J. stored Prod. Res. Vol. 19, No. 4, pp. 163-171, 1983
Printed in Great Britain.
0022-474X/83 $3.00 + 0.00

STORAGE OF BARLEY GRAIN IN IRON AGE TYPE UNDERGROUND PITS

R. A. HILL[1]*, J. LACEY[1] and P. J. REYNOLDS[2]
[1]Rothamsted Experimental Station, Harpenden, Herts, AL5 2JQ, England
[2]Butser Ancient Farm Research Project Trust, Rookham Lodge, East Meon, Hants, England

(*Received in final form* 12 *April* 1983)

Abstract—Factors affecting the storage of barley grain cv. Julia were studied during four seasons in underground pits constructed on Butser Ancient Farm, Hampshire. Grain stored well overwinter except when the rainfall during the storage period was sufficient to increase grain water content greatly. In the wet seasons, the outermost grain in some pits increased to more than 50% water content, spontaneous heating occurred and carbon dioxide concentrations exceeded 30%. Otherwise most grain remained drier than 35% water content, temperatures remained less than 13°C and carbon dioxide concentrations were less than 25%. In good seasons at least 90% of the grain germinated following storage but in bad, less than 5% germinated from some pits. Grain was stored successfully in pits of different shapes and sizes but beehive-shaped pits were less wasteful of grain than cylindrical pits. Most important was an efficient top seal to prevent entry of rain and to retain carbon dioxide, while siting the pit within a round house ensured successful grain storage in all seasons. *Penicillium* species and members of the *Aspergillus glaucus* group were the predominat fungi isolated, supplemented by other species in the damper, outermost grain and in the pit structure. It was concluded that esimates of the population of Iron Age settlements based on pit numbers and size are unreliable.

INTRODUCTION

The underground pit is probably the most abundant and characteristic archaeological feature discovered on Iron Age settlement sites in southern Britain and northern France (Bowen and Wood, 1968). These pits vary widely in shape, size and detail. The predominant cylindrical or beehive shaped pits average over 2.0 m deep by 1.8 m diameter and are thought to have been used specifically for the storage of grain. This interpretation is inspired by references made by classical authors to the practice of storing grain and other foodstuffs in underground pits and further supported by the occasional discovery of carbonised grain within the backfill material. There is some evidence that certain pits of this type were lined with different materials, e.g. clay or basket work (Reynolds, 1974). Employing this interpretation, attempts have been made to compute the populations of Iron Age communities based upon the average quantity of grain assumed *per capita* and the capacity and number of grain pits on a given site (Bersu, 1940). However, such computation depends upon such variables as the number of pits in use at any one time and the life-span of a pit.

Preliminary experiments with underground storage of grain in pits and its microbiology have already been published (Bowen and Wood, 1968; Reynolds, 1967, 1969; Lacey, 1972). These proved that grain could be stored satisfactorily although there was some moulding particularly when the winter was wet. The present investigation sought to determine whether the life of a grain storage pit was finite, what factors caused deterioration of the pit and how grain storage was affected by pit size, shape, lining, preparatory treatment, season and protection from the weather. It was based upon four seasons, 1972–1976, of grain storage in underground Iron Age type pits at the Butser Ancient Farm Research Project Trust in Hampshire (Reynolds, 1979).

MATERIALS AND METHODS

Underground grain storage pits

The design of a typical experimental grain-storage pit is illustrated in Fig. 1. Pits of cylindrical and beehive shapes, of two sizes and with different internal treatments, were compared (Table 1).

*Present address: University of Georgia, Plant Pathology Department, Coastal Plains Experimental Station, Tifton, GA 31793, U.S.A.

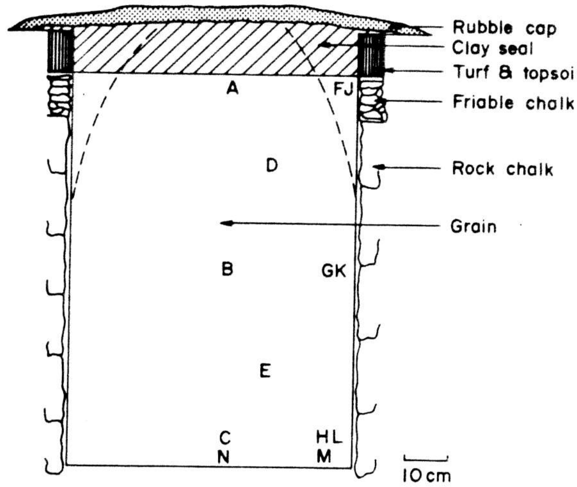

Fig. 1. Vertical section through a cylindrical grain storage pit. *Key:* ---, outline of beehive shaped pit; A–H, sites of temperature sensors, gas sampling points and from which grain was sampled after storage; J–N, Additional grain sampling sites.

Most were dug into chalk rock but one was on a clay-with-flints subsoil (BUTU). Pit shape and size were standardised as far as possible, but exact dimensions could not always be achieved because the chalk rock cracked in both vertical and horizontal planes and irregular blocks of material often fell away from the wall.

The pits were filled with barley grain cv. Julia, which is similar in size and shape to prehistoric barley, harvested with a water content of 15–16% and stored in bins until required. Grain was stored in pits each year from October until April.

Thermistor temperature sensors and gas sampling tubes were placed in the grain at eight points (Fig. 1) during filling and a temperature sensor was placed in soil nearby, 5 cm below the surface. Temperature was recorded and gas samples were taken fortnightly. An Orsat gas analyser was used to measure carbon dioxide concentrations in the samples by absorption in potassium hydroxide solution.

Rainfall was measured daily with a standard 12.7 cm (5 in.) rainguage on the experimental site.

Grain water content before and after storage was determined by drying duplicate samples at 105°C for 16 hr and calculating weight loss as a percentage of the fresh weight of the sample.

Assessment of grain quality

Grain microflora. Microorganisms were enumerated by plating serial dilutions of suspended propagules using the pour plate method with 2% malt extract agar containing 20 i.u. benzyl

Table 1. Pit designations, design and treatment

Designation	Design	Treatment
MAXU	Large, cylindrical	None
UNLU	Small, cylindrical	None
MAXB	Large, beehive	None
BUNL	Small, beehive	None
COVU	Small, cylindrical	Sited within roundhouse
CHUN	Small, cylindrical	Turf and topsoil removed from around pit
FUNL	Small, cylindrical	Inside flamed
BUNC	Small, cylindrical	Walls lined with hazel basket work
CLUN	Small, cylindrical	Walls lined with 2 cm clay
ALGU	Small, cylindrical	Algal growth removed at filling
BUTU	Small, cylindrical	Dug on clay/flint subsoil

All pits were dug into chalk, except for BUTU.
Large pits were 1.25 m dia × 1.5 m deep, capacity 0.9 t (cylindrical) or 1.0 m dia at neck to 1.5 m dia at base × 1.5 m deep, capacity 1.1 t (beehive). Small pits were 0.66 m dia × 1.0 m deep, capacity 0.2 t (cylindrical).

penicillin and 40 μg streptomycin sulphate per ml medium to suppress bacteria. Petri dishes were incubated at 25°C for at least 7 days before counting (Hill, 1979).

Interpretation of results. The degree of contamination by microfungi was used as a measure of edibility. The edibility of grain with fewer than 10^5 fungus propagules/g dry wt of grain was considered good, that with 10^5 to 10^6 propagules/g fair, while grain with more than 10^6 propagules/g, unless these were mainly yeasts, was considered poor.

Germination. The viability of grain after storage was assessed by incubating 50 grains at room temperature (about 20°C) on moist filter paper in each of 10 Petri dishes and counting germinated grains after 5 and 7 days.

RESULTS

Climatic conditions during storage

Soil temperature and rainfall. Records for the four storage seasons, 1972–1976, are shown in Fig. 2. The 1972–3 storage season was mostly cool and dry with soil temperatures decreasing rapidly through October and November from above 20°C to below 10°C. They remained around 10°C through December and January before reaching a minimum of 4°C in February and subsequently rising to 12°C when the pits were emptied in April. Rainfall was generally light with most between mid-November and mid-December when over 20 mm fell.

The 1973–4 storage period was mild with average rainfall. Soil temperature remained above 10°C during March when the minimum of 8.5°C was recorded. Rainfall was light for the first two months, heavy in January and February, then light again for the remainder of the period.

The storage period in 1974–5 was mild and very wet. Soil temperature was still 15°C in February, falling to a minimum of 9°C in March. Rainfall was very heavy in November and January and moderate at other times.

The 1975–6 storage period was cold and very dry. Soil temperature declined to 0°C by mid-December and again at the end of January, reaching a maximum of 12°C in between. At emptying, the temperature was 10°C. Apart from November, the rainfall was very light.

Environmental conditions within the pits

Grain water content. Table 2 shows the grain water content at filling and after storage in the pits in each season. The water content of the bulk of the grain decreased slightly during the dry seasons of 1972–3 and 1975–6. There was a slight increase (about 1%) in 1973–4, but in the wet season of 1974–5 the increase was 8%. After storage, the bulk of the grain was always surrounded by a layer of grain about 2 cm thick that usually had at least double the water content.

Grain temperature. Maximum and minimum temperatures from the centre of the grain bulk in different pits are compared with soil temperatures in Table 3. In three seasons, 1972–3, 1973–4 and 1975–6, the maximum temperatures 5 cm below the soil surface and within the bulk were similar

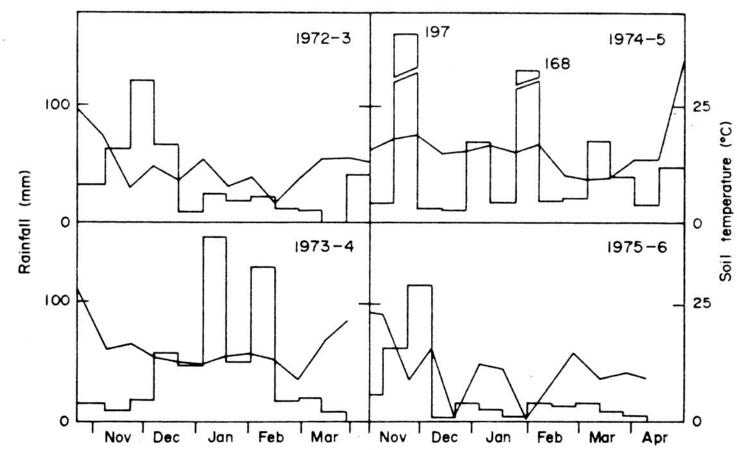

Fig. 2. Fortnightly rainfall (histogram) and soil temperatures (5 cm deep) (graph) close to the storage pits.

Table 2. Grain water content before and after storage in pits and total rainfall during storage, in four seasons

	Storage period			
	1972–3	1973–4	1974–5	1975–6
	Water content (%)			
At filling	16.0	16.0	15.0	16.0
At emptying: Grain bulk	14.7	16.9	23.1	15.1
At emptying: Outermost grain	32.3	54.2	65.0	37.3
	Rainfall (mm)			
Total rainfall during storage	417	532	584	288

although the grain was never as cold as the soil. By contrast, in the mild wet season of 1974–5, the grain in four pits heated spontaneously to more than 25°C (the upper limit of the equipment used). Typically, temperatures increased with depth and distance from the edge to a maximum slightly above the bottom of the pits at about the level of sampling point E. Only grain near the top of the pit (points A and F) cooled almost as much as the soil. Grain temperatures generally gradually decreased to minima in February–March when soil temperatures were also at their lowest.

Carbon dioxide concentration. A consequence of the absorption of water by the outermost grain is that it respires and often sprouts. Respiration by the grain and its associated micro-organisms utilises oxygen from the intergranular atmosphere and replaces it with carbon dioxide. Gas exchange with the atmosphere is prevented by the clay seal above the grain. Table 4 shows the maximum carbon dioxide concentrations found in each pit during the four seasons. The average maximum concentrations of carbon dioxide in the four seasons were, respectively, 25.0, 25.1, 29.9 and 16.1%, varying similarly to the rainfall during the storage period. COVU consistently gave the lowest concentrations of carbon dioxide while CHUN gave high concentrations, perhaps because the removal of turf and topsoil around the pit allowed more water to leak in. Surprisingly, spontaneous heating did not result in large concentrations of carbon dioxide, suggesting that there was good air exchange with the atmosphere in those pits that heated.

Largest concentrations of carbon dioxide were found at the lowest sampling points (C,E,H) and those least close to the clay seal (A,F) but, on any one occasion, the percentage of carbon dioxide in the intergranular atmosphere did not differ by more than about six between the different sampling points. Concentrations at all levels were usually greatest after about eight weeks storage and subsequently declined slowly to 10–15% at the time the pits were emptied in April.

Microbiological studies of grain and pit structures

The microflora of grain at filling. Species normally common on grain during ripening ("field fungi") were isolated from the grain used to fill the storage pits. These included, in decreasing order of abundance, yeasts, *Cladosporium* spp., mycelia sterilia, *Alternaria* spp., *Epicoccum purpurascens*

Table 3. Maximum and minimum temperatures (°C) at the centre of iron Age type pits during grain storage from autumn to spring

	Year							
	1972–3		1973–4		1974–5		1975–6	
	max	min	max	min	max	min	max	min
Soil (5 cm depth)	11.0	0.5	10.5	4.3	9.0	4.5	12.5	0.5
Pit designation								
UNLU	13.0	7.5	11.8	7.5	>25.0*	6.3	—	—
BUNL	10.0	3.0	9.0	1.3	10.7	5.5	—	—
CHUN	12.0	6.8	6.8	2.3	>25.0	4.0	—	—
FUNL	12.3	6.0	11.8	7.8	15.5	6.5	12.0	4.0
CLUN	11.5	6.0	10.5	6.0	9.4	4.0	8.8	4.0
COVU	12.3	6.5	—	—	13.5	8.0	13.3	9.5
BUNC	8.3	3.0	10.0	5.8	—	—	—	—
BUTU	9.5	2.5	—	—	—	—	—	—
MAXU	—	—	10.8	8.0	>25.0	4.8	13.0	12.0
MAXB	—	—	10.0	7.0	>25.0	8.5	12.5	11.5
ALGU	—	—	10.5	6.5	16.0	5.3	9.5	4.8

Key: for treatments see Table 1; *25°C was the upper limit of temperature recording system; —, no record.

Table 4. Maximum concentration of carbon dioxide found at the centre (point B) of Iron Age type underground pits during grain storage overwinter in four seasons

Pit designation	Year 1972–3	1973–4	1974–5	1975–6
	($\%$ CO_2)			
UHLU	24.8	26.5	27.0	—
BUNL	25.4	23.0	26.8	—
CHUN	27.8	45.4	30.0	—
FUNL	24.0	21.5	35.0	22.2
CLUN	25.8	24.8	39.8	20.0
COVU	22.8	13.2	16.8	5.2
BUNC	25.0	14.4	—	—
BUTU	24.4	—	—	—
MAXU	—	25.2	28.6	18.6
MAXB	—	35.6	32.2	15.4
ALGU	—	21.4	32.8	15.2

Key: for treatments, see Table 1; —, no record.

Ehrenb. ex Schlecht., *Aureobasidium pullulans* (de Bary) Arnaud, *Acremonium* spp., *Arthrinium phaeospermum* (Corda) M. B. Ellis, *Botrytis cinerea* Pers. ex Fr. and *Mucor* spp. Storage fungi, including *Penicillium* species, especially varieties of *P. verrucosum* Dierckx and *Aspergillus fumigatus* Fres., were occasionally found. Bacterial populations were not assessed.

The microflora of grain after pit storage. When pits of all types were emptied, two zones could be recognised in the stored grain: the central bulk and a damper, more mouldy outer layer, usually about 2 cm thick. The fungi isolated and their maximum numbers in both zones are shown in Table 5.

During storage, "field fungi" mostly decreased while fungi characteristic of storage became more numerous, particularly in the outer layer. An exception was *Cladosporium*, which sometimes increased in the outer layer. The most important species in the grain bulk were *Penicillium verrucosum* var. *cyclopium* Samson, Stolk & Hadlok, *P. roqueforti* Thom, *P. hordei* Stolk, *P. piceum*

Table 5. Fungi isolated from pit structures and grain after storage (log maximum numbers isolated/g sample)

	Pit structure			Grain	
	Basket lining	Clay lining	Chalk wall	Bulk	Outermost layer
Absidia spp.	—	—	6	—	
Acremonium spp.	—	—	—	5	3
Alternaria spp.	—	—	—	3	—
Aspergillus candidus Link	—	—	—	3	—
A. fumigatus Fres.	—	—	—	3	—
A. glaucus group	—	—	—	5	4
A. versicolor (Vuill.) Tiraboschi	—	—	—	4	4
Aureobasidium pullulans (de Bary) Arnaud	7	—	4	4	4
Chaetomium. spp.	—	2	—	—	6
Cladosporium spp.	6	—	—	4	6
Epicoccum purpurascens Ehrenb. ex Schlecht	5	—	—	3	—
Fusarium spp.	—	4	6	2	4
Geotrichum candidum Link	—	—	—	—	6
Mucor spp.	4	5	5	3	6
Mycelia sterilia	5	—	—	5	5
Paecilomyces spp.	—	2	—	—	—
Penicillium biforme Thom	—	—	—	—	2
P. hordei Stolk	—	—	—	5	—
P. piceum Raper & Fennell	—	—	—	5	—
P. roqueforti Thom	—	—	6	6	6
P. stecki Zaleski	—	—	—	2	—
P. verrucosum Dierckx var. *cyclopium* Samson, Stolk & Hadlok	6	7	6	7	8
P. verrucosum var. *verrucosum* Samson, Stolk & Hadlok	—	—	—	4	—
Other *Penicillium* spp.	6	5	6	4	6
Trichoderma viride Pers. ex Fr.	—	—	—	3	—
Verticillium spp.	—	5	—	—	—
Yeasts, white	6	6	—	9	8
Yeasts, pink	—	—	—	4	3

Table 6. Numbers of fungi isolated from the grain bulk and the outermost grain layer after storage in Iron Age type underground pits in four seasons (means of all pits)

	Storage season			
	1972–3	1973–4	1974–5	1975–6
		(Colonies/g × 10^{-3})		
Grain bulk	61	823	156,775	248
Aspergillus + *Penicillium*	17	95	6984	241
Yeasts	17	717	149,754	6
Outermost grain layer	2914	2900	183,118	28,292
Aspergillus + *Penicillium*	2627	402	1070	27,252
Yeasts	0	1386	181,408	71

Raper & Fennell and species of the *Aspergillus glaucus* group, usually numbering 10^4 to 10^6 propagules/g dry wt, but more in wet years. In the outermost layer these species were supplemented by yeasts, *Geotrichum candidum* Link, *Mucor* spp., *Chaetomium* spp., *Cladosporium* spp., *Aspergillus versicolor* (Vuill.) Tiraboschi and *Fusarium* spp. to give a total of 10^6 to 10^7 propagules/g dry wt.

Effect of season on grain microflora. The numbers of fungi isolated from grain after storage in each of the four seasons are shown in Table 6. The bulk of the grain stored well in the two driest seasons, 1972–3 and 1975–6, when fungal populations were small, usually not exceeding 10^5/g dry wt grain. However, *Aspergillus* and *Penicillium* spp. were perhaps slightly favoured by the lower carbon dioxide levels (17% max.) and lower temperatures in 1975–6 than in 1972–3. In both seasons the outer layer of grain increased in water content to over 30% and became very mouldy (10^6 to 10^7 propagules/g dry wt).

The heavy rainfall of 1974–5 increased grain water content throughout all pits and most grain moulded during storage to a similar degree to the outermost layer (about 10^8 propagules/g dry wt). The outer damp mouldy layer was about 5 cm thick and only weakly delineated from the grain bulk. Carbon dioxide levels were high (almost 30%) and although *Penicillium* and *Aspergillus* were much more numerous than in other years, yeasts predominated.

In the 1973–4 storage period, when rainfall was intermediate between the two dry seasons and the very wet season, most of the grain stored well, but water leaked into several pits resulting in up to 10^7 yeast and 10^6 *Penicillium* and *Aspergillus* propagules/g of stored grain. The thickness of the outer mouldy layer of grain after storage and the carbon dioxide levels were similar to those found in 1972–3.

Effect of pit structure on grain microflora. The fungal content of grain stored in differently treated pits is shown in Table 7. In the dry seasons of 1972–3 and 1975–6 pits differed little: the bulk of the grain stored well regardless of pit design and treatment. However, in the other seasons marked differences were noted.

Pit shape. The outermost layer of damp, mouldy grain in contact with the soil increased noticeably in thickness at the top of cylindrical pits, but this was much less marked in the beehive-shaped pits. Consequently, more grain in good condition could be recovered from

Table 7. Numbers of fungi isolated from the centre of the grain bulk after storage in Iron Age type underground pits

	Year			
	1972–3	1973–4	1974–5	1975–6
Pit designation		(Colonies/g × 10^{-3})		
UNLU	10	6	1504	—
BUNL	20	8	490,530	—
CHUN	42	3644	110	—
FUNL	76	388	8860	55
CLUN	13	5	455	12
COVU	48	66	255	—
BUNC	164	578	—	—
BUTU	144	—	—	—
MAXU	—	3510	418,180	170
MAXB	—	8	415,100	770
ALGU	—	5	75,980	230

Key: For treatments see Table 1; —, no pit or sample not assessed.

beehive-shaped than from cylindrical pits. On average recovery of good grain was 97% from the former and 95% from the latter.

Pit size. With an increase in pit size more grain stored well, particularly in dry seasons, because the volume to wall area ratio was increased. In wet seasons the bulk of the grain was more readily wetted in small pits.

Treatment of small cylindrical pits. By sheltering a pit from rain by siting it within a Roundhouse (COVU), grain could be stored satisfactorily irrespective of season. Carbon dioxide concentrations remained low and fungi were few in all seasons (Table 7).

Partial sterilisation of the pit walls by an intense flame fire before filling with grain (FUNL), lining the pit with hazel basketry (BUNC) or neglecting to scrape algal growth from the surface of the chalk pit walls (ALGU), did not appear to affect the character of the grain microflora during storage. The absence of turf and topsoil from the pit site (CHUN) resulted, in 1973–4, in water leaking into the pit so that the carbon dioxide concentration reached the highest level recorded (45%) and 10^6 yeast propagules/g developed in the centre of the grainbulk during storage. By contrast, no leakage occurred in this pit in the wet season or 1974–5, the grain stored well and there were only 10^5 propagules/g. The reasons for this difference are not known.

Lining the vertical walls of the pit with clay (CLUN) decreased the ingression of water into the grain bulk during the wet season (1974–5) but the concentration of carbon dioxide still increased to a maximum of nearly 40%. The number of yeasts rose to 10^5/g dry wt grain during storage but other fungi remained few.

Microflora of pit structure. Apart from *Acremonium* spp., *Alternaria* spp. and *Botrytis cinerea* all the species found in the grain were also isolated from the chalk, clay or basket linings of the pits. Additionally, *Doratomyces* spp., *Gliocladium roseum* (Link.) Bainier, *Humicola* spp., *Oidiodendron griseum* Robak, *Paecilomyces* spp., *Penicillium nigricans* (Bainier) Thom and *P. oxalicum* Currie and Thom were found only in the soil lining the pits. The numbers and types of fungi found in the walls of pits usually increased during storage, but in 1973–4 they decreased with only one exception. The intense fire in FUNL caused an initial partial sterilization of the pit walls so that numbers of fungi were always small at the start of the storage period, though they subsequently increased even in 1973–4 (Table 8).

Numbers of fungi in the walls of pits used in successive years decreased by the autumn following storage more often than they increased. However, the basket lining of BUNC provided a substrate for fungi especially *Penicillium verrucosum* var. *cyclopium* and there was an increase in propagules from more than 10^6/g in the autumn of 1972 to nearly 10^9 in the autumn of 1973.

Grain viability

Grain always germinated well before storage and also afterwards in 1972–3, 1975–6 and from most pits in 1973–4. The only exception was the unlined, small cylindrical pit lacking turf and topsoil in the seal (CHUN) (Table 9). By contrast, after storage in 1974–5, only grain from the pits covered by a round house (COVU) germinated well. Figure 3 shows the variation in

Table 8. Numbers of fungi isolated from the walls of Iron Age type underground grain storage pits

	Year							
	1972–3		1973–4		1974–5		1975–6	
	(i)	(ii)	(i)	(ii)	(i)	(ii)	(i)	(ii)
Pit designation	Colonies/g × 10^{-3}							
UNLU	90*	1600†	2080	100	240	—	3750	8170
BUNL	—	—	14,000	170	40	—	300	20,540
CHUN	—	—	—	7870	150	—	—	—
FUNL	—	—	1010	3810	60	280	200	—
CLUN	140	780	4190	1960	40	160	230	3270
COVU	—	—	14,250	130	130	—	—	—
BUNC	2180	2510	881,250	10,580	—	—	—	—
MAXU	—	—	12,940	920	100	—	—	—
MAXB	—	—	—	2880	120	30,130	—	—
ALGU	—	—	13,260	2290	350	—	6210	12,670

Key: For treatments see Table 1; —, no pit with this treatment or sample not assessed. Sampling time: (i) autumn, before filling pits with grain; (ii) spring, after emptying pits.

*Composite sample representative of all newly dug chalk pits, i.e. UNLU, BUNL, CHUN, FUNL, COVU, MAXU, MAXB, ALGU.

†Composite sample from all chalk pits.

Table 9. Per cent germination of grain before and after storage overwinter in Iron Age type underground pits

Pit designation	1972–3	1973–4	1974–5	1975–6
		Germination before filling		
	94.8	95.0	88.2	93.6
		Germination after storage		
UNLU	95.5	76.4	10.0	—
BUNL	95.0	92.8	40.0	—
CHUN	85.3	28.0	50.0	—
FUNL	89.5	90.7	3.0	94.5
CLUN	94.4	92.3	16.0	95.2
COVU	96.3	84.3	87.2	93.7
BUNC	94.5	83.6	—	—
BUTU	85.2	—	—	—
MAXU	—	93.3	0.4	97.2
MAXB	—	84.8	5.0	95.9
ALGU	—	85.5	11.0	98.5

Key: For treatments see Table 1; —, no pit with this treatment or sample not assessed.

germination of grain sampled from different points after storage in a typical pit. Grain from the bottom of the pit failed to germinate: germination percentage was low in grain close to the sides while all other grain germinated well, the highest percentage being of grain stored near the middle.

DISCUSSION

As found in pilot experiments (Bowen and Wood, 1968; Lacey, 1972), most barley grain kept overwinter in underground pits stored well unless rainfall during storage was enough to increase the general grain water content greatly. Thus in 1972–3 and 1975–6, grain stored in all pits retained good viability and contained few fungi. There was no evidence of heating and carbon dioxide concentrations were usually less than 25%. In the wetter season of 1973–4, grain in two pits deteriorated following entry of water, development of high carbon dioxide levels and large yeast populations, but grain in all other pits stored well. Although only 28% of the grain in the two deteriorated pits germinated, it may still have been usable, at least as animal feed. With heavy rainfall (1974–5) the sub-soil became saturated and water moved into the grain, increasing the water content enough to allow severe moulding in many pits. Spontaneous heating occurred when the water content of the grain bulk exceeded 24% and the maximum carbon dioxide concentration remained less than 33%. When the carbon dioxide concentration was greater than this, heating was prevented and yeasts became predominant.

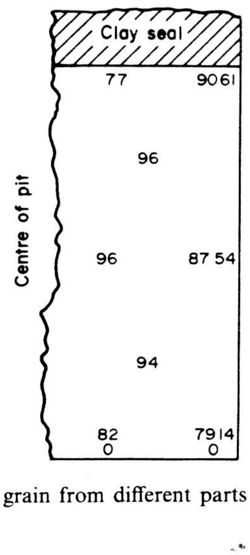

Fig. 3. Percentage germination of grain from different parts of a typical pit (UNLU, 1972–3).

Although grain was stored successfully in pits of a variety of shapes and sizes, the beehive type was less wasteful of grain than the cylinder. Cylindrical pits tended to be transformed into beehive-shaped pits as a result of erosion and seasonal cleaning. Given the advantage of the beehive shape, it is reasonable to suggest that pits of this design were deliberately constructed in the Iron Age. It is also the traditional design chosen by Turkoman tribesmen in Iran and is still in current use.

Treatment of the pits by intense heat from fires, by scraping algae from the walls or by lining the walls with clay had no effect on the grain microflora during storage.

Firing may help to decrease insect infestation and has been thought to account for the presence of carbonised grain in excavated pits. However, it is most unlikely that pits cut into chalk rock were fired since this process quickly destroys the wall structure. Some carbonised seed recently recovered from pits appeared to have germinated before carbonisation and consequently could have come from the outermost grain layer (Reynolds, 1980).

An efficient top seal to prevent entry of rain and the escape of carbon dioxide was important for the successful storage of grain in pits. Valley clay was effective but any malleable and impermeable material could be used, such as animal dung, cob or daub. Protection from the weather through siting a pit inside the Round House ensured successful grain storage. Only grain from this sheltered pit germinated well in all four seasons and did not deteriorate as a result of fungal colonisation.

The functional life of a pit would seem to be unlimited provided a balance of the essential factors for successful storage is maintained. However, after a wet winter, when some outside pits were unsatisfactory, the resulting mass of mouldy grain could have been a deterrent to the re-use of that pit, although the failure was caused not so much by the pit structure as by the weather. If, as seems possible, pits were abandoned for this reason, estimates of Iron Age populations based on pit numbers should be treated with caution.

The formula proposed for estimating the population of Iron Age settlements (Bersu, 1940) depends, among other factors, on the average grain consumption *per capita* and the capacity of storage pits. It also assumes that the grain is stored solely for consumption within the settlement. However, classical authors, e.g. Tacitus, indicate that grain was exported to the European mainland and pits could have been used to store this overwinter prior to export. Other grain may have been used for seed since 85–95% could germinate after good storage although only 10% or less after poor. Pit-stored grain may only have provided a reserve of seed grain as it is likely that much was stored separately in sacks or jars. Crops may also have been autumn-sown, avoiding the need for storage of seed overwinter, since both emmer (*Triticum diococcum* Schülb) and spelt (*T. spelta* L.) have been grown equally successfully at Butser Ancient Farm from both autumn and spring sowing. The presence of carbonised seeds of *Galium aparine* L., an important weed only of autumn sown crops at Butser, in deposits on archaeological sites further supports the view that autumn sowing was practised. Bowen and Wood (1968) suggest further sources of error which make the use of formulae based on grain storage in pits extremely unreliable.

REFERENCES

Bersu G. (1940) Excavations at Little Woodbury, Wiltshire. *Proc. prehist. Soc.* **6,** 30–111.

Bowen H. C. and Wood P. D. (1968) Experimental storage of corn underground and its implications for Iron Age settlements. *Univ. Lond. Inst. Archaeol. Bull.* **7.**

Hill R. A. (1979) The microflora of barley grain with special reference to *Penicillium* species. Ph.D. thesis, University of Reading.

Lacey J. (1972) The microbiology of grain stored underground in Iron Age type pits. *J. stored Prod. Res.* **8,** 151–154.

Reynolds P. J. (1967) Experiment in Iron Age agriculture. *Trans. Bristol Gloucestershire archaeol. Soc.* **86,** 60–73.

Reynolds P. J. (1969) Experiment in Iron Age agriculture. *Trans. Bristol Gloucestershire archaeol. Soc.* **88,** 60–73.

Reynolds P. J. (1974) Experimental Iron Age storage pits: an interim report. *Proc. prehist. Soc.* **40,** 118–131.

Reynolds P. J. (1979) The experimental storage of grain in iron Age type underground sites. Ph.D. Thesis, University of Leicester.

Reynolds P. J. (1980) Bulk storage of grain in prehistory. *La Recherche* (in press).