of deer antler with a deep inner groove into which up to four flint blades have been inserted diagonally (see fig. 2.17.). All flint inserts have traces of sickle gloss and are dated to the 1st half of the 6th millennium cal BC (Gurova, 2014, p. 92; 2016, p. 159). These types of dented and curved sickles were not limited to Karanovo but were also spread to other settlements along the Danube River over to central and Western Europe during the Linienbandkeramik or LBK period and are the type of sickles used by the first farmers of that region (Schlichtherle, 1992, p. 28).

2.4.2. The southern Mediterranean route

Harvesting tools also spread from the Near East towards the South into Egypt. The first sickles were unearthed in the 1930s at the oasis Fayum (see fig. 2.19). They date back to the 5th millennium and have a strong resemblance to the tools used during the Natufian some 5,000 years earlier (see fig. 2.6). The haft is straight, and the flint blades are placed in line to create one continuous cutting edge. The edge appears to have been retouched frequently to keep it sharp (Shirai, 2016, p. 32). Beyond Egypt, no traces of harvesting tools on the southern Mediterranean coast have been encountered to date. Only traces of collected cereal grains have been discovered, mostly in today's Morocco at sites like Kaf Taht El-Ghar or Ifri Oudadane close to the Mediterranean Sea (Morales et al., 2013, p. 11). This archaeological gap between Egypt and Morocco may be because not enough sites have been excavated in Northern-Africa. It could also be that the harvest in this region was done either by hand or with wooden tools (Gibaja et al., 2017b, p. 49). Ethnographic examples show that such reaping methods are still applied today in that region (Anderson & Peña Chocarro, 2015, p. 96).

Figure 2.19. Sickle from the oasis Fayum, Egypt, 5th millennium cal. BC (Shirai, 2016, p. 33).

2.4.3. The Asian route

Harvesting tools also spread towards the East. The oldest tools unearthed so far resemble the dented and curved sickles of the Levant. During excavations at a neolithic settlement dated between the 6th and 3rd millennium BC in Mehrgarh, Pakistan, fragments of a curved and dented sickle have been uncovered (see fig. 2.20). These artefacts could be dated to the 6th millennium cal BC (Lechevallier, 1980, p. 261). Similar artefacts have also been unearthed in today's Azerbaijan dating to the 6th millennium (Arazowa, 2008, p. 435).

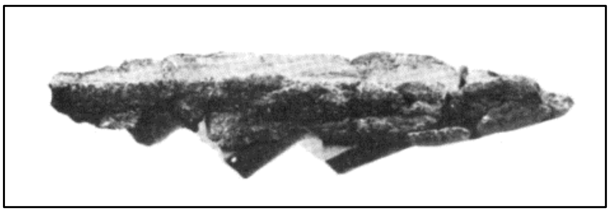


Figure 2.20. Sickle elements from Mehrgarh, Pakistan (Lechevallier, 1980, p. 262).

2.4.4. The northern Mediterranean route

Harvesting tools spread from the Near East together with domesticated cereals very early to Cyprus in the 10th to 9th millennium cal BC (Vigne et al., 2012, p. 8447). In the 7th millennium, these sickles appeared also in the Aegean with first finds on the island of Crete (Mazzucco et al., 2020, p. 6). Thessaly was reached by farmers around 6,600 cal BC. It appears that sickles were an important part of their toolkit with up to 18% of all flint inserts believed to be used for reaping (Mazzucco et al., 2020, p. 9). During that early neolithic period, these tools were of the denticulated and curved type (see fig. 2.1.). Only in two locations (Revenia in Macedonia and Franchthi in the North Peloponnese) the discovered blades were different. These were long blades with visible sickle gloss located parallel to the cutting edge and not at an angle as for earlier tools (Mazzucco et al., 2020, p. 9). They are believed to form part of the angled sickles with single blade in parallel insertion (see fig. 2.3.). At a later stage, in Thessaly around 5,800 to 5,400 cal BC, both types of blades were unearthed at archaeological sites.

In the Balkans and in the South of Italy the spread of agriculture continued with first neolithic settlements established from 6,000 cal BC onwards. Flint inserts with parallel striations, believed to be used in sickles, were detected at the settlement of Crno Vrilo in Zapar, Croatia, dating around 5,900 cal BC. These tools were used concurrently to the denticulated sickles for about 600 years. However, after 5,300 cal BC, inserts belonging to the denticulated sickle type could not be identified in the Balkans anymore (Mazzucco et al., 2020, p. 13). Both sickle types were then spread in the 6th millennium over the entire Italian peninsula, to Southern France, and Southern Spain (Mazzucco et al., 2020, p. 14). Denticulated sickles are found mostly in Southern Italy and Southern Spain, whereas parallel hafted sickles are discovered in Northern Italy, Southern France, and Catalonia (Ibáñez et al., 2008, p.191).

In summary, harvesting implements have seen their shape and morphology change from composite tools like hafted sickles with flint inserts, to simpler handheld devices over the neolithic period. Few reaping tools appear to have been made of alternative materials like shells, wood, or bone. First archaeological traces of such sickles have been identified in the 19th century. Well preserved tools have been discovered during the late 20th century at early neolithic lake site villages in Spain, Italy, and Switzerland. The first sickles are believed to have been made at about 20,000 cal BC in the Near East. From there, they were spread along the Mediterranean coast and into Central Europe before reaching the coast of North-Western Europe in the 4th millennium. However, during the Middle Neolithic of North-Western Europe, remains of such tools are rarely encountered. The potential reasons for that are presented in the next chapter.

CHAPTER 3 - THE MICHELSBERG CULTURE

In this chapter the Michelsberg culture is introduced and compared to earlier and later neolithic periods, especially in North-Western Europe. Not only is this period different in terms of pottery, flint tools, large enclosures, burials, and settlements, but also in agriculture. The term culture is here used as an archaeological concept. It focuses on ceramics, its production techniques, and decorations to delimit a certain region where this type of earthenware was discovered, as in this case the Michelsberg. They can also be called "*style provinces*" (van Gijn & Louwe Kooijmans, 2005, p. 337) to determine a region where a certain style of material culture, can be identified. It should not be confounded with the social identity of people living in the Neolithic. This identity cannot be determined through flint and pottery finds alone (van Gijn & Louwe Kooijmans, 2005, p. 338). Even on ethnographic level, with the additional benefit of a large, preserved, and perishable material culture, social identity cannot be assumed to follow stylistic lines of materials (Lemonnier, 1986, p.180).

3.1. The discovery of the first Michelsberg sites

The Michelsberg culture is defined in the Concise Oxford Dictionary of Archaeology as follows.

> *Middle Neolithic communities occupying the area from Belgium through to the Alps in the period 4,500–4,000 bc. Named after a hilltop camp in the Rhineland, the Michelsberg Culture succeeded the Rössen Culture and is characterized by distinctive pottery forms, including tulip beakers, round-based flasks with tall, conical necks, and vessels with finger-impressed ornament around their rims. The culture has strong affinities with the Western Chassey and the middle Neolithic cultures of southern England, as well as with the TRB cultures of northern Europe. Michelsberg sites include ditched enclosed settlements and flint mines*. (Darvill, 2010)

The first sherds of Michelsberg pottery have reportedly been excavated back in 1809 but were not identified as such (Lüning, 1968, p. 4). Only additional finds of these distinctive sherds in 1884 around the Michaelis chapel in Grombach, close to Bruchsal in South-Western Germany, is seen as the "*birthday*" of this neolithic period (Siebenmorgen & Licher, 2010, p. 15). Four years later, first excavations were undertaken around that chapel on the hill called Michaelsberg and ceramic encountered were thus called the Michelsberg typus by the archaeologist Karl Schumacher. In 1908, the archaeologist P. Reinecke gave these items the official name of Michelsberg culture instead of typus. The ceramics were at that time associated with contemporary finds at lake-site settlements in Southern Germany and Switzerland (Siebenmorgen & Licher, 2010, p. 17). In the 1920s, these sites, around the Alps, were then classified as separate entities, as Schussenrieder or Horgener culture.

Michelsberg has been believed to have its origins in western Germany by H. Reinerth in 1923 (Lüning, 1968, p. 7). Further research was done in the 1960s, when J. Lüning published his ground-breaking work about the Michelsberg period including a five-scale chronology, which is still today, widely accepted (Siebenmorgen & Licher, 2010, p. 17). In his oeuvre, he sees Michelsberg sites originating along the Rhine River due to the discovery of many such archaeological sites during that time. However, in his article of 1998, C. Jeunesse challenged that view and locates the origin of early Michelsberg sites further west towards the Paris Basin. Excavations of very early Michelsberg settlements in the river valleys of the Seine, Aine and Yonne have confirmed this westward shift (Jeunesse, 1998, p. 42).

3.2. The characteristics of Michelsberg

The Michelsberg culture, also known in German as Michelsberger Kultur has been archaeologically defined based on its distinctive pottery (Vander Linden, 2011, p. 299). It is mostly without decoration, of "*lederne Farbe und eine gute Politur*" (Jeunesse, 2010, p. 48). C. Jeunesse (2010) describes it as of leatherly color and good polish (p. 48). The ceramic uncovered in Northern France and South Belgium is tempered with flint, e.g., clay mixed with material to adjust its plasticity (Stilborg, 2001, p. 399), and for the Rhineland and North Belgium with quartz, indicating two different technical traditions (Vermeersch & Burnez-Lanotte, 1998, p. 50).

Remains of large enclosures in the lowlands or around hill tops have been unearthed and dated to the Michelsberg period. These are believed to consist of palisades, wooden walls, and ditches (Kreuz et al., 2014, p. 74). These structures have multiple entrances or separations making them appear not to be of defensive but more of ritual nature (Jeunesse, 2010, p. 49).

Large flint mines were exploited during the Michelsberg period. These mines like in Spiennes, Belgium are dated around 4,300 cal BC, the early Michelsberg period. To collect the flint in these mines, three methods are believed to have been used. The flint nodules were collected from the ground, by digging shallow pits and extracting the nodules. Or these lumps of flint were collected from the steep ridges of the deposit by loosening them from the surrounding limestone cliffs. Alternatively, mining shafts were dug into the ground up to 16m deep to reach the desired flint-bearing layer and there expanded horizontally, where the flint nodules were collected (Collet & Hauzeur, 2010, p. 206). Mining was not only done in Spiennes but also in Rijkholt-St. Geertruid in the Netherlands at the same period (de Grooth, 2010, p. 210). It appears that there was an important flint extracting industry together with a large exchange network for this raw material during the Michelsberg period. This mined flint has been worked upon, to create standardised macrolithic artefacts like horse-shoe shaped scrapers, pointed blades, and triangular or leaf shaped points (van Gijn, 2010, p. 121). In addition, large tools such as axes and up to 25 cm long pointed blades have been knapped as finished or semi-finished items (Collet & Hauzeur, 2010, p. 206). These tools have been found up to 200 to 300 km from these mines in the Rhineland, Westphalia and even up to Southern Germany and the Alps (de Grooth, 2010, p. 210; Kieselbach, 2010, p. 209). They are thus believed to have been an item of exchange. However, in the surrounding areas of these mines, like Belgium, Southern Netherlands, Northern France, and Northern Germany sickle blades made from flint appear to be scarce (Vermeersch & Burnez-Lanotte, 1998, p. 51).

What the Michelsberg period is not known for, are distinctive settlement structures and burial grounds.

Settlement traces of that period are almost unknown. Some storage/garbage pits have been excavated, indicating the presence of housing structures nearby. Also, some fragments of daub i.e., wall covering with wooden imprints have been discovered. However, housing structures with post holes, as seen in the earlier LBK period have not yet been confirmed (Kreuz et al., 2014, p. 75). It appears that the houses of that time did not leave archaeological traces. Also, settlement structures seemed to change from villages or longhouses, as known from earlier neolithic periods, to individual, widely spaced dwellings in the Michelsberg (Jeunesse, 2010, p. 49).

The same applies for burials. Only 400 human remains have been discovered until 2011 for a Michelsberg period stretching over more than 900 years (Lichter, 2010, p. 259). This shows that most of the deceased have been disposed in a manner which leaves no archaeological traces. Among the few human remains unearthed, these were mainly discovered in circular pits or ditches, interpreted as disused silos (Chenal et al., 2015, p. 1313). One of these, in Bergheim, Alsace, France, was filled with amputated limbs and skeletons, an indication of armed violence during that period (Chenal et al., 2015, p. 1324). More recent research shows that among the human remains excavated, some were properly buried, and others appear to have been dumped into these pits. This difference was seen by researchers as on the one side some important person being properly buried and on the other side its servants, be it slaves or soldiers being put to death and thrown into these circular pits (Beau et al., 2017, p. 12).

3.3. Dating and expansion

The Michelsberg period is believed to have started around 4,500/4,400 cal BC in the Paris Basin. It then spread to the Northeast towards Belgium and Southern Netherlands. It expanded also Southeast to the Rhine and Neckar valleys by 4,400/4,300 cal BC. Finally, traces are found in Bavaria and central Germany dating around 4,000 cal BC (Jeunesse, 2010, pp. 46-47; Shennan, 2018, p. 142). Overall, this period stretches from 4,300 to 3,500 cal BC (Siebenmorgen, 2010, p. 7). It covers a zone, which englobes Northern France, Southern Belgium, the Netherlands (excluding the coastal aeras), central Germany with the Rhine valley, the plains below the Alps and up to the Danube River (Jeunesse, 2010, p. 47). Its western origins (Paris Basin) have been confirmed by ancient DNA analysis of 21 individuals from the Michelsberg site of Gougenheim in Alsace, France (Beau et al., 2017, p. 12). The Michelsberg period thus covers a large region and a long period with limited archaeological traces compared to earlier or later periods.

CHAPTER 4 - AGRICULTURE DURING THE MICHELSBERG PERIOD

The focus of this chapter is on the type of agriculture practiced during the Michelsberg period. During that time, a larger variety of cereal types have been consumed compared to earlier or later periods of the Neolithic. However, a smaller range of pulses (lentils or peas) and oil seeds (flax) were planted as well (Kreuz, 2014, p. 94). The most striking feature of that period is the almost complete absence of harvesting tools, despite the wide-spread trace of cereal grains. In this chapter, the way agriculture was practiced during the Michelsberg period will be analysed. Then, the focus will be on how flint tools went missing, and what reasons could explain this event. In the last part, we will explore what other materials could have been used for reaping cereals to explain the absence of flint tools and the presence of collected grains.

4.1. Cereal cultivation

The cultivation of cereals during the Michelsberg period is believed to be different compared to the previous Linearbandkeramik (LBK) period (5,500 to 5,000 cal BC) (Bogucki, 2000, p. 198). During LBK, cereal types were limited to three crops: *Triticum monococcum* or einkorn wheat, *Triticum dicoccum* or emmer wheat and *Hordeum vulgare* or barley (Bakels, 2009, p. 29). In addition, many types of pulses and oil seeds were planted. The working of the soil was believed to be more like an "*intensive garden cultivation*" (Bogaard, 2004, p. 159) with manuring and tilling done on a small surface. Flint-based harvesting tools have been used widely during the LBK and the following Rössen period. These are composite sickles with visible gloss indicating a lengthy use in reaping (Schlichtherle,1992, p. 29). Also, in other regions of Europe, sickles were used extensively during that period. Archaeological finds of entire sickles are known from early neolithic sites as La Draga in Spain (Bosch Lloret et al., 2006) or La Marmotta in Italy (Mazzucco et al., 2022).

During the Michelsberg period, this appeared to have changed radically. The number of cereal types has increased to four, being *T. monococcum*, *T. dicoccum,* and *H. vulgare* as known already from the LBK and now in addition, *Triticum aestivum* or naked wheat (Bakels, 2007, p. 345). *T. aestivum* is believed to have come from the Mediterranean, either via Switzerland through alpine Egolzwil sites, or via the Paris Basin through Chassey settlements, before being introduced in Michelsberg settlements (Kreuz et al., 2014, p. 86).

Pulses like peas and lentils are scarce and oil seeds, like flax and poppy, appear not to have been planted at all during that period. This reduction of the range of planted crops appears not to be due to climatic or soil fertility factors, but more due to cultural factors, as in neighbouring sites like Egolzwil, these crops were still planted (Bakels, 2007, p. 347; Kreuz et al., 2014, p. 88).

With regards to the planting of cereals, a different approach than the LBK small-scale cultivation appears to have been applied. Several authors believe that a "*slash-and-burn*" practice of the soil was undertaken from the Michelsberg period onwards (Bakels, 2009, p. 70; Ehrmann et al., 2009, p. 69; Rösch et al., 2017, p. 14; Schier et al., 2013, p. 104). An experimental project to reconstruct such a slash-and-burn surface has been undertaken in 1998 by O. Ehrmann at Forchtenberg in Baden-Württemberg, Germany. A large stretch of forest was transformed into fields and cultivated over a period of 10 years. Once the trees were removed with neolithic style axes, the surface of the fields was burned. This resulted in a dark, charcoaled layer, with no weeds present. Grains were then planted with the help of digging sticks. The harvest was done by either snapping off the ears with both hands, cutting the stems with a flint sickle or with a flint harvesting knife (see fig. 2.8.). The fastest results were obtained with the sickle. However, in terms or reaped grain volume, snapping off ears using only the hands appeared more suitable, as only the ears were gathered (Ehrmann et al., 2009, p. 65). The grain yield of the harvest was very high for the first year with up to eight tons per hectare (t/ha) for modern cereal types (Schier et al., 2013, p. 104). For ancient types, the yield reached close to 5 t/ha for fertile soils during the first year. The reason for this is because burning fields inhibited weed growth. Also, the dark charcoal colour of these plots absorbed more sunlight and helped the development of the plants (Ehrmann et al., 2009, p. 66). But in subsequent years, the yield dropped sharply to 1.2 t/ha, as the number of weeds and rodents increased, and the fertility of the soil declined. This slash-and-burn practice implied the need to open many new surfaces every year and thus the use of far larger stretches of land than during the LBK. This method, also called "*swidden culture*" (Schier, 2009, p. 32), was initially believed to be applicable only for lake-site settlements in Switzerland and around the Lake Constance. But the discovery of concentrations of highly carbonised black earth in the German Rhineland could indicate the use of this planting method, also in regions of the Michelsberg (Schier, 2009, p. 32; Schier et al., 2013, p. 105).

4.2. Missing harvesting tools

In the detailed work of J. Lüning about the Michelsberg culture from 1968, no mention is given on any harvesting tools or sickle blades unearthed at archaeological sites. He comments on the existence of grinding stones and of cereal marks on pottery shards to imply that cereals were used during the Michelsberg period. But he also says: „*Zwar fehlen für den Ackerbau besonders geeignete und genügend zahlreiche Geräte, doch spricht schon die Verbreitung der Siedlungen in Gebieten mit Lößböden für die wichtige Rolle des Ackerbaus in der Gesamtwirtschaft*" (Lüning, 1968, p. 125). J. Lüning (1968) thus confirms that for agricultural usage, especially useful and sufficient numerous tools are missing, but the distribution of settlements on loess soil confirms the important role of agriculture in the economy (p. 125).

30 years later, in 1998, P. Vermeersch and L. Burnez-Lanotte raised in their article "*La culture du Michelsberg en Belgique: état de la question*" the question of the missing sickles in Michelsberg sites (Vermeersch & Burnez-Lanotte, 1998, p. 49). For nine different sites, they established an overview of the different lithic tools found. Harvesting blades accounted for less than 1% of the total tool assembly. And in certain sites, there was no evidence of any sickle blades (see table 4.1). Both also noted that stones used to grind cereals were more present than sickle blades. They thus raised the following question "*Faut-il en conclure que les gens du MK ont utilisé d'autres méthodes de récolte?"* (Vermeersch & Burnez-Lanotte, 1998, p. 51). P. Vermeersch and L. Burnez-Lanotte (1998) thus asked if we have to conclude that the people of the MK (Michelsberg) used other methods of harvesting (p. 51)?

Table 4.1. Split in % of the most frequent tools at Michelsberg sites of Belgium ("Lame de faucille" being sickle blades): GIV: Givry; GUE: Gué du Plantin; THIE: Thieusies; KEM: Kemmelberg; OPV: Opvelp; ASS: Assent; GEN: Sint-Genesus-Rode; OTT: Ottenburg; MAI: Mairy; SPI: Spiere (Vermeersch & Burnez-Lanotte, 1998, p. 49).

	GIV	GUE	THIE	KEM	OPV	ASS	GEN	OTT	SPI
Grand grattoir	33,4	32,9	33,4	51,6	33,8	56,3	30,2	19,6	50,7
Grattoir unguiforme	1,3	1,4	0,2	0,0	3,8	7,4	2,7	0,4	4,8
Grattoir sur lame	5,7	4,7	3,5	2,7	3,4	3,8	8,1	5,3	2,4
Perçoir	6,0	6,1	14,2	9,8	0,7	1,6	3,0	5,1	5,4
Burin	1,0	12,7	4,9	2,0	0,3	1,0	3,0	0,6	3,7
Couteau à dos	1,9	0,0	1,4	11,7	0,0	0,4	0,0	2,5	0,0
Lame retouchée	28,3	27,2	11,3	12,5	40,9	15,4	31,5	15,2	16,6
Lame de faucille	0,0	0,0	0,5	0,0	0,7	0,0	1,0	0,0	0,1
Flèche foliacée	0,0	0,5	4,0	4,0	2,7	0,3	3,6	2,3	17,4
Flèche triangulaire	2,6	3,3	0,5	0,0	8,0	0,0	0,2	1,3	2,8
Flèche tranchante	0,5	1,4	0,2	3,1	0,0	0,0	0,3	0,7	1,3
Flèche pédonculée	0,0	0,0	0,3	0,8	0,3	0,0	0,0	0,7	0,0
Microlithe	0,0	1,9	0,6	0,0	0,3	1,0	1,0	1,9	0,7
Tranchet	19,4	7,5	14,9	1,2	6,4	5,2	0,3	3,9	3,5
Hache en roche tenace	0,0	0,5	0,4	0,4	1,4	1,1	0,3	1,6	0,0
Hache en silex	0,0	0,0	7,2	0,8	6,4	2,8	13,1	2,7	9,2
Ciseau	0,0	0,0	2,4	0,0	1,4	0,0	0,7	0,4	0,0
Total	**619**	**213**	**656**	**256**	**296**	**944**	**298**	**514**	**753**

In 2009, C. Bakels raised a similar question in her research. Up to that time, only a few blades believed to have been used for reaping, have been excavated in Michelsberg or Chassey (neighbouring cultural complex to Michelsberg in France) sites. Therefore, other harvesting methods needed to be considered. One method could have been the uprooting of entire plants. However, archaeobotanical research did not produce evidence for an increased presence of weeds. This would have occurred if entire stems of cereals and the associated weeds would have been uprooted. C. Bakels suggests another method "*that harvesting was done by hand-picking, or with the use of perishable implements…*" (Bakels, 2009, p. 73). This hand-picking would mean that only the ears were collected, and the stems were left on the field. But these stems were not gathered at a later stage, since cutting implements as sickles were not discovered (Bakels, 2009, p. 73). However, these stems could have served as animal feed.

In 2015, this question of missing sickles was again put forward by C. Bakels and A. van Gijn in their article "*The mystery of the missing sickles in the northwest Michelberg culture in Limburg, The Netherlands*" (Bakels & van Gijn, 2015). Both confirmed the absence of flint sickle inserts, not only for the Michelsberg sites of southern Netherlands, but also for neighbouring Belgium and the German Rhineland. Both rejected again uprooting, as a harvesting method, as the amount of weed recorded in such sites did not increase. However, reaping tools could have been made from other materials than flint. These "*could include sickles of bone, freshwater mussels, wood or even baked clay*" (Bakels & van Gijn, 2015, p. 111).

4.3. Potential explanations

4.3.1. Shortage of flint

The changes in Michelsberg harvesting techniques and tool use could have several explanations.

As flint-based sickles or harvesting knives are rarely found at excavations of Michelsberg sites in North-Western Europe, could the explanation be a shortage of flint? Large-scale flint mining started in the region during the Michelsberg period. Spiennes in Belgium and Rijkholt in the Netherlands were major flint mining sites, from where raw material was distributed widely through western and central Europe. In the Rhine-Meuse delta, blades of mined flint were exchanged beyond the Michelsberg region to sites of the contemporaneous coastal Hazendonk group (3,900 to 3,600 cal BC). These were used there as sickle implements (Bakels & van Gijn, 2015, p. 111). In other regions of Europe, flint based harvesting tools were still widely used during the 4th millennium BC. Many flint reaping tools with visible cereal polish on their blades have been detected in lake-site villages, dated to the Swiss Egolzwil (4,280 to 4,250 cal BC) and Cortaillaud (around 4,200 cal BC) periods (Kieselbach, 2010, pp. 203-204). Some were composite sickles such as used during the LBK (see fig 2.1.). Others were harvesting knives with a single flint blade attached to straight wooden haft (see fig. 2.7.), (Kieselbach, 2010, p. 203). This leads to believe that a shortage of flint could not be the reason for these missing flint sickles. Or, in other words, people during the Michelsberg period had the raw materials to produce flint harvesting tools.

4.3.2. Knowledge to make sickles

Might the Michelsberg people have lost their knowledge to produce flint harvesting tools over time? People from surrounding and contemporary sites as the alpine Egolzwil or Cortaillaud and coastal Hazendonk were able to produce flint-based sickles tools and used them for cereal harvest (Gibaja et al., 2017a, p. 223; van Gijn et al., 2006, p. 164). Also, the knowledge of making other flint implements was still present at Michelsberg sites, as the discovery of axes or scrapers, during excavations shows (Lüning 1968, p. 70). They were clearly expert flint knappers, certainly during the Michelsberg period. It appears thus unlikely that people in the

4th millennium cal BC have only lost their knowledge of making sickle flint blades but still knew how to make axes and other flint tools.

4.3.3. Archaeological hiatus

Could one other potential reason for missing flint inserts be an archaeological hiatus? Already back in 1968, J. Lüning noted the absence of flint harvesting tools during the Michelsberg period. 50 years have passed since then and only a few reaping tools with flint inserts could be identified in Michelsberg assemblages.

But such inserts can easily be detected due to their gloss as seen on numerous LBK sickle blades (Ibáñez et al., 2001, p. 24; van Gijn, 1990, p. 40). Already in 1892, sickle gloss has been identified by Spurrell and reproduced experimentally. In the 1970s a further step in analysing such gloss has been made in the analysis of use-wear traces on flint (Keely 1980; Vaughan 1985). This led to more discoveries of flint-based harvesting tools. However, surprisingly, not in North-western Europe for the Michelsberg period.

Overall, it appears that people during the late 5th and early 4th millennium have deliberately decided not to have flint harvesting tools for reasons unknown to us. But this is not an exception, as also in other regions and periods collected cereals could be found, but not the matching tools to gather these (Häg, 2021, p. 45; Ibáñez et al., 2001, p. 24; 2008, p. 191; Rodríguez-Rodríguez et al., 2014, p.768).

Early neolithic remains of cereals have been discovered in North Africa, but without traces of corresponding flint tools (Rodríguez-Rodríguez et al., 2014, p. 768). The author suggests that in this case either, no reaping was done or that it was a minor economic activity. The first reason does not explain the presence of cereals at the excavated sites. The second reason leads to believe that other harvesting methods as uprooting or the use of wooden mesorias might have been used (Gibaja et al., 2017b, p. 49).

In North Spain, cereal remains dating back to the early Neolithic have been excavated, but without the matching flint sickle blades (Ibáñez et al., 2008, p. 191). It is believed that due to the humidity and the steepness of the fields, the harvest period was longer and snapping off the ears or uprooting were techniques better adapted to this environment than cutting with a sickle (Ibáñez et al., 2001, p. 29).

In the French Jura, a "*sickle paradox*" (Ibáñez et al., 2001, p. 24) for the Middle Neolithic has been postulated. Several lake-site dwellings dating from the 4th millennium cal BC have been excavated with well-preserved remains of cereals discovered within structures representing houses or granaries. But sickle blades are scarce. Only on one site, a sickle blade, made from imported Swiss flint and still fixed into a wooden haft has been unearthed (Ibáñez et al., 2001, p. 24). Harvesting is thus assumed to be done by uprooting or plucking or "*tools similar to the mesorias, which could be made of wood, bone or shell*" (Ibáñez et al., 2001, p. 33).

This is also the case during the late Neolithic Vlaardingen period (3,400 to 2,500 cal BC) (Amkreutz, 2013, p. 395). Here, on mostly coastal sites, flint based harvesting tools could not be identified although cereal traces were found. Recently, a more detailed analysis of flint finds could confirm some potential cereal polish on small flakes. (Houkes et al., 2017, p. 180). Still the evidence on such flakes is very limited and might not be sufficient to confirm the use of flint based reaping tools for that period (A. van Gijn, personal communication, 6th April 2023). This in turn means, that also for the Vlaardingen period, flint harvesting tools are not confirmed and alternative tools made from shell, bone or wood could have been used for reaping.

4.3.4 Cereal trade

Could another explanation for the missing flint harvesting tools be the existence of exchange networks for cereal grains? In many Michelsberg sites only cereal ears have been found and not their corresponding stems and roots (Bakels & van Gijn, 2015, p. 109). This could indicate that the ears were imported without the stems and roots from other sites, where they were collected. This could explain the absence of harvesting tools. But the aera where reaping tools are absent is rather large (Belgium, Southern Netherlands, Northern France, and Northern Germany) and the missing period is rather long, stretching over the entire Michelsberg period (4,400 to 3,500 cal BC). Transporting large amounts of grain over this wide region and over this large time frame appears difficult. Especially when carriages or transport animals were not yet believed to have been used (Ibáñez et al., 2001, p. 24).

In short, it appears that people during the Michelsberg period deliberately decided not to have flint-based harvesting tools. But they were still consuming cereal grains. What other tools could have been used to gather these cereals, and what archaeological traces could they have left for archaeologists to find?

4.4. Next steps

As harvesting tools during the Michelsberg period are scarce, but cereals were consumed, other collection methods appear to have been used to reap cereals. Some authors (Bakels, 2009, p. 73; Bakels & van Gijn, 2015, p. 111; Ibáñez et al., 2001, p. 33; Vermeersch & Burnez-Lanotte, 1998, p. 51) have, over the years, suggested several alternative harvesting techniques, such as uprooting, picking, or cutting cereals with tools made of other, more perishable materials as bone, shell, or wood. However, until now, no experiments involving such tools and materials have been undertaken. For more than 50 years, starting with Lüning in 1968, the missing sickles from the Michelsberg period are a mystery. Why is that so? It seems that without archaeological traces, archaeologists are hesitant to delve into an analysis of alternative types of sickles made of organic materials.

Shell is one such example. This is a widely accessible raw material for people living by streams, rivers or close to the sea. But many scientific articles about shell focus only on their use as food or, if they have been found perforated, as decoration (Gutiérrez Zugasti et al., 2015). Only a few publications mention shell as tools (Cuenca Solana, 2013, p. 44; Gruet, 1993, p. 159; Lammers-Keijsers 2007, p. 76; Verdún-Castelló et al., 2019, p. 75). Only in one publication, shells are mentioned as harvesting tool (Pétrequin et al., 2006, p. 115) after being first classified as decoration (Maréchal et al., 1998, p. 195). The same applies for ethnographic publications where shells used as reaping tools have only been recorded for the Japanese Ainu people (Watanabe, 1973, p. 41). This lack of research on these shell tools could be caused by two reasons. First, there are conservation or taphonomic issues, which make organic materials as shell difficult to be preserved. The most frequent issues with such tools are breakage or combustion of shells thus reducing the chance to find use-wear traces (Bejega García, 2009, p. 65). Secondly, shells discovered during excavations might not be properly analysed for use-wear traces due to unawareness of available methods (Cuenca Solana et al., 2011, p. 79).

The same applies for wooden tools. So far only one early neolithic wooden sickle has been detected at the site of La Draga, Spain. It confirms that tools made from wood were indeed used for cereal harvesting (Terradas et al., 2017, p. 209). More such tools might have been used, but unfortunately have not been preserved archaeologically or recognised as such.

As far as reaping tools of bone are concerned, the only known tools are the deer mandibles which were used by Native Americans (Brown, 1964, p. 382). But these have not been further analysed since the 1960's. Also, boar tusks might have been used as sickles, (Maarleveld, 1985, p. 88) but further trials to confirm this hypothesis were not undertaken.

Thus, the objective of this thesis is to find out which perishable and organic materials, being wood, shell and bone, can be used for collecting cereals. The reconstruction of potential Michelsberg harvesting tools could show how fast and how much cereal was gathered during that period. The use-wear traces left on the tools by the cereal stems can indicate what archaeological traces are to be looked for. All these points would offer a potential solution to the question of the missing sickles. This thesis will thus focus on an experimental approach together, with use-wear analysis to explore the potential use of these alternative tools.

CHAPTER 5 – METHODOLOGY

In this thesis, two methods are employed to test if cereal harvesting tools could have been made of alternative materials such as shells, wood, or bone. These methods are experimental archaeology and use-wear analysis. In experimental archaeology, objects from past times are reconstructed to answer specific questions about their use. In use-wear analysis, macroscopic and microscopic traces on archaeological or reconstructed materials are examined. These traces indicate what surface came into contact with a specific tool.

Experimental archaeology has been employed to reconstruct harvesting tools made of shell, bone, or wood, and then used on cereal fields to reap. The traces left on these tools i.e., use-wear traces have been recorded post-harvest. This chapter first introduces the concepts of experimental archaeology and of use-wear analysis. Then the construction of cereal harvesting tools, the various reaping locations and the different cereal types are explained. Later, the employed collection techniques and tool handling are presented in detail. Finally, quantitative, and qualitative methods used in this experiment are introduced.

5.1. Applied methodologies

5.1.1. Experimental archaeology

Experimental archaeology is seen as "*hypothesis-testing and its role in "bridging" archaeological theory and the material record*" (Currie, 2022, p. 339). In the case of this thesis, the hypothesis to be tested is the following. Flint sickles are confirmed to be mostly absent during the Michelsberg period in North-Western Europe. But cereals were widely consumed during that time and in that region, as proven by archaeological finds. Therefore, tools made of materials other than flint could have been employed to gather these cereals. In terms of archaeological theory, several researchers have formulated the possible existence of such tools (Bakels, 2009, p. 73; Bakels & van Gijn, 2015, p. 111; Ibáñez et al., 2001, p. 33; Vermeersch & Burnez-Lanotte, 1998, p. 51). As these implements were not encountered in archaeological contexts, they could be made of organic materials. As these materials are prone to strong decomposition processes, their traces are disappearing over time. Wood as a material is very susceptible to disappearance as it decomposes rapidly in the open if it is not used as firewood before. Shells and bones also decay quickly, depending on the soil they have been deposited in. Thus, to prove the above hypothesis, the suitability of organic materials as cereal harvesting tools must be demonstrated first. To achieve this, tools must be made, cereal fields reaped, and the results analysed. Only through these experiments can the archaeological theory be linked to the actual material record and could lead to the following reflections:

1) in the case, that with alternative tools, it turns out not to be possible to reap cereals, the hypothesis of harvesting tools made from organic and thus perishable material would need to be abandoned. Other reasons for the presence of grain and the absence of reaping tools during the Michelsberg period would need to be found.

2) in case these constructed sickles or harvesting knives make reaping possible with sufficient grain to feed a family during a year, this opens a new direction for thought. If these tools are efficient in cereal harvesting, then they might have existed back in the 4th millennium. Only decomposition processes such as their decay or difficulties to recognize them at excavations can be the explanation of their absence in the archaeological record. This result can serve as an answer to other neolithic periods where cereal was consumed but no cereal harvesting tools have been found like in the early Neolithic in North Spain, North Africa and Jura region of France, or the Late Neolithic Vlaardingen period in coastal Netherlands.

3) if sickles made with shell inserts are proven to be as efficient as tools made with flint inserts, would there be a need to produce flint-based tools, especially in regions where flint was difficult to obtain (like the coastal sites of the Vlaardingen period)? The fact that the above hypothesis might be correct leads to several other, subsequent hypotheses which influence future analysis of archaeological finds and their traces. If collecting cereals is indeed possible by using tools made from alternative materials, researchers will need to look more deeply into existing archaeological shell, wood, and bone artefacts to find use-wear traces of such use.

5.1.2. Use-wear analysis

Roberto Risch defined: „*The object of study of functional analysis is human work, while its empirical references are the traces visible on all objects that have been manipulated by people*" (Risch, 2008, p. 520). During the 1930s, S.A. Semenov began to look for use-wear traces on stone tools in the former Soviet Union (Semenov & Thomson, 1964). His approach was to find traces, especially on flint, related to the use of these tools. The idea was to locate specific traces which could be linked to the material being cut with that specific tool. This approach spread rapidly through Europe and the United States during the late 20th century. To find these traces, the following three steps are now commonly used:

1) a collection of stone fragments is viewed through a stereo microscope with magnifications of 5x – 60x. Fragments with traces are selected from that collection (Soares et al., 2016, p. 250).

2) these fragments are then observed in detail through the same microscope to find edge damages, and edge rounding, indicating a potential use of these stones, called *„PUAs (Possibly Used Areas)"* (van Gijn, 1990, p. 13).

3) these zones are then analysed further through a metallographic microscope with a magnification of 50x to 400x (Soares et al., 2016, p. 251). If the traces are confirmed with a higher magnification, they are then called *„AUAs (Actually Used Areas)"* (van Gijn, 1990, p. 13).

In the case of sickle inserts, often a prominent, shiny and gloss patina is visible with the naked eye. Under the stereo microscope, a more detailed structure of this patina is visible, such as edge removals, edge rounding and macro abrasions. Striations, and micro polish can be seen under the metallographic microscope (Groman-Yaroslavski et al., 2016, p. 4). Many striations on the patina indicate that the cereals have been cut close to the ground. Few striations indicate that the cereals have been cut well above ground (Clemente & Gibaja, 1998, p. 460).

Today, large data bases exist on a variety of use-wear traces discovered on flint tools. Be it traces created through the contact of flint with plants, bone, wood, ceramics, or other materials, these are described and recorded in detail in places such as the Laboratory for Material Culture Studies at the Faculty of Archaeology of the Leiden University. To find out what material these flint implements have been in contact with, experiments are made with recreated flint tools on a variety of materials. The resulting traces are then analysed and photographed. These data are compared to archaeological material. In case these traces match, it can be inferred that this specific tool came into contact with a specific material (van Gijn, 2010, p. 30).

However, in the case of this thesis, no archaeological use-wear traces of that period have been found on shells, bone, or wood linking them to cereal harvesting activities. Therefore, one of the objectives of this thesis is to first create use-wear traces on tools made from these materials. Once the traces have been recorded and photographed, they can be compared at a later stage to archaeological material. In short, the use-wear analysis applied in the frame of this thesis is employed in an opposite way to the regular analysis of tool traces. Instead of analysing archaeological material and recreating corresponding traces within an experiment, here the experimental traces are created first, and only later compared to archaeological ones.

Combining these two methods, unfortunately leads to an overlap. The" *life-history*" of these tools (van Gijn, 2010, p. 11) cannot be accommodated with the experimental hypothesis. Cereal harvesting tools made from organic materials like shells, wood, or bone have their shape altered during harvest. The tools and the inserts get damaged, rounded, or blunted. In an actual neolithic context, these tools would have been sharpened regularly and missing inserts would have been replaced (Currie, 2022, p. 340). But in this experiment, the tools were used during the entire three-hour reaping time, to obtain a maximum of use-wear traces, regardless of whether they were still effective. In other words, the application of one method (experimental archaeology) to verify the hypothesis of harvesting with alternative materials, collides with another method (use-wear analysis) to preserve as many traces as possible for a future analysis.

5.2. Tool construction

The tools produced for this experiment have been made by D. Pomstra. He teaches experimental archaeology at the Faculty of Archaeology at Leiden University and is involved in experimental reconstruction of tools for the project "*Putting Life into Late Neolithic Houses*" (NWO-AIB.19.020) in the Broekpolder at Vlaardingen, The Netherlands. The pictures in this part show the experimental tools before they were used to harvest cereals.

5.2.1. Hafted sickles with shell inserts

The hafted sickles with shell inserts have been made according to the hafted sickles with flint inserts discovered at the early neolithic site in Karanovo, Bulgaria (Gurova, 2016, p. 160) (see fig. 2.17). Entire sickles of that type have also been discovered at the underwater site of La Marmotta in Italy (Mazzucco et al., 2022, p. 6). They consist of a curved, wooden frame with four to seven flint inserts placed at a 45°angle into a grove of that frame (see Chapter.2.1.2.1; fig. 2.1.). Flint inserts with a similar angular gloss have been identified in LBK and Rössen sites in North-Western Europe (Bakels, 2009, pp. 40, 58; Bakels & van Gijn, 2015, p. 109). These composite tools with a denticulated edge appeared to be widespread in the Early and Middle Neolithic in North-Western Europe. Other early neolithic sickle types like the angled sickle with single blade in parallel insertion (see Chapter 2.1.2.3.) or the angled sickle with oblique flint insert (see Chapter 2.1.2.4.) were discovered mostly in Southern Europe or close to the Alps and not further to the North. Therefore, the denticulated sickle type has been selected to serve as model for these experimental cereal harvesting tools.

The wooden frames of these tools were made from either hazel, yew, maple, willow, or oak wood. They were between 32 to 35 cm long and 2.5 to 4 cm wide. The thickness of these was between 1 to 3 cm. In each frame, a longitudinal groove of 0.8 to 1.2 cm depth has been carved to hold the shell inserts in place. To fix these, spruce pitch has been employed. This pitch consisted of spruce tar, charcoal, and animal grease (D. Pomstra, personal communication, 6th November 2022).

Figure 5.1. (Tool 3887) Hafted sickle with oyster shell inserts (picture by M.-P. Häg).

The shell types for the inserts of these experimental sickles have been chosen according to their potential availability during the Middle Neolithic of North-Western Europe. The first shell type is the flat oyster type (*Ostrea edulis*). Such oyster shells dating from the Neolithic or even earlier have been collected by the author on the beaches of the Dutch North Sea coast. But since these were very brittle, they could not be used as inserts for sickles. Therefore, fresh, flat oyster shells of the same type have been taken for the experiment. These have been broken into pieces and attached with spruce pitch into the wooden handle. The edges of the oyster shell have not been retouched (see fig. 5.1).

The second shell type selected was the freshwater mussel (*Unio crassus*). It was and still is native to the rivers of North-Western Europe and can easily be collected and transformed into inserts. Archaeologically, a late neolithic cereal harvesting knife has been found made from such a freshwater mussel (Pétrequin et al., 2006, p. 115). For the experimental tool, the shells were broken into halves and the sharp and thinner edges placed at a 45°angle into the wooden frame. The cutting edge of all inserts has been retouched to improve its sharpness (see fig. 5.2).

Initially, only four sickles (two with oyster and two with mussels inserts) were planned. Each sickle was to be used on one type of cereals only. The overall effectiveness of shells versus other materials was to be compared. But in early summer 2022, large fields for cereal harvesting could be secured. Thus, the initial concept changed to collect each cereal type with an entire set of hafted sickles with shell inserts. Unfortunately, by then, additional flat oysters were no longer

Figure 5.2. (Tool 3688) Hafted sickle with freshwater mussel shell inserts (picture by M.-P. Häg).

available and only two hafted sickles with oyster shell inserts could be made. Therefore, only two types of cereals (*T. aestivum* and *T. dicoccum)* were reaped with this type of sickle. However, enough freshwater mussel shells could be secured, and four hafted sickles with such shell inserts were made and used to reap all four types of cereals.

5.2.2. Wooden sickle

These experimental wooden sickles follow closely the shape of an archaeological tool found at the site of La Draga, Girona, Spain. This site, dating to the 6th millennium BC (Bosch Lloret, 2006, p. 28), had many wooden tools preserved in a wet environment. This wooden item has been classified as a sickle used for cutting reed and cereals (Terradas et al., 2017, p. 209) and was made of oak (*Quercus sp caducifoli*) (see fig. 2.9; Chapter 2.1.4.1.). So far, it is the only discovered wooden tool believed to have been used to gather cereals. For the cereal harvesting experiment, four sickles were made according to this archaeological example. All tools are 30 cm long, 14 cm wide and 2 cm thick and made of oak wood. They have a long handle to grasp the sickle comfortably and a curved cutting edge (see fig. 5.3). The cutting-edge ends in a point, where cereal stems can be gathered. The cutting edge has been sharpened with a flint tool (D. Pomstra, personal communication, 6th November 2022).

Figure 5.3. (Tool 3889) Oak wood sickle (picture by M.-P. Häg).

5.2.3. Deer mandible

J.A. Brown published an article in 1964 on the use of deer mandibles as harvesting tools. These mandibles are believed to have been used by native North Americans to collect plants, especially grass to roof their houses (Brown, 1964, p. 382); (see Chapter 2.1.4.2.). During experiments, Brown could demonstrate that the use-wear traces left on such mandibles resembled the traces found on archaeological finds. Based on this information, deer mandibles were included as experimental tools. Four tools have been made from two entire deer mandibles. To split these into halves, a flint flake has been used. It took 2.5 min and respectively 4.5 min to saw through the connection between both halves. The sawing took longer for the second mandible, as the edges of the flake were already dull. The tools are between 33.5 cm to 34.5 cm long, 6 to 7 cm wide and maximum 2 cm thick. The mandibles have been used as they were for reaping (see fig. 5.4).

Figure 5.4. (Tool 3671) Deer mandible (picture by M.-P. Häg).

5.2.4. Cattle rib

Archaeological traces of bone implement such as cattle ribs used for cereal harvesting have not been encountered in literature. Still, as this thesis focuses on potential organic materials used for reaping, it was judged interesting to find out if a tool made from bone could be effective. Bone tools are known to have been used widely in the Neolithic such as needles, awls, or points (Lüning,1968, p. 76; Vermeersch & Burnez-Lanotte, 1998, p. 50).

Could a bone tool with a flat shape such as a rib have been used for reaping? First trials were made with cattle ribs bought at the local butcher. These were 15 to 20 cm long and have been boiled at home to remove the remaining meat and grease. By holding these, more than half of the cutting edge was covered by the hand and the remaining edge was too short for gathering and cutting any stems. Therefore, a longer cattle rib was believed suitable for reaping. Such tools were provided by D. Pomstra and he sharpened their edges to increase their effectiveness. These ribs are between 34 cm to 38 cm long, 6 to 3 cm wide and 1.5 to 2 cm thick (see fig. 5.5).

Figure 5.5. (Tool 3891) Cattle rib (picture by M.-P. Häg).

5.2.5. Shells as handheld devices

Small, handheld harvesting tools made from flint have been found in archaeological contexts, as at neolithic lake-site villages of Southern Germany (Schlichtherle, 1992, p. 36); (see Chapter 2.1.3.). These tools were made from a single flint blade covered on one side with pitch tar and placed into a straight wooden frame (see fig. 2.7). These were also made in a simpler format, with a single blade covered unilaterally with tar and then textile or bark. This cover is believed to protect the hand while the flint blade is used to snap off cereal ears (fig. 2.8.; see Chapter 2.1.3.2.); (Anderson, 1999, p. 124).

Another archaeological example of a handheld device is a freshwater mussel shell with a dented cutting edge and two holes in its shell. It is believed to have been used in the late Neolithic as a harvesting knife (see fig. 2.14.); (Pétrequin et al., 2006, p. 115).

Based on these last two examples, similar tools have been created for cereal harvesting. Eight shells (four freshwater mussels and four oysters) have been employed as harvesting knives. For the hand-held oyster shells, two tools were made of entire shells and two were fragments of one larger shell. The entire shells were between 8 to 8.5 cm long, 6.5 cm wide and up to 4mm thick. The oyster fragments were between 6 to 6.5 cm long, 5 to 5.5 cm wide and between 3 to 5mm thick. The oysters are of the flat, Dutch type *Ostrea edulis* (see fig. 5.6).

For the hand-held freshwater mussel, the entire shells were used. They have the following size: Length: 6.5 to 7.5 cm, width: 3.5 to 4 cm and thickness up to 1mm (see fig. 5.7).

The dorsal sides of all oyster and mussel shells were covered with pitch to avoid hurting the harvester's hand while reaping. The sharp, ventral part was left as originally found. The mussel shell was not pierced, as seen in the archaeological example (see fig. 2.13). For the terminology of shells see Appendix D. For more details on each tool see Table 5.1.

Figure 5.6. (Tool 3684) Hand-held oyster shell (picture by M.-P. Häg).

Figure 5.7. (Tool 3681) Hand-held freshwater mussel shell (picture by M.-P. Häg).

Table 5.1. Overview of tools used for cereal harvesting with their experiment number, duration of use, composition, and cereal types (Made by M.-P. Häg).

Experiment nr., testing time	Shell tools				Wooden tool	Bone tools		by hand	
Cereals	Hand-held		Shafted		Sickle	Deer	Cattle	uprooting	picking
Triticum aestivum (Naked wheat)	**3679**	**3683**	**3687**	**3886**	**3888**	**3671**	**3891**		
	Unio crassus (River mussel)	*Ostrea edulis* (European oyster)	*Unio crassus* (River mussel)	*Ostrea edulis* (European oyster)	Oak	Mandible	Rib		
	180 min.	180 min.	180 min.	180 min.	180 min.	60 min.	10 min.	60 min.	30 min.
Triticum dicoccum (Emmer wheat)	**3680**	**3684**	**3689**	**3887**	**3890**	**3674**	**4167**		
	Unio crassus (River mussel)	*Ostrea edulis* (European oyster)	*Unio crassus* (River mussel)	*Ostrea edulis* (European oyster)	Oak	Mandible	Rib		
	180 min.	180 min.	180 min.	180 min.	180 min.	65 min.	5 min.	60 min.	30 min.
Hordeum vulgare (Barley)	**3681**	**3686**	**3690**		**3899**	**3673**	**4166**		
	Unio crassus (River mussel)	*Ostrea edulis* (European oyster)	*Unio crassus* (River mussel)	/	Oak	Mandible	Rib		/
	180 min.	180 min.	180 min.		180 min.	60 min.	8 min.	60 min.	
Triticum monococcum (Einkorn wheat)	**3682**	**3685**	**3688**		**3889**	**3672**	**3900**		
	Unio crassus (River mussel)	*Ostrea edulis* (European oyster)	*Unio crassus* (River mussel)	/	Oak	Mandible	Rib		
	180 min.	180 min.	180 min.		80 min.	180 min.	7 min.	60 min.	30 min.

5.3. Harvesting locations

5.3.1. Lauresham, Lorsch, Germany

The reaping was done in two locations in South-Western Germany during the month of July 2022. The first site was at the city of Lorsch, located to the south of Frankfurt and close to Mannheim. This city is known for its UNESCO world heritage site of a Carolingian monastery dating from the 9th century AD. In connection with this monastery, an open-air museum has been built in 2014. The museum is called "*Lauresham Open-Air Laboratory for Experimental Archaeology*" (Kropp, 2022, p. 112) and reproduces on a 4.1 hectare surface an early medieval farmstead complete with rebuilt houses, barns, mills, manors, fields, and animal pens. Much in this museum focuses on experimental archaeology and, among others, ancient farming practices. C. Kropp and his team have been explaining Carolingian farming to the general public and have reconstructed ancient agricultural methods in an experimental setting. In this farmstead, five fields have been established as "*ridge-and -furrow fields*" (Kropp, 2022, p. 114). These are each 100m long and 6m wide and have a 60 cm high ridge in the middle of each field. One of these fields has been planted with *Triticum aestivum,* or naked wheat in an organic method. This means that no pesticides and herbicides have been used and therefore grass and invasive weeds as the thistle or the blueweed were present. The fields were planted in a three-field crop rotation, replicating what assumably was done in Carolingian times. The absence of chemicals made it an ecologically friendly field but with its challenges in reaping cereals (see Chapter 5.4.1.). *Hordeum vulgare* or naked barley was also planted in the same way on a nearby ridge-and-furrow field. But it could not be reaped, as the plants have withered, due to the absence of rain in the month of May 2022. *Triticum dicoccum* or emmer wheat could be gathered close to the open-air laboratory. It was planted on a large, flat field nearby in a conventional way with the use of herbicide and pesticides.

5.3.2. Heidfeldhof, Stuttgart, Germany

The second location was at the University of Hohenheim in Stuttgart, Germany. This university specialises in agricultural sciences, (Uni-Hohenheim, 2023) has extensive fields, where a large variety of cereals are planted, tested, combined, and improved. At one of these experimental sites, the „*Heidfeldhof,*" different crops have been planted. These are among others *Triticum aestivum* (naked wheat), *Triticum monococcum* (einkorn wheat), *Triticum dicoccum* (emmer wheat), *Triticum spelta* (spelt), *Triticum durum* (durum wheat), *Hordeum vulgare* (barley), *Glycine max* (soybeans) and *Zea mays* (maize). These fields are managed by a team of researchers and employees of the University of Hohenheim and are used to answer specific research questions. For the harvested field of *Hordeum vulgare* or barley, the team focused on the improvement of fertilisers and was managed by M. Streck. For the reaped field of *Triticum monococcum* or einkorn wheat, another team focused on crossbreeding and was run by S. Rrecaj. All cereals at the Heidfeldhof are planted conventionally with the use of pesticides and fungicides.

5.4. Harvested cereals

Four types of cereals were collected during the experiment. These were *Triticum aestivum* (naked wheat), *Triticum dicoccum* (emmer wheat), *Hordeum vulgare* (barley), and *Triticum monococcum* (einkorn wheat). Traces of these cereals have been found during archaeological excavations at Michelsberg sites (Bakels & van Gijn, 2015, p. 110). It is therefore assumed that these four types of cereals have been planted, reaped, and eaten during that period and thus could be used for the experiment.

5.4.1. Triticum aestivum

Figure 5.8. Organically grown field of Triticum aestivum at Lauresham (picture by M.-P. Häg).

Triticum aestivum, or naked wheat, has been harvested in Lauresham in Lorsch, Germany. As the field was within the open-air museum, it was planted organically (without pesticides and herbicides) on a ridge-and-furrow field (see fig. 5.8). The furrows are believed to have generated taller stems and a higher yield, especially in dry years during the Middle Ages (Kropp, 2022, p. 116). The field was not very densely planted. Especially its borders were almost empty of *Triticum aestivum*. The cereal plants were mixed with grass and some weeds like thistle, which were still green upon harvest and thus made reaping difficult. The soil type of this field was clay with a small proportion of sand (Kropp, 2019, p. 16). The cereal plants were about 1m high with a stem thickness of 3-5mm. For sickle reaping, the *Triticum aestivum* had to be cut together with the grass. This resulted in more harvested volumes, but less *Triticum aestivum* collected. The grass and weed were not separated post-harvest, but bound with rope into sheaves, and put upright to dry. At the end of a day's harvest, all these sheaves were brought into a barn. The harvest was done from 9th July to 10th July 2022 under a clear sky and an average temperature of 26°C. *Triticum aestivum* was later also gathered at the Heidfeldhof, Stuttgart, with hand-held shell tools used as harvesting knives since the results in Lauresham with these tools were poor (see Chapter 6.2.1 and 6.2.3.).

5.4.2. Triticum dicoccum

Figure 5.9. Triticum dicoccum field at Lauresham (picture by M.-P. Häg).

Triticum dicoccum, or emmer wheat, has also been harvested at Lauresham in Lorsch, Germany. The field was outside the open-air museum and planted with black emmer (*Triticum dicoccum var. atratum*) in a conventional way, with the use of pesticides and herbicides (see fig. 5.9.). The soil type of this field was a high proportion of sand, making the earth loose and plants easy to uproot (Kropp, 2019, p. 16). The plants were about 1.4m high with a stem thickness of 2-3mm. The harvest was done from 11th July to 13th July 2022 under a clear sky and an average temperature of 25°C. At the Heidfeldhof, in Stuttgart, red *Triticum dicoccum* was also collected. The field had a similar soil composition (sandy and dry) compared to Lauresham. A deer mandible was tested there, as at Lorsch the harvesting results with that tool were poor (see Chapter 6.1.4.).

5.4.3. Hordeum vulgare

Figure 5.10. Hordeum vulgare field at Heidfeldhof (picture by M.-P. Häg).

Hordeum vulgare, or barley, has been harvested at the Heidfeldhof in Stuttgart. The field was about 20m wide and 100m long. It was conventionally planted with the use of herbicides and pesticides (see fig. 5.10). Therefore, no undergrowth or weeds were present. The *Hordeum vulgare* plant was only 60 cm tall but with a stem 3mm to 5mm thick. At the beginning of the harvest, the plants were only up to 80% dry, which resulted in reaping many green stems. This had the effect that the edges of the tools became green, and that more effort was needed to reap these. On the 3rd day of the harvest, most stems were completely dry, and they emitted a snapping sound while being cut. The reaping was done from 15th to 17th of July 2022 under a clear sky, with little wind, and temperatures of around 25°C.

5.4.4. Triticum monococcum

Figure 5.11. Triticum monococcum field at Heidfeldhof (picture by M.-P. Häg).

Triticum monococcum, or einkorn wheat, was also harvested at the Heidfeldhof, Stuttgart, on strips of field 1.2m wide and several dozen meters long. These strips were planted with only one type of cereals and in this case *Triticum monococcum*. This plant grows very high (1.40m) has very thin stems of about 2 to 3mm in diameter and therefore tends to swing in the wind quite strongly (see fig. 5.11.). As the cereal was rather dry, the ears had the tendency to break off once gathered by hand. *Triticum monococcum* has been planted in a conventional way, meaning with the use of pesticides and fungicides. This led to the absence of insects, animals, and other plants around the stems. Still, the bottom parts of the stems were covered densely with dried, grass-like leaves. This dense and dry organic material made it difficult to cut the cereals close to the soil. Also given the fact that no weed or undergrowth was growing next to the cereals, they were very prone to uprooting. Even with a sharp tool like a hafted sickle with shell inserts, the stems had to be cut at least 30 cm above soil level in order not to collect the root of the plant. As the stems were not brittle, they could not be hacked through by a blunt tool like a wooden sickle. Instead, the stems got uprooted. Snapping off the ears of *Triticum monococcum* also proved difficult. Not only were the stems very thin and difficult to break, but these moved in the wind, which made them difficult to catch and collect. Cereal harvesting took place from 26th to 28th July 2022 under a clear sky with moderate wind and temperatures reaching up to 28°C.

5.5. Tool use

The harvest of cereals was done on fields planted with the above-mentioned four different types with 26 different tools made from organic materials (see table 5.1). The reaping was done during the entire experimental period by one person only, the author. This is believed to contrast with the Neolithic period, where cereal harvesting was thought to be a communal effort (Bogaard, 2004, p. 159). Also, the author had no earlier experience in harvesting cereals, which differs to actual or earlier farmers who were believed to be handling tools more dextrously (González et al., 1994, p. 325). As mentioned by P. Anderson "*none of us had enough previous experience with sickle harvesting to feel that we gave the tools a truly fair trial*" (Anderson & Whittaker, 2015, p. 108). Both points had the effect, that the results gathered throughout this experiment, be it harvested surface, reaping speed or collected grain yield could be considered a minimum and not a maximum output.

5.5.1. Tool handling

As the harvester was left-handed, all tools have been used with the left hand. This means that the ears or stems of the cereals have been collected with the right hand and brought to the left hand for reaping. The number of stems which could be grasped with the right hand depended upon the diameter of these (between 2mm to 6mm), the cutting height and the sharpness of the tool. Often, the number of stems grasped was higher at the beginning of a harvest, when the tool cutting edges were sharp. Also, the way of collecting changed from cutting the stems straight off, to sawing, ripping, or uprooting these. The technique very much depended on the sharpness of the tool, the type of cereals cut and the composition of the soil (see Chapter 5.4. for details).

After reaping the first stems, they were placed behind the harvester, at the border of the field. As the harvest progressed, the harvester had to walk between the cutting edge of the field and the border, where he deposited the collected plants. At that border the reaped stems were put together in large piles with all ears pointing into one direction. The aim of this precise piling was to bind these together to sheaves, measure their diameter, have them stand up and dry under the sun before moving them to a barn in the evening. This traditional operation was done at the Lauresham Open-Air laboratory while reaping *Triticum aestivum* and *Triticum dicoccum*. In Stuttgart, for *Hordeum vulgare*, and *Triticum monococcum,* the stems were gathered at the border of the field but not bound together.

The reaping experiments were done by the harvester alone, without the help of others. This absence of support impacted the harvesting speed. The cereals were not only cut during the one hour harvesting time, but the stems had also to be carried to the edge of the field and gathered into sheaves. This carrying of the stems was needed in order not to stand on the already cut ears and thus maintain a high yield of collected grains. It is estimated that this walking too and froth resulted in a loss of harvesting speed of 1/3 of the entire reaping process.

To exclusively gather cereal ears, a different technique was employed. The ears were snapped off their stems by hand or by a hand-held shell, used as harvesting knife. For that, the right hand grabbed the stems, and the left hand snapped the ears off with the shell. Alternatively, only one hand was used to grab the ears and push them over the cutting edge of the shell tool. The other hand was then used to gather the reaped ears and transfer them into a collection bag in absence of a collection basket. To gather solely by hand, one hand was employed to snap off the ears and the other to collect these and transfer them to a collection bag. Alternatively, both hands were also used each to snap the ears off, resulting in a faster collection rate than with shell tools.

5.5.2. Tool sharpening

All tools were used without sharpening during the entire cereal harvesting period i.e., maximum three hours. During the harvest, certain tools lost some of their inserts, others became blunt, and some developed severe edge rounding. However, all these tools have been used as they were during the entire reaping period. None of the inserts were replaced. No edge was ground, and no insert was retouched to try to improve the harvest outcome. This ultimately resulted in some experiments being stopped, as some tools were too blunt to continue to reap cereals.

The reason for not sharpening these tools was that the use-wear traces generated during the harvest had to be preserved for future analysis under the microscope. If the tools had been regularly ground, the use-wear traces developing on them from earlier collection would have disappeared. Also, the evolution of these traces over the entire three-hour harvest could not be monitored if they would have been frequently sharpened.

In real life context of the Neolithic, it appears that these tools would have certainly been honed regularly. This would have resulted in smaller remains of tools than the ones recorded. These remains would have ultimately been discarded at the end of their use-life. Further details can be found in Chapters 5.1.2 and 8.1.

5.5.3. Cereal harvesting period

The harvesting time was fixed at a maximum of three hours for each tool. This amount of time was believed sufficient to generate enough use-wear traces visible under the microscope. During the harvest, these three hours were divided into hourly periods. Each tool was thus being used for one hour. After that, a report was written on the field about the progress of the harvest. Noted were visible damages on the tools, subjective feelings of the harvester about the progress of the harvest and quantitative results in m² and volume of stems or ears reaped. The following hour, another tool was used to avoid employing the same tool during three hours in a row. The advantage of this method was to use each tool on different days and time periods. Ideally, a tool would be used for three one-hour periods on three different days and on three different parts of the field. However, some tools could not be used for the planned three hours. Also, the uprooting and snapping of ears by hand has been done only for one hour. This was started as an afterthought during the experiment. The aim was to compare the reaping results achieved with bare hands in comparison with the results achieved with tools.

5.5.4. Quantitative harvest calculations

During the harvest, the size of the collected area was measured in m². To do so, the width of the field was measured, and 1m wide strips were marked on the soil. Along these strips, the harvest was conducted. Once the reaping time was over, the length of the harvested area was measured and multiplied by the width of the strip. For example, after the first hour, the harvester had cut 12m of *Triticum aestivum* with a wooden sickle on a 1m wide strip of field (see Appendix B). This resulted in 12m² (12m x 1m) of reaped area. For strips 1.2m wide, as encountered for *Triticum monococcum* at the Heidfeldhof in Stuttgart, the entire strip was harvested, and the achieved length multiplied with the width of 1.2m.

The grain yield or "*amount of food produced on an aera of land*" (Collins, 2023), has been calculated in three different ways:

1) for cereals reaped with their stems, the circumference of each bundle of collected stalks was measured. The reaped and piled-up plants were lifted from the ground, a string was wrapped around them and tightened until they could not move any more. The length of that string, wrapping them, was measured. All bundles made during the one-hour harvest period were measured this way and the results added together (see Appendix F). Cereals which have been collected with grass and weeds as *T. aestivum* have not seen their grain yield been revised downwards to exclude these grass and weeds. This applies also for cereal stems being uprooted.

The root with the attached earth increases the volume and weight of the sheaves compared to cereals collected without roots. This difference has not been considered. The reason for that is that sorting out the earth or the grass in the field was too time consuming and the sheaves have been measured as they were.

2) for cereals gathered by hand or with hand-held shells used as harvesting knives, only the ears were collected. These were put into a bag attached to the harvester's belt as the harvest progressed. After each one-hour period, the content of that bag was measured by its length, width and height resulting in a volume of collected ears. The result was added together to record the total volume reaped for a specific surface. The detailed volumes can be seen in Appendix F.

3) finally, the actual grain yield of the reaped fields has been obtained from the person in charge at Lauresham and Heidfeldhof. This cereal yield is indicated in t/ha, meaning ton over one hectare or 1,000kg over 10,000m² of surface (OECD, 2023). In the case of this experiment the yield for organically grown *Triticum aestivum* at Lauresham was 8.3 t/ha (Dorn et al, 2023). The field of *Hordeum vulgare* (M. Streck, personal communication, 21st February 2023) had a grain yield of 5.5 t/ha and *Triticum monococcum* of 5.8 t/ha (S. Rrecaj personal communication, 2nd February 2023). For *Triticum dicoccum* the grain yield of the field at Lauresham could not be obtained. Therefore, the grain yield from the field at the Heidfeldhof has been used. This yield was 7.9 t/ha (S. Rrecaj, personal communication, 2nd February 2023*)*. As both fields were planted conventionally and had a sandy soil composition, a similar grain yield was assumed. To compute the overall grain yield of a field to the harvested surface during the experiment, the following calculation was done:

a) the grain yield was broken down from t/ha to kg/m². In the case of *Triticum aestivum* this would be 0.83 kg per m² (8.3 t/ha = 8,300 kg/10,000m² =0.83 kg per m²), 0.79 kg/m² for *Triticum dicoccum,* 0.55 kg/m² for *Hordeum vulgare* and 0.58 kg per m² for *Triticum monococcum*.

b) the grain yield was then calculated based on the harvested surface. When 19m² of *Triticum aestivum* was gathered during the first hour with a hafted sickle with oyster shell inserts, this would result to close to 16 kg of grain reaped (19m² x 0.83 kg = 15.77 kg); (see Appendix B). This amount of about 16 kg is therefore the calculated grain yield of the surface reaped with a hafted sickle with oyster shell inserts for one hour.

This latest calculation has been used to compute all grain yields during this experiment. The detailed results are presented in the quantitative result section (see Chapter 6.1 and 6.2.). However, the recorded volume of cereals as described in part 1) and 2) has not been used in the results section, as it is believed to be less precise than using the official grain yield of each harvested field.

The cereal harvesting speed has also been calculated. For that, the surface (in m^2) was divided through the minutes spent reaping (usually 60 min.). This results in a m^2/min. figure, which could be compared to the different cereals and tools. As an estimated 1/3 of the reaping time has been used to transport the stems to the border of the field, it had to be added to the recorded reaping time (see Chapter 5.5.1.). This made the results comparable to other cereal harvesting experiments (see Chapter 8.2.4).

5.5.5. Climatic conditions

Climatic conditions were harsh during the entire month of the harvest (July 2022). There was no rain, strong sunshine, few clouds, moderate wind, and temperatures starting at 18°C in the morning and culminating at 28°C in the early afternoon. No shade was available on the fields and dust from the plants and the soil was noticeable. The harvesting time varied but started between 8.00h to 10.00h in the morning and lasted until 17.00h to 19.00h in the evening. An earlier start was not possible due to the long commute of the harvester to the fields. Due to the high temperatures especially in the afternoon, the more tiring reaping work with sickles was done in the morning and around lunch time. The easier work of snapping off ears by hand or with hand-held shells used as harvesting knives, was done mostly in the late afternoon.


Figure 5.12. Clothes used during harvest (picture by C: Kropp).

The harvester used a special clothing kit to protect himself from these climatic conditions (see fig. 5.12.). Steel capped working shoes were very helpful to shake off the earth from uprooted cereals. Military grade long trousers with deep pockets, allowed to keep all necessary reporting tools close at hand. Long sleeved cotton shirts avoided sun burns on arms. A cap with neck protection prevented sun strokes and avoided sunburns in the neck. Working gloves were essential to grasp the cereal stems during hours of gathering without hurting the hand. The summer heat did not affect the reaping results, as the harvester was well protected through his outfit and had ensured to have sufficient drinking water for the entire day.

5.5.6. Cereal harvesting technique

Reaping cereals was done in two ways.

Firstly, to harvest the stems, they were gathered with the right hand and then cut with the left hand. Once a group of stems have been cut, they were held in the right had and another group of stems were gathered and cut. This was done until the right hand was full of cut stems and no more could be collected (see videos in Appendix G).

The harvest height depended very much on the type of cereal stems. For shorter cereals like *H. vulgare*, the harvester tried to cut as close as possible to the ground. The reason for that is the bundling of the stems to sheaves. The longer the stems, the easier it was to bind these together. In the case of *H. vulgare*, with its 60 cm of average stem length, this binding was difficult to achieve, therefore the cut was done as close to the soil as possible. For *T. monococcum,* with its 1.40m stem length, binding these to sheaves was much easier. In this case, the cutting height was around 30 cm above the soil, also due to the dried leaves at the base of the plant, which made cutting at a lower height difficult.

During the reaping, the harvester bended in front of the to be collected plants. For *H. vulgare,* he bowed deeper, close to the soil and for *T. monococcum,* less, a maximum of 30 cm above the soil. For the other two cereal types, he reaps about 15 to 20 cm above ground. Once the stems are cut, the harvester straightens up and carries the stems to the collection point at the edge of the field. There, he drops the stems to the ground or on one of the already present bundles of cereals. Done, he returns to the cutting edge of the field and repeats the gathering, reaping, and transporting of the stems until the gathering time of one hour has passed. This frequent moving between the harvesting zone and the deposition zone of the cereals enabled the harvester to straighten his back regularly and not stay in a crouched position for the entire hour. This reduced the overall speed of the harvest, as the walk between gathering and deposition got longer and longer. But it enabled the harvester to reap the entire day without getting too tired. But during the first days of harvest, it was difficult to keep leaning forward the whole time, especially at the end of a full day's work. Therefore, at the end of the first day, when the harvester was tired, he either kneeled in front of the stems or sat in front of them to relax his back. These positions were not as efficient as bending but avoided a potential back ache. They were only taken at the beginning of the harvesting experiment while collecting *Triticum aestivum*. Later, the bent position could be upheld the entire day.

Secondly, to gather only the ears, the harvester stood right next to the plants. He had a bag attached to his belt into which the reaped ears were dropped. To reap, he first grabbed the stems with the right hand, then snapped them off with his left hand with the cutting edge of a shell. Sometimes, it was also possible to gather the ears and snap them off in one movement with one, the left hand. Then, the ears were transferred to the right hand. Once this hand was full of ears, they were transferred to the collecting bag. It was a very static harvesting technique, as the harvester moved only forward once all surrounding ears were reaped. As such, the progress in the field was very slow. Back ache due to bending was most of the time not an issue, as the stems were 1m to 1.40m high, which enabled an easy grasping of the ears. Only for *Hordeum vulgare*, with its height of only 60 cm, the harvester had to stoop forward the entire time to gather the ears, resulting in strong back ache.

5.5.7. Tool cleaning and casting

During the cereal harvest, all tools were cleaned at lunch and dinner breaks. For that, each tool was cleaned with on-site available drinking water and then with a 96° alcohol solution. Soap could not be used for cleaning, as not enough water was available on the field. Once the tools were clean and dry, a cast was made on both sides of the cutting edge (side A and side B) of each tool. The casts were made after each hour of harvesting to record the changes on the cutting edges.

5.6. Procedure of use-wear analysis

5.6.1. Macroscopic analysis

All tools have been analysed visually before the harvest and after. This analysis englobed the description of each tool and the numbering of each side and their cutting inserts. The objective was to see the differences between the initial stage and the final stage of use. All tools received a 4-digit experiment number, which was given out by the Laboratory for Material Culture Studies at the Faculty of Archaeology of Leiden University (see table 5.1.). This number was written on each tool with a waterproof marker. In addition, each side of the tool was designated as side A or B. For handheld shells, side A was the outside of the tool and side B the inside. For all other tools, the sides have been given randomly. In addition, each hafted sickle shell insert was given a number (Roman number I, II, III, IV, V, IV) to enable to track the changes on each of the individual inserts.

5.6.2. Tool description and drawing

All tools have been described before the harvest on an experiment form of the Laboratory for Material Culture Studies at the Faculty of Archaeology of Leiden University (see Appendix C). Once the reaping was done, the tools were described again. The type of macroscopic use-wear traces on the cutting edges of the tools were noted. In addition to this description, all tools have been drawn at a scale 1:1 on side A and side B. On these drawings, the exact position of microscopy pictures has been noted by giving it a continuous number like "*Image 1,2,3*", etc. This has been repeated after the harvest with further continuous numbers of the taken images. This method had the advantage that, after the gathering, it was possible in many cases to find back the original location where pictures were initially taken and to compare these with the images done post-harvest.

5.6.3. Photography

All tools have been photographed before and after the harvest experiment. For that, a Nikon D 7200 digital single lens reflex camera has been used with two objectives. For close-up pictures an AF-S Micro Nikkor 60mm f 2.8G ED objective has been used. For larger images an AF-S Nikkor 18-105mm f 3.5-5.6 G ED zoom objective has been employed. All items were photographed on both sides with the zoom objective. Then close-ups have been made on both sides with the macro-objective. These blow-ups have been made with the help of a stacking software called Helicon focus (version 7.5.3). This software enables to take several pictures of the same tool with different focus and stacks these together. This enables to obtain perfectly focused images. Also, short videos were made of harvesting *T. aestivum* (see Appendix G).

5.6.4. Casting

Casts of the cutting edges of all tools have been taken. The objective was to have a model of each cutting edge to monitor the changes on these over the entire harvesting process. To make the casts, Provil novo base and Provil novo catalyst from Kulzer GmbH were used. These two creams were mixed in a ratio 1:1 resulting in a light green synthetic paste. The cutting edge of each tool was then covered on each side (side A and side B) with this paste. After a short while, the paste hardened and could be peeled off the cutting edge. Each cast was then placed into a separate plastic bag with a detailed description. The description included the tool number, the side of the cutting edge, the number of cast and the roman number of the insert (for example: 3888, Side A, cast 1, V). The casts were taken before the harvest (cast 0) then after one hour of gathering (cast 1) and then two hours after harvesting (cast 2). A cast after three hours of collecting (cast 3) was not taken, as the result could be seen directly under the microscope at the laboratory.

5.6.5. Stereo microscopy

Before and after the harvest, all reaping tools were analysed under a stereo microscope. For that, a Leica M 80 instruction microscope has been used. The microscope is connected to a Leica MC 120 HD camera to provide a digital picture. The pictures were taken at three magnifications (7.5x, 25x and 60x) and saved on a scale bar of 2mm (for 7.5x), 1mm (for 25x) and 500µm (for 60x). Certain locations on the tool were photographed in these three magnifications before the harvest started. These locations have been noted on the drawing of the tool and have been numbered starting from location 1 before the gathering, until the last location just after the harvest. Frequently, the same location has been photographed before and after the reaping to compare especially the transformations of the cutting edge.

5.6.6. Metallographic or incident light microscopy

A metallographic microscope has been used to analyse the different tools at higher magnifications. For that, a Leica DM 2700 M metallographic microscope together with a digital camera Leica MC170 HD has been employed. Pictures were made with two magnifications (100x and 200x) and saved with a 200µm (for 100x) and a 100µm (for 200x) scale bar. Pictures were taken of all four deer mandible and of an entire set of tools (six tools) before the harvest and later, after the reaping, of all tools. This enabled the comparison of some tools before and after the harvest. Unfortunately, not all tools could be photographed with the metallographic microscope before the reaping due to time constrains.

CHAPTER 6 – CEREAL HARVESTING RESULTS

This chapter presents quantitative results of the experimental harvest done with tools whose cutting edges were made from shell, wood, or bone. Four different cereal types have been tested, as *Triticum monococcum* or einkorn wheat, *Triticum dicoccum* or emmer wheat, *Triticum aestivum* or naked wheat, and *Hordeum vulgare* or barley. First, the total reaped surface in m² for each tool is presented according to each cereal type. Then, from this data, the harvesting speed per m²/min. has been calculated. In the second part of this chapter, the collected surface for each tool by cereal type is analysed and the grain yield of each harvest is computed. The cattle rib tools are not included in these overviews, as the experiment had to be halted after only a few minutes. The background data for these tables are presented in Appendix A and B. All figures in this chapter have been made by the author.

6.1. Reaping with sickles

The reaped surface per square meter achieved with each tool during the harvest has been recorded. These results are being presented in overviews according to tool types and cereal types. This enables a comparison of the area reaped by the same tools on different cereal fields and indicates how effective these tools were. A direct comparison can be made between *Triticum monococcum, Triticum dicoccum and Hordeum vulgare,* as all these cereal types have been planted densely on fields with sandy soils and with the use of herbicides and pesticides. However, *Triticum aestivum* has been planted organically on a strongly clay-based soil and was therefore heavily mixed with grass and weeds. It can therefore only be indirectly compared to the other results.

In addition to the reaped aera, the harvesting speed of each tool has been calculated. This is done by dividing the recorded aera by the amount of time (usually 60 min.). The result is presented as m² per minute. For comparison's sake, only the first hour of reaping has been computed in the overviews, because several tools have only been used for one hour (deer mandible, uprooting and snapping off by hand). Also, some tools suffered damages after the first hour, like the loss of inserts, which strongly reduced the harvesting speed. The background data of these overviews can be seen in Appendix A.

The aim of this calculation is not only to compare the speed of a cereal harvest achieved between the actual tools and different cereal types, but also to compare them to experiments done by other researchers (Juel Jensen, 1994, pp. 120-121; Mazucco et al., 2022, S2); (see Chapter 8.2).

6.1.1. Hafted sickles with oyster shell inserts

The hafted sickles made with oyster shells inserts have been by far the most effective cereal harvesting tools during this experiment. Two sickles with oyster shell inserts were made and they have been used on *Triticum dicoccum* (Tool 3887) and *Triticum aestivum* (Tool 3886) (see Table 5.1.). After the first hour of harvest, tool 3886 had already lost two out of its five inserts. This made collecting *Triticum aestivum* slower by 1/3 compared to *T. dicoccum*, where no inserts have fallen off (see fig. 6.1.).

In terms of aera harvested, 57m² of *T. dicoccum* could be reaped within three hours. For *T. aestivum*, this was only 41 m². Overall, 98m² were gathered in six hours. If two more such sickles would have been available, a similar surface *of T. monococcum* and *H. vulgare* could have been reaped. This would make the potential output stand close to 200m² of grain reaped for just 12 hours of work.

The effectiveness of hafted sickles made with oyster shell inserts can be traced back to the material of the oyster itself. The cutting edges of the inserts are already sharp when placed into each sickle. Also, they do not need to be retouched as it is the case for freshwater mussel shell inserts. During the harvest, the shell material of the oyster flakes off under the pressure of the cereal stems. This flaking generates new and sharp cutting edges. It does not lead, as for the mussel shell, to a blunt edge, which would need sharpening. However, through such flaking, each oyster shell insert is getting shorter quickly and would need to be replaced by a new insert at the latest three hours into reaping.
With both sickles, a high reaping speed could be achieved. The gathering of *Triticum aestivum* took 0.32m² per minute, or three min. per m² although it has been reaped on a ridge-and furrow field (Kropp, 2022, p. 116) where grass and weeds were cut with the cereals (see video in Appendix G). This is one of the highest speeds recorded during these experiments (see fig. 6.2.). During the next two hours, the speed dropped to 0.21m²/min. and 0.17m²/min respectively after two inserts fell off that tool (see Appendix A). The reaping speed of *Triticum dicoccum* with 0.31m² per min. is slightly lower than with *T. aestivum* but more grain could be collected, as only cereal stems were gathered. This speed increased during the 2nd hour to 0.35m²/min, making it the fastest harvest within the entire experiment.

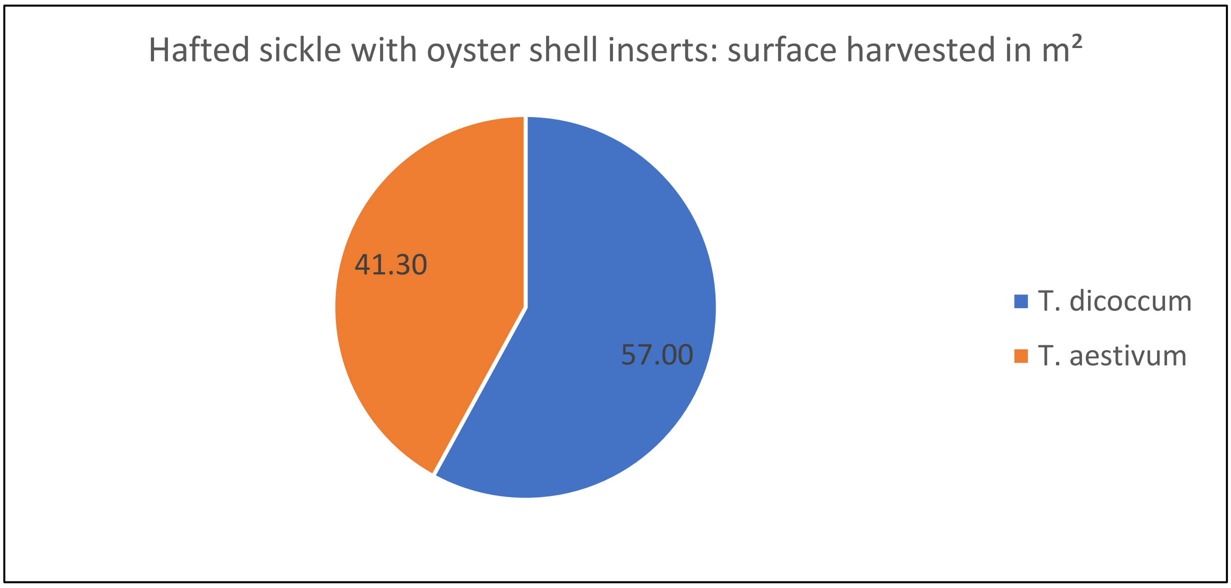


Figure 6.1. Harvesting results of hafted sickles with oyster shell inserts.

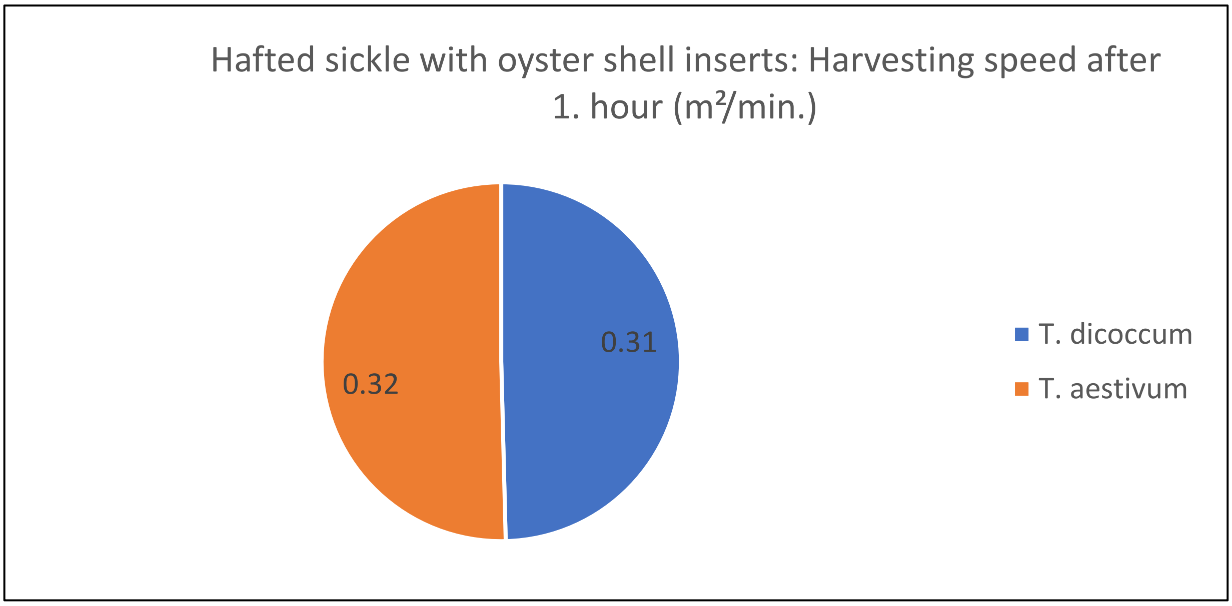


Figure 6.2. Harvesting speed achieved with hafted sickles with oyster shell inserts.

6.1.2. Hafted sickles with freshwater mussel shell inserts

Four hafted sickles were made with freshwater mussel shells inserts. These have been used for three hours each on four cereal types. Over the course of these three hours, the cereal harvesting technique changed from cutting to sawing and then to uprooting, as the inserts became blunt. This resulted in a decrease of the reaped aera between 5% to 20% (see Appendix A).

The reaping of *Triticum monococcum* resulted in a total of 23m² surface reaped after three hours (see fig. 6.3). This is due to an insert falling off after the first hour, slowing down the harvest by about ¼ compared to the first hour (see Appendix A). Also, the plant had thin, grass-like stems, which were swaying in the wind (see Chapter 5.4.4.) and these were difficult to grasp and cut through. The second lowest result with close to $30m^2$ was achieved with *Triticum aestivum*. The cereals were growing among grass and weeds, which, gathered, blunted the mussel shell inserts strongly (see video in Appendix G). The second-best results were recorded with *Hordeum vulgare*. Although the plant itself was only 60 cm tall, the cutting was smooth, fast, and resulted in almost $37m^2$ of surface being collected in three hours. The dryness of the stems at the end of the harvest is believed to have made the reaping easy. Finally, almost $48m^2$ of *Triticum dicoccum* was gathered in three hours. This was $10m^2$ more compared to the other three cereal types, but still $10m^2$ less than with the hafted sickle with oyster shell insert. This result was due to the brittle stems of the plant, which were easy to cut.

In terms of speed, *Triticum dicoccum* could be cut fastest with $0.28m^2$ per min. or 3.6 min. per m^2 achieved (see fig. 6.4.). It was followed by *Hordeum vulgare* and *Triticum aestivum*. *Triticum monococcum* resulted in the slowest speed with only $0.16m^2$ per min. of cereals cut during the first hour. This speed dropped further to $0.12m^2$/min. after one insert fell off.

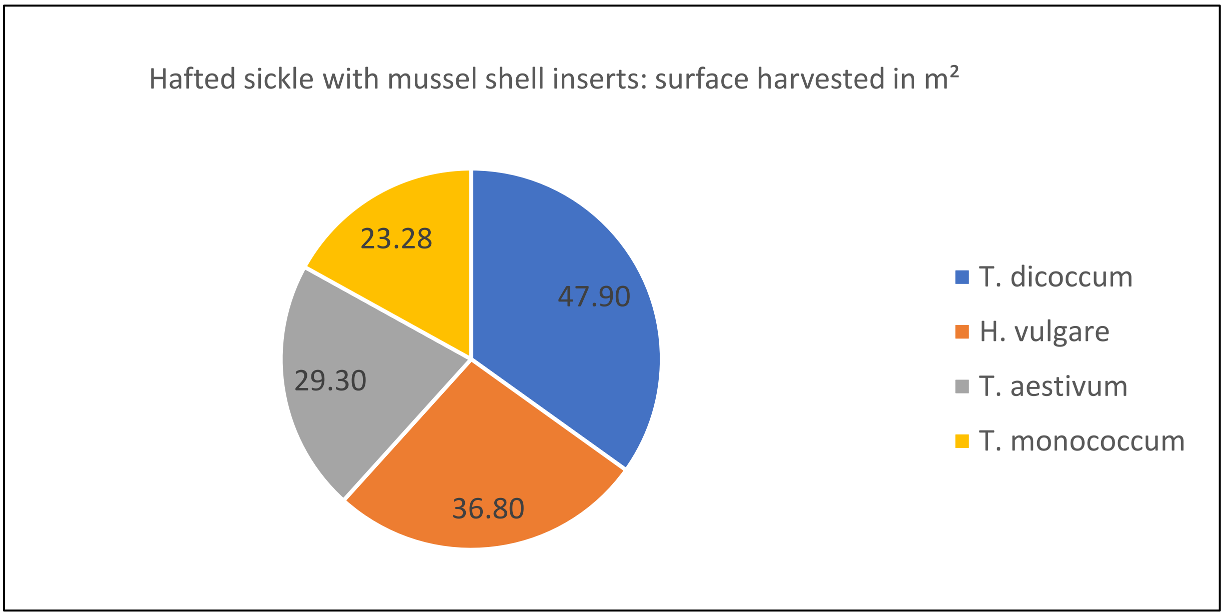


Figure 6.3. Harvesting results of hafted sickles with mussel shell inserts.

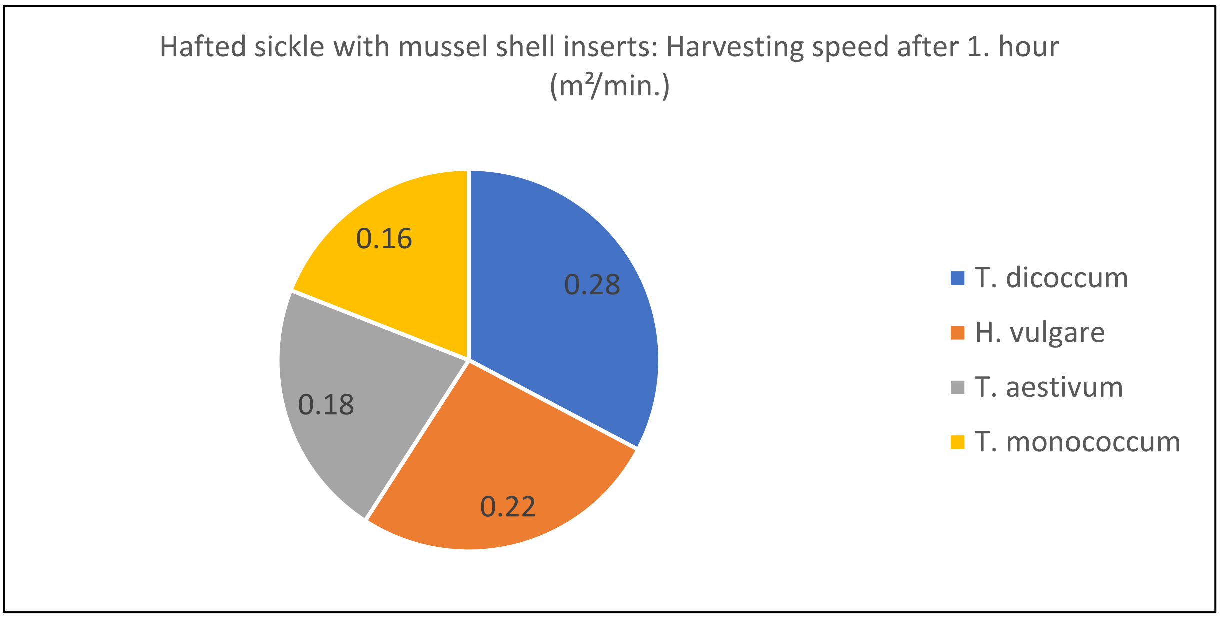


Figure 6.4. Harvesting speed achieved with hafted sickles with mussel shell inserts.

6.1.3. Wooden sickles

The overall result in terms of surface harvested is far more mixed with this tool than with the hafted sickles. The worst recorded performance was while reaping *Triticum monococcum*. Only 4m² of stems could be collected within the first hour and the harvest was stopped after a total of 80 min. (6m² harvested) due to poor results. Even if the experiment would have continued for three hours, only a maximum of 12m² could have been reaped. Because of the thin, grass like appearance of *Triticum monococcum,* with stems not as brittle as with other cereals, this plant was difficult to cut, saw, or hack through. Also, the stems were swaying strongly in the wind, which made them hard to grasp. Only a few stems could be ripped through, and most were uprooted.

Triticum aestivum and *Hordeum vulgare* gave far better results with more than 30m² of field reaped in 3 hours each (see fig. 6.5.). Interestingly, the organically grown field of *Triticum aestivum* which was interspersed with grass and weeds led to similar results as the conventionally planted *Hordeum vulgare* field (see video in Appendix G). However, in the case of *Hordeum vulgare*, 100% of the harvest were cereal stems, whereas for *Triticum aestivum* an estimated 40% of the harvest were not cereals thus reducing the collected grain volume.

The largest surface harvested was again achieved with *Triticum dicoccum* (51 m²). It is 20m² more than for any other cereals and even higher than obtained with a hafted sickle with mussel shell inserts. Surprisingly, the plants were mostly uprooted and not cut or sawn through, as the soil of the field was sandy and loose.

Thus, reaping with a wooden tool can be effective, depending on the brittleness of the cereal plant and the soil type. Dry and thick stems like *Hordeum vulgare*, *Triticum aestivum* or *Triticum dicoccum* led to a large surface being harvested, whereas thin, grass-like cereals like *Triticum monococcum* led to only small aeras being reaped. Sandy soils like for the *T. dicoccum* field lead to an easy and quick uprooting and a fast harvest.

This result is also reflected in the harvesting speed. *Triticum dicoccum* is reaped the fastest with 0.23m² per min. or 4.3min. per m² (see fig. 6.6.). In the following two hours, the speed even increased to 0.33 and 0.3m²/min. making it one of the fastest reaping in this experiment (see Appendix A). This increase is due to a dryer field the second day of harvest, with plants easier to uproot. *Triticum aestivum* and *Hordeum vulgare* were slower to be collected with 0,20 and 0.15m²/min. respectively. Slowest to gather was also *Triticum monococcum* with 0.07m²/min. due to its thin stems which were difficult to separate from the roots.

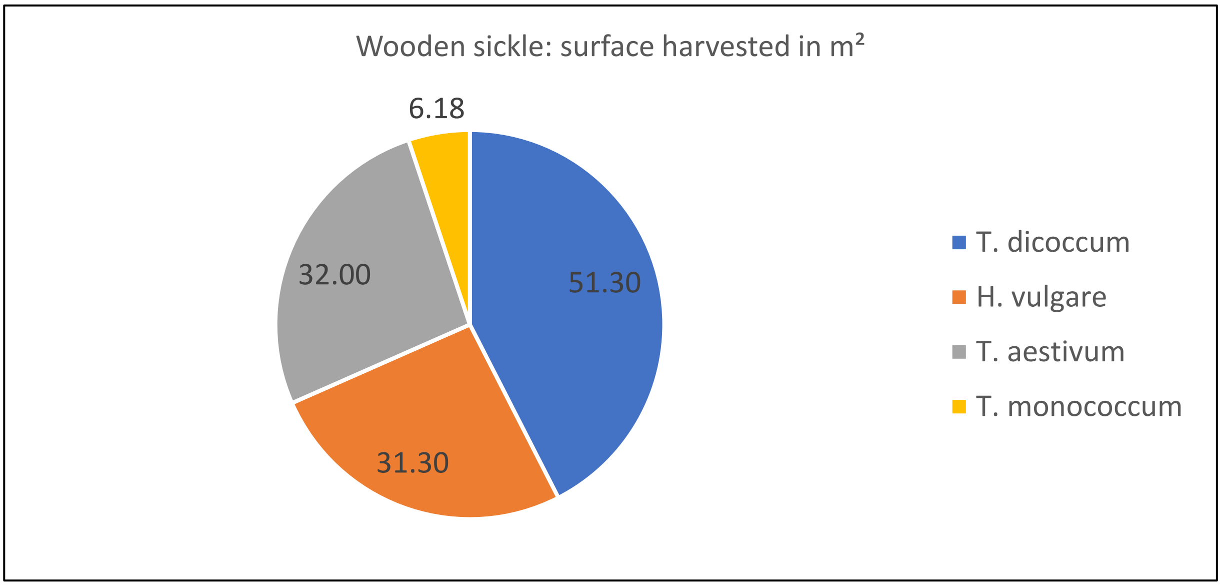


Figure 6.5. Harvesting results of wooden sickles.

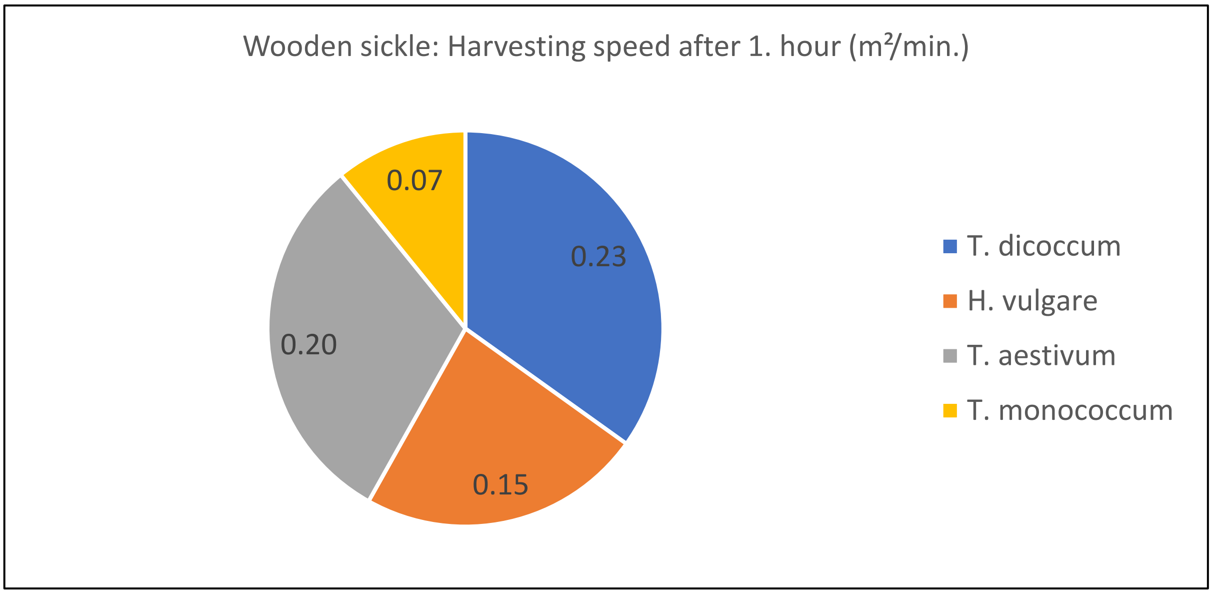


Figure 6.6. Harvesting speed achieved with wooden sickles.

6.1.4. Deer mandible sickles

Using deer mandibles as tools to harvest cereals was very tiring and slow. Many stems could not be ripped through and were being uprooted (see video Appendix G). Therefore, the experimental harvesting time was reduced to one hour for *T. dicoccum,* with close to $11m^2$ collected*, T. aestivum* ($9m^2$) and *H. vulgare* ($7.5m^2$) (see fig. 6.7.). *T. dicoccum* could unfortunately not properly gathered in Lauresham with the deer mandible, due to the very sandy soil composition. The stems could not be sawn through, as they uprooted easily, and the experiment was stopped after 5 min. A second trial was done at the Heidfeldhof for one hour, where the stems could be sawn through due to a more compact soil composition.

Surprisingly however, *Triticum monococcum* could be collected for the entire three hours. It resulted in a total of more than $20m^2$ of surface harvested (see Appendix A). This result is higher than achieved with a wooden sickle and almost at the same level as a hafted sickle with mussel shell inserts. The reason for that is that the thin grass like stems of *T. monococcum* were easy to rip through in a sawing motion. In addition, as the tool has a long frontal part i.e., diastema (see terminology in Appendix E); (Fletcher et al., 2010, p. 6), it was easy to saw above the dry leaves covering the base of the plant. Also, since the plant had an average height of 1.40m, cutting at 30 to 50 cm above the soil resulted in a stem sufficiently long to be bound into sheaves.

In terms of speed, all cereals were reaped between 0.11 to $0.18m^2$ per min. or a maximum of 5,5 min. per m^2 (see fig. 6.8.). This is rather slow compared to the other tools where certain cereals (especially *Triticum dicoccum*) were collected much faster. However, for *Triticum* *monococcum,* the speed even increased the 2nd hour to 0.12m²/min (see Appendix A). This is an indication that the tool was fully functional during the entire three-hour harvest, as the teeth of the mandible stayed sharp.

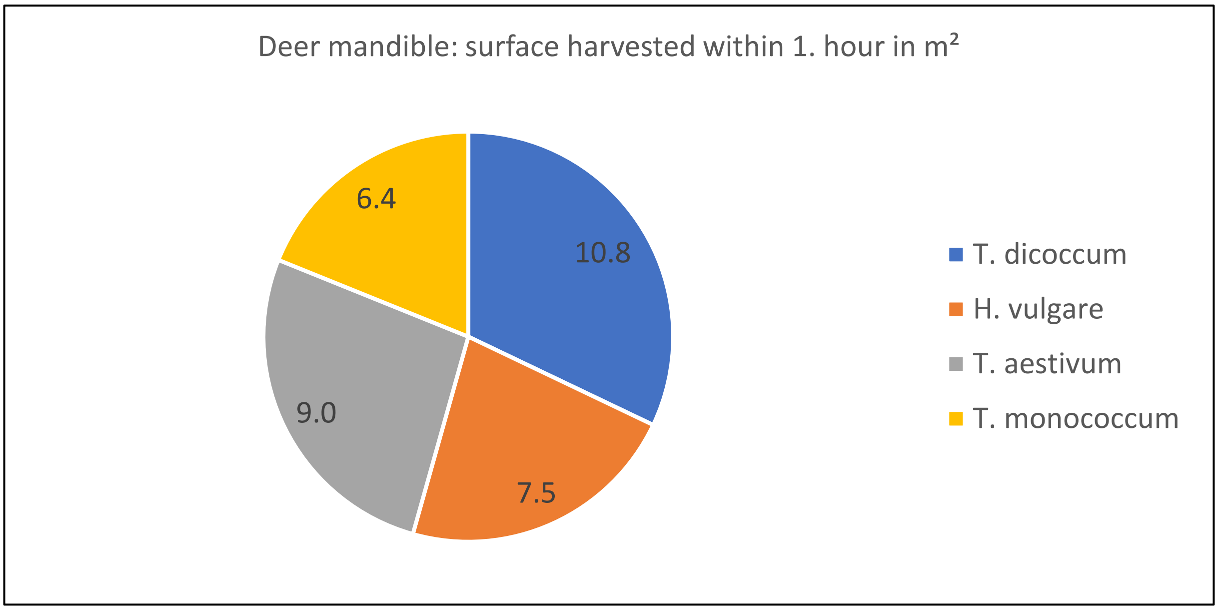


Figure 6.7. Harvesting results of deer mandibles after 1. hour.

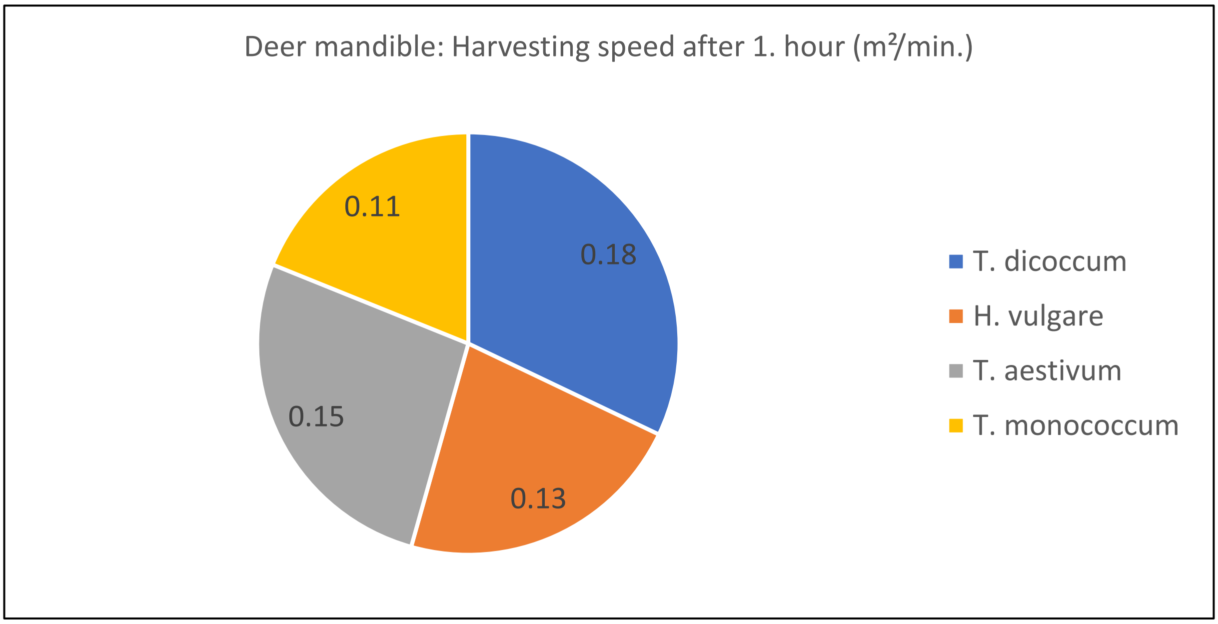


Figure 6.8. Harvesting speed achieved with deer mandibles.

6.1.5. Uprooting entire cereal stems

To compare the efficiency of these different alternative tools, an additional tool has been included to the experiment, the hand. The objective was to compare the efficiency of uprooting entire cereal stems by hand to cutting these with different types of sickles. One advantage of uprooting is that the entire plant can be used for roofing, as animal feed or as fertiliser (see Chapter 2.1.1). A disadvantage of this method is the collection of soil together with the roots. It needs to be shaken or cut off after the harvest, otherwise the humidity of the earth might cause the ears to rot. (Anderson 1999, p. 124; Ibáñez et al., 2001, p. 26). Also, this technique not only collects the entire cereal plant but also the weed and grass from the field, and they must be separated afterwards. A condition for uprooting is that the soil of the field must be sufficient dry and friable (Anderson & Sigaut, 2015, p. 86), like very sandy or volcanic soil.

As such, all four cereal types were harvested for one hour each by uprooting the entire plant (see fig. 6.9.). *Triticum dicoccum* was the cereal type where the largest aera (almost 18m²) could be reaped. Extrapolated over three hours of collecting, this would have resulted in 53.40m² of harvested field, the second-highest result in this experiment (see Appendix A). The reason for this strong performance could be that the field was very sandy and that the cereal plants were easy to uproot. This was also the initial reason for the deer mandible not performing well on this field as the soil was too loose and the stems could not be ripped through but got uprooted.

Surprisingly, the result of uprooting *Triticum monococcum* was also very good. By extrapolating the result of 10m² per hour reaped over the entire period of three hours, the harvested surface would have been around 30m². This would have been by far the best result for this cereal type within all tested tools (see Appendix B). In other words, collecting *Triticum monococcum* by hand is the most effective way. This might be because the thin and flexible stems of *Triticum monococcum* are difficult to cut, saw or rip through with sickles made from shell, wood, or teeth. But pulling them out of a friable and loose soil, as done in the experiment, was far easier.

For *Hordeum vulgare*, a 9.2m² surface was uprooted after one hour. This would have resulted in 27.6m² of harvested aera after three hours. This is less than with a shell or wooden sickle but better than with a mandible (see Appendix B). The short height of that plant (60 cm) might be a reason that uprooting is more difficult than with higher plants. The harvester must bend very low to grab the stems and pull them out of the ground.

Finally, the harvested aera of *Triticum aestivum* was the smallest with only 5m² reaped within one hour. This is because the cereal plants were mixed with grass and weeds. Also, the soil is not sand but clay and pulling out these plants together is difficult, as their roots are interlocked, and large amount of earth is uprooted at the same time. It was easier to pluck the *Triticum aestivum* stems one by one like flowers, than to grab a bundle of stems and try to pull them out.

But on conventional fields, with loose soil and where herbicides and pesticides are used, the plants can be uprooted much more easily.

In terms of speed, *Triticum dicoccum* has been reaped the fastest with 0.30m² per min. or 3.3min. per m² due to the loose soil it was growing on (see Chapter 5.4.2.). Uprooting other cereal types was far slower with speeds 45% to 75% lower compared to *Triticum dicoccum* (see fig. 6.10.). Especially gathering *Triticum aestivum* from an organically planted field full of grass and weeds was not effective.

For certain periods of the Neolithic, where flint sickles have been absent, it was assumed that cereals could have been uprooted (Ibáñez et al., 2001, p. 33). But this assumption appears difficult to confirm on this experimental level. Uprooting is easy and sometimes even better than using a tool on conventional fields with soils treated with herbicides and pesticides and therefore without weeds and grass. It is also possible on loose and sandy, for example volcanic soil (Anderson & Sigaut, 2015, p. 86). But on an organically planted field with a hard clay soil and where cereal plants grow with grass and weeds, as seen on *Triticum aestivum* in the Lauresham Open-Air Laboratory, it is challenging. In other words, harvesting cereals through uprooting appears almost impossible to have been done in the Neolithic of North-Western Europe on hard clay soils. The plants could not be pulled out of a rather humid and compact soil but had to be plucked one by one.

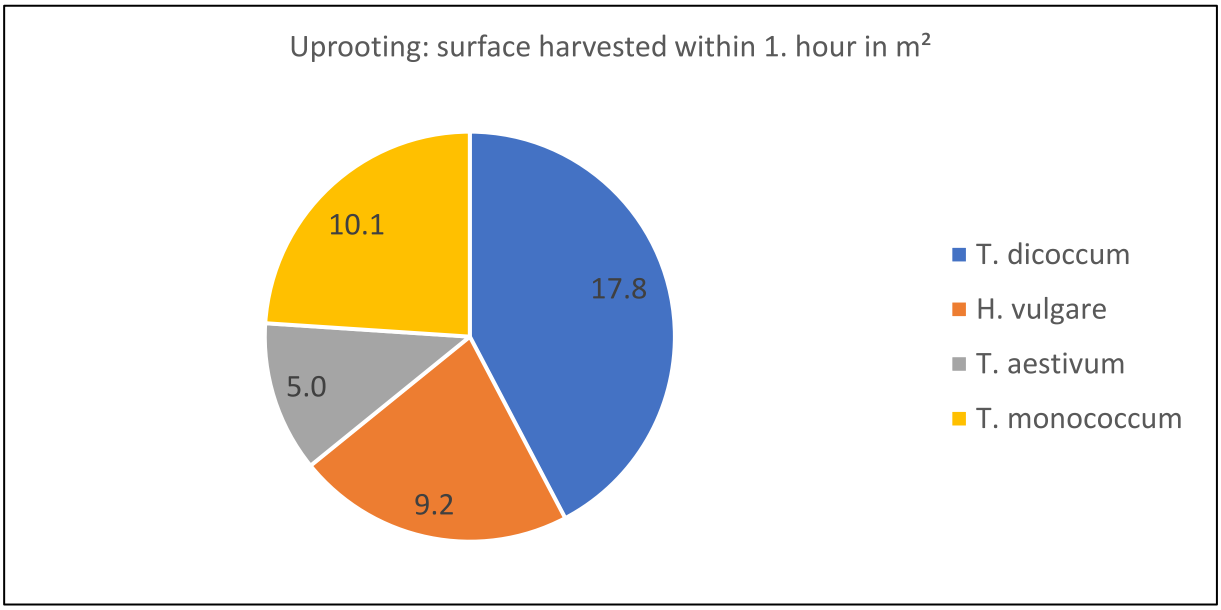


Figure 6.9. Harvesting results of uprooting cereal stems.

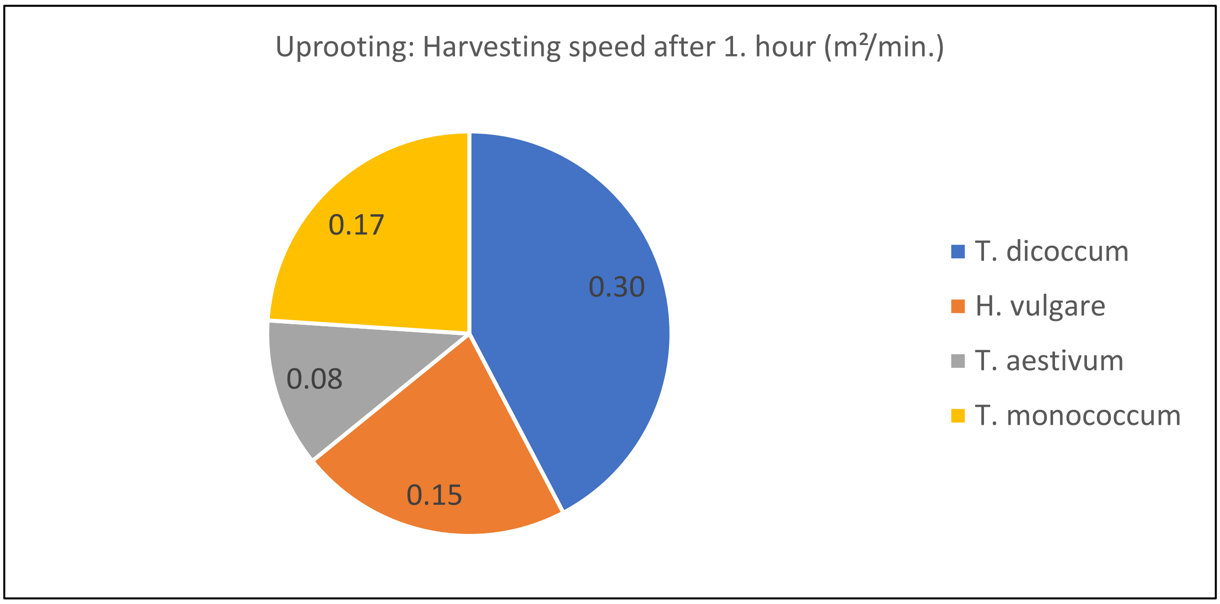


Figure 6.10. Harvesting speed achieved by uprooting cereal stems.

6.2. Snapping off cereals

After reaping cereals with sickles, hand-held shells were used as harvesting knives. These knives have been made from entire oyster and mussel shells. These have been used to snap off just the ears, while the stem of the plants was kept standing on the field. The resulting harvested surface was, in comparison with the use of sickles, rather poor. On average, the harvesting knives only reaped 1/3 of the surface achieved with sickles and, therefore, much less grain was collected. Still this method had its advantages. It was easier to gather cereals ears than with sickles, as the harvester does not need to bend forward to grasp the stems close to the ground. He can just stand next to the plants and snap the ears off one by one without strong physical effort (see Chapter 5.5.6.). Also, the harvest was clean of weeds and grass, as only the ears were collected. The stems were left standing in the field to be used for other purposes as animal feed or future fertilizer (Ibáñez et al., 2001, p. 32). For *Triticum dicoccum* and *Triticum monococcum,* this method had the added advantage that these plants have a breakage point at the base of their ears. They can easily be separated from the stems by bending them backwards without the need to pull the ears upwards (Peña Chocarro, 2015, p. 103).

6.2.1. Hand-held oyster shell

About $12m^2$ of *Triticum dicoccum* could be gathered with an entire hand-held oyster shell within three hours (see fig. 6.11.). The plant was high and sturdy, making it easy to snap off the ears. Next was *Hordeum vulgare* with $7m^2$ surface collected in the same amount of time. There, an oyster fragment has been used. This was a very tiring harvest, as the plant is on average only 60 cm high, and the harvester had to bend steeply forward to snap the ears off the stems.

For *T. aestivum* a first attempt was made at Lauresham on organically grown cereals. The reaping was very slow since the ears had to be plucked one by one as the plants were spaced quite far apart. The experiment was stopped due to this slow progress. A second attempt was made later at the Heidfeldhof on conventionally grown *T. aestivum*. The plants were standing close to each other, and the stems were dry. This made snapping off the stems with even the entire oyster shell easy. Close to $5m^2$ of surface could be reaped at the Heidfeldhof.

However, the most difficult to harvest was *Triticum monococcum*. As the plant stems were long, thin, and swayed strongly in the wind, it was difficult to grasp the ears and snap them off. The ears themselves were very brittle and frequently broke off in the middle whilst been cut. This resulted in less than $4m^2$ of surface of *Triticum monococcum* being gathered in three hours, although it was cut with an oyster shell fragment fitting well into the hand.

In terms of speed, the overall velocity compared to sickle tools is far lower, reaching a maximum of $0.08m^2$ per min. or 12.5 min per m^2 for *T. dicoccum* (see fig. 6.12.). For other cereals, the speed is even less, with down to $0.02m^2$ per min. or 50 min. per m^2 for *Triticum monococcum*. With such a low speed, it is questionable if it makes sense to collect this cereal at all, or if reaping with a sickle or a mandible would be more effective.

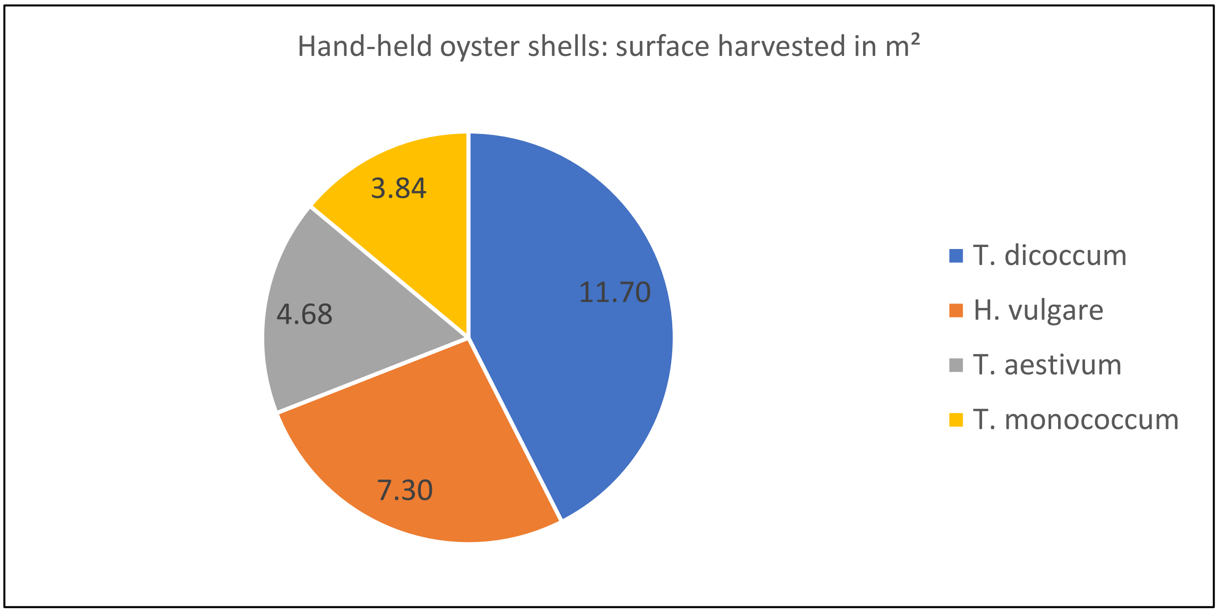


Figure 6.11. Harvesting results of handheld oyster shells.

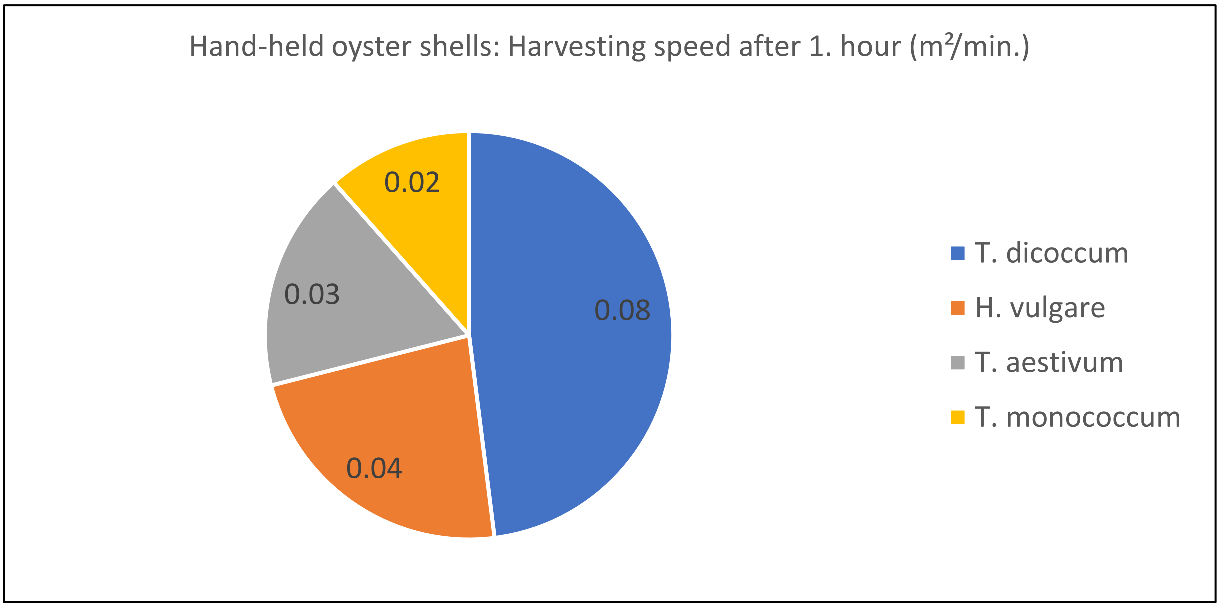


Figure 6.12. Harvesting speed achieved with handheld oyster shells.

6.2.2. Hand-held mussel shell

After the harvest, three out of four hand-held mussel shells showed strong edge breakage. This loss of cutting edge led to a slowdown of the reaping surface and speed. In comparison, the harvested surface of *Triticum dicoccum*, where the mussel shell did not break, was 2/3 larger than for the other cereals (see Appendix A). The surface collected was therefore between 11m² for *T. dicoccum* and 4m² for *T. monococcum*. The results achieved were thus like the ones obtained with the hand-held oyster shells (see fig. 6.13.).

The same applies also for the speed, although most hand-held mussel shells have seen their frontal part been completely worn off by the cereal stems. If these cutting edges would have stayed intact, a higher cereal harvesting speed compared to the hand-held oyster shells could have been achieved.

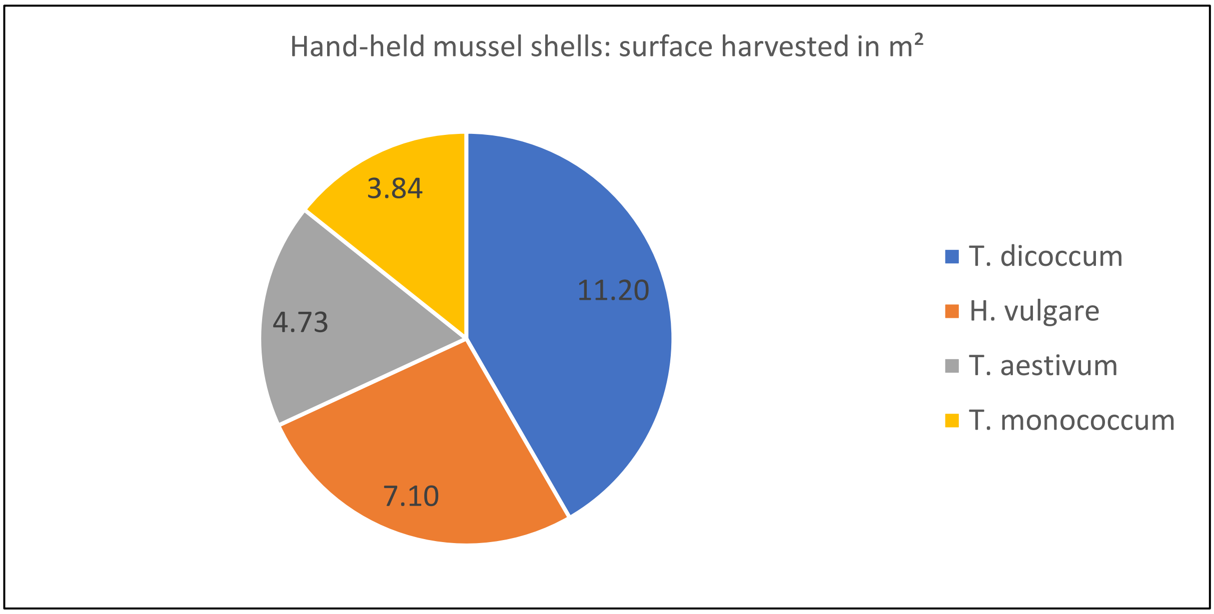


Figure 6.13. Harvesting results of handheld mussel shells.

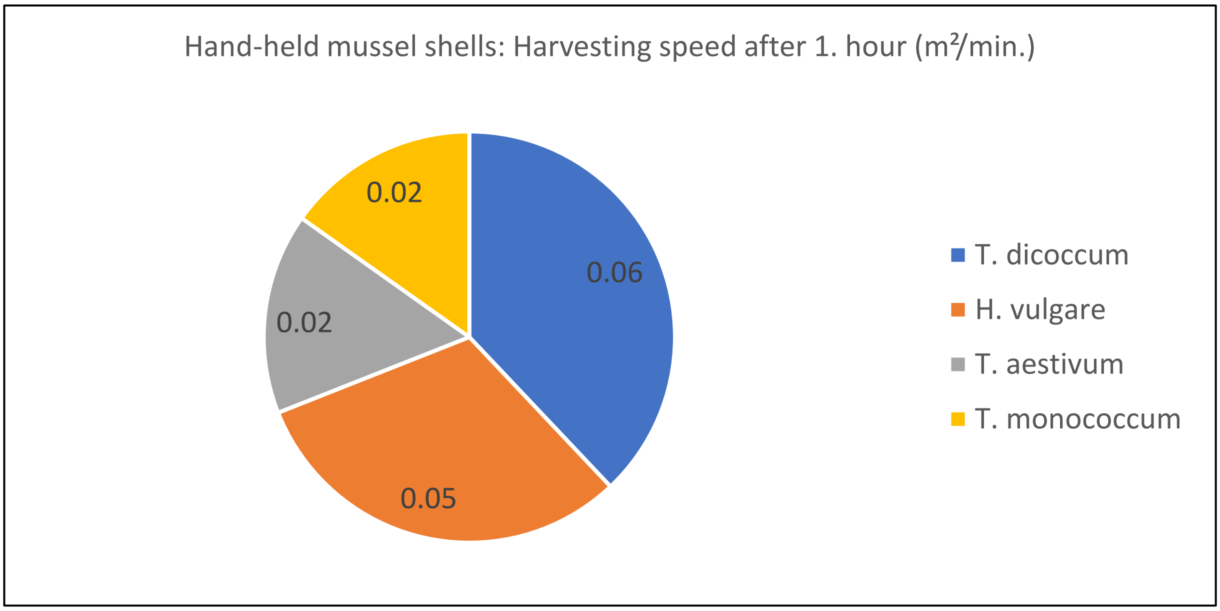


Figure 6.14. Harvesting speed achieved with handheld mussel shells.

6.2.3. Snapping ears off by hand

To judge the effectiveness of the above two types of hand-held shell used as harvesting knives, a trial was made using just the bare hands to snap off cereal ears. The idea was to compare the results of hand collecting against reaping with hand-held shells used as harvesting knives. Could snapping off ears by hand not be faster and easier? As such, three cereal types were selected to be hand-snapped for one hour. *Hordeum vulgare* was excluded from the trial, as it was judged too short and therefore too tiring to gather. In addition, the field of *T. aestivum* in Lauresham has not been included in this trial, as the cereals were growing too far apart. Instead a conventionally planted field of *T.aestivum* at the Heidfeldhof has been selected.

Surprisingly, it appeared that collecting by hand was often faster and gave better results per surface than with a hand-held shell tool (see fig. 6.15.). Of *Triticum aestivum,* 2.5m² surface could be gathered within one hour (see Appendix A). This was done by snapping off the ears from the stems with the thumb nail. Extrapolated over three hours of harvest, this would amount to 7.5m². This is 60% more surface harvested than with either a hand-held mussel or oyster shell. For *Triticum monococcum* 1.68m² of aera could be reaped by hand. This would result in more than 5m² gathered after three hours, or 30% more than achieved with a hand-held shell tool. Only for *Triticum dicoccum* the achieved surface reaped by hand was lower than with hand-held shells. Only 3m² could be reaped during the first hour, or extrapolated 9m² over three hours, compared to 11m² of surface with hand-held shell tools (see Appendix A).

This was also visible in terms of speed. The hand-snapping of *Triticum aestivum* and *Triticum monococcum* resulted in a velocity 25% to 50% higher compared to hand-held shell tools (see fig. 6.16.). Only for *Triticum dicoccum*, it was slower. In short, snapping off ears by hand could be a viable option compared to snapping off ears with a hand-held shell tool. Hand-snapping had the advantage that no material needs to be gathered and sharpened as for shell tools. But it had the disadvantage that the finger of the harvester, after one hour, are starting to hurt, and therefore these volumes and speeds cannot be sustained during an entire workday.
But does the process of harvesting cereals need to be fast, to be effective? Maybe this way of reaping has a particular function of, for example, collecting grain without weeds. It can also enable physically and psychologically weaker people like children or the elderly to contribute to the collective result. It can also allow to collect grain from surfaces with a low plant density. For snapping off ears, the speed of reaping appears not to be the decisive factor. The entire process of grabbing, gathering, snapping off, and storing the ears is defining the speed and

therefore the yield of that type of harvest. The cutting performance of the tool, as for the sickles, appears not to be the major factor.

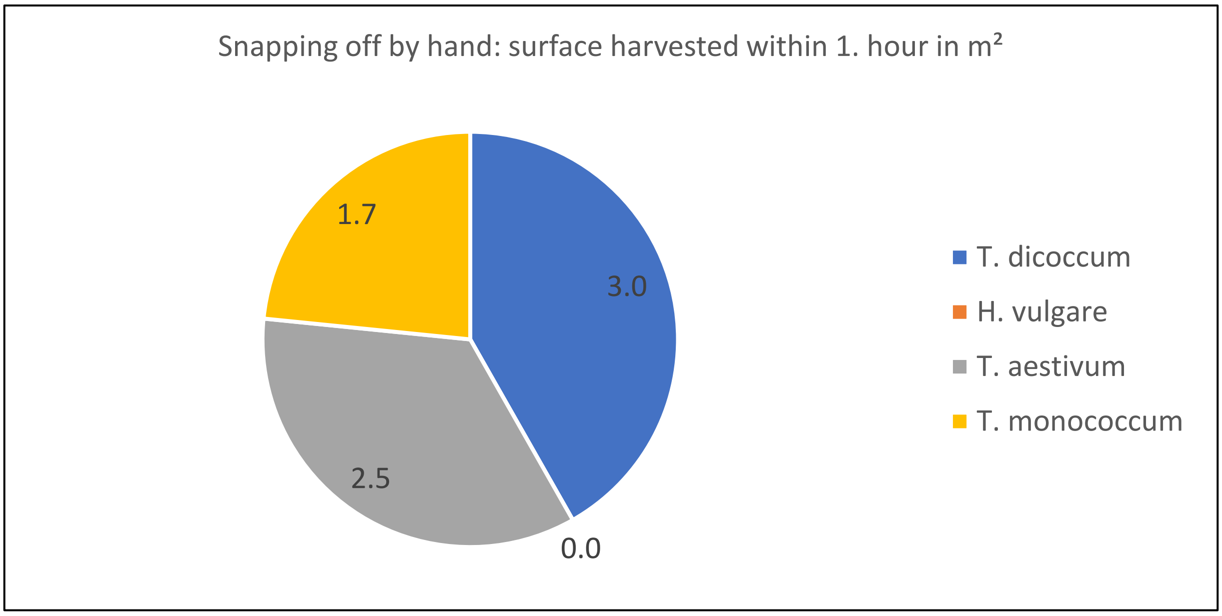


Figure 6.15. Harvesting results of snapping off ears by hand.

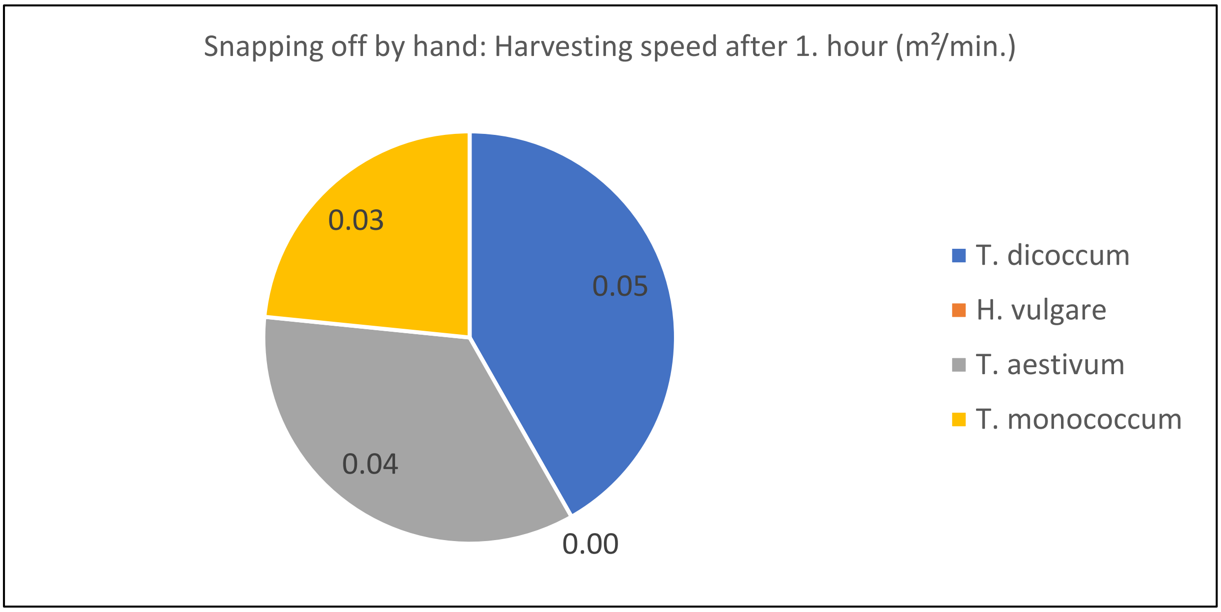


Figure 6.16. Harvesting speed achieved by snapping off ears by hand.

6.3. Harvested surface and grain yield by cereal type

This section presents two types of overviews. The first overview focuses on the harvest results per m² achieved for each cereal type. It shows how much surface from the same type of cereals has been collected over a given period by different tools. The bar graphs indicate the harvested surface after one hour. Subsequent results with the same tool during the next hours have been added to each bar. Higher results are found on the left and lower results are shown on the right side of the graph. A detailed overview of the data can be seen in Appendix B.

The second overview presents the grain yield of these cereal types. The overall data regarding the yield of each cereal type has been obtained from the person in charge of the reaped fields. This yield is given in t/ha or ton per hectare. Based on this data, the yield in kg per m² of harvested surface has been computed. It indicates how much grain (in kg) was collected with the tools used during this experiment (see Chapter 5.5.4.).

This yield in kg per tool and per cereal type has then been compared to research data on human cereal consumption. Several scientists have tried to estimate how much grain a person would need to survive for one year. This consumption volume is estimated to be between 120 to 350 kg (Bogaard, 2004, p. 43; Davis, 1991, p. 163; Foxhall & Forbes, 1982, p. 72; Halstead, 1981, p. 317; Hillman, 1973, p. 229; Perles & Monthel, 2001, p. 165; Renfrew et al., 1982, p. 278). For the present calculation, an average of 200 kg of grain per person per year has been considered. To cover the yearly needs of a family of five as suggested by A. Bogaard, (Bogaard, 2004, p. 43), this would mean 1,000 kg of grain to be collected. Based on both averages, the amount of time needed to gather this amount has been computed. This calculation is based on an average workday of 14 hours (Anderson & Peña Chocarro, 2015, p. 94). If, for example, 15.77 kg of grain can be collected within one hour, with a hafted sickle with oyster shell inserts, as in the example of *T. aestivum*, (see fig. 6.18.) the harvested amount after one day would be about 221 kg (15.77 kg x 14 = 220.78 kg). For a family of five, with an estimated annual need of 1,000 kg of grain, therefore less than five days of harvest are needed (221 kg x 5 = 1,105 kg).

6.3.1. Cereal harvesting results of Triticum aestivum

Triticum aestivum, has been collected with nine different tools. The results were very different in terms of harvested surface (see fig. 6.17.). The hafted sickles with oyster or mussel shell inserts and the wooden sickle achieved the best results with at least 29m² surface reaped within three hours. With the deer mandible, it was possible to harvest 9m² within one hour. This means an extrapolated 27m² gathered within three hours. Uprooting stems contributed to 5m² of harvested surface or computed 15m² for three hours. With the hand-held oyster and mussel shells and by hand not even 5m² could be collected within 3 hours. The worse results were recorded with the cattle rib. Reaping had to be stopped after a few minutes, as the tool became blunt very fast and did not cut through the stems after that (see Appendix B).

In terms of grain yield, the best result could be achieved with the hafted sickle with oyster shell inserts (see fig. 6.18.). More than 15 kg of *T. aestivum* could be collected within one hour. This yield drops sharply to 10 kg and 8 kg during the following two hours, after the sickle lost two inserts (see Appendix B). Other tools like the wooden sickle or the hafted sickle with mussel shell inserts only achieved a yield of close to 10 kg per hour. Worse are the hand-held oyster and mussel shells with a yield of less than 1.5 kg per hour. Snapping off ears by hand resulted in 2 kg of yield per hour, which was a better result than with hand-held shell tools. Contrary to our expectations, the yield of the organically grown *Triticum aestivum* was with 8.3 t/ha even higher than conventionally planted cereals like *T. dicoccum*. This might be due to the fact, that a modern cereal strain was sown and was highly productive. (Dorn et al., 2023). It could also be that the yield of 8.3 t/ha was calculated including the collected grass and weeds, as the sheaves, which were bound together and stored, included these. To take a more conservative approach, the official, average yield of organically grown *T. aestivum* in Southern Germany could be used. This was 3.8 t/ha in 2020 according to the latest available data from the association of organically growing farmers Bioland (Bioland, 2023). Using this data, the grain yield for *T. aestivum* would be for a sickle with oyster shell inserts 7.22 kg (3.8 t/ha / 8.3 t/ha x 15.77 kg = 7.22 kg), for a sickle with mussel shell inserts 4.17 kg, for an oak wood sickle 4.6 kg, for a deer mandible 3.4 kg, for uprooting 1.9 kg, for a hand-held oyster shell 0.7 kg for a mussel shell 0.5 kg and for hand-snapping 1 kg.

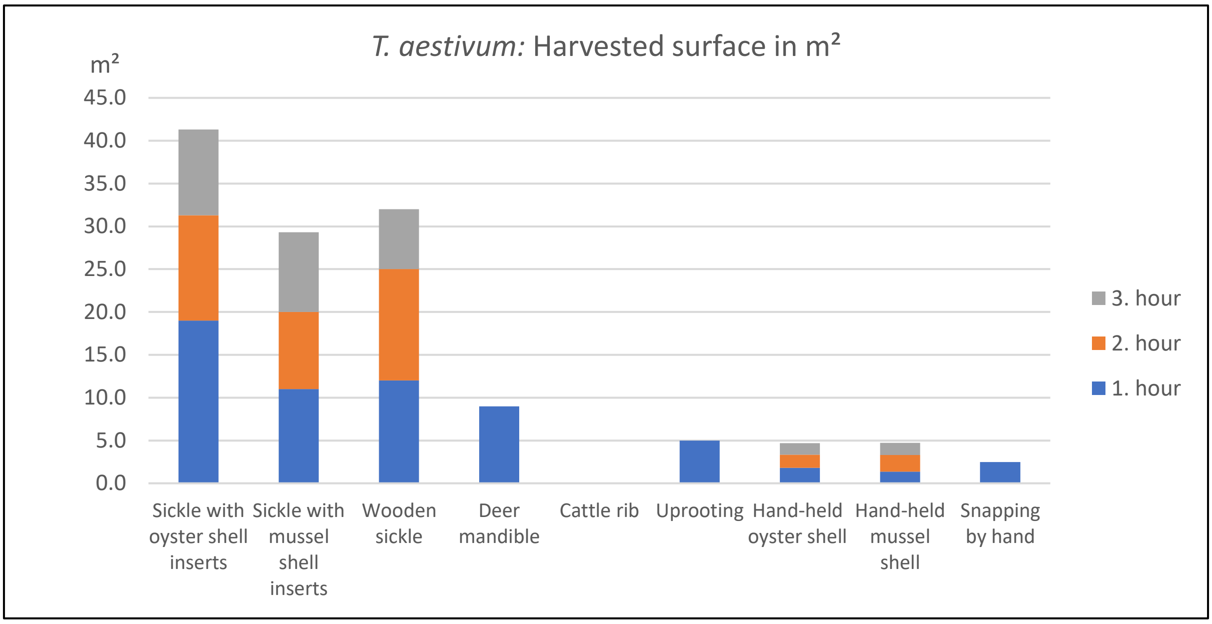


Figure 6.17. Harvested surface in m² of T. aestivum.

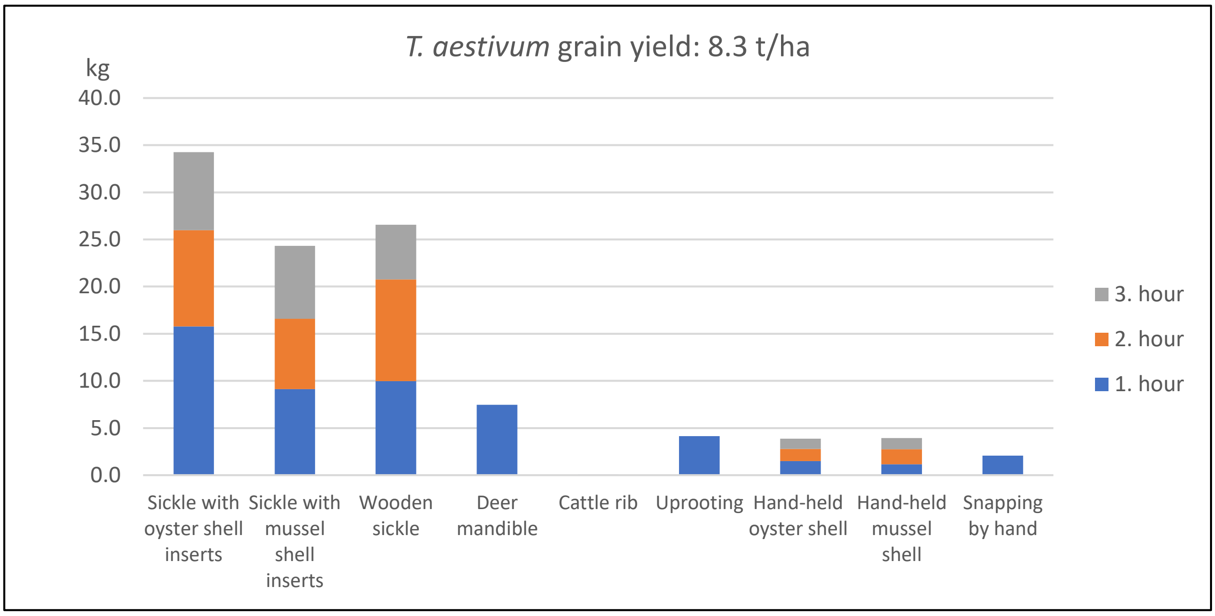


Figure 6.18. Grain yield in kg of T. aestivum obtained with different tools (Dorn et al, 2023).

6.3.2. Cereal harvesting results of Triticum dicoccum

Triticum dicoccum was the cereal which could be harvested the easiest and fastest of all tested types of grain. Out of the nine tested tools, four of them resulted in at least 47m² of cereals collected after three hours (see fig. 6.19.). Even uprooting, although only tested for one hour, could achieve as much as a hafted sickle with shell inserts, or a wooden sickle. The mandible also yielded more than 10m² of surface after one hour. Cattle rib, as already seen with *Triticum aestivum,* did not cut through the stems of *T. dicoccum*. The cutting edges became blunt very fast and resulted only, after a lot of hacking, to uproot the stems. As such, reaping with this tool proved impossible and the trial had to be abandoned. Snapping off ears with shells also yielded good results, although far less in comparison when sickles were used.

The grain yield of *Triticum dicoccum* was reported with 7.9 t per hectare slightly lower than the above *T. aestivum*. Reaping with a hafted sickle with oyster shell inserts resulted in a maximum of 14.77 kg of grain harvested per hour. Within a 14-hour workday, this would mean about 207 kg of grain could be gathered with such a sickle (14.77 kg x 14 h = 206.78 kg). This would be the needed yearly grain volume for one person (see fig. 6.20. and Appendix B). With a wooden sickle or a deer mandible, around 10 kg of grain could be collected per hour. Handheld tools resulted in around 2-4 kg of reaped grain. But this grain consisted only of ears, making it easier to use at a later stage (see Appendix B).

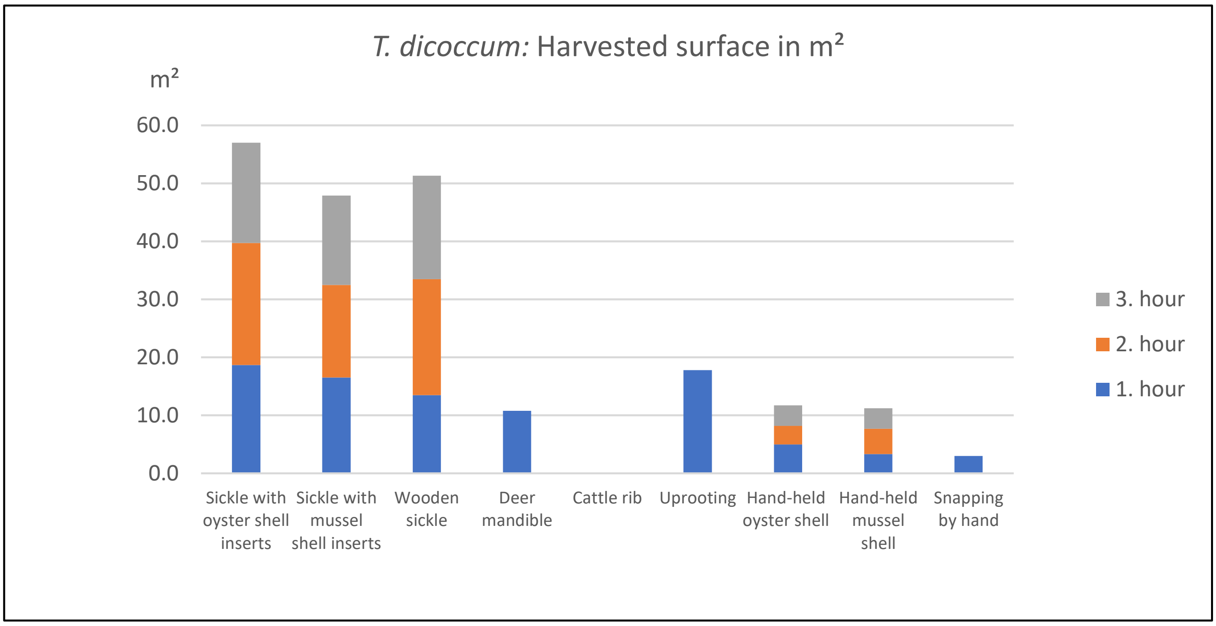


Figure 6.19. Harvested surface in m² of T. dicoccum.

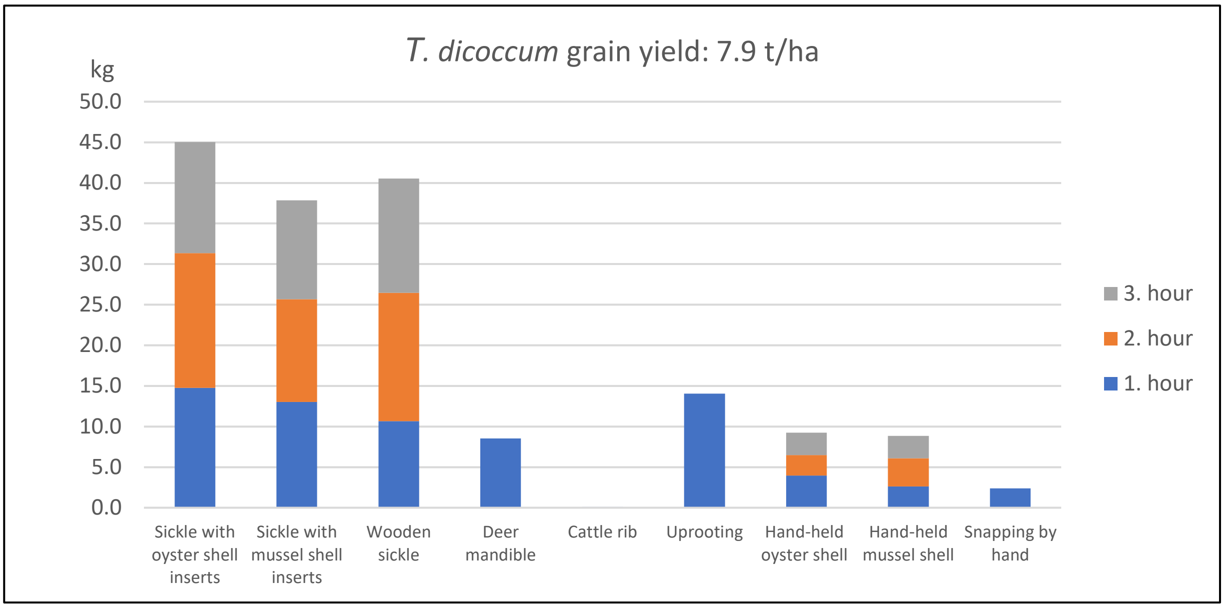


Figure 6.20. Grain yield in kg of T. dicoccum obtained with different tools (S. Rrecaj, personal communication, 2nd February 2023).

6.3.3. Cereal harvesting results of Hordeum vulgare

Hordeum vulgare has been collected with seven different tools. Also, here the sickles (shell and wood) were the most effective with more than 30m² of surface harvested after three hours (see fig. 6.21.). But also uprooting and the deer mandible proved to be suitable for reaping substantial surfaces. However, the cattle rib proved unsuitable, and the harvest was abandoned after a few minutes. Surprisingly, snapping off ears was quite successful with close to 8m² reaped with the hand-held oyster and mussel shells. This is a better result than for *T. aestivum*, although the reaping was more difficult due to the low height of the plant.

The grain yield for *Hordeum vulgare* is significantly lower than compared to *T. aestivum* and *T. dicoccum*. A harvest with a hafted sickle with mussel shell inserts resulted in a yield of only 7 kg of grain per hour, about half compared to the same tool with *T. dicoccum* (see fig. 6.22.). But the spread of results between the different tools is also smaller. Be it by uprooting, using a wooden sickle or the deer mandible, the yield lies between 4 to 5 kg grain per hour. With hand-held shell tools, it was possible to collect close to 1.5 kg of cereals. To achieve the needed annual grain amount for one adult, about 2 full working days of 14 hours are needed with a hafted sickle with mussel shell inserts (7.32 kg x 14h x 2 = 204.96 kg). To collect sufficient *Hordeum vulgare* to feed a family of five, thus 10 days are needed (see Appendix B).

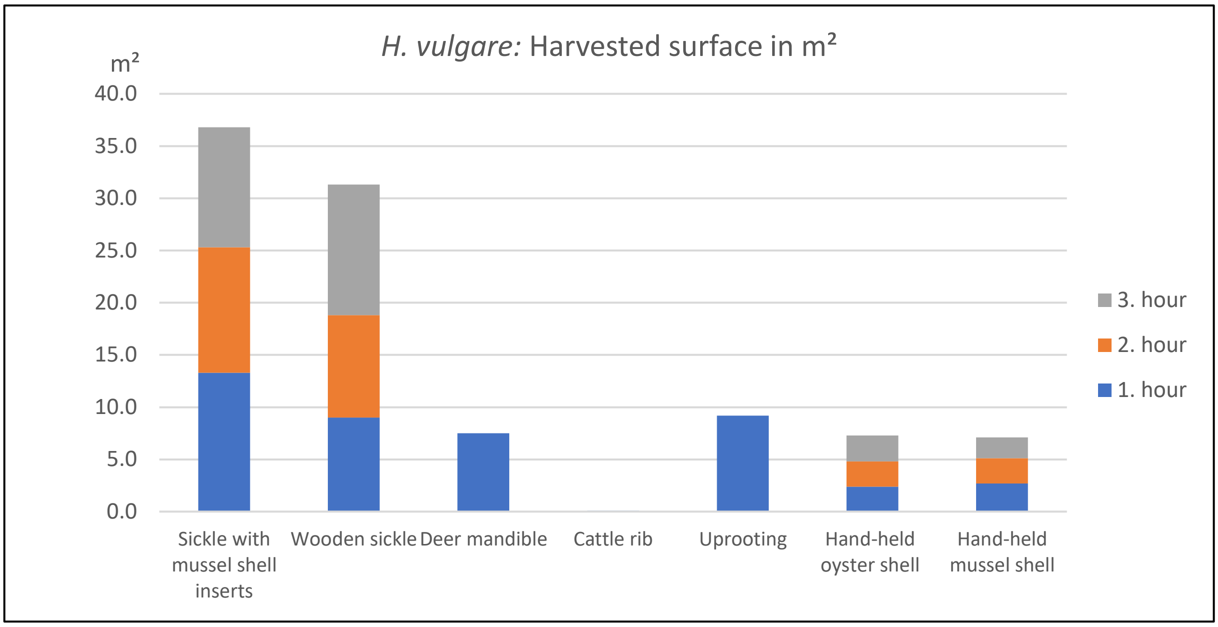


Figure 6.21. Harvested surface in m² of H. vulgare.

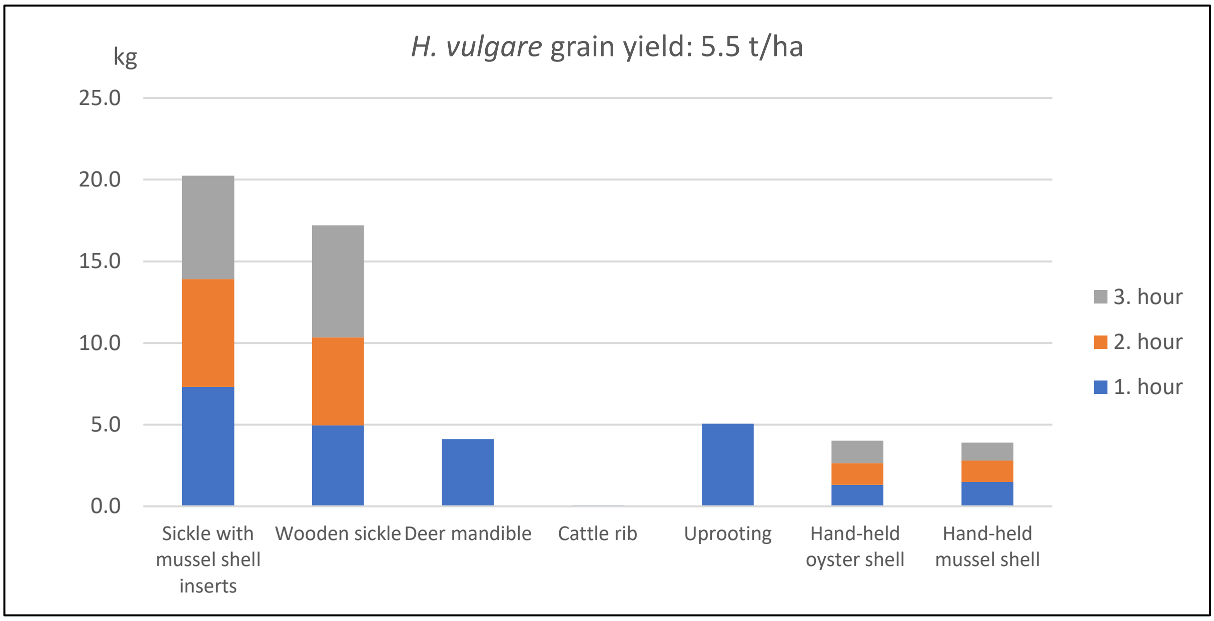


Figure 6.22. Grain yield in kg of H. vulgare obtained with different tools (M. Streck, personal communication, 21st February 2023).

6.3.4. Cereal harvesting results of Triticum monococcum

Surprisingly, for *Triticum monococcum*, uprooting appears to be the best harvesting method (see fig. 6.23.). Extrapolating the 10m² of uprooted surface after one hour, would mean about 30m² reaped in three hours. This is better than any of the results obtained with the other tools. This could be because the soil of the field is sandy and loose, no grass and weeds are present and therefore the roots can be easily extracted. The plant is very high and can be easily grasped. In contrast, the wooden sickle is not very effective as it cannot cut or saw through the stems.

Even a chopping motion does not separate the stems from the roots. Also, the hand-held shell tools are the least effective tools with no more than 1.2m² collected within one hour.

The grain yield achieved by each tool for *Triticum monococcum* is among the lowest of all tested cereals. It reaches close to 6 kg grain per hour by means of uprooting or with a hafted sickle with mussel shell inserts (see fig. 6.24.). With the deer mandible, a maximum of 4 kg can be collected. The use of handheld shell tools results in less than 1 kg of grain collected per hour. This is due to a combination of a low yield and a small, reaped surface. To achieve the annual grain volume for one person, a minimum of 2.5 full working days of 14 hours each are needed. To feed an entire family of five people, 12 days are needed (see Appendix B). From a cereal yield and harvesting perspective, this is the least attractive grain to reap.

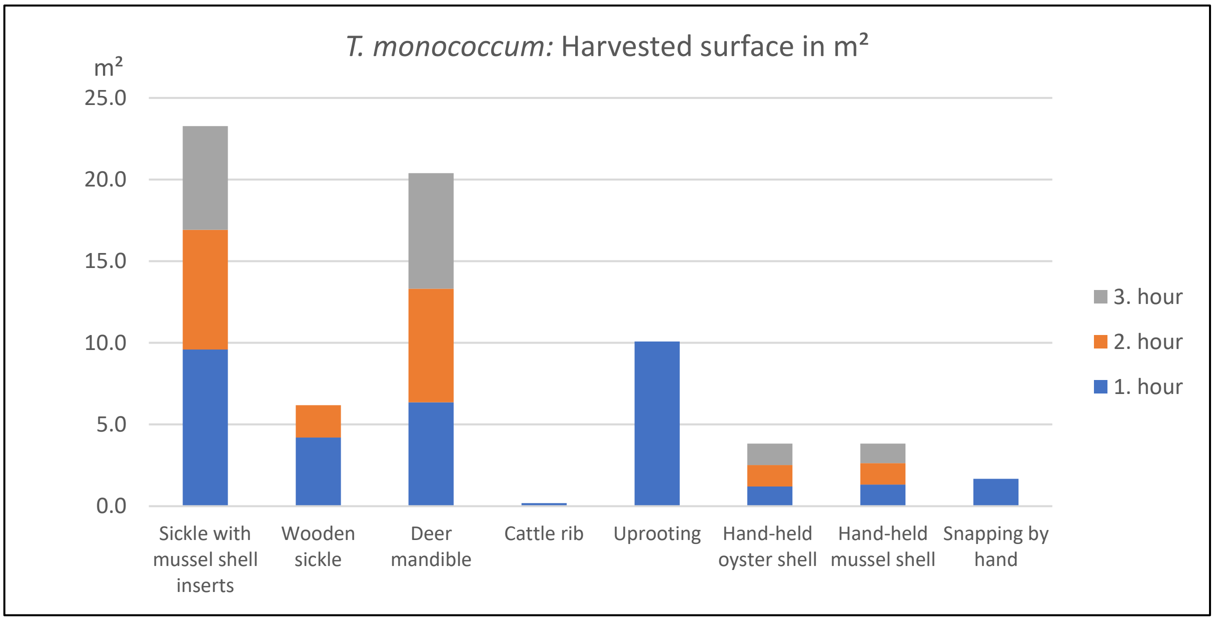


Figure 6.23. Harvested surface in m² of T. monococcum.

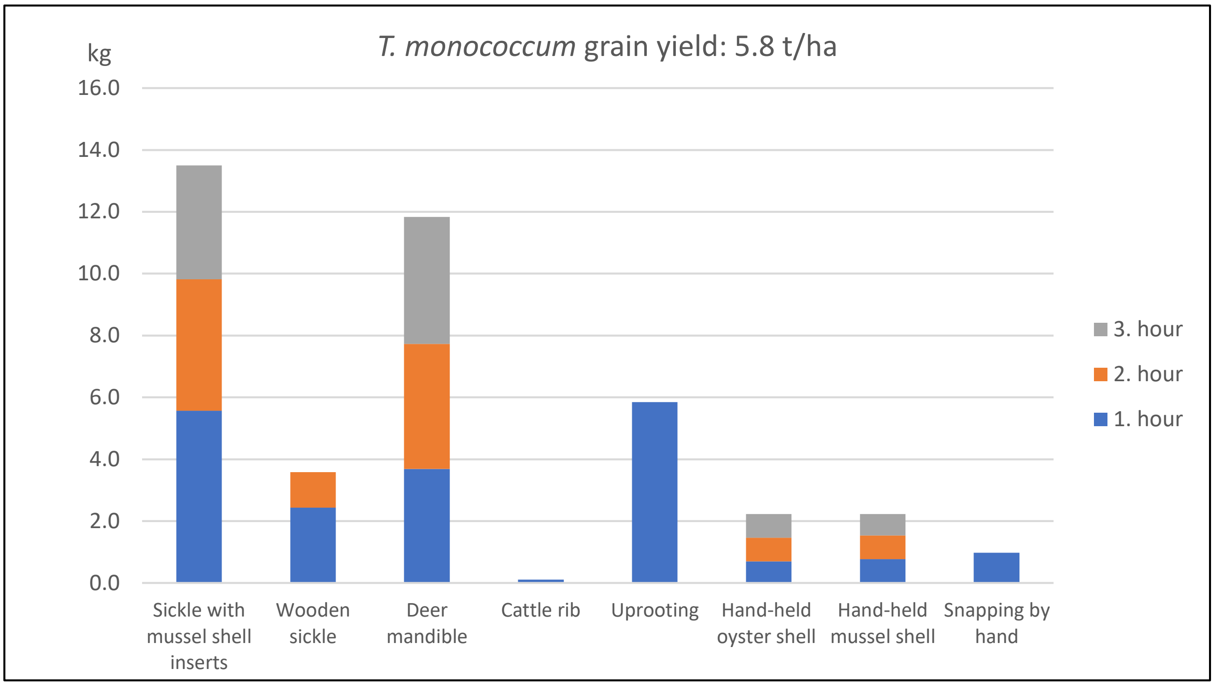


Figure 6.24. Grain yield in kg of T. monococcum obtained with different tools (S. Rrecaj, personal communication, 2nd February 2023).

6.3.5. Cereal harvesting results by the hour

In this overview, the overall surface reaped per hour has been compared across all tools and all cereal types (see fig. 6.25.). The total surface collected per hour remained stable during the first and second hour of the cereal harvest. This is both valid for gathering done with sickles (blue) and done with harvesting knives (orange). Only during the third hour a decline is visible. This is due to the increased bluntness of the tools and due to some missing inserts. Harvester fatigue would not be a reason for this reduction, as the harvest is done in 1-hour segments over several days. This meant that the third hour harvest was not necessarily done at the end of a tiring day but could be also at the beginning of the next.

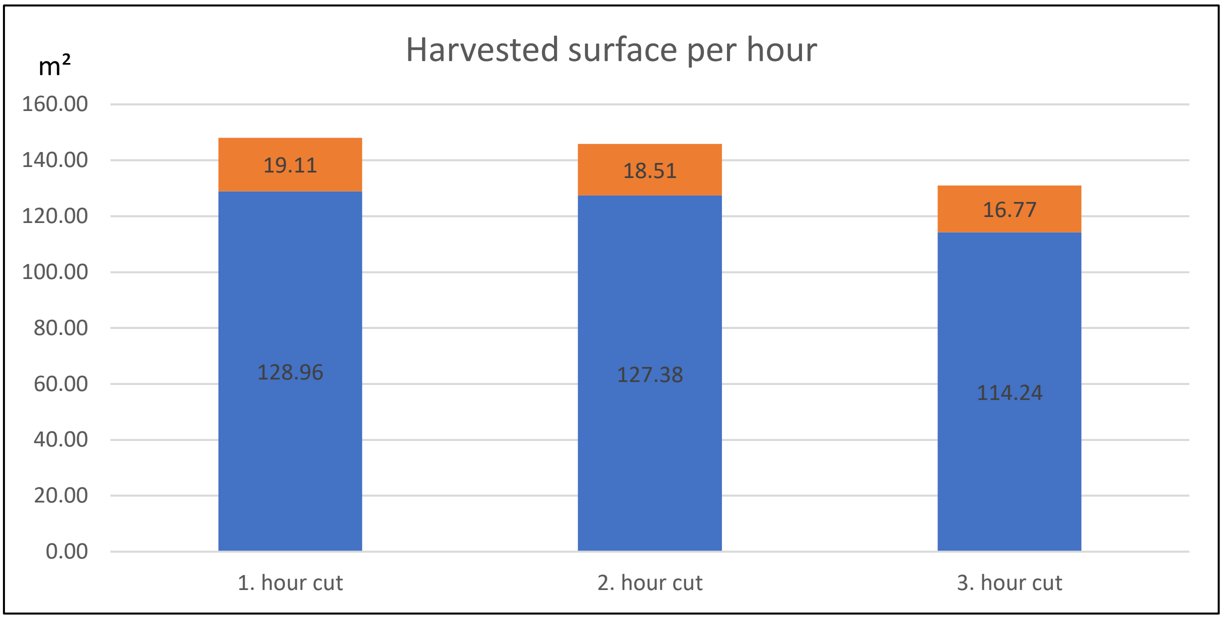


Figure 6.25. Overall harvested surface per hour.

6.4. Conclusion of quantitative harvesting results

The best performing tool type in this experiment was the hafted sickle with oyster shell inserts followed by the hafted sickle with mussel shell inserts, the wooden sickle, and the deer mandible. The cattle ribs, by contrast, were not effective. Uprooting by hand also proved adequate, particularly with *T. monococcum* but not with *T. aestivum*. This supports the claim that uprooting cereals in organically planted fields on compact soils is difficult and might not have been widely practiced in neolithic North-Western Europe (Bakels, 2009, p. 73; Bakels & van Gijn, 2015, p. 111). It might only be suitable in very dry and loose soils as seen in ethnographic context on the island of Lanzarote (Anderson & Peña Chocarro, 2015, p. 95).

Hand-held shell tools used as harvesting knives are slow and snapping ears off by hand is often faster. This puts into question the effectiveness of these tools.

The speed recorded during the experiment was between 0.35m²/min. for hafted sickles with oyster shell inserts, 0.33m²/min for a wooden sickle, down to 0.02m²/min, for handheld shell tools. This shows the bandwidth of speed which can be achieved with different tools.

In terms of cereal types, *T. dicoccum* was easiest to harvest, and generated the largest amount of grain. It was followed by *T. aestivum*, although this type was grown organically and was densely mixed with grass and weeds. Other, earlier experiments have shown than cereals grown organically have a poor yield (Juel Jensen, 1994, p. 131). But this did not happen in this case, which might be due to the use of a modern, high-yield cereal type. But it could also be the case, that the calculated yield includes the grass and weeds collected from the field. In this case the yield would need to be revised downwards. *T. monococcum* was the slowest to collect due to its slim and swaying stems, which were difficult to be cut, sawn or ripped through.

In terms of grain yield, *Triticum dicoccum* achieved the highest result with up to 16 kg of grain collected per hour. This is due to a high basic yield of the plant itself and the largest surface being reaped. *Triticum aestivum* followed closely with a maximum of 15 kg gathered per hour, although the grain, being organically grown, made a harvest difficult. With *Hordeum vulgare,* 7 kg of grain could be reaped per hour due to a lower overall yield and a smaller surface collected. Worst was *Triticum monococcum* with only 5 kg grain per hour harvested due to a low grain yield, and low surface harvested. It appears questionable if this cereal can be gathered with these tools within a sufficient time to cover the yearly needs of a person (see Appendix B).

In total the following surface has been reaped:

Table 6.1. Overview of harvested surface (in m²) and number of hours needed to reap four cereal types. The average speed of harvesting is indicated in m²/min (Made by M.-P. Häg).

Cereal types	Total surface harvested (in m²)	Hours harvested	Average speed m²/min.
Triticum dicoccum	210.80	18.00	0.20
Hordeum vulgare	99.29	14.00	0.12
Triticum aestivum	128.61	18.00	0.12
Triticum monococcum	69.48	15.00	0.08
Total	**508.18**	**65.00**	**0.13**

CHAPTER 7 - RESULTS OF THE USE-WEAR ANALYSIS

Following the quantitative cereal harvesting results, these tools were also analysed qualitatively for use-wear traces. A macroscopic study under a stereo microscope (up to 60x magnification) paired with a microscopic analysis under a metallographic microscope (up to 200x magnification) were undertaken to identify possible traces. To record these, digital photographs were taken of each tool before and after the harvest. The objective of the macroscopic inquiry was to monitor traces visible to the naked eye like shortening of the cutting edge, development of dents, nudges, and traces of edge rounding. The microscopic study had the objective to record the minute changes cereal stems leave on harvesting tools, like striations, polish, and detailed edge rounding. All images have been taken by the author.

7.1. Use-wear traces on hafted sickles with oyster shell inserts

T.aestivum and *T. dicoccum*, could easily be cut with hafted sickles with oyster shell inserts during the first hour of harvesting. Later, when inserts started falling off, or got rounded and shorter, the cutting was gradually replaced by sawing. During the last hour, when the remaining inserts were so worn off that they were barely visible standing out of the haft (see fig.7.1. d.), the sawing changed to uprooting. Also, cutting straight i.e., cutting in a 90° angle to the field edge, was not possible anymore and the stems had to be cut or sawn off in an arc motion i.e., cutting in an 45° angle to the edge of the field. Still, the overall cereal reaping was fast and easy.

Both sickles showed strong macroscopic use-wear traces after the three-hour cereal harvest. Their wooden hafts had a glossy sheen on both sides of the inserts and at the handle. The former developed due to the friction of the haft with the cereal stems and the latter due to the harvester's hand on the handle. Especially on the sickle which collected *T. aestivum*, the anterior part was heavily worn, due to two fallen out inserts (see fig. 7.1.b.). The wooden handle there is used down to the groove and strongly dented, as the cereal stems could directly erode the shaft (see fig. 7.1.a before and b after). Inserts falling off a sickle appears to be a frequent occurrence during reaping, as recorded during other experimental harvests (Mazzucco et al., 2022, p. 7).

Another visible change was the shortening of inserts. Before the harvest, the inserts had a minimum height of 1.5 cm above the rim of the shaft. After three hours of harvesting, it was reduced to a maximum 0.5 cm above that rim. Thus, within three hours, about 1 cm of oyster shell material have been eroded due to the friction against the cereal stems (see fig. 7.1.c, d). But this has not made the cutting edges dull. On the contrary, whenever a part of the layered oyster shell has flaked off, a new sharp edge was created. Once an edge was getting rounded, the pressure of the cereal stems made one layer of the shell flake off and the edge was sharp again. In other words, oyster shells were staying sharp during the entire harvesting process. However, they were shrinking in size due to the permanent flaking off their layered structure (see fig. 7.1. c. before and d. after).

This could also be seen in the size of the surface reaped with the hafted sickle with oyster shell inserts (No. 3887) cutting *Triticum dicoccum* (see fig. 6.19). The surface increased from 18.7m^2 the first hour, to 21m^2 the second hour, before reaching, during the third hour with 17.3m^2, almost the level of the first hour (see Appendix B). This constant or even increased result is an indication that the inserts stayed sharp during the entire harvest.

Other than shortening, some inserts also showed strong edge rounding. These oyster fragments did not completely disappear into the haft under the heavy friction of the cereal stems but instead became heavily rounded (see fig. 7.1.g.).

Also, polish was visible to the naked eye, but surprisingly it was seen more on the wooden haft of the sickles than on the inserts themselves (see fig. 7.1.b.). Reason for that might be, that the haft was exposed during the entire harvest to strong cereal friction. The inserts on the other hand were gradually worn down and only a limited amount of polish could develop on the remaining part (see fig. 7.1.c, d).

The inserts also changed their shape from an original pointed and sharp shape to a smaller, and flatter shape (see fig 7.1.a before and g. after). This change was due to the cutting edge becoming shorter and rounded. However, the part of the insert inside the haft retained its original rectangular size (see fig. 7. 1.e. with insert in haft and f. with insert extracted).

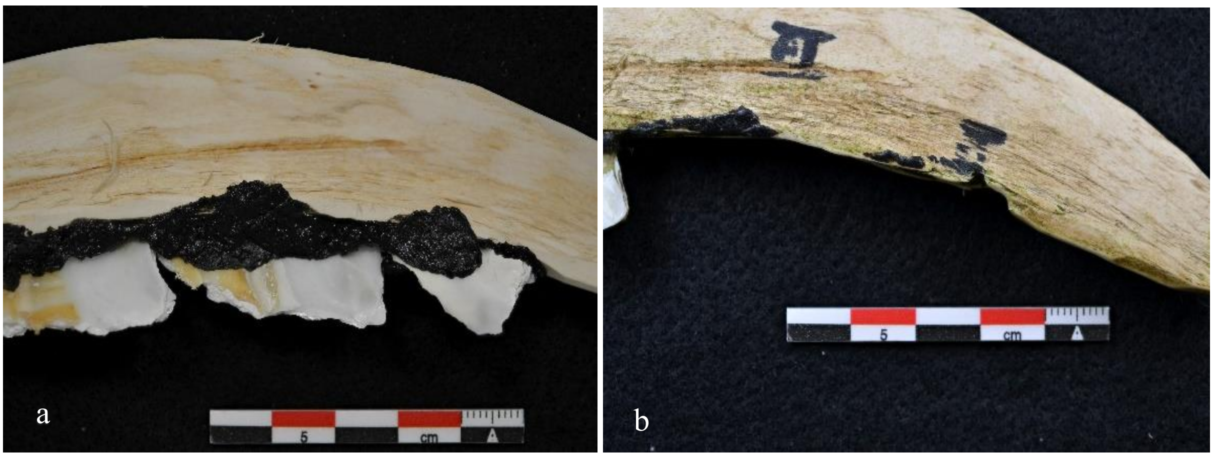


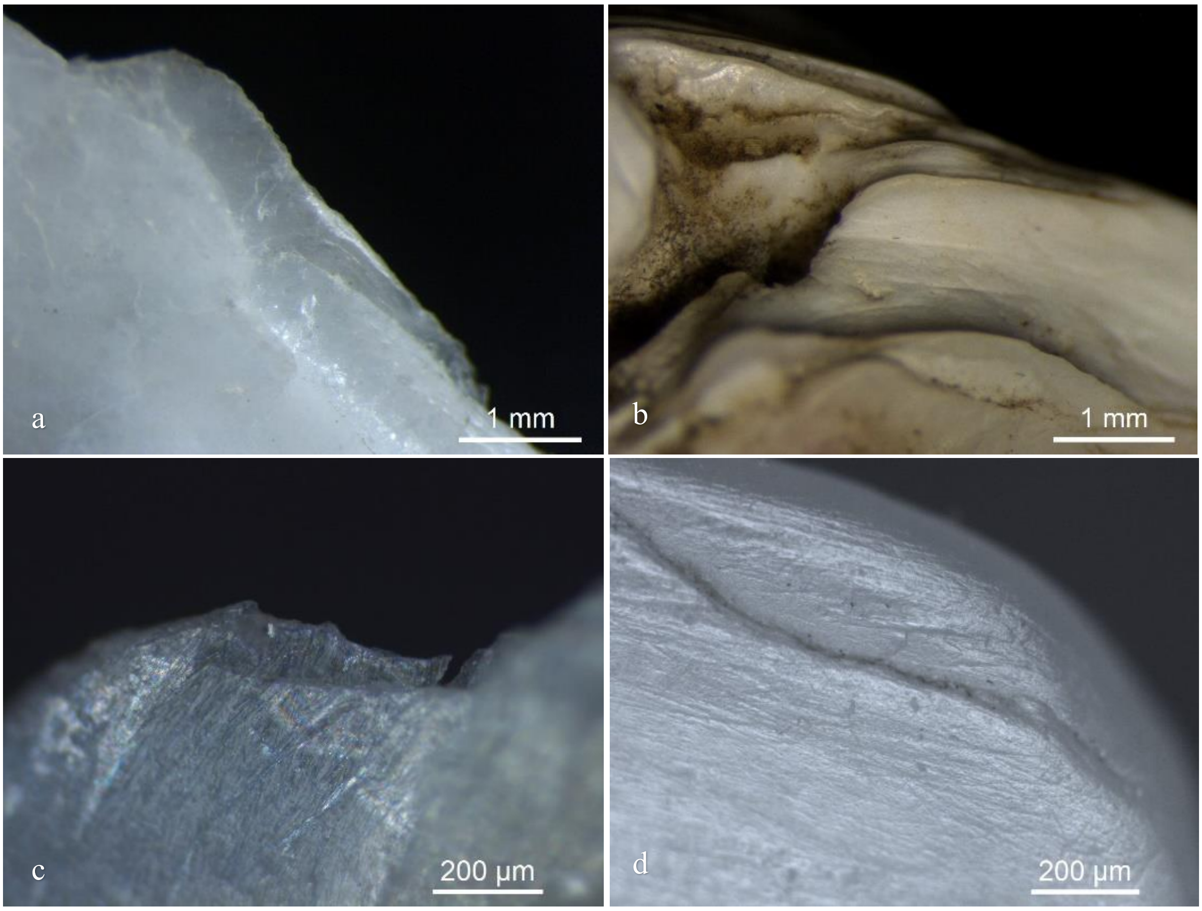
Figure 7.1.a. + b. (Tool 3886) Hafted sickle with oyster shell inserts before and after harvesting T. aestivum. Two inserts have fallen out during reaping. The wooden haft is coloured by grass stems and has a strong dent on the side due to cereal stem friction.

c. + d. (Tool 3887) Oyster shell inserts before and after harvesting T. dicoccum. Strong shortening and edge rounding visible.

e. + f. (Tool 3886) Oyster shell inserts after reaping T. aestivum. The external part is heavily worn. The internal part has kept its original shape.

g. (Tool 3887) Oyster shell insert after harvesting T. dicoccum with strongly rounded and diminished edge.

In terms of microscopic traces, each edge has changed from a sharp, crystalline structure (see fig. 7.2.a, c) before the harvest, to a very rounded, almost amorphous shape (see fig. 7.2.b, d). This shows the erosion the stems have exerted on the soft and layered material of the oyster shell. Also, many striations were visible. Most of these were oriented parallel to the cutting edge of the tool and were very thin (see fig. 7.2.d, e, f). Some polish can be seen on the edges, but it does not cover the entire surface of the insert. It is of silvery colour and very shiny (see fig. 7.2.d, e, f). In short, the oyster shell was flaking off under the pressure of the cereal stems. This flaking resulted in constant sharp edges, which facilitated an easy and fast harvest. But it also consumed the oyster shell itself, reducing its size rapidly.



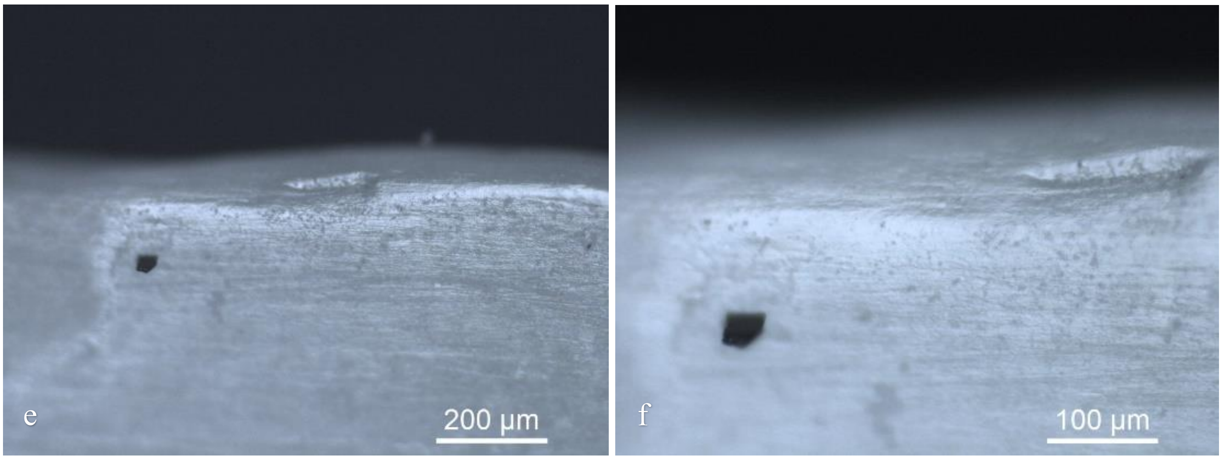


Figure 7.2.a. + b. (Tool 3886 + 3887) Oyster shell insert before and after harvesting.

c. + d. (Tool 3886) Oyster shell insert before and after harvesting T. aestivum. Edge rounding, striations, and polish visible.

e. + f. (Tool 3887) Oyster shell insert post-harvest T. dicoccum. Edge rounding, polish, and striations visible.

7.2. Use-wear traces on hafted sickles with freshwater mussel shell inserts

The four hafted sickles with inserts made from freshwater mussel shells have been used for three hours each to collect cereals. During the first hour of each harvest, it was easy to cut through the stems. Later, when the inserts were getting rounded and therefore duller, the cutting was mostly replaced by sawing. To avoid uprooting the stems, the reaping technique was changed from straight cutting to cutting in an arc motion. This change did help cutting the stems during the second hour. But during the last hour, the cutting edges of the tools were so rounded, that more and more stems were uprooted instead of cut or sawn through. While harvesting *T. monococcum,* one insert has fallen off. But the haft was not as damaged and worn as the one from the hafted sickle with oyster shell inserts used on *T.aestivum* . It appears that *T. monococcum* had not such an abrasive effect on the wooden haft as *T. aestivum* mixed with grass and weeds (see fig. 7.3.a. before and b. after).

All tools had visible edge rounding on the inserts after the harvest. The retouches made pre-harvest were still visible afterwards, but they were less steep and sharp than at the beginning (see fig. 7. 3.c. before and d. after). Also, some polish was visible on these rounded edges (see fig. 7.3.d). In comparison to the hafted sickle with oyster shell inserts, the mussel shell inserts have kept their initial shape. The edges were used and rounded, but the mussel shell material did not flake off as the oyster shell with its layered structure. This can also be seen once the inserts have been detached from their wooden shaft. Their shape was still very much like the original insert (see fig. 7.3.e. before and f. after). It appears thus, that the mussel shell was more resistant to friction from cereal stems than the oyster shell. However, the shell edges were getting blunt and rounded, resulting in lower results than with a comparable hafted sickle with oyster shell inserts.

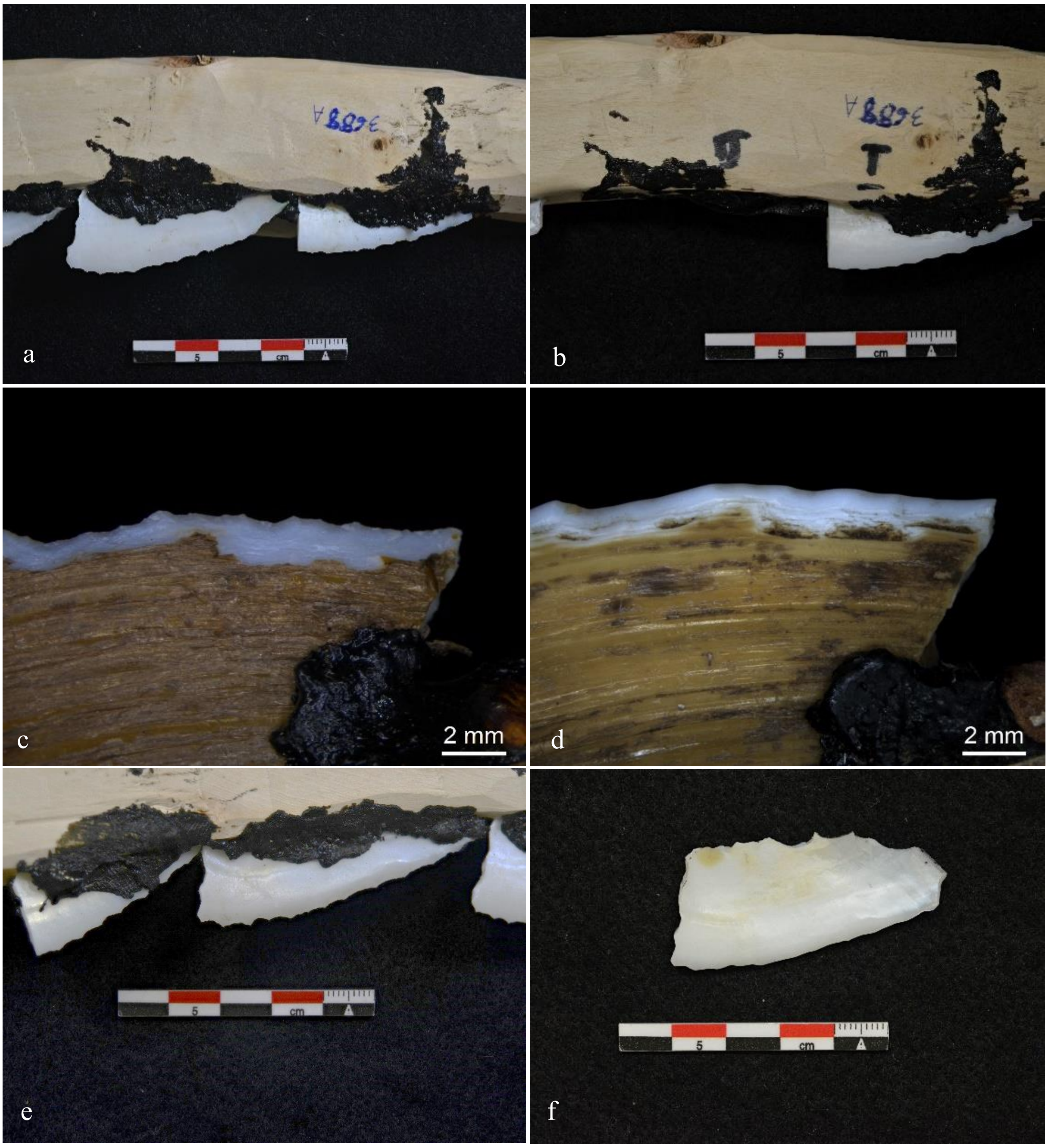
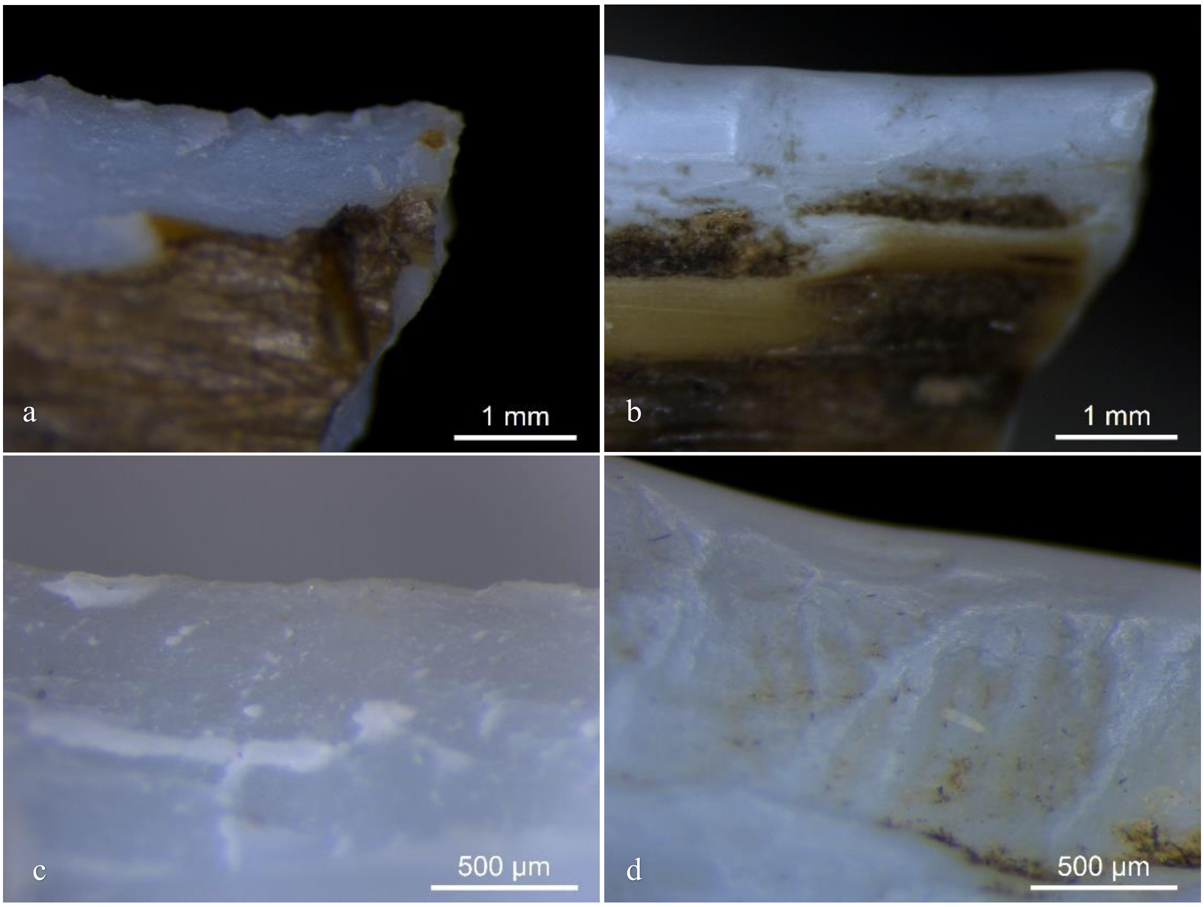


Figure 7.3.a. + b. (Tool 3688) Hafted sickle with mussel shell inserts before and after harvesting T. monococcum. One insert is missing, and the cutting edge is rounded.
c. + d. (Tool 3690) Mussel shell insert before and after harvesting H. vulgare. Strong edge rounding visible.
e. + f. (Tool 3688) Mussel shell inserts before and after harvesting T. monococcum. Shape of insert is almost unchanged.

The microscopic analysis showed that, in comparison to oyster shells, freshwater mussel shells did not wear off that strongly. It was thus possible to compare the same locations before and after use. Before the harvest, the cutting edges had a crystalline and angular surface (see fig. 7.4.a, c, e). After the harvest, this changed to a rounded surface showing striations and polish (see fig. 7.4. b, d, f). This polish did not extend very much beyond the cutting ridges, although the tool had been used for three hours (see fig. 7.4.b, d). The polish appears flat and smooth with visible striations (see fig. 7.4.g, h.). These striations follow a parallel pattern to the cutting edge (see fig. 7.4.f). In short, after three hours of gathering, the shell inserts appeared severely rounded with edge rounding, visible polish, and parallel striations, which led to a decline in the surface harvested. Outside of this experimental setting, these inserts would have been retouched at least once during that period, to keep the edges sharp and thus the results up.



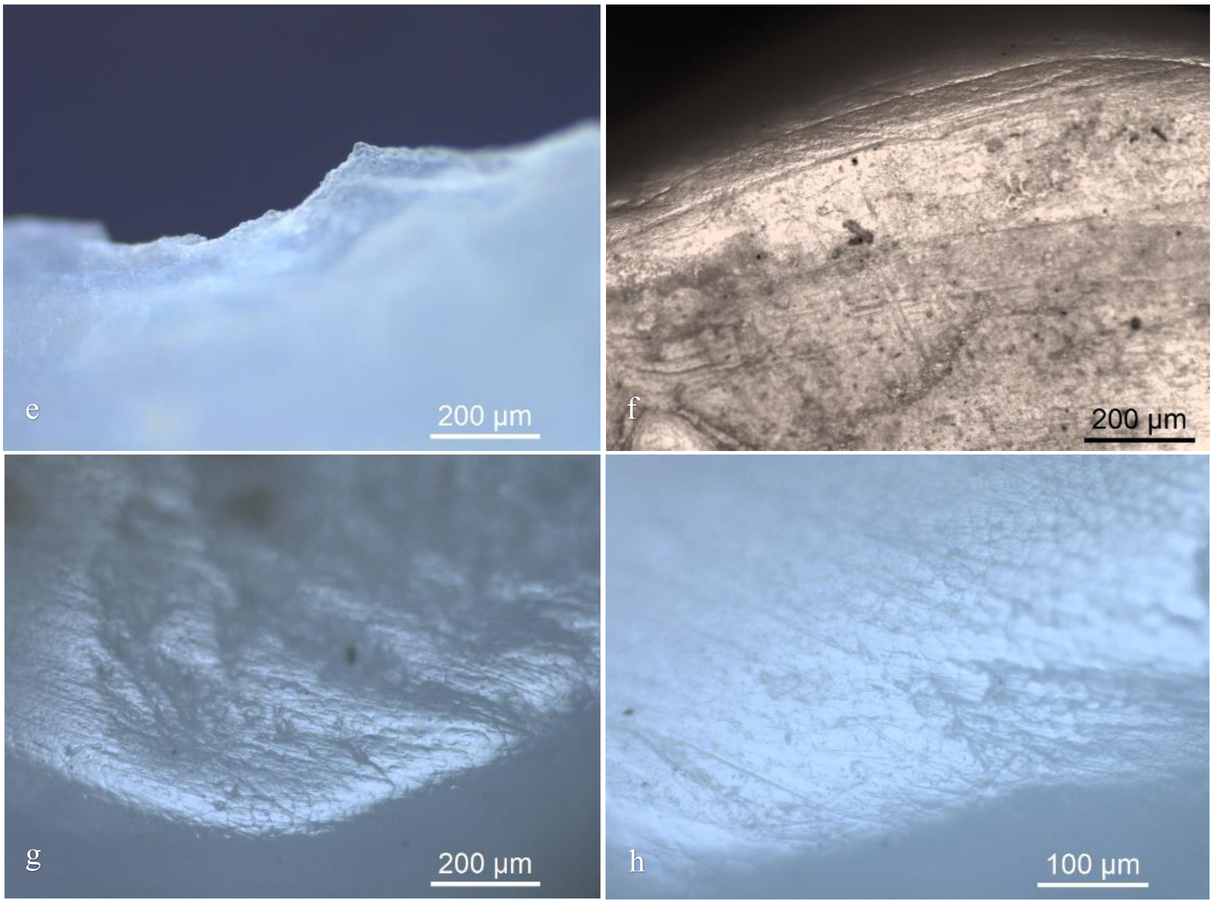


Figure 7.4.a. + b. (Tool 3690) Mussel shell insert before and after harvesting H. vulgare with edge rounding and polish.

c. + d. (Tool 3687) Mussel shell insert before and after harvesting T. aestivum with edge rounding, polish, and striations.

e. + f. (Tool 3687) Mussel shell insert before and after harvesting T. aestivum with polish, parallel striations, and edge rounding.

g. + h. (Tool 3689) Mussel shell insert after harvesting T. dicoccum with edge rounding, striations, and polish.

7.3. Use-wear traces on wooden sickles

Three wooden oak sickles could be used during the entire three hours for reaping, but the harvesting technique was different for each of them. *Triticum dicoccum* has been mostly uprooted with that tool, as the soil of the field was sandy and loose. The sheaves were made with the roots still attached to their stems, which resulted in heavier and more voluminous sheaves than with other cereals. With this wooden sickle, *Hordeum vulgare* stems could be easily ripped through, and did almost not get uprooted. As the stems became dryer over the harvest, ripping became even easier and a characteristic cracking sound could be heard while collecting, indicating the dryness of these stems. For *Triticum aestivum,* the harvest was done first through cutting, then changed to ripping and finally to uprooting. This was mainly due to the cutting edge of the tool, which became very dull, dented, and rounded during these three hours. This is because grass and weed had also to be cut, resulting in strong edge damages (see fig.7.5.b.).

One wooden sickle was used only during 80 min while collecting *Triticum monococcum* (see table 5.1). This plant was difficult to cut, saw, or hack through and the experiment had to be stopped midway. The reason for that was the thin, grass like appearance of the stems of that plant, which were not as brittle as compared to other cereals. To cut through them, a sharp edge was needed as from a sickle with shell inserts and not a blunt wooden sickle. Under pressure from the wooden tool, the stalks of *T. monococcum* just bended. This led to many stems being uprooted during the harvest. To avoid that, the cutting height had to be adjusted to 50 cm above soil in comparison to the average 15 to 20 cm with other cereals. Still, at this height many stems were uprooted. Once out of the soil, separating the roots from the stems was difficult. The wooden cutting edge could not cut or rip through the stems. Instead, the tool slid along the stems towards the ears. There, either the ears came loose and could be collected or had to be snapped off by hand. Overall, it took much more time to reap this cereal than any other.

Overall, the visible change on all these wooden tools was the strong rounding of the cutting edge. The best example could be seen on the tool cutting *Triticum aestivum* (see fig. 7.5.a. before and b. after). Not only was the rim, after the harvest, discoloured by grass, but it was also very rounded. In some locations, no edge remained, but instead a flat surface of several millimetres developed, against which the cereal stems were hitting during the harvest (see fig. 7.6.b). After the edge became blunt, cutting was no longer possible. Collecting was then only done through uprooting or hacking through the stems. This blunting of the rim developed because wood (although oak wood) is a softer material in comparison to the hafted sickles with shell inserts. It therefore got rounded faster (see fig. 7.5.c. before and d. after). Also, polish had started to develop on the cutting edges and at the tip of the tool. This appeared like a whitish cover on the wood spreading several millimetres on both sides of the cutting edge (see fig. 7.5.d.).

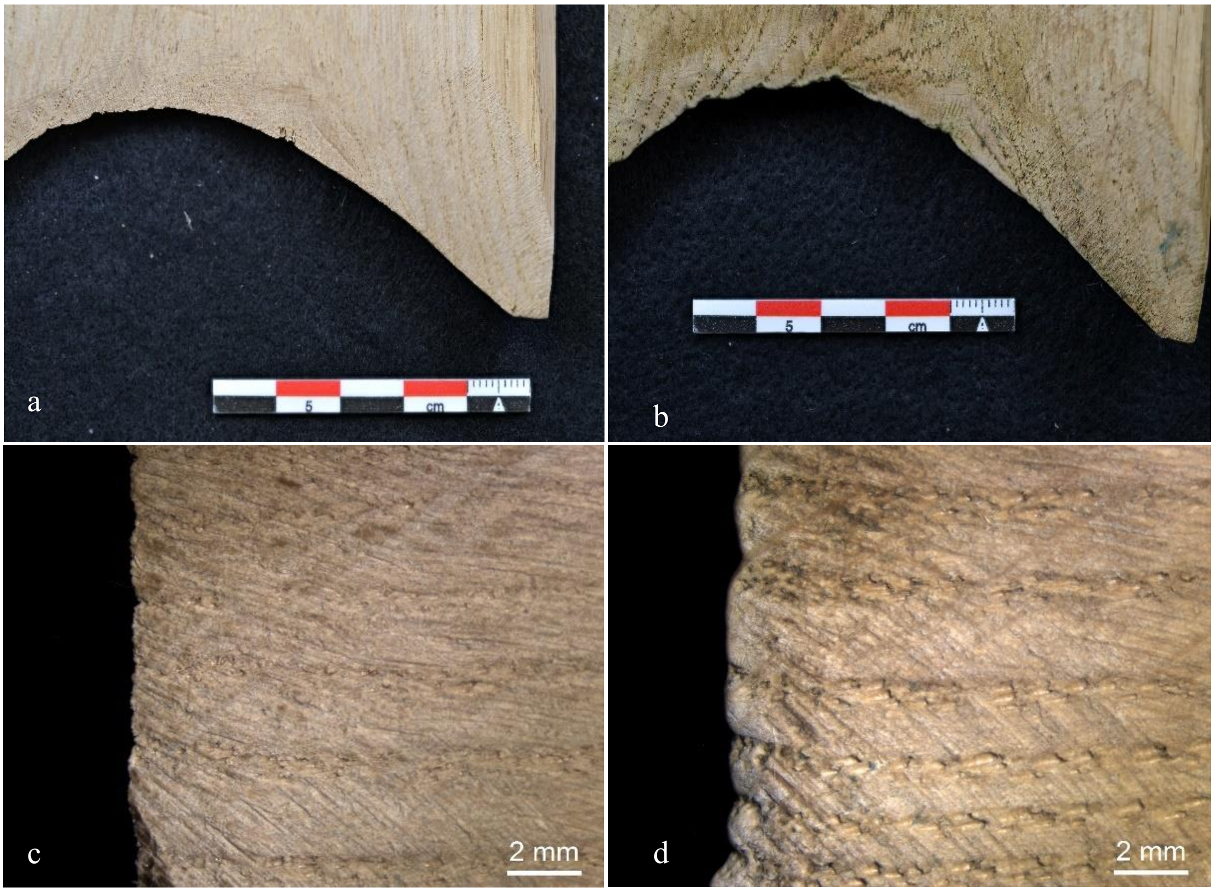


Figure 7.5.a. + b. (Tool 3888) Wooden sickle before and after harvesting T. aestivum. Strongly dented cutting edge and discoloration due to cutting grass.

c. + d. (Tool 3899) Cutting edge of wooden sickle before and after harvesting H. vulgare. Strong edge rounding and polish visible.

Microscopic traces of use wear were more pronounced and visible on wooden sickles than on hafted sickles with shell inserts. The cutting edges changed from a sharp, straight cutting profile (see fig. 7.6.a, c) to a very rounded and dented edge with visible traces of whitish polish (see fig. 7.6.b, d). These changes were especially obvious on the tool used to cut *T. aestivum* (see fig. 7.6.b) but less on other cereals like *H. vulgare* (see fig. 7.6.d). This is because with *T. aestivum*, grass and weeds were also cut, damaging the tool stronger than harvesting only cereal stems. The polish stretched several millimetres into the tool for *T. aestivum* (see fig. 7.6.b). For *H. vulgare* it was only a thin band on the cutting edge (see fig. 7.6.d.). A brownish polish had also developed on the harder, darker parts of the wood being in contact with the cereal stems. Striations were visible at a 90° angle to the cutting edge (see fig. 7.6.e, f).

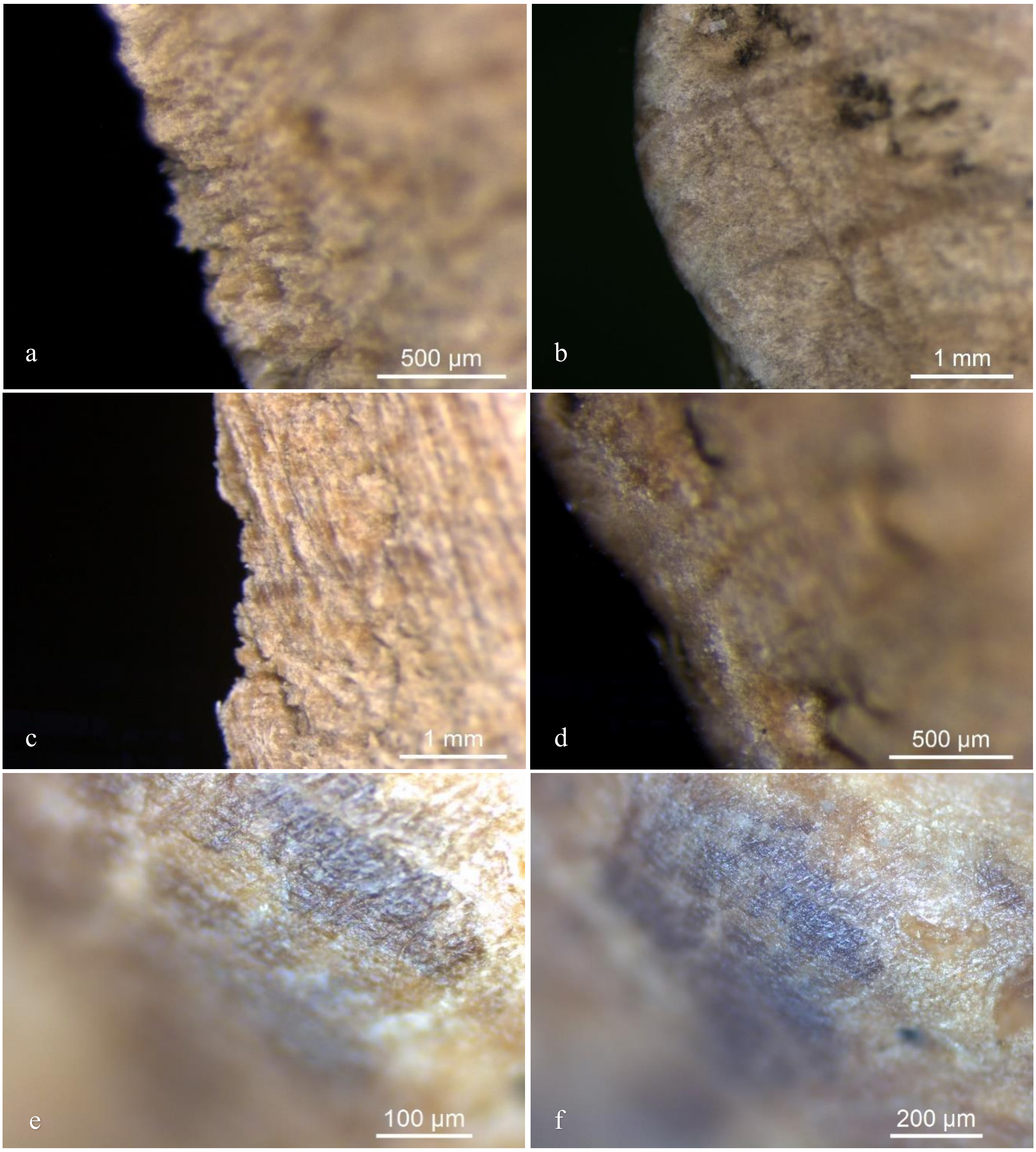


Figure 7.6.a. + b. (Tool 3888) Wooden sickle before and after harvesting T. aestivum with strong edge rounding and whitish polish.

c. + d. (Tool 3899) Cutting edge of wooden sickle before and after harvesting H. vulgare with edge rounding, and polish.

e. + f. (Tool 3899) Cutting edge of wooden sickle after harvesting H. vulgare with polish, striations, and edge rounding.

7.4. Use-wear traces on deer mandibles

The cereal harvest done with deer mandibles proved more difficult in comparison to other above-mentioned tools. As the mandible was naturally dented, the gathering could only be done through a sawing motion to rip through the cereal stems. The mandibles had "*incisors*" at the front (for terminology see Appendix E); (Fletcher et al., 2010, p. 6), which frequently touched the soil. These were thus often damaged, and some broke off completely (see fig. 7.7.a.). Also, as these incisors were touching the soil, it led to a higher cutting level (about 25 to 40 cm above ground) than for other tools. This higher cutting level was an issue for short cereals like *Hordeum vulgare*. Given an average 60 cm total height, cutting at a 30 cm height resulted in a remaining stem of only 30 cm. This made the gathering and binding of stems to sheaves more challenging.

Some mandibles had spaces between their teeth, resulting in stems getting stuck between them while reaping. These had to be removed manually, before continuing the harvest, thus reducing the collecting speed (see fig. 7.7.b before and c after). Another alteration was, that some teeth became loose during the harvest. Further collecting could have resulted in the loss of some of these. Also, the bone material at the anterior or "*diastema*" and posterior or "*ramus*" part of the mandible (see terminology in Appendix E); (Fletcher et al., 2010, p. 6) showed some edge rounding (see fig. 7.7.d. before and e. after) and polish. This polish developed when cereal stems were brushed against it. This bone itself did not saw through stems. This was done with the teeth of the mandible or "*corpus*" (see terminology in Appendix E); (Fletcher et al., 2010, p. 6).

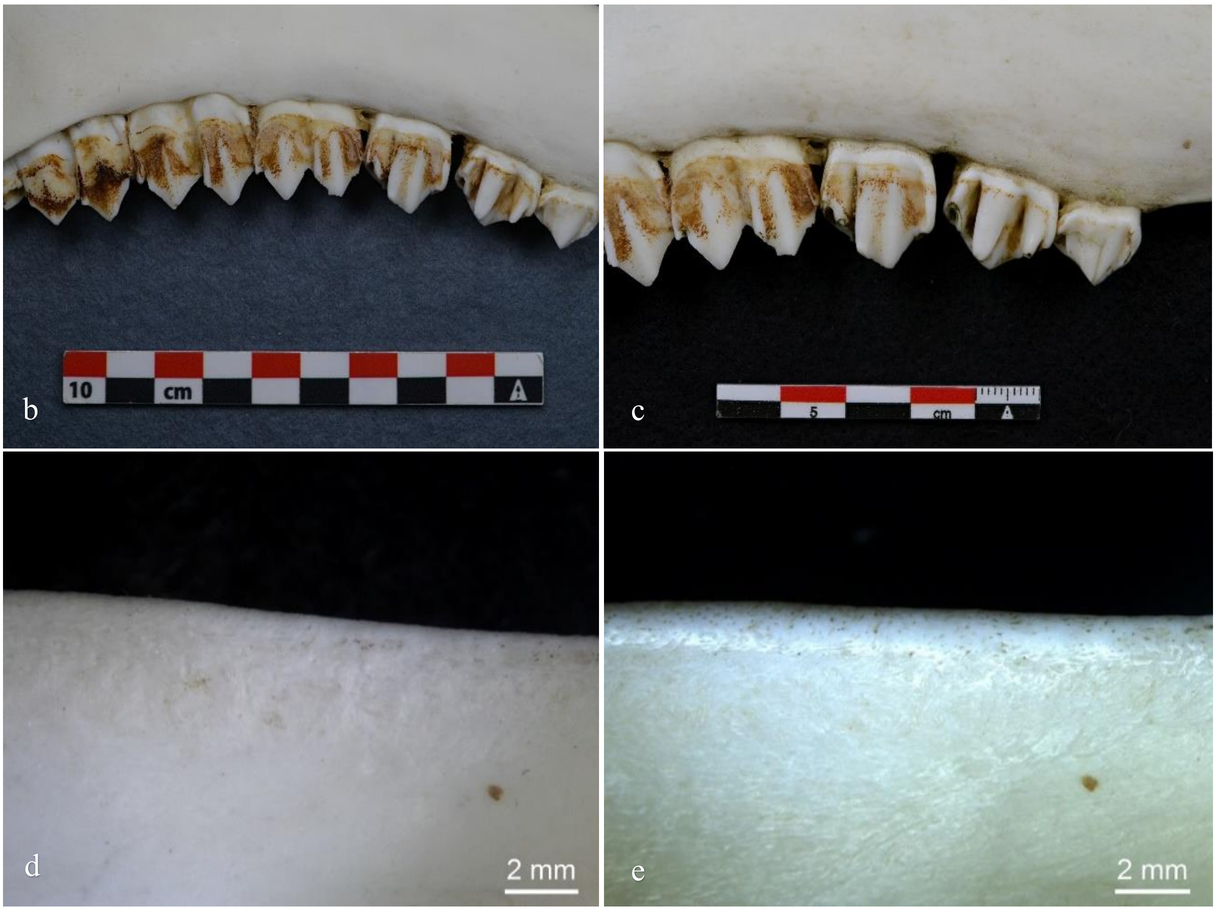


Figure 7.7.a. (Tool 3672) Deer mandible after harvesting T. monococcum. Front teeth have dropped off due to soil contact.

b. + c. (Tool 3671) Deer mandible teeth before and after harvesting T. aestivum. Space between teeth visible with discoloration and slight rounding on the bone.

d. + e. (Tool 3674) Deer mandible before and after harvesting T. dicoccum. Diastema shows edge rounding and polish.

Under microscopic view, the teeth, used for sawing off the stems, remained basically unchanged during the entire harvest. These teeth had already many striations, edge damages and polish, due to their usage by the live animal (see fig. 7.8.a. pre-harvest). Three hours of gathering did not increase the marks on these teeth, given the hardness of the material (see fig. 7.8.b. post-harvest). But use-wear traces are visible on the diastema of the mandible. These are edge rounding and polish on the location where most cereal stems hit the tool (see fig. 7.8.c. before and d. after). Also, striations parallel to the cutting edge are visible (see fig. 7.8.d.). On the ramus, polish, and striations are also visible. These might be due to holding the mandible by its base during the entire harvest (see fig. 7.8.e, f.). Overall, the deer mandible was the tool with the least use-wear traces.

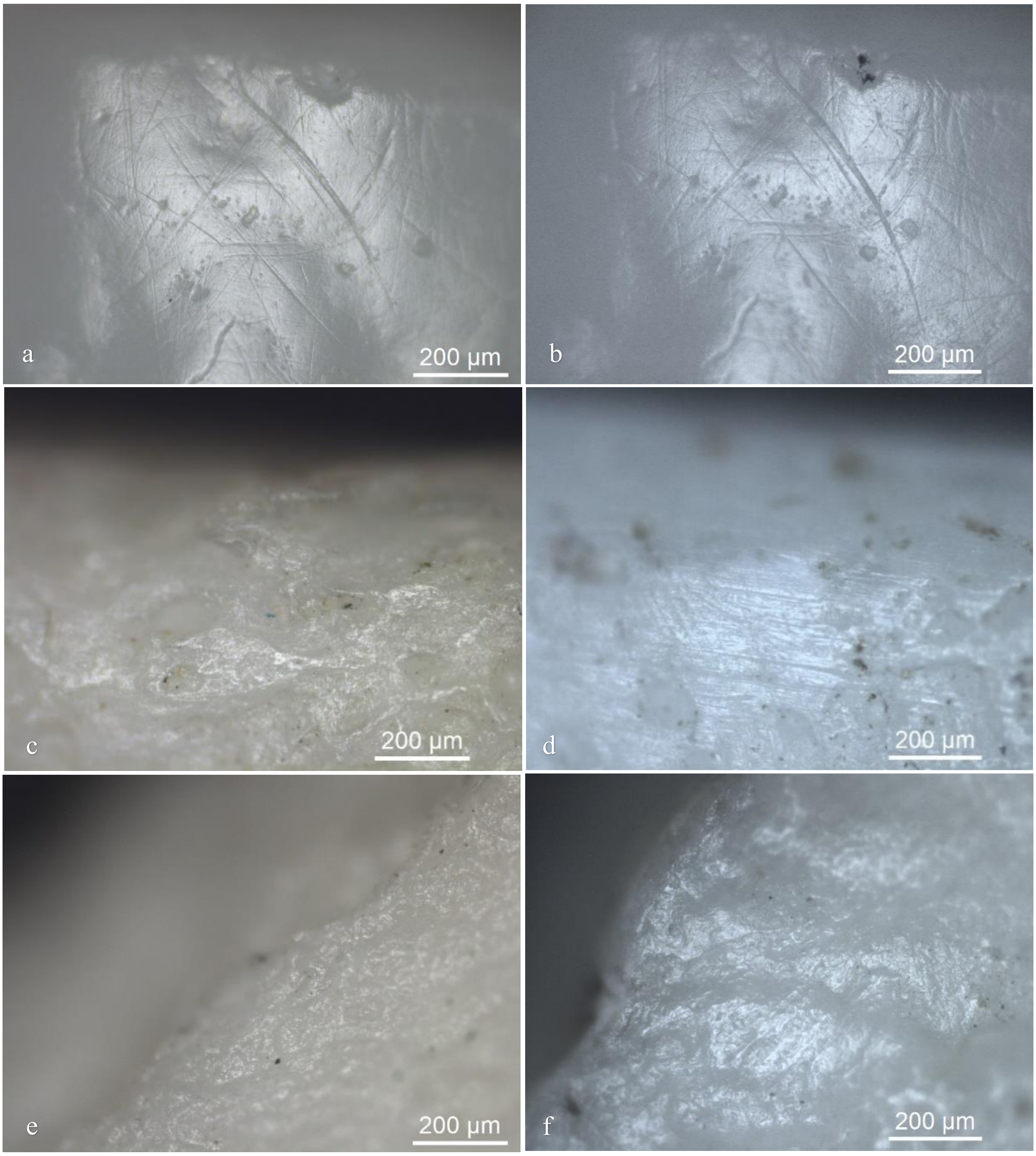


Figure 7.8. a. + b. (Tool 3673) Deer mandible tooth before and after harvesting H. vulgare. No apparent changes on the tooth even under the microscope.

c. + d. (Tool 3672) Deer mandible diastema before and after harvesting T. monococcum. Parallel striations, polish and rounding visible.

e. + f. (Tool 3671) Deer mandible ramus before and after harvesting T. aestivum with traces of polish and few striations due to tool handling.

7.5. Use-wear traces on cattle ribs

The cattle rib had been the only tool not suitable to harvest any of the four cereal types during this experiment. Within a few minutes of reaping, the previously sharpened cutting edges became dull to an extent that gathering was not possible (see fig. 7.9.a. before and b. after). Also, the edge of the cattle rib used to reap *Triticum aestivum* had a greenish colour. This is an indication that grass was cut together with the cereal, which made the cutting edge becoming rounded even faster (see fig. 7. 9.c. before and d. after).

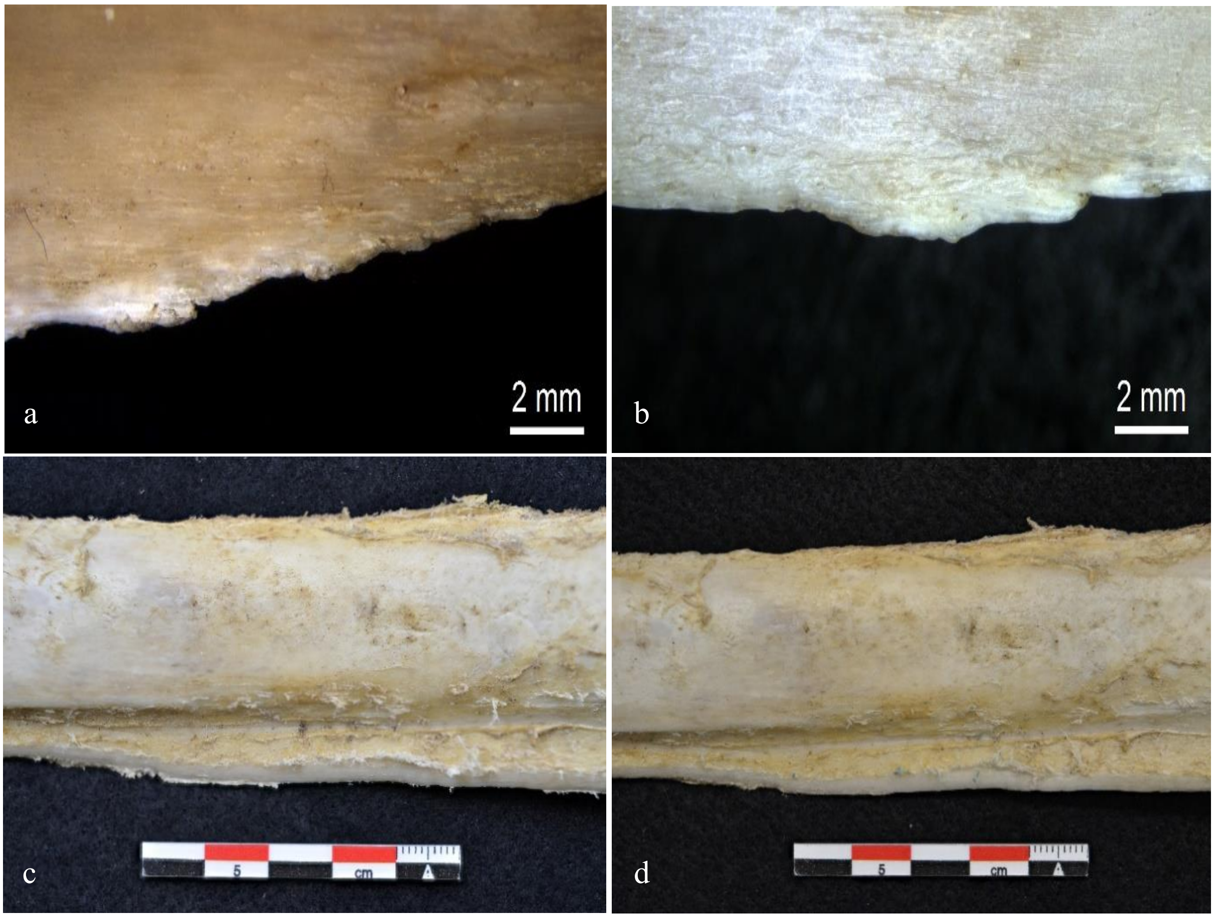
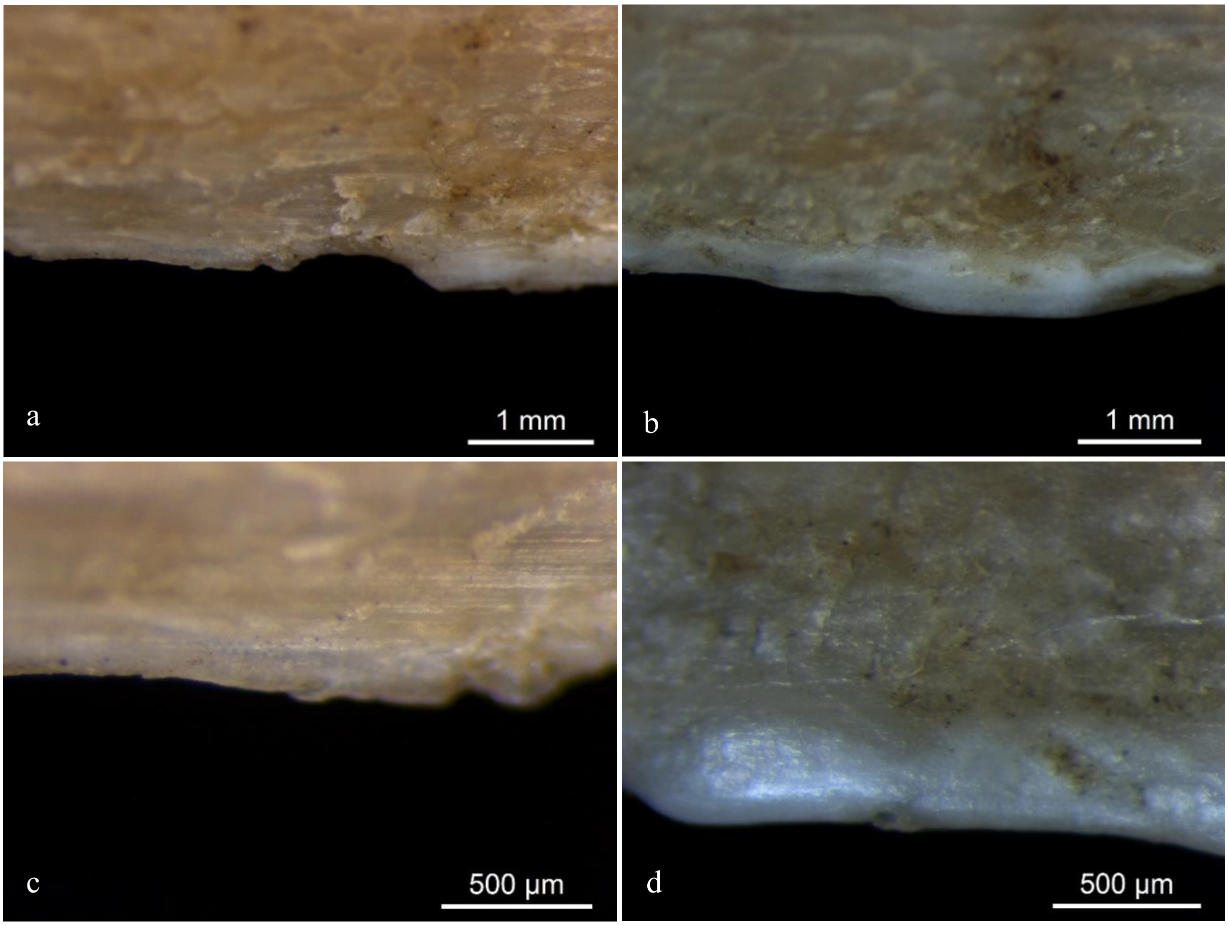


Figure 7.9.a. + b. (Tool 4167) Cattle rib sickle before and after harvesting T. dicoccum. Cutting edge is severely rounded with early traces of polish.

c. + d. (Tool 3891) Cattle rib sickle before and after harvesting T. aestivum. Cutting edge is rounded after only 10 min. of use.

Under the microscope, severe edge rounding traces were visible, which have developed within a few minutes of use (see fig. 7.10.a. before and b. after). This shows that the stems were not cut by the tool, but that they only hit the bone and thus created a polished surface. Striations parallel to the cutting edge were visible on the bone **before** the harvest as it had been sharpened (see fig. 7.10.c.). These striations disappeared after only a few minutes of collecting (see fig. 7.10.d.). However, perpendicular striations had developed (see fig. 7.10.e. before and f. after). Bone as material appears thus as too soft to cut through cereal stems. A similar effect could also be seen on the deer mandible where rounding and polish on the bone parts (ramus and diastema) developed quickly.



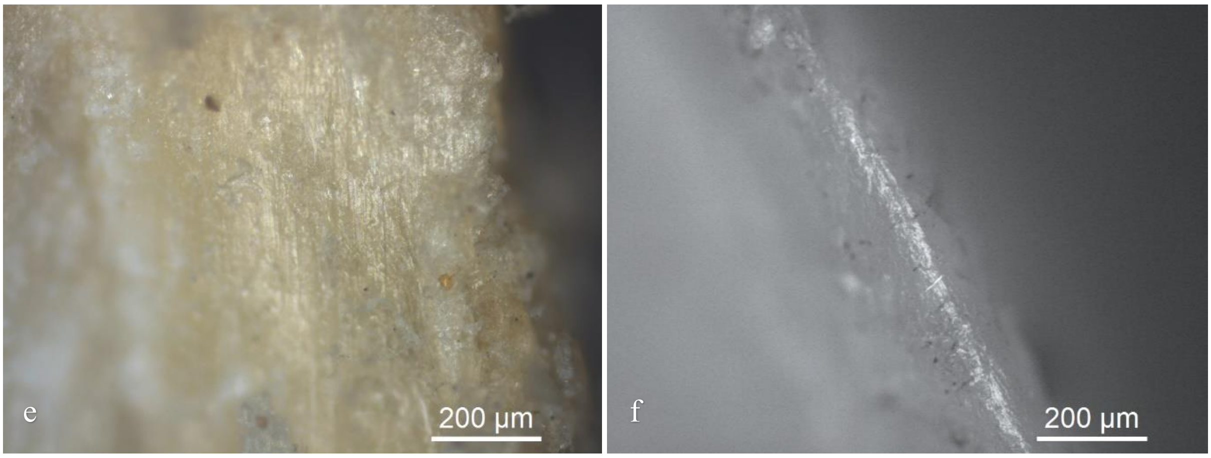


Figure 7.10.a. + b. (Tool 4167) Cutting edge of cattle rib before and after harvesting T.dicoccum. The edge is very rounded and polished.

c. + d. (Tool 4167) Cutting edge of cattle rib before and after harvesting T. dicoccum. Sharpening marks disappeared after only 5 min. of reaping. Polish, strong edge rounding and few striations visible.

e. + f. (Tool 3891) Cutting edge of cattle rib before and after harvesting T.aestivum. Polish and rounding visible.

7.6. Use-wear traces on hand-held oyster shells

Out of the four harvesting knives made from oyster shells, two were entire shells and two were strongly curved fragments. The entire specimens, due to their large size, were more difficult to handle with one hand. But it did not influence the speed of the harvest. However, pulling the ears over the cutting edge to snap them off, needed some stretching of the hand. Sometimes, the ears had to be grasped first with the other hand before snapping them off with the tool. With the smaller oyster fragments, it was easier with one motion of the hand to grasp the ears, push them over the cutting edge and snap them off.

The handheld oyster shells underwent major transformation during the three hours of cereal harvesting. During the first hour, the brown outer shell material of the oyster flaked off very easily. Later, when the harder, mother of pearl material of the oyster has been reached, the overall flaking stopped (see fig. 7.11.a. before and b. after). Instead, small dents developed in locations where most ears were snapped off over the edge. These dents deepened during the harvest as the oyster shell flaked off little by little (see fig. 7. 11.c. before and d. after). Still, the entire edge stayed sharp the whole time. This was also felt on the thumb of the harvester, as it started to hurt after only one hour of collecting.

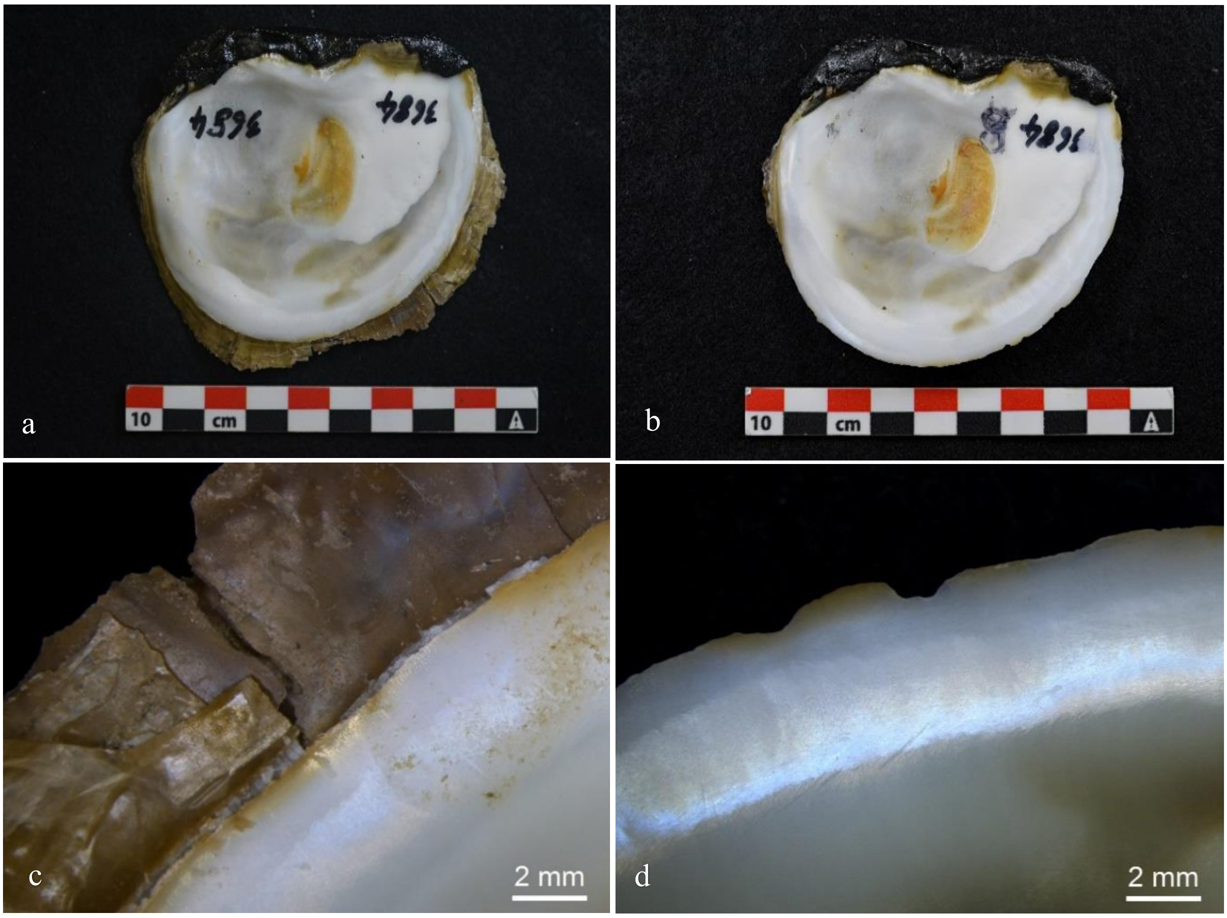


Figure 7.11.a. + b. (Tool 3684) Hand-held oyster shells before and after harvesting T. dicoccum. Brownish shell material has disappeared, and cereal stems have made dents into the shell.

c. + d. (Tool 3684) Hand-held oyster shell before and after harvesting T. dicoccum. Dents and striations visible inside the shell.

Microscopic traces like polish and striations were visible in these dents (see fig. 7.12.a, b). These striations were perpendicular to the cutting edge (see fig. 7.12.b.) but also at a 45° angle (see fig. 7.12.c, d). This angle depended on the part of the shell being used to snap off the ears. If the ears had been pulled over the ventral end of the oyster, the striations were perpendicular to the cutting edge (see terminology in Appendix D); (Budha, 2016, p. 11). If the ears had been pulled over the edge on the posterior or anterior end of the shell, the striations showed a 45°angle to the cutting edge. Slight edge rounding and polish was visible in the dented part of the shell (see fig. 7.12.e, f) where the ears had been pulled over that surface. But the spread of that polish is limited to the cutting edges only and did not spread beyond it. Even inside these edges, only the outer rim shows polish, whereas the inner part was not covered (see fig. 7.12.e, f). This might be due to the action of the thumb gliding over the edge while cutting the ears (Anderson & Sigaut, 2015, p. 88).

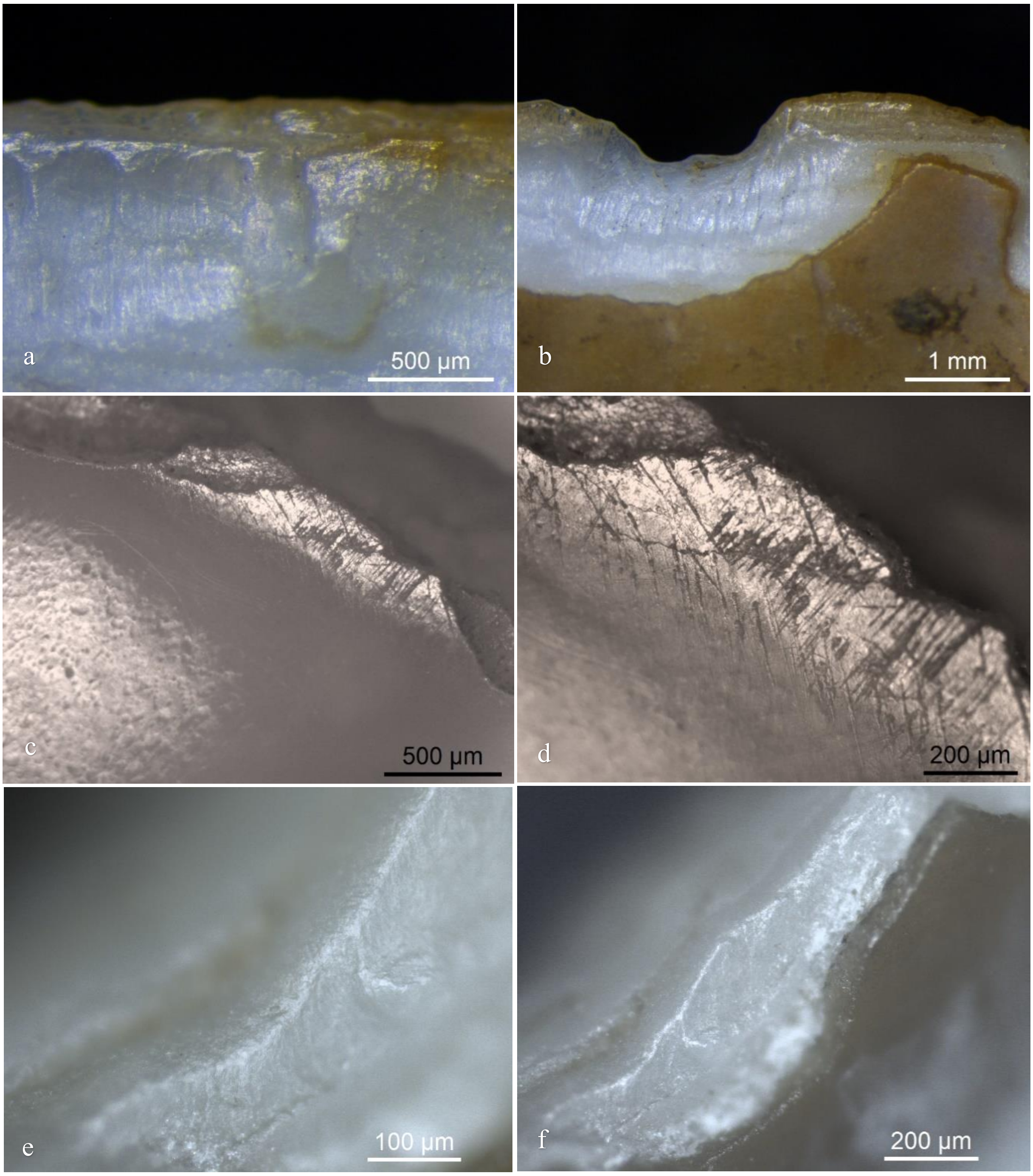


Figure 7.12.a. + b. (Tool 3684) Hand-held oyster shell after harvesting T. dicoccum. Perpendicular striations visible at cutting edge.

c. + d. (Tool 3683) Hand-held oyster shell after reaping T. aestivum. Edge rounding, polish, and striation at 45° angle visible.

e. + f. (Tool 3686) Hand-held oyster shell after harvesting H. vulgare. Edge rounding and polish visible at cutting edge.

7.7. Use-wear traces on hand-held freshwater mussel shells

Out of the four hand-held mussel shells, three showed strong damage after the cereal harvest, especially at the anterior end (see terminology in Appendix D); (Budha, 2016, p. 11). This sharper but also thinner edge of the mussel shell was used at the beginning for reaping ears, as they could be snapped off easily without pulling them upwards. For that, the thumb pulled the ears over the cutting edge of the tool and snapped them off at the same time. This movement resulted in small dents forming rapidly at the edges of the shell. These dents developed into cracks and then the entire anterior part of the shell started breaking off. At the end of three hours of collecting cereals, ¾ of the tools had lost up to 30% of their cutting edges (see fig. 7.13.a. before and b. after). After the anterior end had fallen off, the tool was turned around and the posterior end was used for the remaining harvest. As this part was thicker and less sharp, the ears could not be snapped off as easily as before but were pulled over the edge and upwards to break them off. Even on the only hand-held mussel shell, where the anterior end was still intact after the harvest, dents on the cutting edge were visible (see fig. 7.13.c. before and d. after). Collecting *Triticum dicoccum* and *Triticum monococcum* was more difficult than reaping *Triticum aestivum* and *Hordeum vulgare* with this tool. This is because the ears of the first types break apart easily while handled. As the mussel shell is strongly curved inwards, many ears, once snapped off from their stems, broke in the middle of the shell. They then frequently fell to the ground and could not be collected. A tool with a flatter inner surface (as the oyster shell) resulted in fewer ears being broken and dropping to the ground. This did not affect the overall surface harvested but only the volume collected, as not all ears snapped off could be gathered.

In addition, the interior part of the mussels changed in appearance. The initial inner, brownish layer gradually started to be worn off by the friction of the cereal stems, up to the point where only shiny, mother of pearl material was visible (see fig. 7.13.e. before and f. after).

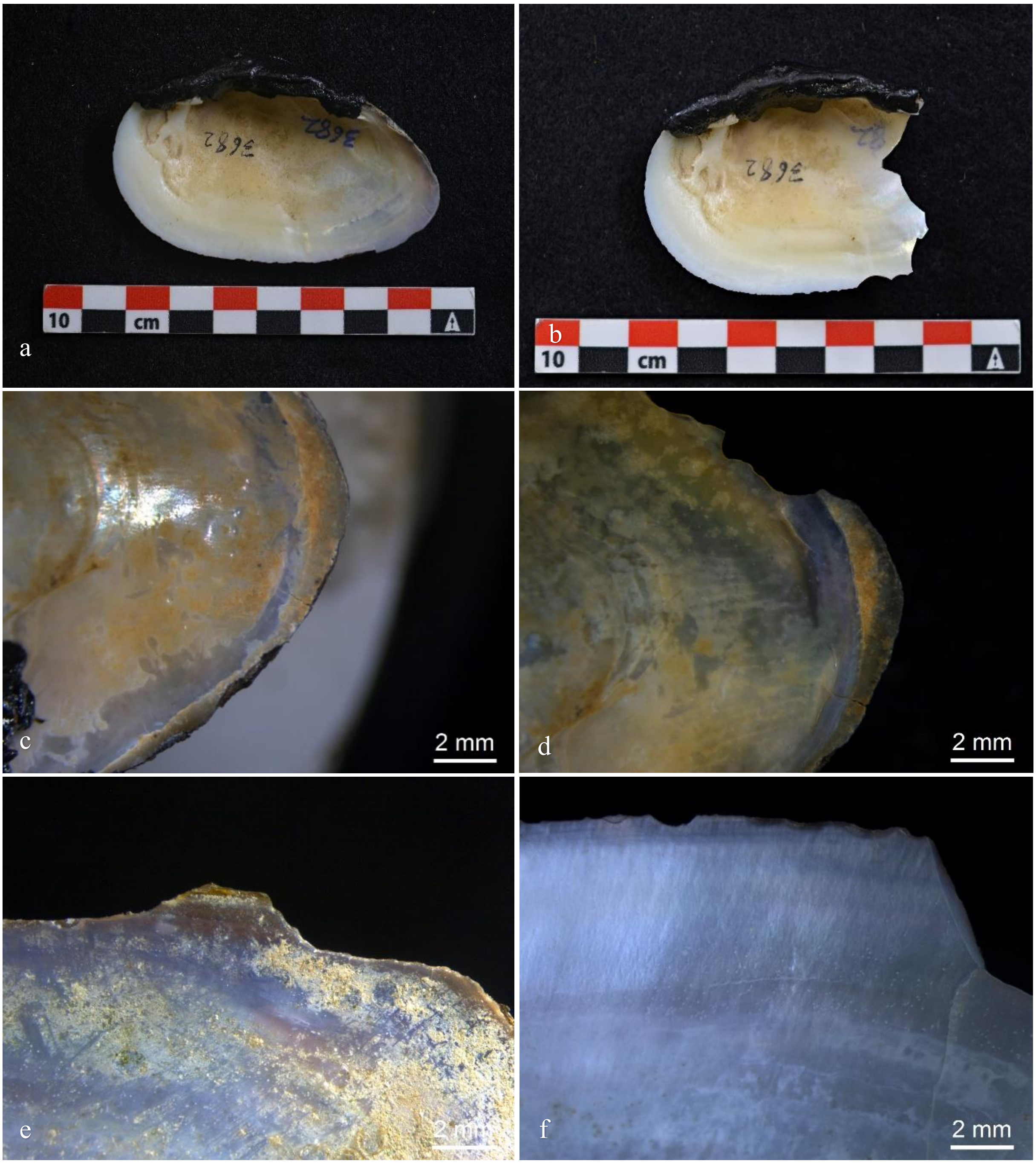


Figure 7.13.a. + b. (Tool 3682) Hand-held mussel shell before and after harvesting T. monococcum. Strong damage at anterior end after snapping off ears.

c. + d. (Tool 3680) Hand-held mussel shell before and after harvesting T. dicoccum. Edge damages at anterior end.

e. + f. (Tool 3681) Hand-held mussel shell before and after harvesting H. vulgare. Post-harvest abrasion traces visible on shell interior.

On a microscopic level, edge rounding was visible on the cutting edges. This not only happened at the original edges of the shell (see fig. 7.14.a before and b after) but also at parts which broke off later during the harvest (see fig. 7.14.c.). Some polish was visible under the microscope as it had developed next to ridges close to the cutting edges (see fig. 7.14.c, d). It did not extend very far even after a three-hour use. Some striations are also visible, and these are parallel to the outer cutting edge, where cereal stems have brushed against the shell while been cut (see fig. 7.14.d).

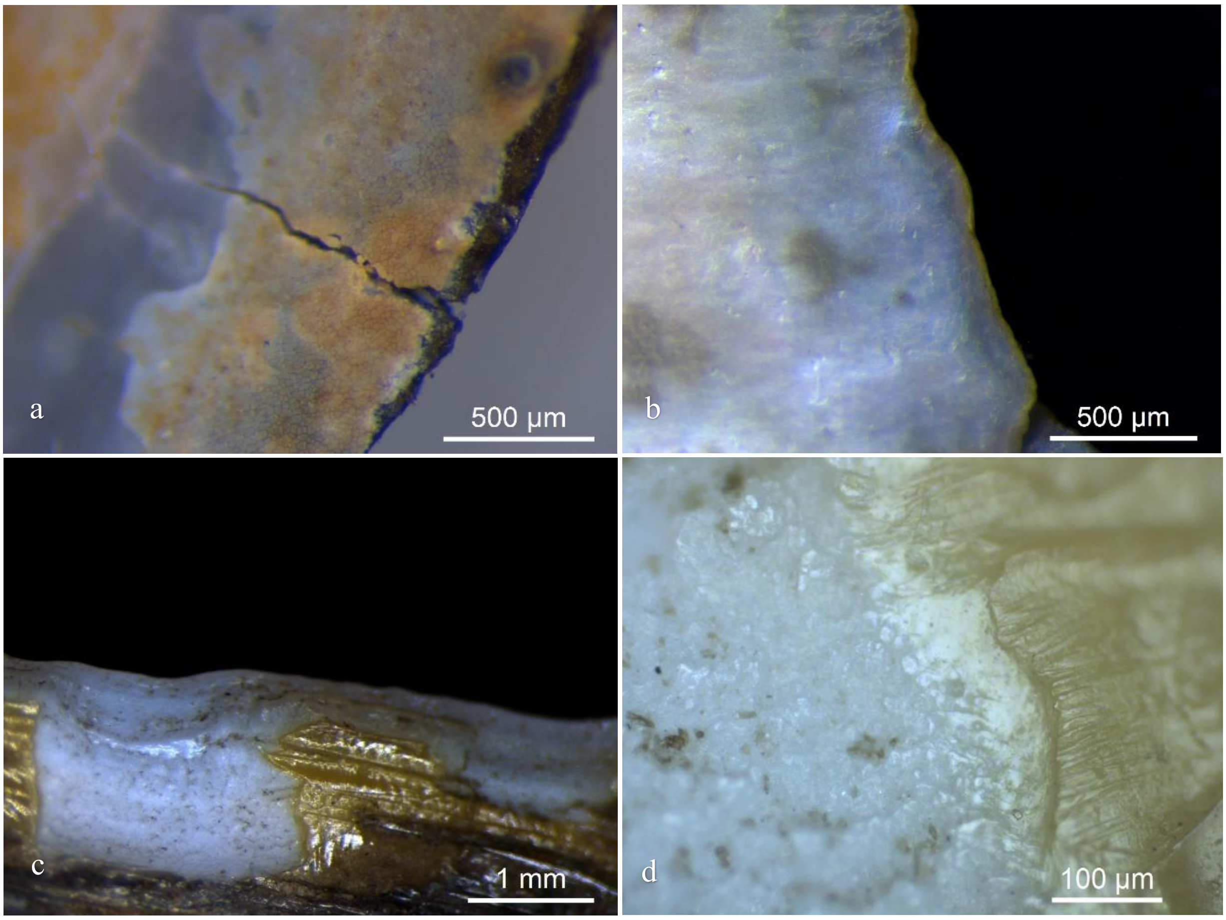


Figure 7.14.a. + b. (Tool 3680) Hand-held mussel shell before/after harvesting T. dicoccum. Cutting edge became dented and rounded.

c. + d. (Tool 3679) Hand-held mussel shell after harvesting T. aestivum. Visible rounding at cutting edge, polish at border to brownish outer layer and parallel striations.

7.8. Analysis of qualitative harvesting results

All tools used during the experimental cereal harvest showed marked use wear traces. These traces were macroscopic as gloss on shells or bone, worn cutting edges and strong abrasions on inserts, but also microscopic as striations, polish, and edge rounding.

Oyster shell inserts showed the strongest alterations during this experiment, as large parts of the cutting edges were worn off by the action of the cereal stems. Still, these were also the most effective tools, staying sharp throughout the entire cereal harvest.

Mussel shell inserts were less affected by the abrasion of cereal stalks, as they showed less edge rounding and their original retouches were still visible after the harvest. However, they became blunt rapidly, thus reducing the collecting speed and forcing the harvester to change his technique from cutting to sawing, ripping, and finally uprooting. Use-wear traces were very visible, be it striations, polish, edge rounding and edge damages.

The cutting edges of the oak wood sickles were also strongly altered during the harvest. They became rounded, developed a polish and could after a short while not cut through stems anymore. These were then either hacked through or uprooted. Use-wear traces as polish, heavy rounding of edges and striations were very visible. Also, the edges of the tools changed, depending on the different type of cereals gathered. *T.aestivum* and especially the grass cut together, damaged the wooden edge very strongly. *T. monococcum* with its thin stems and loose roots, enabled uprooting and the cutting edge suffered only small damages.

Deer mandibles almost did not change their shape during the harvest. The teeth as cutting agent remained in terms of use-wear traces the same. Only the bone segments before and behind the teeth (diastema and ramus) showed some polish, and striations. Finally, the damaged incisor teeth at the front part of the mandible could be seen as additional indication for a cereal harvest.

Following this experiment, cattle ribs are believed not to be a suitable tool to harvest cereals. The experiment showed that the edges of these became rounded and blunt within a few minutes and could not sustain a prolonged grain harvest.

Hand-held shells, be it oysters, or freshwater mussels, showed strong alterations after being used to snap off cereal ears for three hours. Not only did the outer shell became worn away but also the harder inner shell became dented, cracked up and in cases fell off. Use-wear traces were visible as polish, striations, and edge rounding. Very visible were the abrasion of the interior shell, changing from a dull brownish color to a shiny bluish surface.

All these actions left long-lasting traces on all tools. These could easily be identified with the naked eye or through a microscope. Since such obvious reaping traces were visible on experimental tools it is believed, that also on archaeological material such marks could be found. A future step would therefore be to compare the above presented traces with Michelsberg material from North-Western Europe and determine if similar marks could be found. In case these were present in archaeological finds, it could explain the use of alternative materials to make sickles and harvesting knives during that period.

<u>CHAPTER 8</u> – DISCUSSION

The experiments made for this thesis have shown that cereals can be collected with tools made from alternative materials. Shell, wood, and deer mandible have proved effective at gathering large amounts of grain within a short period of time. But this cereal harvesting experiment had also raised a few questions which will be discussed hereafter.

The tools used during the experiment were not sharpened or repaired throughout the entire harvest. This is because honing cutting edges or replacing inserts that have dropped out, would have affected the visibility of use-wear traces. Therefore, even if inserts fell out, or a tool became blunt, these were used until the end of the three-hour harvesting period. But how would these tools have been treated during a neolithic cereal harvest?

During the experiment, several quantitative results could be obtained. These were the harvested surface, the speed of reaping and the grain yield. In this chapter these results are put in relation to the estimated annual grain consumption of an individual and a family. In addition, the number of people needed for a harvest, and the grain yield achieved with ancient cereal types has been estimated. These results have then been compared to data from earlier cereal harvesting experiments. The aim was to verify if the achieved grain yield, the number of harvesters and the reaping speed are sufficient to cover the yearly needs of a group of people living during the Michelsberg period.

Archaeological remains of reaping tools made from alternative materials such as shells, wood and bone have rarely been found. A reason for that could be, that specific use-wear traces, for archaeologists to look for, are basically unknown. However, during the use-wear analysis of this experiment, a variety of traces were discovered on the employed tools. These, being edge rounding, striations, polish, or the shape of inserts, are very distinctive. Comparing these, with archaeological finds can help to identify sickles and harvesting knives. Thus, to find tools in an archaeological context, what shapes, forms and traces should we be searching for?

Finally, this thesis deals with the question if other, alternative materials, could have been used as tools for harvesting cereals during the Michelsberg period. But until now it does not cover the fundamental issue of why such tools are missing. In this discussion, different hypotheses will be presented and discussed to why these tools went missing in the first place.

8.1. Unchanged tools

During this cereal harvesting experiment, some shell inserts have fallen out, and cutting edges became blunt on shell, wood, or bone tools. Still, these tools have been mostly used for the entire three hours with these missing inserts or damages. In total, 1/3 of the hafted sickles with shell inserts have experienced one or several losses of inserts (2 sickles out of 6), In ¾ of all hand-held mussel shells (3 out of 4), a large part of their anterior cutting edge fell off. Finally, in ¼ of the wooden sickles, severe edge rounding took place. These damages not only resulted in a decline of the collected grain yield, but also forced the harvester to adapt his cutting technique, leading to a slower speed. How could these tools have been used back in the Neolithic?

8.1.1 Sickle repairs

The hafted sickles with shell inserts were the tools which experienced the most damage during this experiment. Not only did some inserts fell off during the harvest, but also one wooden shaft was strongly damaged (see fig. 7.1.b). The wooden part, where the two inserts fell off, became strongly dented and the groove to hold these in place was severely flattened.

A sickle with such strong damage might need to have a new wooden shaft made from scratch. However, producing such a handle is more time-consuming than making an insert, be it flint or shell. The difference in production time between a shaft and an insert became apparent in this experimental research. Once the wood was available, making a handle for a sickle took roughly 1.5 hours, whereas making a shell insert only took a few minutes (D. Pomstra, personal communication, 2nd February 2023). This difference has also been noted in archaeological examples. Entire hafted wooden sickles with flint inserts, as excavated in La Marmotta, Italy, show that the wooden shafts have been used over a long period of time. This is visible, as some flint inserts have few use-wear traces and others more. The former were newly inserted blades whereas the latter were older blades still being used. (Mazzucco et al., 2022, p. 7). Also, wooden sickle handles of the neolithic PPNB period found in the Near East show traces of decoration. This could indicate that these wooden shafts were particularly cared for and used during a long period (Astruc, 2012, p. 674; Bar-Yosef, 1987, p. 161).

Inserts on the other hand, appeared to be made more according to the task at hand, subsequently used, retouched, reused, and finally discarded. Thus, it can be assumed that lost inserts are replaced regularly instead of making an entire wooden shaft from scratch (Mazzucco et al., 2022, p. 7). This regular replacement of inserts has the advantage of keeping the harvested yield up and ensuring that the wooden shaft is not being damaged beyond repair as seen as in this cereal harvesting experiment.

But how could this replacement be done? To exchange an insert on the spot, the harvester would need to have some spare parts with him and be able to heat some tar on the field to fix them into the sickle. This appears challenging to do in the middle of a harvest. On the one hand, a harvest must be done rapidly to ensure that the entire grain can be cut, dried, and put into a barn before the next rain (Ibáñez et al., 2001, p. 29). On the other hand, lighting a fire close to, or on a field of dry cereals might be a risky undertaking. The entire harvest might go up in smoke by just wanting to replace an insert. Alternatively, the repairs could have been done back at the village (Mazzucco et al., 2018b, pp. 94-95; van Gijn, 2010, p. 68).

To do so, and to reap cereals at the same time, people would need to use more than one sickle. One can image, that a certain number of these tools would have been brought to the field in the morning. During the harvest, once a sickle lost an insert, it was exchanged for another sickle. The damaged tools would not be repaired on the spot but put aside and brought back home later. After the harvest, these tools would then have been repaired at the farmhouse with the suitable tools and the convenience of a hearth to heat the tar.

This could be the way in which sickles were used during the Neolithic at the lake-site village of Egolzwil 3 in Switzerland. The village was assumed to be in existence for only nine years from *"4,278 to 4,270 BC"* (Gibaja et al., 2017a, p. 216). But a total of 10 complete sickles with wooden hafts and inserted flint blades together with seven flint inserts have been found at this site (Gibaja et al., 2017a, p. 220). These, as described in Chapter 2.1.2.4, appear to have been used to collect cereals with one single, large, and obliquely hafted flint blade. Once the cutting edge of this insert became blunt, it was sharpened through retouching. Alternatively, the insert was pulled out of the wooden shaft, flipped around, and shafted back in, to use the opposite cutting edge. For that, the groove had to be adapted by either enlarging the hole or by adding tar to fix the insert into the haft (Gibaja et al., 2017a, p. 219). This work appears rather long and difficult to be done, in parallel to a harvest. Also, the discovery of entire sickles and loose inserts within the remains of farmhouses, indicates that these changes were probably done at the village itself and not in the fields. Also, the presence of as many as 10 entire sickles in this village shows that reaping appears to be a communal effort with many people participating at the same time and not an individual undertaking.

8.1.2. Wooden tool sharpening

The cutting edges of the oak wood sickles have not been sharpened during the entire cereal harvest. However, after the first hour of reaping, these edges quickly became blunt and the motion of reaping changed from cutting to sawing, ripping, and uprooting. As such, the cutting edges of these tools needed grinding. This could have been done with a flint blade or a rough stone like a sandstone. This action would have to be done regularly throughout the day to keep the cutting edge sharp and the reaping speed up. This process is of course possible in the field with the necessary tools, as it is easier to sharpen a wooden blade than to replace a flint insert in a sickle. But this frequent, hourly tool honing might distract from the task at hand: harvesting as much grain as possible in the smallest amount of time. One can imagine that like for the hafted sickles with shell inserts, multiple wooden sickles were used simultaneously. These would, at the end of the working day, been brought back to the village or farmhouse to be grinded. This is what might have happened at the lake-site village of La Draga, Spain, where so far, the only early neolithic wooden sickle has been discovered. The sickle was unearthed within the village, with recognisable use-wear traces indicating a reaping use (Terradas et al., 2017, p. 209). It appears that it has been discarded, before being sharpened, as the use-wear traces were still recognisable.

In short, to collect cereals back in the Neolithic, it seems that tools were frequently sharpened, the inserts regularly replaced and that several tools were used at the same time. These instruments appear then to have been repaired in the farms or villages, where 6,000 years later they have been found by archaeologists.

8.2. Quantitative results

8.2.1. Grain consumption rates

In the Neolithic, a cereal-heavy diet i.e., "*cereals provide the bulk (80% or more) of the diet*" (Bogaard, 2004, p. 43), was believed to be prevalent. To collect the necessary grain for such a diet, a certain volume needed to be gathered. The exact amount of how much grain was needed per year and per person has been hotly debated in archaeology. Estimations range between 120 to 350 kg of grain (Bogaard, 2004, p. 43; Davis, 1991, p. 163; Foxhall & Forbes, 1982, p. 72; Halstead, 1981, p. 317; Hillman, 1973, p. 229; Perles & Monthel, 2001, p. 165; Renfrew et al., 1982, p. 278). But given the grain yield of the worked fields in this experiment, the applied harvesting techniques, and the used tools, how long does it take to collect that amount?

For that calculation, several assumptions have been made. The first is the personal grain consumption rate per person. As different authors postulate different rates ranging between 120 to 350 kg of cereal grains a year, an average of 200 kg per person has been assumed. As the harvester had to feed his or her dependents as well as himself, a hypothetical neolithic family of five has been postulated (Bogaard, 2004, p. 43). This would mean that, to feed such a family for an entire year, a minimum 1,000 kg of grain is needed.

The gathering of cereals in North-Western Europe is usually done in the months of July or August (in the case of this experiment it was July), when the days are long. As such, harvesting hours have been estimated to be between 12 to 14 hours per day (Anderson & Peña Chocarro, 2015, p. 94, Juel Jensen, 1994, p. 120). For this calculation, a 14-hour workday has been assumed.

The reaped surface used for this calculation has been based of the best-performing tools in this experiment. These were the hafted sickles with oyster shell inserts, with which a maximum of 19.0 m² of *T. aestivum* and 18.7 m² of *T. dicoccum* could be harvested within the first hour. For *H. vulgare* and *T. monococcum* the best results could be achieved with the hafted sickles with mussel shell inserts, being 13.3 m² and 9.6 m² of surface respectively. All these results have been obtained by only one person and within the first hour of each harvest. Results during subsequent hours were frequently lower due to inserts getting blunt or dropping out (see Appendix A).

Based on these assumptions the needed workdays to achieve the required grain volumes have been computed. For *T. aestivum*, the use of a hafted sickle with oyster shell inserts and based on a reported grain yield of 8.3 t/ha, resulted in 15.77 kg of grain collected (see Appendix B). Within a 14-hour day, this added up to close to 220 kg of grain gathered, which is higher than the yearly consumption rate of one person (200 kg) (see table 8.1). With *Triticum dicoccum,* one's needs can be covered almost as fast. With 14.77 kg of grain collected during the first hour by using a hafted sickle with oyster shell inserts, this results in about 207 kg of harvested cereal per day. The lower yield of *Hordeum vulgare* with a maximum of 7 kg of grain gathered per hour with a hafted sickles with mussel shell inserts, would results in 102 kg of grain collected in one day. Two full workdays are thus needed to achieve one's yearly needs in grain. Finally, *Triticum monococcum* with a maximum of 5 kg of grain collected with a hafted sickle with mussel shell inserts, enables to gather only 78 kg of grain per day. A minimum of 2.5 days of work are therefore needed to gather enough grain for the year. For a hypothetical family of five, to reap a minimum of 1,000 kg (200 kg x 5 people) of grain, this would mean about five days' work for *Triticum aestivum* or *Triticum dicoccum*, 10 days for *Hordeum vulgare* and 13 days for *Triticum monococcum*. In other words, it is possible with high yield cereals, these experimental tools, the documented speed, and one harvester to gather sufficient cereals to sustain a family of five for a year (see table 8.1).

Table 8.1. Overview of workdays needed to achieve the yearly grain consumption rate. Based on actual grain yield, harvested surface, use of hafted sickles with shell inserts and one harvester (Made by M.-P. Häg).

Single-person harvest	*T. dicoccum*	*H. vulgare*	*T. aestivum*	*T. monococcum*
	Yield: 7.9 t /ha	**Yield: 5.5 t /ha**	**Yield: 8.3 t /ha**	**Yield: 5.8 t /ha**
Max. surface harvested in first hour (in m²)	**18.70**	**13.30**	**19.00**	**9.60**
Max. grain reaped in first hour (in kg)	**14.77**	**7.32**	**15.77**	**5.57**
Grain reaped after 14-hour work day (in kg)	**206.82**	**102.41**	**220.78**	**77.95**
Days needed to reap 200 kg of cereal	**0.97**	**1.95**	**0.91**	**2.57**
Days needed to reap 1,000 kg of cereal	**4.84**	**9.76**	**4.53**	**12.83**

8.2.2. Persons involved

The above calculations were done under the assumption that just one person with a hafted sickle with shell inserts is harvesting cereals, as has been done during this entire experiment. But a cereal field, once ripe, must be reaped rapidly, to ensure that all grain is collected. This period is limited between one week in dryer climates to three weeks in wetter climates (Fuller et al., 2010, p. 16; Ibáñez et al., 2001, p. 29). This short period results in a "*labour bottleneck*" (Fuller et al., 2010, p. 16), where the harvest needs to be done by as many people as possible to collect all cereal grains.

Assuming a hypothetical neolithic family of five, as done by A. Bogaard (Bogaard, 2004, p. 43), two people could be working together to harvest an entire field. One would be cutting the stems, the other collect these, carry them to the edge of the field and bind them to sheaves (Anderson & Peña Chocarro, 2015, p. 94). This would avoid the drawback of this experiment, where one person was harvesting, but also collecting the stems, carrying them to the border of the field, and binding them together. Another option to improve the results would be, to have one additional person to collect the stems from the sparsely planted borders of the fields, as seen in the experiment with *T. aestivum.* These could be collected by hand or with shell-based harvesting knives. The collection by hand, as shown in the experiment, is not fast, but has the advantage of collecting only ears. It also enables the collection of grain from weed infested locations (Anderson, 1999, p. 123), which with a sickle would be too cumbersome to reap. It is a rather easy work, as the harvester stands close to the plants and snaps the ears off without bending forward. This work could therefore be done by a person with less physical strength like children or the elderly.

During the harvest, such a combination of physically stronger and weaker people, working together could improve further the reaping results. For example, one or two stronger harvesters could reap the cereals with sickles. One or two others could carry the stems to the border of the field, put them together and bind them to sheaves. They could also snap the ears off from plants difficult to reach with a harvesting knife and leave the stems as animal feed or as fertiliser. If most above-mentioned group members participate in the harvest, the amount of time to achieve the yearly grain needs can thus be reduced significantly and the harvest becomes a truly communal effort (Bogaard, 2004, p. 159).

For calculation purposes, the assumption has been made, that only two people with hafted sickles with shell inserts would be harvesting cereals. This would result in double the surface and volume of grain being reaped, together with the collecting time reduced by half. For *T. dicoccum* this would mean 37.4m² of harvested surface per hour instead of 18.7m² achieved by only one person. For *Triticum aestivum* and *Triticum dicoccum,* the needed reaping days will thus be reduced from 5 days to two days and half. *For H. vulgare* the period will be shortened from 10 days to 5 days and for *T. monococcum* from 13 days to about 7 days (see table 8.2.). Therefore, two persons working together would already result in a cereal yield sufficient to cover the yearly needs of that group and be fast enough to reap the cereals fields within one-week, well within the minimum harvesting period (Ibáñez et al., 2001, p. 29).

Table 8.2. Overview of workdays needed to achieve the yearly grain consumption rate. Based on actual cereal yield, harvested surface, use of hafted sickles with shell inserts and two harvesters (Made by M.-P. Häg).

Multi-person harvest	***T. dicoccum***	***H. vulgare***	***T. aestivum***	***T. monococcum***
	Yield: 7.9 t /ha	**Yield: 5.5 t /ha**	**Yield: 8.3 t /ha**	**Yield: 5.8 t /ha**
Max. surface harvested in first hour (in m²)	**37.40**	**26.60**	**38.00**	**19.20**
Max. grain reaped in first hour (in kg)	**29.55**	**14.63**	**31.54**	**11.14**
Grain reaped after 14-hour work day (in kg)	**413.64**	**204.82**	**441.56**	**155.90**
Days needed to reap 200 kg of cereal	**0.48**	**0.98**	**0.45**	**1.28**
Days needed to reap 1,000 kg of cereal	**2.42**	**4.88**	**2.26**	**6.41**

8.2.3. Ancient yield calculation

One added difficulty in this calculation is the fact that all cereal types harvested in this experiment are of the modern, high-output cereal type. These cereals have such a high yield, that even when planted in the experimental Carolingian type ridge and furrow field (Kropp, 2022, p. 114), they still achieve a high yield like modern conventionally planted fields (Dorn et al, 2023). But how much grain yield can we expect from cereals planted back in the neolithic period? Researchers have estimated the grain yield achieved in the Neolithic to be between 500 kg to 1,000 kg per hectare (Bogaard, 2004, pp. 23-25; Halstead, 1981, p. 318; Perles & Monthel, 2001, p. 165). P. Halstead has calculated that yields around the Mediterranean coast would be around 500 kg to 800 kg in Galilee and between 800 kg to 1,000 kg in neolithic Greece (Halstead, 1981, p. 318). Experiments made in more northern countries like at the Little Butser farm in the UK during the 1970s resulted in yields of up to 2,000 kg per hectare (Reynolds, 1999, p. 270). Other experiments with ancient cereal types at the Forchtenberg site in Germany resulted in yields of 1,500 kg on fields being laboured with antler or wooden hoes (Schier et al., 2013, p. 102). With a slash and burn technique, as assumed happened during the Michelsberg period (see Chapter 4.1.), a yield of up to 5,000 kg per hectare could be achieved (Ehrmann et al., 2009, p. 66).

The spread in grain yields is thus estimated between 500 to 5,000 kg per hectare. The Mediterranean results of 500 kg to 1,000 kg per hectare appear low for a wet environment as was believed to exist in North-Western Europe. The results from Forchtenberg appear too high, as the oldest cereal types used during this experiment are from the 19th century and might already be too productive in comparison to the assumed neolithic types. The average yield of 2,000 kg per hectare of grain from the Little Butser farm could be suitable for the calculations of this experiment. The climate in the neolithic Michelsberg period appears to be like in today's North-Western Europe with much rain and mild winters (Teetaert et al., 2019, p. 356; Kalis, 2010, p. 37). Also, the reported poor soil quality at the Little Butser Farm which resulted in low but rather consistent yields each year (Reynolds, 1999, p. 267) could be taken as a basis for Michelsberg agriculture. Therefore, this yield of 2,000 kg per hectare has been taken as grain yield calculation.

Based on this yield, the surface results of the cereal harvesting experiments have been recalculated. The aim was to determine how much grain could be collected with the experimental tools on a field planted with cereals having a grain yield of maximum 2,000 kg per hectare and with only one person reaping. The results were as follows. For *Triticum dicoccum,* close to 4 kg of grain per hour could have been gathered with a hafted sickle with oyster shell inserts (18.70m² per hour x 2,000/10,000 kg = 3.74 kg). For *Triticum aestivum,* this would be 3.80 kg of grain per hour, for *Hordeum vulgare* 2.66 kg and for *Triticum monococcum* 1.92 kg per hour (see table 8.3).

To reap sufficient grain for a family of five by harvesting alone, as done in the experiment, 19 days are needed for *Triticum dicoccum* (3.74 kg x 14 hours x 19 days =994.84 kg), as for *Triticum aestivum*. 27 days are needed for *Hordeum vulgare* and 37 days for *Triticum monococcum*.

If at least two people are participating in the harvest, the collecting speed could be doubled with the resulting reaping being done within 9 to 19 days (see table 8.4.). This period appears suitable for a wet environment like North-Western Europe, as three weeks of harvesting time have been also estimated for humid Northern Spain (Ibáñez et al., 2001, p. 29).

Table 8.3. Overview of workdays needed to achieve the yearly grain consumption rate. Based on a lower grain yield, harvested surface, use of hafted sickles with shell inserts and one harvester (Made by M.-P. Häg).

Single-person harvest on lower yield	*T. dicoccum*	*H. vulgare*	*T. aestivum*	*T. monococcum*
	Yield: 2.0 t /ha	**Yield: 2.0 t /ha**	**Yield: 2.0 t /ha**	**Yield: 2.0 t /ha**
Max. surface harvested in first hour (in m²)	**18.70**	**13.30**	**19.00**	**9.60**
Max. grain reaped in first hour (in kg)	**3.74**	**2.66**	**3.80**	**1.92**
Grain reaped after 14-hour work day (in kg)	**52.36**	**37.24**	**53.20**	**26.88**
Days needed to reap 200 kg of cereal	**3.82**	**5.37**	**3.76**	**7.44**
Days needed to reap 1,000 kg of cereal	**19.10**	**26.85**	**18.80**	**37.20**

Table 8.4. Overview of workdays needed to achieve the yearly grain consumption rate. Based on a lower grain yield, harvested surface, use of hafted sickles with shell inserts and two harvesters (Made by M.-P. Häg).

Multi-person harvest on lower yield	*T. dicoccum*	*H. vulgare*	*T. aestivum*	*T. monococcum*
	Yield: 2.0 t /ha	**Yield: 2.0 t /ha**	**Yield: 2.0 t /ha**	**Yield: 2.0 t /ha**
Max. surface harvested in first hour (in m²)	**37.40**	**26.60**	**38.00**	**19.20**
Max. grain reaped in first hour (in kg)	**7.48**	**5.32**	**7.60**	**3.84**
Grain reaped after 14-hour work day (in kg)	**104.72**	**74.48**	**106.40**	**53.76**
Days needed to reap 200 kg of cereal	**1.91**	**2.69**	**1.88**	**3.72**
Days needed to reap 1,000 kg of cereal	**9.55**	**13.43**	**9.40**	**18.60**

8.2.4. Cereal harvesting speed calculations

The speed in which cereals are harvested, has also been the subject of research, done on historic and pre-historic times and in experimental archaeology (Juel Jensen, 1994, pp. 120-121). The velocity is usually calculated in m² per minute and varies greatly between modern experiments and historic data. It stretches in experiments from 0.4 to 1.4m²/min for flint implements (see table 8.5.) and in historic Roman times from 2.1 to 3.4m²/min. supposedly with iron sickle blades (Juel Jensen, 1994, pp. 120-121) (see table 8.6.). But unfortunately, these figures omit information on how densely the fields were planted, what type of tools were used, how many hours the harvester worked and if the harvest was a communal affair.

Table 8.5. Overview of experimental results with different harvesting tools (Juel Jensen, 1994, p. 120).

Table XI. Experimental results of harvesting efficiency.

Experimental types	Production pr m^2/min.
Steensberg 1943:	
Harvesting impl.; flint (5 types)	0.5–0.8
Bronze sickles (2 types)	0.8
Scythes (1 Viking/1 Roman)	1.6–2.9
Contemp. metal sickle (2 types)	1.7
Korobkova 1981:	
Harvesting knives; flint (15 types)	0.4–1.1
Copper sickle (1 type)	0.9
Contemp. metal sickle (1 type)	1.9
Frank 1990:	
Harvesting impl.; flint (2 types)	0.8–1.4

Table 8.6. Overview of historical harvest results (Juel Jensen, 1994, p. 121)

Table XII. Historic record on harvesting efficiency.

Country	Period	Field	m^2/min.	Refs. (in Lüning 1951: 112–14)
Italy	1st Cent. B.C.		3.4	Varro
Spain	1st Cent.	Wheat	2.2	Columella
Spain	1st Cent.	Barley	3.4	Columella
Italy	5th Cent.	Barley	3.4 (good male)	Palladius
Italy	5th Cent.	Barley	2.1 (med. male)	Palladius
Germany	19th Cent.		2.6/2.8 (male)	Hamm 1853
England	19th Cent.		2.8 (female)	Hamm 1858
Germany	19th Cent.		1.4	Rau 1896
Germany	19th Cent.		3.4 (good male)	Röder 1940
Germany	19th Cent.		3.4 (good female)	Röder 1940

More recently, similar experiments were undertaken with the following results. In 2019, a team around N. Mazzucco had reaped 400m² of *Triticum aestivum* in Tuscany, Italy during 15 hours with a reported total yield of 150 kg. In 2016, they managed to reap 80m² of *T. monococcum* within 10 hours in the Provence, France. Finally in 2020, close to Burgos, Spain, they harvested 300m² of *Hordeum vulgare* in 8 hours (Mazucco et al., 2022, S2). For *T.aestivum* this would result in a speed of 0.44m² per minute (400m²/15 hours/60 min), for *T. monococcum* 0.13m²/min. and for *H. vulgare* 0.63m²/min. The grain yield for *T.aestivum* was compounded to 10 kg per hour (150 kg/15h) (see table 8.7.).

Table 8.7. Overview of experimental harvesting results (Mazzucco et al., 2022, S2).

Experimental results in the Mediterranean	Surface harvested in m²	Hours harvested	Total yield in kg	Harvesting speed in m²/min.	Yield in kg per hour
Tuscany, Italy, *T.aestivum*	**400**	**15**	**150**	**0.44**	**10.00**
Provence, France, *T. monococcum*	**80**	**10**		**0.13**	
Burgos, Spain, *H. vulgare*	**300**	**8**		**0.63**	

In the frame of this cereal harvesting experiment, the reaping speed was recorded at a maximum of 0.35m² per min for *T. dicoccum* (see Chapter 6.1.1.) achieved with a hafted sickle with oyster shell inserts. For hand-held shell tools, the speed was around 0.08 to 0.02m²/min (see Chapter 6.2.1.). These figures are lower than the velocity recorded in the experiments of H. Juel Jensen in the 1990s or in historic data. This reduced speed could be due to the following reasons: 1) the inexperience of the harvester, 2) a lower efficiency of the experimental tools compared to tools with flint or metal inserts, or 3) the loss in time by carrying the cut stems to the border of the field.

The first point appears not to be very relevant. In other experiments the impact of an unexperienced harvester compared to an experienced one has been seen either as low (Frank, 1985, p. 19; Juel Jensen, 1994, p. 119) or as high (Anderson & Whittaker, 2015, p. 108; González et al., 1994, p. 325). This means, that the results achieved throughout this experiment by one unexperienced harvester, be it harvested surface, reaping speed or collected grain yield could be considered a minimum and not a maximum output.

The second reason could be applicable for sickles made with metal blades. The cutting speed of these is about 2/3 faster than with hafted sickle with flint inserts (see table 8.5 and 8.6).

The third point appears to be the most significant. An estimated 1/3 of the harvesting time has been used for carrying the stems to and from the field (see Chapter 5.5.1.). Without carrying the stems, the collecting speed would have increased by 1/3, resulting in a maximum speed of 0.53m²/min (0.35m² /0.66) for *T. dicoccum* with a hafted sickle with oyster shell inserts. For hand-held shell tools the speed would reach 0.12m²/min. Thus, the absolute reaping speeds achieved during this experiment would have been between 0.53m²/min. and 0.12m²/min (see table 8.8.). These speeds are similar or above the recent experimental results on *T.aestivum* and *T. monococcum* (see table 8.7.); (Mazucco et al., 2022, S2) and are similar to earlier experimental results from the 1990s (see table 8.5). To achieve these speeds, the reaper would have to gather cereals the entire hour and be in a bent position the whole time. This makes the collection more tiring. But the harvesting speed would have increased, and more cereals would have been reaped and collected.

Table 8.8. Overview of fastest harvesting speeds achieved during the experiment including and excluding carrying and binding stems (Made by M.-P. Häg).

Experimental results in Germany	Tools used	Surface harvested in m²	Hours harvested	Speed in m²/min. incl. carry stems	Speed in m²/min. (reaping only)
Lauresham, Germany, *T. dicoccum*	Sickle with oyster shell inserts	**21**	**1**	**0.35**	**0.53**
Lauresham, Germany, *T. aestivum*	Sickle with oyster shell inserts	**19**	**1**	**0.32**	**0.48**
Lauresham, Germany, *T. dicoccum*	Wooden sickle	**20**	**1**	**0.33**	**0.50**

Harvesting done with tools made from alternative materials such as shells, wood or bone can thus result in a similar grain yield and speed as tools made from flint inserts. If, as in this case, there are almost no differences in reaping cereals with shell or with flint inserts, could both materials have been used?

Making flint inserts appears more time consuming than making shell inserts. The "*chaîne opératoire*" of flint, which "*reconstructs the organisation of a technological system*" (Sellet, 1993, p. 106) could be as follows: first, the flint must be mined, the nodules worked upon, transported as finished or semi-finished items, knapped into flake or blade inserts before finally been used as tools (de Grooth, 1998, p. 362; van Gijn, 2010, p. 122). For shells, the *chaîne opératoire* appears simpler and faster. They can be gathered close to home on a beach or river, broken into the needed shapes and inserted into a wooden handle. However, for oysters, being a sea water shell, these had to be first transported from the coast to the hinterland, where Michelsberg sites were located. This could point to an exchange of goods between coastal populations like Hazendonk and inland Michelsberg. In other words, both materials, be it flint, or shells are easily available and could have been used interchangeably in an Michelsberg context.

Also, there are several examples, where at neolithic sites of North-Western Europe, lithic harvest implements have been treated in a special way.

At the location of Schipluiden, in the Netherlands, dated 3,700 cal BC, flint sickles have been made only with imported stone. The edges of these sickles have, after use, been intentionally retouched and burned before being discarded. The aim appeared to "*kill*" the object before returning it to nature, as harvesting might still be seen as a "*circumspect"* activity (van Gijn et al., 2008, p. 198). Since flint was imported from Michelsberg mines to this site, other goods might have been exchanged for it. It could be that oyster shells, were such a material. Be it as material for ornaments or tools these could have been collected along the coast and brought into

Michelsberg terrain to be transformed there into inserts and put into sickles. These would then be used as harvesting implements, as shown in the experiments of this thesis. Once these inserts were used up, they would have been discarded and their perishable remains might not have lasted until today. This could explain why in Michelsberg areas, harvesting tools are rarely found, but traces of cereal were discovered.

Another example where reaping tools could have a special significance, rather than just being a harvesting implement, are querns, which in the early neolithic LBK period of North-Western Europe have being intentionally fractured and rubbed with ochre before being disposed of (Verbaas & van Gijn, 2008, p. 197). Also, later, during the western TRB (3,400 to 2,900 cal BC), sickles were almost exclusively identified in burial contexts (van Gijn, 2010, p. 174).

Also, at other neolithic sites in Europe cereal harvesting tools have a special importance. At the Middle Neolithic site of Egolzwil 3 in Switzerland, flint inserts found in wooden shafts of sickles were made from large flint blades and were frequently retouched, for them to stay sharp during the harvest. The shafts themselves were believed to have been used over a long period of time and their grooves been frequently enlarged to hold different flint inserts (Gibaja et al., 2017a, p. 219). But could these shafts also hold inserts made from other materials like shell? These shells might not have been preserved, thus the exclusive archaeological focus on sickle inserts. But as the actual experiment shows, these shells could have been as effective in cutting cereals than flint.

Another example for such an assumed double use, would be the site of La Draga, Girona, Spain, where many wooden handles were unearthed, believed to be used as sickle hafts. Surprisingly, almost all these shafts were found without inserts (Bosch Lloret, 2006, pp. 34, 49, 65-67, 83, 114). Could therefore the type of inserts vary between flint or shell depending on the harvesting needs? At this site, many flint, wood and shells tools were discovered, indicating that these materials were readily available and used to make tools. However, specific shell reaping tools have, at this site, not been identified (Clemente Conde & Cuenca Solana, 2011, p. 139). But wooden sickles have been, thus indicating an alternative use of materials also in harvesting tools (Terradas et al., 2017, p. 209). The same applies at the site of Costamar, Spain, where in an antler piece, a deep groove suggests a large flint blade being inserted and used for cutting cereals (Flors et al., 2012, p. 2). The blade itself was missing, but the author nevertheless assumed the insert to be a flint blade (see Chapter 2.1.2.4.). Still also a shell insert could have been used.

In summary, sickles or harvesting knives, be it with flint or shell inserts achieve similar grain yields and harvesting speeds. This could indicate that these might have been used interchangeably to reap. But flint inserts have been preserved and therefore could be analysed, whereas shell or wood have, in most cases, not been discovered in archaeological contexts. This might have created a research bias where only preserved materials have been extensively analysed and other potential suitable materials have been overlooked.

8.3. Archaeological traces

How could the remains of these tools be identified in archaeological excavations?

For hafted sickles with oyster shell inserts, it can be assumed that in most cases the wooden shaft will have decomposed or will have ended up as firewood. However, oyster shell inserts might have been preserved. But these might be rather small and therefore difficult to recognise as a possible tool. These, if intact, will present themselves often as small triangular or rectangular parts of a shell. They consist of a larger, almost rectangular bottom, which has been the segment of the insert hafted into the wooden shaft. The above cutting part will be either pointed or strongly eroded due to the flaking off during the harvest. So, these inserts could be between 2 to 5 cm in length and 1 to 1.5cm in width with at least one side of pronounced, rounded edges, and some hafting traces, as seen during the experiments. Given that oyster shells are flaking easily, the remains encountered might be even smaller and therefore more difficult to determine (see also Chapter 7.1).

For hafted sickles with mussel shell inserts, their potential remains could be larger. As seen in the experiments, the cutting edge of these have not been rounded or worn off as much as the oyster shell inserts. But, in a neolithic cereal harvest, these inserts would have been regularly retouched while still in the wooden sickle haft. This would continue until they are too short to be retouched any more. This would reduce the widths of the inserts strongly and the mussel shell inserts would then have a similar width as the oyster shell inserts (1 to 1.5cm). The cutting edges will show traces of retouch and some edge rounding, polish, and striations but the rounding will not be as pronounced as for the oyster shell (see also Chapter 7.2.).

The wooden sickle is believed to be sharpened regularly, with a sharp stone, shell, or a rough stone like a sandstone, during harvest. This will, over time, extend the cutting edge more and more inwards. The shape of the cutting edge, which at the beginning looked like a “C” (see fig. 5.3.) will, after frequent honing, look more like a lying “U”. The handle will appear longer, and the body of the sickle will get shorter. If the tip of the sickle is also being frequently retouched, both the tip and the cutting-edge will retreat towards the back, and the tool will end up having a lying “L” shape. The end of the sickles use life has arrived, when there is no more wood left to sharpen the cutting edge. The tool will then be either discarded as a strongly “L”-shaped/ “U”-shaped piece of wood, breaks up during the harvest or is finally burned as firewood. Thus, the remains of such discarded wooden sickles will be difficult to find. They could be discovered in waterlogged sites, where wooden artefacts are often well preserved as happened at La Draga, Spain, where the only existing wooden harvesting tool has been discovered.

The deer mandible will have suffered the least changes over the harvest. The teeth of the mandible, as seen in the results, hardly show any use-wear traces related to cereal harvesting. Thus, looking exclusively at these teeth, it would be difficult to distinguish between a mandible used for food compared to one used for collecting grain. But additional features might hint at a difference between both. The absence of front teeth, or incisors, can be an indicator for a harvesting tool. Archaeological tools used by native Americans for gathering grass, show an absence of these front teeth (see fig. 2.10); (Brown, 1964, p. 382). Also, during this experiment, deer mandible incisors were damaged or have dropped out when they touched the soil (see fig. 7.7.a). Further use-wear traces can be located on the front bone or diastema of the mandible. As cereal stems were hitting this bone every time during reaping, they left a strong polish and edge rounding, which points towards its use as reaping tool (see also Chapter 7.4.).

Cattle ribs might not show any harvesting traces, as in this experiment they could not be used for reaping any of the cereals. They might therefore also not have been used archaeologically as such tools.

Hand-held shell tools used as harvesting knives show traces, which could be seen in an archaeological context. Oyster shells or fragments of them, with strong abrasion of their outer, brownish layer and dents in their inner, mother-of-pearl part, could point towards a cereal harvesting use (see Chapter 7.6).

As for hand-held mussel shells, one has been encountered in an archaeological context at Chalain, Jura, France (Pétrequin et al., 2006, p. 115). Therefore, a dented cutting edge or a broken off anterior end could indicate its use for cereal harvesting (Maréchal et al., 1998, p. 195). Also, characteristic for both shell types is the strong abrasion of their interior surface after use. Oyster and mussel shells frequently have a brownish deposit on their inner surface (see fig. 7.11.c.; 7.13.e.). Once used for reaping, the inner part of the shell, -especially the one close to the cutting edge-, gets polished by the stems. This results in a very clean inner shell surface with polish and striations (see fig. 7.11.d. and fig. 7.13.f.).

Overall, it can be concluded that, be it shells, wood or bone, use-wear traces left from harvesting are clearly visible on these tools. But how can these traces be found among archaeological assemblages, especially if there are many?

On coastal shell middens with large volumes of discarded shells, finding the few ones used as tools is like searching for the proverbial needle in the haystack. Some researchers have therefore proposed different ways of finding such tools. Some focus only on bivalve shells as potential tools (Lammers-Keijsers, 2007, p. 22), others look for alterations, like burning or holes (Cuenca Solana, 2013, p. 41), which can point to a tool use. But in sites where only few shells have been unearthed, it might be worthwhile to analyse all these finds under different microscopes to discover potential use-wear traces. As known Michelsberg sites are removed from the seacoast, the number of discovered sea shells is limited (Colas, 2007, p. 331; Lüning, 1968, p. 79). We can therefore assume, that these were transported there with a purpose be it as material for decorations or tools, but not as food, as seen on costal sites.

8.4. Why are sickles missing?

In the fourth chapter of this thesis, potential explanations have been put forward as to why flint-based sickles or harvesting knives were not found in the Michelsberg period of North-Western Europe. These were shortage of flint, lost skills of flint knapping, cereal trade between communities, or an archaeological hiatus. Unfortunately, none of these above points could plausibly explain why flint-based reaping tools were absent during such a long period of 900 years (see Chapter 4.3.). This absence appears not only the case during the Michelsberg period. In other periods, cereals are present in the archaeological record, but the corresponding reaping tools are not. Be it in the early Neolithic of North Africa or North Spain, the Middle Neolithic Jura region in France, or the late Neolithic in coastal Vlaardingen or alpine Horgen, there were times where flint-based sickles or knives seems to largely disappear from the archaeological record (Ibáñez et al., 2001, p. 24; 2008, p. 191; Rodríguez-Rodríguez et al., 2014, p. 768; Schlichtherle, 1992, p. 33; van Gijn & Bakker, 2005, p. 295). But, as cereal remains have been discovered, tools must have been used to gather these. As these have not been excavated, it has been speculated that other materials than flint might have been used to harvest. These alternative materials have so far only rarely been discovered in an archaeological context presumably due to bad preservation and poor visibility.

But why would people in the Neolithic abandon a well-established technology like the flint knapping to replace it with another technology, when they were clearly still expert flint knappers, certainly during the Michelsberg period? Seen from the viewpoint of us modern archaeologists, this appears non-sensical. Maybe archaeological theory can help to find an answer to this paradox.

The work, of ethnologist P. Lemonnier can shed light on the reason as to why such choices are made. Following his research in New Guinea on the technological preferences made by indigenous groups, he discovered that these decisions are made for a reason. These are rarely of technological nature or geared towards efficiency. They are often made "*to mark difference*" to other surrounding groups (Lemonnier, 1986, p. 173) These groups make a conscious election to refuse a particular technology, although being aware of its existence through contact with its neighbours (Lemonnier, 1986, p. 161). And although these choices appear "*without any logic of material efficiency or progress" (*Lemonnier, 1993, p. 24), they are lived by, and thus influence the way these people see their world. This could also be the case for sickles and knives made with alternative materials used to reap cereals in the 4th millennium of North-Western Europe. People during the Michelsberg period were proficient flint knappers and had access to good quality raw material but have decided not to use flint for their sickles or harvesting knives. They made a conscious choice of using either their hands or tools made with shells, wood, or bone to gather their cereals.

This decision could be dictated by the material agency of the employed materials. Material, through its mere presence, is believed to influence humans and situations. N. Boivin mentions "*If material is alive only because humans interact with it, it is also true that humans are alive only because they have material to engage with*" (Boivin, 2008, p. 138). The shape, texture, colour, and structure of material let human use it in a certain way. For flint, its variety of colour, texture and ring when stuck (van Gijn, 2010, p. 167) has led people to make tools out of it.

For shells, this could be the same. The ease with which these can be found along rivers, or along the sea, can bring humans to collect them first for food, then as decoration, due to their colour and interesting shapes and then as tools due to their suitable material properties. The usefulness of a cutting edge of bivalve shells as oyster or mussels has been recognised on many occasions in archaeological and ethnological contexts (Clemente Conde & Cuenca Solana, 2011, p. 139; Lammers-Keijsers, 2007, p. 77). Why should this not be the case to collect cereals? The shells just need to be broken apart and placed in a wooden shaft and a fully functional hafted sickle is made. They thus can be easily transformed into cutting implements without a particular skill or acquired technique needed.

Beyond the pure material agency, a material engagement theory can also be applied. The focus is not on the material itself, but on the relation such material can have with the users or "*the material engagement approach allows for a dynamic reciprocal relationship between brains, bodies, and things"* (Malafouris, 2018, p. 13). Thus, the body, being mostly the hand but also the brain, combines material features and human handling. In our case, using an entire shell as harvesting knife, would be such an example. The natural shape of the shell is guiding the hand of the harvester. The thumb fits into the central, concave part of the shell to reap the cereal ears. The unretouched sharp edge of the shell can be used to snap off the cereal ears. The thumb glides over the cutting edge to the central part of the shell to reap. No learning of a specific harvesting technique is needed. The harvester just needs to take advantage of the natural shape of the shell to be able to gather cereals.

To make such cereal harvesting tools, the concept of the craft theory can be applied. Skills and knowledge of how to make and use things are the focus here. According to T. Ingold, one must submit to the material first, before mastering it later (Ingold, 2018, p. 161). For cereal harvesting, this would mean that one must select the needed materials to make harvesting tools according to one's need or cultural preferences and then develop the skill on how to reap. This approach does not necessarily focus on the most efficient or fastest way of achieving one task, but more on a cultural level of what a group of people believe is the adequate way to create a tool or finish a task. This is comparable to the approach of P. Lemonnier regarding choices being made based on social and cultural aspects and not on tool efficiency and technology (Lemonnier, 1993, p. 24). In our case of the missing flint sickle blades from the Michelsberg period, people might have the desire to reap with tools not made from flint, although flint-based tools are proven to be effective, and the necessary technology is known. This would be a clear distinction to other surrounding communities. This decision might lead to the use of unsuitable material, as seen in the experiment. Cattle ribs, for example, were easy to make, but did not yield any harvesting results. The ribs were flat and could be sharpened, and thus appeared to be a suitable material for cereal harvesting, However, in the end they were not. On the other hand, hafted sickles with oyster shell inserts appeared not suitable at the beginning, especially because of their layered structure prone to frequent flaking. But these oyster shell inserts placed at an angle in a wooden sickle frame, as done in earlier LBK or Rössen context, proved very suitable for gathering cereals. The skill of making a "*traditional*" sickle with flint inserts has been transferred to the making of sickles with other, shell-based inserts and has proven effective.

Finally, looking at the entanglement theory, humans are caught in a web of dependencies relative to the things they are using. Ian Hodder explains this as "*humans get caught in a double-bind, depending on things that depend on humans*" (Hodder, 2011, p. 164). In the case of reaping, this means that domesticated cereals are dependent on humans for them to be planted and collected (Harlan, 1999, p. 3). This in turn means that humans have, when the grain is ripe, a narrow time frame of one to three weeks (Fuller et al., 2010, p. 16; Ibáñez et al., 2001, p. 29) to gather these. In case this frame is not met, the harvest cannot be brought in, and people go hungry the next winter. Therefore, tools are needed, which enables a harvester to collect enough grain within a short time frame. Humans must thus prepare for a harvest, by ensuring that all tools are ready, sharpened and repaired and that they are effective enough to achieve the annual grain yield. Tools which are not effective, like the cattle ribs proved to be, will not be used, as they are too slow to complete the harvest within this tight time frame. Also, enough persons must be ready during this time frame to achieve the harvest collectively (Fuller et al., 2010, p. 23). It appears that, many choices in the neolithic tool kit might be due to cultural and not technological reasons, but efficient tools are still needed to conclude the harvest in time. Thus, people in the Neolithic are entangled by their surrounding material be it cereals or organic harvest inserts. However, they still have the choice what materials to use, if it satisfies the basic requirement of achieving the reaping on time.

With respect to the Michelsberg period, materials like shells, wood or bone which can be used for harvesting, have been available. The shape of these materials was suitable for reaping without changing the material itself. There was no need to learn new tool-making skills as well as new techniques. But these tools must be sufficiently effective to allow a rapid harvest and thus ensure the survival of the group. Therefore, changing the material from flint to shell, wood, or bone, does not appear to be a major technological revolution. People took advantage of the materials available around them, materials they were familiar with, used their existing skills and could thus harvest effectively to fulfil their cereal needs. So, it appears that this change had more of a cultural dimension with the deliberate aim to use other materials, instead of flint. One example could be the oyster shells. Given that Michelsberg sites mostly stretch inland and not along the North Sea coast, securing oyster shells for tooling appears to be a challenge. It could be argued that there was an exchange of materials between coastal groups and Michelsberg sites. In Schipluiden (a coastal Hazendonk site), where flint tools imported from Michelsberg mines have been discovered, oyster shells could have been the material exchanged to Michelsberg settlements.

8.5. Conclusion on alternative harvesting tools

Tools used in the Middle Neolithic have not remained unchanged, as seen throughout the experiments of this thesis. In their "*life-history*" (van Gijn, 2010, p. 11) they have been retouched, their inserts replaced, and repaired before being discarded. Also, it appears that for a harvest, many tools were used together at the same time, and mended later in settlements, where they have later been found by archaeologists.

These shell, wood and mandible implements, as used during these experiments, have proved to be effective not only in reaping cereals in general, but also in ensuring that a group of people can survive with enough grain over an entire year. As seen during the experimental harvest, the entire reaping can be done with only one person. However, additional harvesters can increase the collecting speed and reaped grain volumes. The efficiency of these tools is not only demonstrated with modern high yield cereal types as encountered on the reaped fields but could also be achieved on lower yield grain types as the 2t/ha yield encountered at the Little Butser farm in the UK. Even with the latter type, sufficient cereal grain can be reaped within a three-week period to feed a group of five person during an entire year. Also comparing these results to other, earlier experiments on harvesting, the speed and yield achieved in this experiment is comparable to flint tools. This raises the question if shell inserts could have been used interchangeably with flint inserts in wooden shafts during the Neolithic.

The traces collected on the experimental tools are easily recognisable and could also be found in an archaeological context with the help of microscopes. More challenging is to discover sickle inserts among the same organic material, as, for example, shell middens. To recognise these potential implements, specific shapes of inserts, discoloration and polishes that have developed during the experiment, could help. In terms of shapes, this could be small, rectangular oyster or mussel flakes with strong edge rounding. Also, shells showing strong abrasion traces on its inside could be a candidate. For wood, it could be strongly rounded pieces with polish and striations. Any of these characteristics found on archaeological material would need a further, detailed microscopic analysis to confirm the usage of these tools. This could be the methodology applied already on flint tools by classifying them as *„PUAs (Possibly Used Areas)"* first and as *„AUAs (Actually Used Areas)" later* (van Gijn, 1990, p. 13).

Finally, the choice to change from flint to alternative harvesting tools might have been made due to cultural reasons and not made due to technological or efficiency reasons. People could thus differentiate themselves from other groups, especially during the Michelsberg period, where they still knew how to make flint tools. The only technical limitation these people had, was the need to enable a cereal collection within a maximum of three weeks to ensure the survival of the group for the next year.

CHAPTER 9 – CONCLUSION

This experiment has shown that cereals can be reaped with other tools than instruments made with flint inserts.

Hafted sickles, specifically with oyster shell inserts, have proven to be very effective in achieving a high grain yield and quick harvesting speed. This is because, throughout the harvest, the oyster shell layers were flaking off gradually, maintaining a sharp cutting edge. However, these inserts were getting worn off very easily. Their edges got rounded fast, polish and striations develop quickly and after two to three hours of reaping they needed to be replaced. These tiny inserts may further break apart over time. Thus, they are difficult to be recognised in an archaeological context. However, as most Michelsberg sites are inland, remains of shells are generally few and can therefore be analysed for use-wear traces. These shells might have been imported as ornaments or for tool production, maybe in exchange for flint from the Michelsberg mines.

Similarly effective were the hafted sickles with freshwater mussel shell inserts. With these, it was possible to achieve a high grain yield, but the reaping speed was slower than with sickles with oyster shell inserts. This is due to a different composition of the shell. The mussel shell is compact and gets rounded and blunt while reaping but does not flake off as the oyster shell. However, after several hours of harvesting, the edges were rounded, and polish and parallel striations appeared. To maintain the effectiveness of these inserts, they would need to be retouched. In an archaeological context, these inserts would be easily recognisable as they would be of a rectangular shape, only slightly rounded with polish, striations, and with potential retouches visible.

The wooden sickles had, surprisingly, been the third best tools in this experiment. With these, large volumes of stems could be uprooted or cut. However, the soil of the fields must be loose or sandy as seen in the case of *T. monococcum* or *T. dicoccum*. The entire stalks can be used for roofing or as animal feed once separated from their ears. The cutting edge of these tools would need to be sharpened regularly, after at least two to three hours. This action will gradually change the shape of the sickle until they are completely worn off. In an archaeological context, only one such tool has been found, at the site of La Draga, Spain. However, it can be assumed that wooden sickles would have been used also in other sites during the Neolithic such at the

Michelsberg period. But most of these, at the end of their use-life, might have been discarded, thrown into a fire, or decayed and therefore became archaeologically invisible.

The deer mandible enabled to saw through cereals stems but with a lower speed than the above tools. The tool did not show any use wear traces on the cutting edge, but instead on the front (diastema) and back (ramus) bones. There, striations, polish, and edge rounding could be detected. In an archaeological context, a deer mandible is easily recognisable due to its shape. But whether it has been used as a sickle would need to be confirmed through the absence of the front teeth and a detailed microscopic use-wear analysis of the diastema and ramus.

The cattle ribs were not effective during the experiments, although their cutting edge has been sharpened before the harvest. It was just not possible to cut, saw or rip through any of the cereal stems. Therefore, these were believed not to be suitable for harvesting cereals.

Handheld devices like oyster or mussel shells were employed to gather only the cereal ears. The tools were very effective in snapping off these ears, but in comparison to sickles, the recorded speed was low. Even the advantage of collecting cereals without stems or weeds, does not compensate for this low speed. In terms of use-wear traces, striations, polish, and inner surface abrasions are clearly visible on these tools.

Finally, hand-harvesting techniques like snapping off ears or uprooting have been tried. In some cases, these proved to be more effective than other harvesting tools.

In the case of snapping off ears, this was almost always faster than the handheld shell tools, which leads to believe that collecting by hand might have been more widespread than the use of hand-held tools. Overall, all hand-held methods were very slow and could only be considered suitable for more weed-infested fields with sparsely growing cereal plants or for harvesters unable to make strong physical efforts, as for example children or the elderly.

As for uprooting, this method worked very well for *T. monococcum,* as in a sandy soil the stems were easily pulled out. But in fields with a soil having a high clay content and being organically planted, as seen at the ridge and furrow field at Lauresham, uprooting is difficult. Such fields, where cereal plants are mixed with weeds and grass appear to be usual in the Neolithic, especially in North-Western Europe with a humid climate. Therefore, uprooting cereal stems may not have been practiced widely in this region (Bakels, 2009, p. 73).

With regards to the research questions formulated in Chapter 1, how can these be answered?

Question 1

"*Can tools, whose cutting edges are made from shells, bone, or wood, be used to harvest cereal plants?"*

The reaping of cereals worked well with hafted sickles made from shell inserts, wooden sickles, and deer mandibles. Results from hand-held shell tools used as harvesting knives were rather poor as snapping ears off with bare hands was faster and easier than using hand-held shell tools. Tools made from cattle ribs were not effective. Also, uprooting cereal plants in an organically planted field appeared difficult, especially with heavier soils as experienced at Lauresham. The damp, local climate allowing green grass and ripe cereals to grow together would hinder large-volume uprooting of cereal stems. Therefore, this technique appeared not to have been used in North-Western Europe. In summary, most of the tested tools made with alternative materials could be used to harvest cereals.

Question 2

"What kind of use-wear traces are visible on such tools after reaping cereals and how can they be recognised archaeologically?"

Post-harvest use-wear traces were very much visible on the cutting edges of most tools, be it edge rounding, polish, and striations. Even after only a one-hour use, such traces were already clearly discernible. It can therefore be assumed, that these traces would still be preserved also on archaeological material dating back to the 4th Millennium cal BC. Could it be that these other materials, due to their perishability, have not been found or have not been recognised as such? As seen in Chapter 8.3., the remains of used shells inserts are often very small, very brittle and might have been overlooked during excavations. They might also be classified wrongly, as seen at the site of Chalain, France, where they were first classified as ornaments (Maréchal et al., 1998, pp. 161-162). Wooden sickles are believed to disintegrate completely and are thus even more difficult to be discovered, especially so because discarded ones, may have ended up as firewood. Still, one has been excavated in La Draga, Spain, which indicates that, in other lake-site villages, such sickles might be found. Finally, deer mandibles are difficult to detect as tool used for harvesting. Their teeth do not show any use-wear traces from reaping and only minute marks on the bones can hint to a sickle use. As such, an in-depth analysis of existing archaeological shell, bone or wooden artefacts is needed to discover such use-wear traces. This would in turn confirm that the rare finds of alternative harvesting tools as in La Draga, or Chalain are not exceptions to the rule, but very much part of a larger assembly of tools about to be discovered.

Question 3

"*What reaped surface, grain yield and harvesting speed can be obtained with such tools in comparison to tools with flint inserts?*

These tools, especially the hafted sickles with shell inserts allow to harvest a sufficiently large surface of cereals (up to 20 m² within one hour) with a speed of up to 0.35 m²/min. to collect enough grain during a harvest period of maximum three weeks. The experiments thus show that, reaping cereals with sickles or harvesting knives made of alternative materials was as fast and with a similar grain yield and harvested surface than using sickles with flint inserts (see Chapter 8.2.4.). This leads to believe, that flint could not be the only possible material used for reaping. Alternative materials such as shell, wood, and bone, could have been used alternatively.

Question 4

"*Can enough grain be collected with these tools to cover one or a group of people's grain needs for the year?"*

Given that a harvest must be achieved in the shortest possible time frame to secure a largest amount of grain, a maximum of one to three weeks of collecting time has been postulated (Ibáñez et al., 2001, p. 26). The experiments and subsequent calculations show that even cereal fields with low grain yields of only two tons per hectare, can cover the yearly needs of a family of five (1,000 kg) within 1.5 to 2.5 weeks. Also, a cereal harvest is believed to be a communal effort. As such more than two people (as calculated for this experiment) are believed to be involved in such a task. This collective action would lead to a further volume increase of collected grains. Also, the results are believed to be higher outside of this experimental frame if farmers, with a better knowledge of sickle handling and not archaeologists would have been employed for reaping (see Chapter 5.5.).

Question 5

"*Why do sickles or harvesting knives made with flint inserts disappear in the Michelsberg period?"*

Flint as a material for tools was widely available during the Michelsberg period including the knowledge to produce complex flint tools. But people of that period and region decided not to use such material. The probability is considerable, that instead they used tool made of alternative materials as described and tested in this thesis. This choice might be due to cultural preferences on the one hand, as harvesting tools were made without flint. On the other hand, axes and scrapers were still made with it. However, this change in the toolkit of the Middle Neolithic, was likely not a purely free and independent choice. The material used and the cereal reaped also conditioned this choice. The imperative during a harvest was to achieve a certain reaping speed and grain volume. This could be achieved with tools made with shell, wood, or mandibles, but not with bone. Therefore, these materials could have been chosen, as they were different from flint, but as effective, available locally, or in the case of oysters, available through exchange. The selection of materials to make sickles or harvesting knives then became a cultural choice. People decided consciously not to employ flint inserts in their cereal harvesting tools during the 900 years of the Michelsberg period in the entire North-Western Europe. They decided, in the words of Lemonier "*to mark difference*" (Lemonnier, 1986, p. 173) to their neighbours.

In summary, it can be stated, that after the use of 26 tools on four different cereal fields, and an exhaustive data analysis, implements made from alternative materials such as shell, wood or teeth could have been employed for cereal reaping during the Michelsberg period. The efficiency in terms of speed and surface harvested, appears to be equal to sickles or harvesting knives with flint inserts. In this case, the selection of materials to build reaping tools would have been very much a cultural and not a technological choice, as long as these tools enable a harvest within a few weeks. It is now up to us archaeologists, to find among the excavated remains of shells, wood, and mandibles of that period, use-wear traces pointing towards a cereal harvest use.

CHAPTER 10 - FUTURE STUDIES

Cereal harvesting tools made of alternative; organic materials have proven to be effective in reaping four cereal types believed to be present during the Michelsberg period. The use-wear traces generated on these tools during the harvest, such as edge rounding, striations and polish are clearly visible on a macroscopic and microscopic level. These sickles and harvesting knives appeared to be as effective as flint-based tools with regards to the reaping speed and amount of collected grain. More importantly, these shell, wood and teeth inserts allow to reap enough grain during a short period to at least sustain a family of five during an entire year. These materials also appeared to have replaced the earlier used flint inserts of the LBK and Rössen period, not only because of their efficiency but due to a cultural choice, whose reason remains unknown.

Obviously, this thesis raised new questions with regards to materials used, tool efficiency and archaeological traceability. More specifically the following recommendations for future research can be made.

With regards to materials, a direct comparison between harvesting tools made with flint inserts versus tools made with shell inserts, wood or teeth should be undertaken. The resulting reaped surface, harvest speed and grain yield can be used to evaluate the effectiveness of each tool. For that analysis, the tools need to be of equal shape, such as a composite sickle with denticulated inserts. Also, an identical field with the equivalent type of cereals and the same harvester with its corresponding technique must be employed to have comparable results. With these conditions in mind, it can be determined if sickles with flint inserts are faster, or more effective than tools with shell inserts, wooden sickles, or mandibles.

Uprooting cereal stems was challenging with plants growing organically on a compact clay soil, due to the large number of weeds. However, this could only be experienced while collecting *T. aestivum* on a ridge and furrow field in Lauresham. All other fields used during the experiment had a sandy soil and were conventionally planted with the use of herbicides and pesticides. However, it is believed that the fields in the Neolithic would be more of the Lauresham type, with much grass and weed mixed between the cereal plants. Therefore, as a future step, the four cereal types should be collected on organically planted fields with the same soil type. If *T.monococcum, T. dicoccum* and *H. vulgare* would have been gathered during the experiment on this type of fields, how would the grain yield and harvesting speed have changed?

Use-wear traces on alternative harvesting tools have been almost absent in archaeological context. The exception has been traces found on one wooden sickle in La Draga, Spain and on one freshwater mussel shell in Chalain, France, indicating harvesting activities. During this experiment, a large database of images of use-wear traces has been created at the Laboratory for Material Culture Studies at the Faculty of Archaeology at Leiden University. The next step would be to actively search for possible shell inserts in archaeological excavations and compare these traces with the recorded traces of this experiment. If similar traces can be confirmed on these archaeological objects, this could strengthen the theory that cereals in the Neolithic were also collected with tools made of other materials than just flint.

Finally, a reflection would need to be undertaken on the value of flint in archaeology. As described in this thesis, flint could have not been the only cutting agent for cereals, but instead one of many material options. We archaeologists have so far only focussed on flint, as this is usually the best-preserved material on a neolithic site. Here we may have another example that the absence of certain evidence cannot be taken at face value. The absence of flint sickles does not mean that the harvest was not done with sickles. This thesis shows that flint was just one material chosen among many possible others to produce sickles. The disappearance of flint sickles, during the Michelsberg period, does not necessarily mean that sickles as tool category disappeared: maybe they simply were made from other materials and have, till today, not been recognised as such. Therefore, we archaeologists have first to develop the awareness that even tiny fragments of other materials like shell, wood or teeth were likely used as tools. Only a thorough use-wear analysis of these might clarify their function. This experiment could thus be a first step to raise this awareness and might lead to interpreting archaeological finds differently in the future.

ABSTRACT

During the Michelsberg period (4,400 to 3,500 cal BC), harvesting tools were rarely discovered at excavations in North-Western Europe, be it in Belgium, Southern Netherlands, Northern France, or Northern Germany. But cereal consumption was widely practiced, as grains discovered in these settlements show. Several researchers have, over the last 50 years, highlighted this discrepancy of missing harvesting tools and presence of cereal grains. They have tried to explain that, during this 900-year Michelsberg period and over a surface of several hundred square kilometres, cereals had to be collected either with the help of bare hands or with tools made from other, organic materials. But so far none of such traces have been detected in excavations. The aim of this paper is to present, through experimental archaeology and the analysis of use-wear traces, that tools made from organic material such as shell, wood and bone could have been used to gather cereal plants. To achieve this aim, a large variety of experimental tools have been created and tested on different fields of typical cereal types of the Michelsberg period. These were *Triticum monococcum* or einkorn wheat, *Triticum dicoccum* or emmer wheat, *Triticum aestivum* or naked wheat, and *Hordeum vulgare* or barley. The result of these harvest experiments has been analysed quantitatively with regards to the achieved harvested surface, grain yield, and harvesting speed. The use-wear traces created by these different cereal plants during the harvest have also been studied. They are polish, striations, edge rounding and edge damages, which have been evaluated under different microscopes to reveal typical shapes these cereals leave on tools. The results of that harvesting experiment and use-wear analysis are presented in this thesis and could serve as reference to interpret archaeological material *differently* in the future.

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APPENDICES

Appendix A

Overview of harvesting results in m² reaped and speed per m²/min. (Made by M.-P. Häg).

	Surface: in m²					Speed m²/min.		
Hafted sickle with oyster shell inserts	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	18.7	21.0	17.3	**57.00**	19.0	0.31	0.35	0.29
T. aestivum	19.0	12.3	10.0	**41.30**	13.8	0.32	0.21	0.17

	Surface: in m²					Speed m²/min.		
Hafted sickle with mussel shell inserts	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	16.5	16.0	15.4	**47.90**	16.0	0.28	0.27	0.26
H. vulgare	13.3	12.0	11.5	**36.80**	12.3	0.22	0.20	0.19
T. aestivum	11.0	9.0	9.3	**29.30**	9.8	0.18	0.15	0.16
T. monococcum	9.6	7.3	6.4	**23.28**	7.8	0.16	0.12	0.11

	Surface: in m²					Speed m²/min.		
Wooden sickle	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	13.5	20.0	17.8	**51.30**	17.1	0.23	0.33	0.30
H. vulgare	9.0	9.8	12.5	**31.30**	10.4	0.15	0.16	0.21
T. aestivum	12.0	13.0	7.0	**32.00**	10.7	0.20	0.22	0.12
T. monococcum	4.2	2.0	0.0	**6.18**	4.8	0.07	0.03	0.00

	Surface: in m²					Speed m²/min.		
Deer mandible	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	10.8	0.0	0.0	**10.80**	10.8	0.18	0.00	0.00
H. vulgare	7.5	0.0	0.0	**7.50**	7.5	0.13	0.00	0.00
T. aestivum	9.0	0.0	0.0	**9.00**	9.0	0.15	0.00	0.00
T. monococcum	6.4	7.0	7.1	**20.40**	6.8	0.11	0.12	0.12

	Surface: in m²					Speed m²/min.		
Hand-held oyster shell	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	5.0	3.2	3.5	**11.70**	3.9	0.08	0.05	0.06
H. vulgare	2.4	2.4	2.5	**7.30**	2.4	0.04	0.04	0.04
T. aestivum	1.8	1.5	1.3	**4.68**	1.6	0.03	0.03	0.02
T. monococcum	1.2	1.3	1.3	**3.84**	1.3	0.02	0.02	0.02

	Surface: in m²					Speed m²/min.		
Hand-held mussel shell	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	3.3	4.4	3.5	**11.20**	3.7	0.06	0.07	0.06
H. vulgare	2.7	2.4	2.0	**7.10**	2.4	0.05	0.04	0.03
T. aestivum	1.4	1.9	1.4	**4.73**	1.6	0.02	0.03	0.02
T. monococcum	1.3	1.3	1.2	**3.84**	1.3	0.02	0.02	0.02

	Surface: in m²					Speed m²/min.		
Cattle rib	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	0.1			**0.10**	1.0	0.0017		
H. vulgare	0.1			**0.09**	0.9	0.0015		
T. aestivum	0.1			**0.10**	1.0	0.0017		
T. monococcum	0.2			**0.18**	1.8	0.0030		

	Surface: in m²					Speed m²/min.		
Uprooting	**1. hour**	**2. hour**	**3. hour**	**total**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	17.8			**17.80**	17.8	0.30		
H. vulgare	9.2			**9.20**	9.2	0.15		
T. aestivum	5.0			**5.00**	5.0	0.08		
T. monococcum	10.1			**10.08**	10.1	0.17		

	Surface: in m²					Speed m²/min.		
Snapping off	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**average/hour**	**1. hour**	**2. hour**	**3. hour**
T. dicoccum	3.0			**3.00**	3.0	0.05		
H. vulgare	0.0			**0.00**	0.0	0.00		
T. aestivum	2.5			**2.50**	2.5	0.04		
T. monococcum	1.7			**1.68**	1.7	0.03		

Appendix B

Overview of harvesting results in m² per hour, grain yield per kg and days to collect an annual cereal consumption. (Made by M.-P. Häg).

	Surface: in m²				Yield: 7.9 t /ha			Cereal consumption	
T. dicoccum	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**1. hour**	**2. hour**	**3. hour**	**Days to reap 200 kg grain**	**Days to reap 1,000 kg grain**
Sickle with oyster shell inserts	18.70	21.00	17.30	**57.00**	14.77	16.59	13.67	**0.97**	**4.84**
Sickle with mussel shell inserts	16.50	16.00	15.40	**47.90**	13.04	12.64	12.17	**1.10**	**5.48**
Wooden sickle	13.50	20.00	17.80	**51.30**	10.67	15.80	14.06	**1.34**	**6.70**
Deer mandible	10.80			**10.80**	8.53	0.00	0.00	**1.67**	**8.37**
Cattle rib	0.10			**0.10**	0.08	0.00	0.00	**180.83**	**904.16**
Uprooting	17.80			**17.80**	14.06	0.00	0.00	**1.02**	**5.08**
Hand-held oyster shell	5.00	3.20	3.50	**11.70**	3.95	2.53	2.77	**3.62**	**18.08**
Hand-held mussel shell	3.30	4.40	3.50	**11.20**	2.61	3.48	2.77	**5.48**	**27.40**
Snapping by hand	3.00			**3.00**	2.37	0.00	0.00	**6.03**	**30.14**
total	**88.70**	**64.60**	**57.50**	**210.80**					

	Surface: in m²				Yield: 5.5 t /ha			Cereal consumption	
H. vulgare	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**1. hour**	**2. hour**	**3. hour**	**Days to reap 200 kg grain**	**Days to reap 1,000 kg grain**
Sickle with mussel shell inserts	13.30	12.00	11.50	**36.80**	7.32	6.60	6.33	**1.95**	**9.76**
Wooden sickle	9.00	9.80	12.50	**31.30**	4.95	5.39	6.88	**2.89**	**14.43**
Deer mandible	7.50			**7.50**	4.13	0.00	0.00	**3.46**	**17.32**
Cattle rib	0.09			**0.09**	0.05	0.00	0.00	**288.60**	**1443.00**
Uprooting	9.20			**9.20**	5.06	0.00	0.00	**2.82**	**14.12**
Hand-held oyster shell	2.40	2.40	2.50	**7.30**	1.32	1.32	1.38	**10.82**	**54.11**
Hand-held mussel shell	2.70	2.40	2.00	**7.10**	1.49	1.32	1.10	**9.62**	**48.10**
total	**44.19**	**26.60**	**28.50**	**99.29**					

	Surface: in m²				Yield: 8.3 t /ha			Cereal consumption	
T. aestivum	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**1. hour**	**2. hour**	**3. hour**	**Days to reap 200 kg grain**	**Days to reap 1,000 kg grain**
Sickle with oyster shell inserts	19.00	12.30	10.00	**41.30**	15.77	10.21	8.30	**0.91**	**4.53**
Sickle with mussel shell inserts	11.00	9.00	9.30	**29.30**	9.13	7.47	7.72	**1.56**	**7.82**
Wooden sickle	12.00	13.00	7.00	**32.00**	9.96	10.79	5.81	**1.43**	**7.17**
Deer mandible	9.00			**9.00**	7.47	0.00	0.00	**1.91**	**9.56**
Cattle rib	0.10			**0.10**	0.08	0.00	0.00	**172.12**	**860.59**
Uprooting	5.00			**5.00**	4.15	0.00	0.00	**3.44**	**17.21**
Hand-held oyster shell	1.82	1.54	1.32	**4.68**	1.51	1.28	1.10	**9.48**	**47.42**
Hand-held mussel shell	1.38	1.93	1.43	**4.73**	1.14	1.60	1.19	**12.52**	**62.59**
Snapping by hand	2.50			**2.50**	2.08	0.00	0.00	**6.88**	**34.42**
total	**59.29**	**37.77**	**29.05**	**128.61**					

	Surface: in m²				Yield: 5.8 t /ha			Cereal consumption	
T. monococcum	**1. hour**	**2. hour**	**3. hour**	**total in m²**	**1. hour**	**2. hour**	**3. hour**	**Days to reap 200 kg grain**	**Days to reap 1,000 kg grain**
Sickle with mussel shell inserts	9.60	7.32	6.36	**23.28**	5.57	4.25	3.69	**2.57**	**12.83**
Wooden sickle	4.20	1.98		**6.18**	2.44	1.15	0.00	**5.86**	**29.32**
Deer mandible	6.36	6.96	7.08	**20.40**	3.69	4.04	4.11	**3.87**	**19.36**
Cattle rib	0.18			**0.18**	0.10	0.00	0.00	**136.84**	**684.18**
Uprooting	10.08			**10.08**	5.85	0.00	0.00	**2.44**	**12.22**
Hand-held oyster shell	1.20	1.32	1.32	**3.84**	0.70	0.77	0.77	**20.53**	**102.63**
Hand-held mussel shell	1.32	1.32	1.20	**3.84**	0.77	0.77	0.70	**18.66**	**93.30**
Snapping by hand	1.68			**1.68**	0.97	0.00	0.00	**14.66**	**73.31**
total	**20.82**	**9.60**	**9.60**	**69.48**					

Appendix C

Experiment form from the Laboratory for Material Culture Studies at the Faculty of Archaeology of the Leiden University:

Experiments use-wear analysis Piece no. __________

User name: _______________
Date: ____________________

Tool type: ___________________ Grain size: fine medium coarse

Raw material: ________________ Hafting: _______________________________

Retouch: _______________________ Edge angle: ____________________________

Used edge: _____________________

Material:____

____

____

State: dry fresh soaked Hardness: soft medium hard

Additives or pollution: ____

Type of surface worked on: ____

Motion: cutting sawing shaving scraping planing whittling graving

boring piercing chopping adzing wedging pounding grinding

Contact surface: _________________ Angle worked: ____________________

Loading: static dynamic Depth of insertion (mm): ____________

Duration (in min.): _______________

Detailed description of experimental procedure and activity carried out:

____

____

____

Tool effectiveness (describe also its deterioration through time):

____

____

Cleaning procedures: soap alcohol acetone HCL KOH ultrasonic tank

Photographic documentation:____

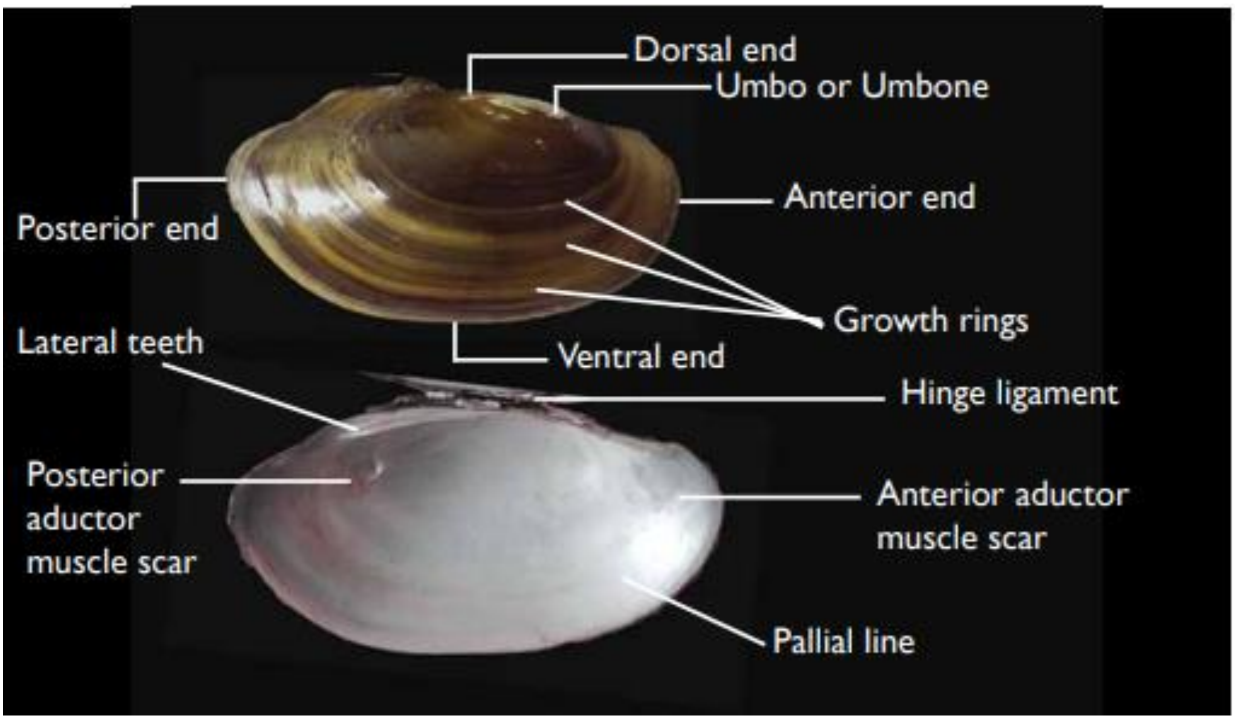
Piece no._______

Sketch of the way tool is handled and used.

Drawing (scale 1:1) of tool indicating used edge by red pencil and damage during work blue pencil:

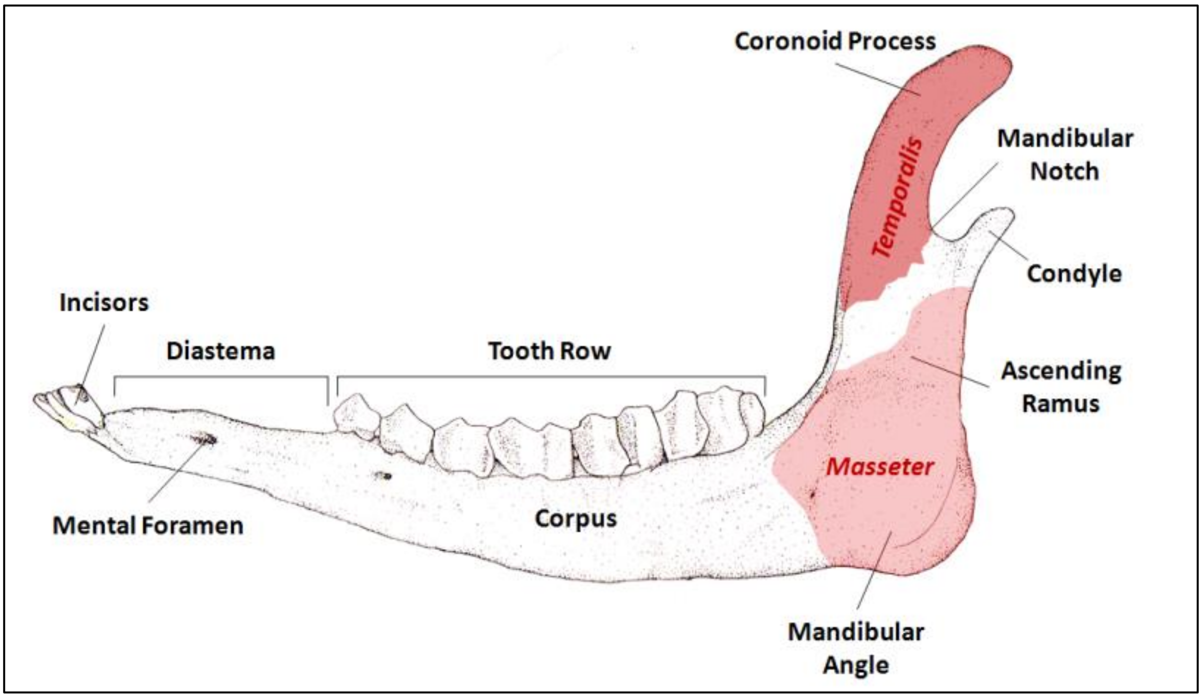
Appendix D

Bivalve shell terminology (Budha, 2016, p. 11)



Appendix E

Generalised diagram of typical ungulate mandible (Fletcher et al., 2010, p. 6)



Appendix F

Description of tools used during these harvesting experiments (Made by M.-P. Häg).

1. *Sickles*

1.a. Hafted sickles with oyster shell inserts

Figure F.1 Hafted sickle with oyster shell inserts (Tool nr. 3886)

Tool name: Hafted sickle with seawater oyster shell inserts

Tool number: 3886

Haft: Made from willow wood

Hafting: Made with spruce pitch combined with charcoal and lard.

Inserts: Made from fragments of seawater oyster shells

Fragments are inserted in an 45° angle into the haft and edges are not retouched.

No. of Inserts: 5

Orientation of inserts: Four inserts aligned with the outer shell facing the side A of the tool and one inserts aligned with the inner shell facing the side A (see fig. F.1.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum aestivum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum aestivum* and grass with the left hand in 1-hour intervals with cutting height 0.1m to 0.2m above ground. Grasped with right hand ½ dozen stems and cut straight through them. Grasped then more stems to cut. At the end had 2-3 groups of cut stems in right hand to be put aside. Later tried to cut the stems in an arc motion and not straight. Sunny and hot day with a bit of wind.18°C to 26°C temperature.

Status of sickle after use: The two front inserts have fallen off during harvesting (No. 4. and No. 5)

Tool effectiveness: The tool could easily cut through the cereals stems during first ½ hour. Later shell edges became shorter, and cutting was slowly replaced by sawing as motion. After

3 hours most stems were still cut/ sawn but almost not uprooted. Changing from straight cutting to arc shape cutting was also effective, as all blade edges were used. Lost No. 4 & 5 blade after 1.st hour, but tools was still very effective. After 3 hours the blades were very much used and shorter than at the start. It shows that oyster shells stay sharp during entire harvest but are getting smaller and would need to be replaced eventually.

Harvesting area: 1. hour: 19m², 2nd hour: 12.3m², 3rd hour: 10m² Total: 41.3m².

Volume in circumference of stems reaped: 1. hour: 3m, 2nd hour: 4m, 3rd hour: 2.2m. Total: 9.2m.

Figure F.2. Hafted sickle with oyster shell inserts. (Tool nr. 3887)

Tool name: Hafted sickle with seawater oyster shell inserts

Tool number: 3887

Haft: Made from oak wood

Hafting: Made with spruce pitch combined with charcoal and lard.

Inserts: Made from fragments of seawater oyster shells

Fragments are inserted in an 45° angle into the haft and edges are not retouched.

No. of Inserts: 6

Orientation of inserts: Two inserts aligned with the inner shell facing the side A of the tool and four inserts aligned with the outer shell facing the side A (see fig. F.2.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum dicoccum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum dicoccum* in 1-hour intervals 0.1m to 0.3m above ground. Grasped with right hand a dozen stems high up (30 cm) and could cut/saw straight through them with the left hand. When grasped lower (10 cm above ground) only uprooting was possible. Sunny and hot day with a bit of wind. 21°C to 25°C temperature.

Status of sickle after use: All inserts are still attached.

Tool effectiveness: Tool cuts easily through the stems during first ½ hour. Later as edges became used stems are more uprooted or sawn off. The lower the stem is cut; the more uprooting happens. The higher, the more cutting/sawing can be done. Still fast work in harvesting stems. Cutting edges of the shell get markable shorter and worn after 3 hours of reaping. Some inserts, as second from the back, (Nr. 2) are almost entirely used up. Still most inserts are still sharp although heavily used and rounded. Wooden haft at frontal part is also rounded and shiny.

Harvesting area: 1. hour: 18.70m², 2nd hour: 21.0m², 3rd hour: 17.30m² Total: 57.0m².

Volume in circumference of stems gathered: 1. hour: 2.70m, 2nd hour: 2.50m, 3rd hour: unknown m. Total: 5.2m.

<u>1.b. Hafted sickles with mussel shell inserts</u>

Figure F.3. Hafted sickle with mussel shell inserts (Tool nr. 3687)

Tool name: Hafted sickle with freshwater mussel shell inserts

Tool number: 3687

Haft: Made from maple wood

Hafting: Made with spruce pitch combined with charcoal and lard.

Inserts: Made from fragments of freshwater mussels

Fragments are inserted in an 45° angle into the haft and edges are retouched.

No. of Inserts: 5

Orientation of inserts: Three inserts aligned with the inner shell facing the side A of the tool and two inserts aligned with the outer shell facing the side A (see fig.F.3.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum aestivum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum aestivum* and grass in 1-hour intervals with cutting height 0.1m to 0.2m above ground. Grasped with right hand ½ dozen stems and cut with the left hand straight through them. Grasped then additional stems to cut. After having cut 2-3 groups of stems, they were put aside with the right hand. After a while tried also cutting in an arc motion and not straight. Sunny and hot day with a bit of wind. 24°C to 25°C temperature.

Status of sickle after use: All inserts are still attached.

Tool effectiveness: Tool could easily cut cereals during first hour. Later edges became rounded, and cutting was replaced by ripping through the stems. Changing from straight cutting to cutting in an arc shape improved the cutting for a while. The first two blades were mostly used for cutting, whereas the last blade almost was not in contact with the stems. During the last 2 hours the efficiency is reduced due to back ache of harvester and since more grass than cereals had to be cut. Still very effective tool.

Harvesting area: 1. hour: 11m², 2nd hour: 9m², 3rd hour: 9.3m² Total: 29.3m²

Volume in circumference of stems gathered: 1. hour: 2.45m, 2nd hour: 3.00m, 3rd hour: 2.50m. Total: 7.95m.

Figure F.4. Hafted sickle with mussel shell inserts (Tool nr. 3688)

Tool name: Hafted sickle with freshwater mussel shell inserts

Tool number: 3688

Haft: Made from hazel wood

Hafting: Made with spruce pitch combined with charcoal and lard.

Inserts: Made from fragments of freshwater mussels

Fragments are inserted in an 45° angle into the haft and edges are retouched.

No. of Inserts: 4

Orientation of inserts: All aligned with the inner shell facing the side A of the tool (see fig.F.4.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum monococcum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum monococcum* with left hand in 1-hour intervals with cutting height 0.2m to 0.4m above soil. Lower part of plant is covered with dry weed and difficult to cut. Lost one tooth, second from the back (no. 2) during the 2nd hour. It made gathering more difficult as the remaining cutting surface consisted of only the first two inserts. Sunny and hot day with a bit of wind. 20°C to 28°C temperature.

Status of sickle after use: One insert missing (No. 2)

Tool effectiveness: Tool was sharp to cut cereals during first ¾ h. Later as the shells became rounded, the motion is more ripping than cutting. After losing one blade the effectiveness is further reduced to more ripping, hacking, and even uprooting. At the end could only harvest 3-4 stems at a time.

Harvesting area: 1. hour: 9.6m², 2nd hour: 7.32m², 3rd hour: 6.36m². Total: 23.28m².

Volume in circumference of stems gathered: 1. hour: 2.7m, 2nd hour: 2.40m, 3rd hour: 2.1m. Total: 7.2m.

Figure F.5. Hafted sickle with mussel shell inserts (Tool nr. 3689)

Tool name: Hafted sickle with freshwater mussel shell inserts

Tool number: 3689

Haft: Made from yew wood

Hafting: Made with spruce pitch combined with charcoal and lard.

Inserts: Made from fragments of freshwater mussels

Fragments are inserted in an 45° angle into the haft and edges are retouched.

No. of Inserts: 4

Orientation of inserts: All aligned with the inner shell facing the side A of the tool (see fig. F.5.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum dicoccum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum dicoccum* with left hand in 1-hour intervals with cutting height 0.2m to 0.3m above ground. Grasped up to a dozen stems and cut them in one go. Later could only grasp fewer stems as tool was less sharp. Started by cutting through the stems and slowly moved to sawing and uprooting as tool became blunt. Sunny and hot days with a bit of wind and temperature between 20°C to 23°C.

Status of sickle after use: Unchanged

Tool effectiveness: Tool was sharp to cut cereals during first hour and progress was fast. Later as shells edges became rounded, the stems got more sawn and later uprooted. Progress slowed, but still easy to work. By keeping a cutting height above 0.20m, the stems could be cut. Lowering the cutting height resulted in sawing or uprooting of the stems. Tool cutting edges got rounded during the harvest, but otherwise tool did not change in shape.

Harvesting area: 1. hour: 16.5m², 2nd hour: 16.0m², 3rd hour: 15.4m². Total: 47.9m²

Volume in circumference of stems gathered: 1. hour: 2.15m, 2nd hour: 2.60m, 3rd hour: 2.40m. Total: 7.15m.

Figure F.6. Hafted sickle with mussel shell inserts (Tool nr. 3690)

Tool name: Hafted sickle with freshwater mussel shell inserts

Tool number: 3690

Haft: Made from hazel wood

Hafting: Made with spruce pitch combined with charcoal and lard.

Inserts: Made from fragments of freshwater mussels

Fragments are inserted in an 45° angle into the haft and edges are retouched.

No. of Inserts: 4

Orientation of inserts: One aligned with the inner shell facing the side A of the tool. Other three inserts have the outer shell facing the side A of the tool (see fig. F.6.).

Harvesting duration: 3 hours

Reaped cereals: *Hordeum vulgare*

Detailed description of experimental procedure and activity carried out:

Harvested *Hordeum vulgare* with the left hand in 1-hour intervals with cutting height 0.1m to 0.12m above ground. Grasped up to a dozen stems to cut them in one go. Later grasped only ½ dozen stems as tool edges became rounded. Started by cutting through the stems and slowly moved to sawing and uprooting as tool became blunt. Sunny and hot midday with a bit of wind. 24°C to 25°C temperature.

Status of sickle after use: Unchanged.

Tool effectiveness: The tool was sharp to cut cereals during the first hour and progress was fast. Later as shells edges became rounded, stems got sawn and uprooted. Progress slowed, but still easy to work. Especially the lower cutting height compared to the wooden sickle enabled easier gathering of the stems and collection on heaps. Tool shape did not change significantly compared to the beginning.

Harvesting area: 1. hour: 13.3m², 2nd hour: 12m², 3rd hour: 11.5m². Total: 36.8m²

Volume in circumference of stems gathered: 1. hour: 3.70m, 2nd hour: 3.40m, 3rd hour: 3.50m. Total: 10.60m.

1.3 Wooden sickles:

Figure F.7 Wooden sickle made from oak. (Tool nr. 3888)

Tool name: Oak wood sickle.

Tool number: 3888

Haft: Made entirely from oak wood (see fig. F.7.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum aestivum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum aestivum* with the left hand in 1-hour intervals 0.1m to 0.2m above ground. *Triticum aestivum* is strongly mixed with grass and weeds as the field is planted without pesticides and herbicides. Sunny with a bit of wind. 20°C to 26°C temperature.

Status of sickle after use: Strongly dented cutting edge.

Tool effectiveness: Tool cuts easily through cereal stems, green grass and weeds during the first hour. Tool edge gets rounded fast (after about 1 hour) and later can only rip through grass and *Triticum aestivum*. Size of gathered bundles gets smaller as frequent ripping is needed to separate stems from roots. At 3rd hour tool efficiency gets worse where stems can only be uprooted. The edge of tool is then strongly dented and about 3mm thick. Still this wooden sickle is the 2nd most effective tool during the experiment.

Harvesting area: 1. hour: 12m², 2nd hour.: 13m², 3rd hour: 7m² Total: 32m²

Volume in circumference of stems gathered: 1. hour: 2.4m, 2nd hour: 2.3m, 3rd hour: 2.85m Total: 7.55m (high volume of roots due to uprooting).

Figure F.8. Woden sickle made from oak (Tool nr. 3890)

Tool name: Oak wood sickle.

Tool number: 3890

Haft: Made entirely from oak wood (see fig- F.8.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum dicoccum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum dicoccum* with the left hand in 1-hour intervals 0.2m to 0.25m above ground. Grasped ½ dozen stems and pulled sickle through them. Cereals are planted in conventional style with pesticides and herbicides used. Stems could be easily uprooted since soil is loose as no undergrowth exists. In harder soil (e.g., tractor tracks) stems could be cut/ripped off the roots. Sunny and cloudy with a bit of wind. 19°C to 21°C temperature.

Status of sickle after use: Slightly dented cutting edge.

Tool effectiveness: Tool uproots most of stems, as soil is loose. Only about 20% of stems are cut or chopped off. After 3 hours tool edge is slightly dented and used but not as much as for *Triticum aestivum*. Progress is fast as loose soil enable easy collecting of entire stems.
Harvesting area: 1. hour: 13.50m², 2nd hour: 20.0m², 3rd hour: 17.8m². Total: 51.3m².
Volume in circumference of stems gathered: 1. hour: 2.35m, 2nd hour: 2.35m, 3rd hour: 2.4m. Total: 7.1m.

Figure F.9. Wooden sickle made from oak (Tool nr. 3899)

Tool name: Oak wood sickle.
Tool number: 3899
Haft: Made entirely from oak wood (see fig. F.9.).
Harvesting duration: 3 hours
Reaped cereals: *Hordeum vulgare*
Detailed description of experimental procedure and activity carried out:
Harvested short *Hordeum vulgare* cereals stems (60cm height) with the left hand in 1-hour intervals 0.2m to 0.25m above the soil. Plant stem is thick and sometimes still green. Grabbed few stems (3-4) and pull through the stems with the sickle. If pulled too low, entire plant gets uprooted. Sunny and cloudy with a bit of wind. 22°C to 24°C temperature.
Status of sickle after use: Dented cutting edge.
Tool effectiveness: Tool can only pull through a few cereal stems (3-4) at a time. Shortness of plant makes it difficult to grab stems. Slow work as only few stems can be grasped at a time and 2-3 pulls with the sickle are needed to separate them from the roots. Uprooting happens if pulling is done too close to the soil. At last day, work is faster, as cereals are almost dry and cracking sound is heard while pulling through the stems. This sound was not heard earlier. The tool is also not humid anymore from cutting.
Harvesting area: 1. hour: 9.0m², 2nd hour: 9.80m², 3rd hour: 12.5m², Total: 31.30m²

Volume in circumference of stems gathered: 1. hour: 2.1m, 2nd hour: 2.95m, 3rd hour: 3.45m. Total: 8.50m.

Figure F.10. Wooden sickle made from oak (Tool nr. 3889)

Tool name: Oak wood sickle.

Tool number: 3889

Haft: Made entirely from oak wood (see fig. F.10.).

Harvesting duration: 1.2 hours

Reaped cereals: *Triticum monococcum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum monococcum* with the left hand in 1-hour intervals 0.5m to 0.6m above soil. The lower part of plant is entangled with weed and thus difficult to cut. The plant stems are thin and flexible making gathering difficult. Cutting the stems low leads to uprooting. Cutting them higher means only few stems can be harvested in one go. Sunny and cloudy with a bit of wind. 18°C to 20°C temperature.

Status of sickle after use: Slightly damaged cutting edge

Tool effectiveness: Tool can cut through cereal at 50cm height for 30 min. After that, the tool cutting edge became blunt, and only uprooting and pulling through few stems was possible. When a plant was uprooted, the stem could not be cut off, as it slipped along the cutting edge of the tool. The ears had to be broken off by hand. After 1.2 hours stopped reaping due to poor results. Thin and flexible stems of *Triticum monococcum* make harvesting with a wooden sickle difficult.

Harvesting area: 1. hour: 4.2m², 2nd 20 min.: 1.98m², Total: 6.18m²

Volume in circumference of stems gathered: 1. hour: 1.1m, 2nd 20 min.: 0.90m, Total: 2.00m.

1.4. Deer mandible

Figure F.11 Deer mandible sickle. (Tool nr. 3671)

Tool name: Deer mandible sickle

Tool number: 3671

Haft: Made entirely from bone and teeth (see fig.F.11.).

Harvesting duration: 1 hour

Reaped cereals: *Triticum aestivum*

Detailed description of experimental procedure and activity carried out:

Triticum aestivum mixed with grass were harvested for 1 hour. Cutting height: 0.2m to 0.3m above ground. Grasped 2-3 stems with right hand and saw them off with left hand off their root. Sunny and hot morning with a bit of wind. 20°C temperature.

Status of sickle after use: Front teeth became damaged. Otherwise, unchanged

Tool effectiveness: Progress is very slow as only a few stems could be cut at one time. Sawing through these stems required much strength as grass and weeds were mixed with the stems. As this mandible had a gap between the second and third front teeth, stems got frequently stuck in this gap and had to be removed manually before continuing harvesting. The entire mandible was rather long and the cutting distance to the soil was therefore higher than with other tools. Also, some teeth, at the front part of the mandible, fell off while scratching the soil. Speed of reaping started to drop when some teeth were getting loose.

Harvesting area: 1. hour: 9.00m²

Volume in circumference of stems gathered: 1. hour: 2.1m.

Figure F.12 Deer mandible sickle. (Tool nr. 3674)

Tool name: Deer mandible sickle

Tool number: 3674

Haft: Made entirely from bone and teeth (see fig.F.12.).

Harvesting duration: 1.05 hours

Reaping cereals: *Triticum dicoccum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum dicoccum* in two locations. Black *Triticum dicoccum* for 5 min. in Lauresham, Lorsch and red *Triticum dicoccum* for 60 min. in Heidfeldhof, Stuttgart. There grasped with right hand 4-6 stems and saw them off with the left hand about 0.20m to 0.35m above ground. Sunny morning and midday with a bit of wind. 18°C to 25°C temperature.

Status of sickle after use: Front teeth became damaged. Rest remained unchanged.

Tool effectiveness: In Lorsch harvesting *Triticum dicoccum* could only be done by uprooting, since the soil was very loose. The cutting edge did not cut through stems at all, and the experiment was stopped after 5 min as the progress was very slow.

At the Heidfeldhof, Stuttgart it was possible to saw through the stems and not uproot the entire plant. The soil was more compact than in Lorsch and the plant dryer with thick (0.3 – 0.5mm), brittle stems. Sawing was fast with only 1-2 sawing motions needed to cut a handful of the 1.20m long stems. The tool remained effective the entire harvesting period with no visible damages on it. Mandible lost some front teeth by frequently hitting the soil.

Harvesting area: 1. hour: 10.80m

Volume in circumference of stems gathered: 1. hour: 3.70m.

Figure F.13 Deer mandible sickle. (Tool nr. 3673)

Tool name: Deer mandible sickle

Tool number: 3673

Haft: Made entirely from bone and teeth (see fig. F.13.).

Harvesting duration: 1 hour

Reaped cereals: *Hordeum vulgare*

Detailed description of experimental procedure and activity carried out:

Harvested *Hordeum vulgare* for 1 hour with a cutting height of 0.20m to 0.25m above ground. Grasped 4-6 stems with right hand and saw them off with the left one. Later changed to uprooting stems. Sunny and hot morning with a bit of wind. 24°C to 28°C temperature.

Status of sickle after use: Front teeth became damaged. Rest of tool is unchanged.

Tool effectiveness: Tool could cleanly saw stems off at the beginning. Later only uprooting was possible, and progress became very slow as many stems were still green. The next day sawing was again possible as stems were drier. But could only grasp few stems to saw them through. Taking more stems, resulted in getting stuck while sawing through. Mandible lost some front teeth as it frequently touched the soil. No change in efficiency over the 1 hour as tool did not become blunt.

Harvesting area: 1. hour: 7.50m

Volume in circumference of stems gathered: 1. hour: 3.25m.

Figure F.14 Deer mandible sickle. (Tool nr. 3672)

Tool name: Deer mandible sickle

Tool number: 3672

Haft: Made entirely from bone and teeth (see fig. F.14.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum monococcum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum monococcum* for 3 hours with a cutting height of 0.30m to 0.40m above ground. Grasped with right hand 1/2 dozen stems and saw them off with left hand at 1/4 of plant height. Plant has thin stems (0.2 – 0.3mm) making it easy to saw through. Sunny and hot morning with a bit of wind. 21°C to 25°C temperature.

Status of sickle after use: Front teeth completely lost. One central tooth became loose. Otherwise, unchanged.

Tool effectiveness: Tool was effective in sawing stems off. At the beginning the stems could be cut in just one movement. Later several sawing movements were needed to separate them. One tooth became loose, and some stems got stuck between the teeth. Still in a slow but constant work most stems could be sawn off. Only few stems got uprooted. The mandible lost all her front teeth as this part frequently touched the soil. No change in efficiency over the 3 hours as tool did not become blunt.

Harvesting area: 1. hour: $6.36m^2$, 2nd hour: $6.96m^2$, 3rd hour: $7.08m^2$. Total: $20.4m^2$

Volume in circumference of stems gathered: 1. hour: 2.15m, 2nd hour: 2.35m, 3rd hour: 2.45m. Total: 6.95m.

1.5. Bone sickle

Figure F.15. Sickle made from cattle rib. (Tool nr. 3891)

Tool name: Cattle rib sickle

Tool number: 3891

Haft: Made entirely from bone (see fig. F.15.).

Harvesting duration: 0.1 hours

Reaped cereals: *Triticum aestivum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum aestivum* and grass with the left hand during 10 min. 0.2m to 0.3m above ground. Grasped with right hand 2-3 stems and tried to saw them off their root. Sunny and hot afternoon with a bit of wind. 24°C temperature.

Status of sickle after use: Unchanged

Tool effectiveness: Tool was not effective at all. Could not cut through the stems. Tried a hacking motion, by hitting several stems with the bone. But they would not come loose. Tried hacking one stem after the other and could hack free some stems. No sawing possible as edge had no sawing structure. Grass was more difficult as it was still green. It did not get hacked free as with the cereal stems. Stopped the experiment after 10 min, as no progress was seen in reaping.

Harvesting area: First 10 min.: Estimated 0.1m².

Volume in circumference of stems gathered: Estimated 0.1m.

Figure F.16. Sickle made from cattle rib. (Tool nr. 4167)

Tool name: Cattle rib sickle

Tool number: 4167

Haft: Made entirely from bone (see fig. F.16.).

Harvesting duration: 0.05 hours

Reaped cereals: *Triticum dicoccum*

Detailed description of experimental procedure and activity carried out:

Tried to harvest *Triticum dicoccum* with the left hand during 5 min. 0.1m to 0.2m above ground. Grasped with right hand 2-3 stems and tried to cut or saw them off their root.

Sunny noon with a bit of wind. 24°C temperature.

Status of sickle after use: Unchanged

Tool effectiveness: Tool was not effective. Could not even cut through a few dry stems for first few minutes. Chopping at the stems did not uproot nor cut the plant. It just hit the stems without breaking them. Stopped the experiment after 5 min, as no progress was seen in harvesting.

Harvesting area: First 5 min.: estimated 0.1m² as not recorded.

Volume in circumference of stems gathered: First 5 min.: estimated 0.1m as not recorded.

Figure F.17. Sickle made from cattle rib. (Tool nr. 4166)

Tool name: Cattle rib sickle

Tool number: 4166

Haft: Made entirely from bone (see fig. F.17.).

Harvesting duration: 0.08 hours

Reaped cereals: *Hordeum vulgare*

Detailed description of experimental procedure and activity carried out:

Harvested *Hordeum vulgare* with the left hand during 8 min. 0.1m to 0.12m above ground. Grasped with right hand 2-3 stems and tried to cut or saw them off their root.

Sunny evening with a bit of wind. 24°C temperature.

Status of sickle after use: Unchanged

Tool effectiveness: Tool was not effective. Could cut through a few dry stems for first few minutes but not through green stems. Once the edge became blunt, cutting was not possible at all. Tried to chop and saw through the stems but could only remove 2-3 stems at a time. Stopped the experiment after 8 min, as no progress was seen in reaping.

Harvesting area: 8 min.: 0.09m²

Volume in circumference of stems gathered: 8 min.: 0.30m

Figure F.18. Sickle made from cattle rib. (Tool nr. 3900)

Tool name: Cattle rib sickle

Tool number: 3900

Haft: Made entirely from bone (see fig. F.18.).

Harvesting duration: 0.07 hours

Reaped cereals: *Triticum monococcum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum monococcum* with the left hand during 7 min. 0.2m to 0.3m above ground. Grasped with right hand 2-3 stems and tried to saw them off their root.

Sunny morning with a bit of wind. 18°C temperature.

Status of sickle after use: Unchanged

Tool effectiveness: Tool was not effective. Could cut through stems for first few minutes. Once the edge became blunt cutting was not possible anymore. Tried to rip through the stems but that did not work. No sawing possible as edge had no sawing structure. Stopped the experiment after 7 min, as no progress was seen in reaping.

Harvesting area: 7 min.: 0.18m²

Volume in circumference of stems gathered: 7 min.: 0.30m.

2. Shells as harvesting knife

2.a. Handheld oyster shells

Figure F.19. Oyster shell as harvesting knife. (Tool nr. 3683)

Tool name: Hand-held oyster shell

Tool number: 3683

Material: Entire flat oyster shell

Protection: Spruce pitch combined with charcoal and lard coated around the dorsal part of the shell (see fig. F.19.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum aestivum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum aestivum* ears in 1-hour intervals with cutting height 1.0m above soil. Gathered 1-2 ears with right hand and cut with left hand and the sharp, rounded part of shell. Thumb lies inside the shell and shell is held with the inside facing up. Transferred cut ears in right hand and put in collection bag attached to belt. Sunny and hot day with a bit of wind. 23°C to 28°C temperature.

Status of sickle after use: Outer brown oyster shell disappeared during harvest.

Tool effectiveness: The oyster shell is a bit too big to be held comfortably and to be able to hold and cut ears with one hand. It is easier with mussel shells. Cutting edges are sharp and cutting is easy and fast. Outer (brown coloured) shell rim gets used up fast and after 1 hour the picking is done only on the mother of pearl edge of the oyster. Heavily used parts of the oyster are flaking off, creating dents in the cutting edge. But these dents stay sharp as blunt material is worn off. Overall tool stays sharp the entire time and only slowly reduces its sizes as parts are flaking off.

Harvesting area: 1. hour: 1.815m², 2nd hour: 1.54m², 3rd hour: 1.32m². Total: 4.68m²

Volume of ears gathered: 1. Hour: 0.0328m³, 2nd hour: 0.0336m³, 3rd hour: 0.0336m³. Total: 0.1m³.

Figure F.20. Oyster shell as harvesting knife. (Tool nr. 3684)

Tool name: Hand-held oyster shell

Tool number: 3684

Material: Entire flat oyster shell

Protection: Spruce pitch combined with charcoal and lard coated around the dorsal part of the shell (see fig. F.20.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum dicoccum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum dicoccum* ears in 1-hour intervals with cutting height 1.2m above soil. Gather 2-3 ears with left thumb and cut with rounded part of shell. Thumb lies inside the shell and shell is held with the inside facing up. Gathered ears move to right hand and are transferred to collection bag attached to belt. Sunny and hot days with a bit of wind. 24°C to 29°C temperature.

Status of sickle after use: Outer brown shell disappeared during harvest.

Tool effectiveness: The oyster shell is a bit too big to be held comfortably and to be able to hold and cut ears with one hand. Cutting edges are sharp and picking is easy and fast. Outer (brown coloured) shell rim gets used up rapidly and picking after 1 hour is done on mother of pearl edge of the oyster. Heavily used parts of the oyster are flaking off, creating dents in the cutting edge. Tool size and sharpness stays similar even after 3 hours of use.

Harvesting area: 1. hour: 5.0m², 2nd hour: 3.20m², 3rd hour: 3.5m². Total: 11.70m²

Volume of ears gathered: 1. hour: not measured, 2nd hour: 0.0266m³, 3rd hour: 0.0256m³. Total: 0.522m³

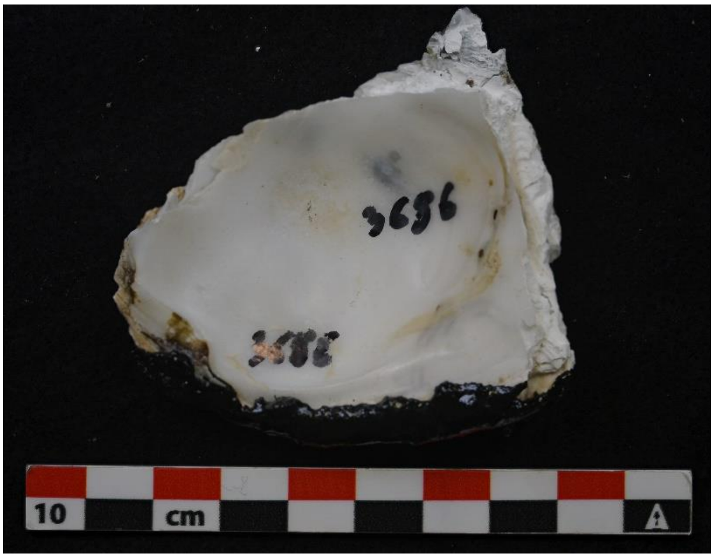


Figure F.21. Oyster shell as harvesting knife. (Tool nr. 3686)

Tool name: Hand-held oyster shell

Tool number: 3686

Material: ½ of a flat oyster shell

Protection: Spruce pitch combined with charcoal and lard coated around the dorsal part of the shell (see fig. F.21.).

Harvesting duration: 3 hours

Reaped cereals: *Hordeum vulgare*

Detailed description of experimental procedure and activity carried out:

Harvested *Hordeum vulgare* ears in 1-hour intervals with cutting height 0.6m above soil. Gathered 1-2 ears with thumb of left hand and cut with sharp part of shell. Thumb lies inside the shell. Gathered ears are then transferred to right hand and put into collection bag attached to belt. Sunny and hot day with a bit of wind. 25°C to 26°C temperature.

Status of sickle after use: Cutting edge gets slowly used up.

Tool effectiveness: This fragment of an oyster shell has the right size to be held comfortably and to hold and cut ears in one hand. The shell edges stay sharp over 3 hours of harvesting. Heavily used parts of the oyster are flaking off, creating two dents in the cutting edge. No major changes in tool size and form after 3 hours of work. The tool edge gets green the first day from unripe *Hordeum vulgare*. The next day, as the plant gets dryer the edge does not change color. As the edge is sharp, pulling the stems over it, hurts the fingers already after only 1 hour of harvesting. Overall slow progress of picking.

Harvesting area: 1. hour: 2.4m^2, 2nd hour: 2.4m^2, 3rd hour: 2.50m^2. Total: 7.30m^2

Volume of ears gathered: 1. hour: 0.016m^3, 2nd hour: 0.00,16m^3, 3rd hour: 0.0176m^3. Total: 0.0496m^3

Figure F.22. Oyster shell as harvesting knife. (Tool nr. 3685)

Tool name: Hand-held oyster shell

Tool number: 3685

Material: ½ of a flat oyster shell

Protection: Spruce pitch combined with charcoal and lard coated around the dorsal part of the shell (see fig. F.22.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum monococcum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum monococcum* ears in 1-hour intervals with cutting height 1.2m above soil. Gathered ears one by one with thumb of left hand and cut with sharp part of shell. Thumb lies inside the shell. Gathered ears are transferred to right hand and put in collection bag attached to belt. Sunny and hot day with a bit of wind. 25°C to 26°C temperature.

Status of sickle after use: Cutting edges are slowly getting used up.

Tool effectiveness: This oyster shell has the right size to be held comfortably and to hold and cut ears in one hand. Shell stays sharp over the 3 hours of harvesting. During reaping little flakes of shell are falling off, making cutting edges stay sharp and picking easy. Dents are forming in cutting edge, as these are the more heavily used segments of the oyster. No major changes in tool size and form after 3 hours of work. Difficult to collect *Triticum monococcum* as stems sway in the wind and ears are at different height. Need to pluck them off one by one. Also, the ears break off in the middle frequently while picking as they are very brittle. Slow progress.

Harvesting area: 1. hour: 1.20m², 2nd hour: 1.32m², 3rd hour: 1.32m². Total: 3.84m²

Volume of ears gathered: 1. hour: 0.01156m³, 2nd hour: 0.0144m³, 3rd hour: 0.0144m³. Total: 0.04036m³

2.b. Handheld mussel shells

Figure F. 23. Mussel shell as harvesting knife. (Tool nr. 3679)

Tool name: Hand-held mussel shell

Tool number: 3679

Material: Entire freshwater mussel shell

Protection: Spruce pitch combined with charcoal and lard coated around the dorsal part of the shell (see fig. F.23.).

Harvesting duration: 3 hours

Reaped cereals: *Triticum aestivum*

Detailed description of experimental procedure and activity carried out:
Harvested *Triticum aestivum* ears in 1-hour intervals with cutting height at 1.0m above soil. Gather single ears with right hand and cut with left hand via the anterior end of the shell. Thumb lies inside the shell. Gathered then cut ears in right hand and transferred to collection bag attached to belt. Sunny and hot day with a bit of wind. 22°C to 27°C temperature.
Status of tool after use: Frontal part has fallen off. Cutting edges get damaged.
Tool effectiveness: The dense field of *Triticum aestivum* at the Heidfeldhof, Stuttgart makes it easy to pick ears. The tool's pointed part was very good in cutting ears. But after 1 h 20min. the edge of the shell started breaking off. Used then the thicker edge on the other side of the shell, which was less cutting but more about ripping the ears off. But still it was faster than cutting with the pointed edge. Easy picking as the stems were thick (0.5mm) and the wind does not sway them. The ears also did not break during the harvest making it faster. But after 3 hours of picking ears, only 70% of the tool was left.
Harvesting area: 1. hour: 1.375m², 2nd hour: 1.925m², 3rd hour: 1.43m². Total: 4.73m²
Volume of ears gathered: 1. hour: 0.0304m³, 2nd hour: 0.0336m³, 3rd hour: 0.0304m³. Total: 0.0944m³

Figure F. 24. Mussel shell as harvesting knife. (Tool nr. 3680)

Tool name: Hand-held mussel shell
Tool number: 3680
Material: Entire freshwater mussel shell
Protection: Spruce pitch combined with charcoal and lard coated around the dorsal part of the shell (see fig. F.24.).
Harvesting duration: 3 hours
Reaped cereals: *Triticum dicoccum*

Detailed description of experimental procedure and activity carried out:
Harvested *Triticum dicoccum* with the left hand in 1-hour sequences with a cutting height of about 1.20m. Hold shell with four fingers and use thumb to pull 1-3 ears over cutting edge to pick them off. Shell lies horizontally in hand with inner part facing up. Used then right hand to collect and transfer ears to collection bag. As stems are of similar height, they are easy to pick. Sunny and hot noon with a bit of wind. 26°C to 28°C temperature.
Status of tool after use: Shell remained intact. Cutting edges became dented.
Tool effectiveness: The ears are easy to pick as they are dry. But once cut, they tend to break off in the middle. Used pointed, anterior end of shell for picking, as it was faster than the posterior, thicker end. Edge starts slowly breaking off, leaving a slightly serrated edge. But still the entire shell was usable during the entire harvesting time in contrast to similar shells on other cereals. As small parts of edge break off, the below edge remains sharp. Overall slow progress compared to sickles.
Harvesting area: 1. hour: 3.30m², 2nd hour: 4.40m², 3rd hour: 3.50m². Total: 11.20m²
Volume of ears gathered: 1. hour: 0.018m³, 2nd hour: 0.016m³, 3rd hour: 0.028m³. Total:0.062m³

Figure F. 25. Mussel shell as harvesting knife. (Tool nr. 3681)

Tool name: Hand-held mussel shell
Tool number: 3681
Material: Entire freshwater mussel shell
Protection: Spruce pitch combined with charcoal and lard coated around the dorsal part of the shell (see fig. F.25.).
Harvesting duration: 3 hours
Reaped cereals: *Hordeum vulgare*

Detailed description of experimental procedure and activity carried out:
Harvested *Hordeum vulgare* with the left hand in 1-hour sequences with a cutting height of 0.5m. Hold shell with 4 fingers and used thumb to pull 2-3 ears towards cutting edge to cut them off. Used then right hand to gather cut off ears and transfer them to the collection bag. As *Hordeum vulgare* stems are short (60 cm height) collecting is difficult as harvester must bend deeply forward. Another way is to sit on the soil and pick the ears. Sunny and hot afternoons with a bit of wind. 25°C to 28°C temperature.
Status of tool after use: Frontal part has fallen off. Cutting edges get damaged.
Tool effectiveness: Picked the ears one by one. Easy to pick when ears are dry but need more force when they are still green. Pointed, anterior part of shell allows fast picking as cutting edge is thin and sharp. But after 1 hour the edge starts breaking off, leaving a serrated edge. Tried also thicker, posterior edge on other side of shell. It works, but more effort is needed to pluck ears. During second and especially 3rd day ears are dryer and are breaking off easier with a cracking noise. Also, they are more brittle, break off in the middle.
Harvesting area: 1. hour: 2.70m², 2nd hour: 2.40m², 3rd hour: 2.00m². Total: 7.10m²
Volume of ears gathered: 1. hour: 0.02m³, 2nd hour: 0.0192m³, 3rd hour: 0.0192m³. Total:0.0584m³

Figure F. 26. Mussel shell as harvesting knife. (Tool nr. 3682)

Tool name: Hand-held mussel shell
Tool number: 3682
Material: Entire freshwater mussel shell
Protection: Spruce pitch combined with charcoal and lard coated around the dorsal part of the shell (see fig. F.26.).
Harvesting duration: 3 hours

Reaped cereals: *Triticum monococcum*

Detailed description of experimental procedure and activity carried out:

Harvested *Triticum monococcum* with the left hand in 1-hour sequences. Hold shell with 4 fingers and use thumb to pull ears towards cutting edge to pick them off. Use then right hand to gather cut off ears and transfer them to the collection bag. Also use right hand sometimes to grasp moving stems to be able to cut them. Sunny and hot day with a bit of wind. 23°C to 26°C temperature.

Status of tool after use: Frontal part has fallen off. Cutting edges get damaged.

Tool effectiveness: Slow progress in picking ears as stems move strongly in the wind and are difficult to catch. Also, the different height of the ears make work slow. Finally, the ears frequently break off in the middle once picked, as they were very dry. Also pointed, anterior end of shell starts breaking off during first hour, reducing the cutting edge. Tool gets shorter during the 3 hours and only the rounded, posterior end remains as cutting edge. Still picking is possible at the same rate as at the beginning, showing that a sharp edge is not always necessary.70% of shell is left after harvest.

Harvesting area: 1. hour: $1.32m^2$, 2nd hour: $1.32m^2$, 3rd hour: $1.20m^2$. Total: $3.84m^2$

Volume of ears gathered: 1. hour: $0.016m^3$, 2nd hour: $0.0144m^3$, 3rd hour: $0.0144m^3$. Total:$0.0448m^3$

3. Harvesting by hand

Harvesting cereals with one's bare hand came as an afterthought in the experiment. As more and more results were achieved in terms of reaped space and volume, it appeared interesting to compare these results to a collecting method using no tools except one's own hands.

3.a. Picking by hand

To compare the effectiveness of shells as harvesting knives in picking cereals also picking by hand was done. Initially both hands were used to grasp the cereals and picking the ears off. Later only one hand was used, and the other gathered the ears to be picked. The right hand catches the ears, and the left hand picked the ears off by bending them against their natural angle, resulting in a clean and effortless cut. Earlier tries to pick the ears by just pulling at the ears was not successful, as the ear tended to break in the middle or that more energy and effort was needed to break them off the stem. Once broken off, the ears were collected in the right hand, before being transferred to a collecting bag attached to the harvester's belt.

3.b. Uprooting by hand

To compare the effectiveness of sickles also uprooting by hand has been tried on all four cereal types. Uprooting is done with the left-hand grabbing about a dozen to 1/2 dozen stems and pulling them out of the soil. Once out, the roots are hit against a hard object (e.g., working shoe of the harvester) to remove the earth and then put aside on a pile of stems. The reaping goes fast and rather effortless thanks to the absence of weeds and the looseness of the soil. But after close to an hour the strength to pull out is reduced and fewer stems can be grabbed to be pulled out. Sometimes also the other arm is used to grab stems and pull them out. For *Triticum aestivum* uprooting was more difficult. As it was an organically planted field, much grass and weeds were mixed in the field with the cereals. Also, the soil was more compact. As such each individual *Triticum aestivum* stem had to be plucked like a flower from the field.