Traditional Underground Grain Storage in Clay Soils in Sudan Improved by Recent Innovations

A.T. Abdalla*, C.J. Stigter**#, N.I. Bakhiet***, M.C. Gough****, H.A. Mohamed*, A.E. Mohammed* & M.A. Ahmed***

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Summary

In the central clay plain of the Sudan, traditional subsistence farmers and small farmers that also produce for local markets want to keep the region near food self-sufficiency. They combine annual production of sorghum with underground pit storage of part of the harvest. With increasing climate variability this food security is coming more and more under pressure. Farmers recently experimented with pit innovations that would allow storage for more than one season. These innovations were quantified and further improvements were suggested. It was found that in the most abundantly occurring cracking clay soils, wide shallow pits, using thick chaff linings, with wider above ground soil caps, are most suitable for longer term storage.

Résumé

Amélioration du système traditionnel de stockage souterrain des céréales dans les sols argileux au Soudan

Les agriculteurs de la région argileuse centrale du Soudan pratiquent une agriculture d'autosubsistance tout en vendant une partie de leur récolte. Pour la conservation des céréales, une méthode traditionnelle basée sur un stockage dans des fossés souterrains est pratiquée. Cette technique ne permet cependant pas une conservation de plus d'une saison suite aux variations des conditions climatiques. Une nouvelle méthode a été initiée, quantifiée et améliorée. Elle consiste à creuser des fossés larges, peu profonds, garnis de pailles hachées et couverts par une couche épaisse de terre. Cette technique prometteuse garantit une conservation de longue durée même dans les sols argileux, très sensibles aux fissures qui sont abondants dans la région.

Introduction

The Sudanese government has been advised that increasing climate variability caused longer sequences of dry as well as wet years (1, 15, 17). Subsistence farmers in marginal areas such as central Sudan, but also those producing for themselves as well as for local markets, depend on rainfed production and traditional storage to the next harvest. Improving storage for longer duration at the village level is thought to be part of the solution to this change of climate (2, 14). The storage systems in use are warehouses and underground pits, so called matmuras (12). Small farmers use small size pits, from 2 to 10 tonnes, as a food security store. Medium and big farmers use pits up till more than 50 tonnes as alternative banks for gaining credit early next season (5, 6). The government even uses very big pits of up to 300 tonnes as strategic food reserves against famine.

For long term storage, warehouses are subject to high infestation by store pests (10, 11). Darling (8) already wrote that pit storage was so successful that modern technology sought to extend its scope rather than supersede it. Main underground pit advantages are high efficiency of protection against insects, mites, fire and theft as well as low construction and operational costs (1, 5, 6). However, main disadvantages are (a) increasing moisture content (mc) of the grain with time of storage, that leads to mould damage, lower grain quality and reduction of viability and some nutritional value (4); (b) operational difficulties such as manual work for filling and emptying the pits and (c) rain water damage occurring to the pit cap and its immediate environment (1, 9).

The main scientific issue of underground storage is that the mc of the grain in pits is observed to increase, by water ingress. Diminishment of moisture transfer must therefore be the main goal of modification of pit design. Abundant research has shown that the unsafe mc of sorghum grain is above 13.5% (e.g. 2, 3, 7, 13). Below this value also long term storage has been shown to preserve the grain in good condition.

To increase the period of safe storage, farmers started to experiment with innovations of shallower but wider

* and *** University of Gezira, P.O. Box 20, Wad Medani, Sudan (*Dept. of Environmental Sciences & Natural Resources; ***Dept. of Agricultural Economics).

** Department of Environmental Sciences, Wageningen University, Duivendaal 2, 6701 AP Wageningen, Netherlands (#corresponding author); ****40 Cherry Orchard, Chestfield, Whitstable, CT5 3NH, Kent, UK.

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pits (about 0.5 m deep) and lining of pits with chaff. Shallower pits have the advantage of less wall surface for entering cracks and drier bottoms if cracks are covered at the surface. Chaff should form a barrier against diffusion of water vapour from the walls and the bottom. Originally, chaff was only used as a cover on top of the grain, but now it was also applied at the bottom and sides of the pits, with the hope to keep the grain drier for a longer time (1, 6). Other linings were also tried (1).

The research reviewed wanted to quantify and this way scientifically better understand the consequences of such innovative measures and of other improvements that could be made (1 – 4). Participation of farmers was sought for use of their expertise, for improved understanding of their needs and for better dissemination and extension of the results (5, 6, 15). The research combined physics of water (vapour) contents and transports, and of the influence of temperature and its gradients, with chemistry and biology of grain with respect to quality (viability, nutritional values, toxins) and damage in storage due to moulds and insect pests (1, 13). The research is an example of increasing use of agrometeorology/-climatology for protection and improvement of agricultural production in developing countries (14, 16), where they also have a traditional base (15, 17). The latter is also exemplified by this research.

Materials and methods

Three villages with different types of soil were selected in Jebel Muoya area (3): Fangoga el Jabal (cracking clay soil), Awlad Mahala (non-cracking clay soil) and Kumur el Nair (sandy soil), hereafter referred to as villages A, B and C respectively. Data collection was done through: (i) a survey and a pilot questionnaire in the study area; (ii) contact with farmers, concerned government officials, research institutions, NGOs and local extension personnel; (iii) a main questionnaire for about 10% of the households in the three villages, to investigate how they value the underground pit storage; (iv) field experiments for investigating, through monitoring, pit mc, temperature (T) and carbon dioxide (CO_2) with regard to the influences of types of lining, depth of the pits and treatment of the surface around the pit; (v) laboratory determinations of grain quality aspects (4).

Experimental work ran for three years, from January 1993 to January 1996, on land also used by local farmers for underground storage. In the course of time small pits with different dimensions (diameter, depth) and capacity (2-4 tonnes) were investigated. They were unlined, lined with a mixture of mud/dung/straw (abandoned after two years) and lined with chaff, on which attempts by farmers for improved storage existed.

The pits were remotely monitored continuously by solar powered data loggers using well calibrated thermistors for T and by reethorpe moisture sensors for mc on vital places throughout the grain (1 – 4). Most of these were at or near the surfaces most liable to grain damage due to moisture ingress. Occasionally CO_2

Table 1

Review of pits as used in three soils (first year) and additionally (add.) in soil A (village A) for two more years. Soil A (in village A): Cracking clay (black cotton) soil, Soil B (in village B): non-cracking clays (Azaza soil), Soil C (in village C): highly sandy soil. Deepest pits were used in the first year, shallowest pits in the third year

1st year of experiments	2nd year (add.)	3rd year (add.)
Pit A, village B, Ml	Pit I, Unl, rs	Pit W, Unl, wc
Pit B, village B, Un l	Pit II, Unl, wc	Pit X, Unl
Pit C, village B, Ch	Pit III, Ch	Pit Y, Ch
Pit D, village B, Un l	Pit IV, Unl	Pit Z, Ch, wc
Pit E, village B, Ml	Pit V, Ml	Pit W1, Unl, wc
Pit F, village B, Ch	Pit VI, Ch	Pit X1, Unl
Pit G, village B, Un l	Pit VII, Ml	Pit Y1, Ch
Pit H, village B, Ml	Pit VIII, Unl	Pit Z1, Ch, wc
Pit I, village B, Ch	Pit IX, Unl, wc	[W1, X1, Y1, Z1 = ns]
Pit J, village C, Unl, ns	Pit X, Unl, rs	
Pit K, village C, Ch	Pit XI, Unl, rs	
Pit L, village C, Ml	Pit XII, Ch	
Pit M, village C, Un l	Pit XIII, Ml	
Pit N, village C, Ch, ns	Pit XIV, Unl	
Pit O, village C, Ml, ns	Pit XV, Unl, ns, wc	
Pit P, village A, Unl		
Pit Q, village A, Ml		
Pit R, village A, Ch		
Pit S, village A, Ml		
Pit T, village A, Unl		
Pit U, village A, Ch		

Ch= chaff; Ml= Mixed lining; Unl= unlined; ns= no sensors; rs= roughened surface; wc = widened surface cap concentration was measured in some of the unlined pits. Visual and other tests (mould [aflatoxin], caking, colour, smell, taste, and grain viability) were carried out by experienced farmers and/or the authors when opening pits at the end of the experiments.

The first year pits had 1.5 m diameter and 1.5 m depth, distributed in the villages as six pits in village A, nine pits in village B and six pits in village C. In the second year, fifteen new shallower pits (all in village A) were 1.6 m in diameter and 1.0 m in depth. Nine pits had the same three linings as in the first year. To improve closing off of cracks, six of the pits received surface treatments such as roughening of the surface around the pit with different methods or covering that surface with soil as extended pit cap of different widths. In the third year, eight new still shallower pits were added (all in village A), with 3.5 m diameter and 0.5 m depth, four of them with the improved surface treatments. All pits are detailed in table 1. We exemplify here with only some representative pits. Additional scientific, technical and socio-economic details may be found in papers that already appeared on this research (1 – 6).

Results and discussion

1.Grain temperatures and moisture contents

Temperatures and moisture contents in underground stored bulk grain may be understood the same way as temperatures of soil and soil moisture contents below field capacity. Both are porous media in which thermal conductivity goes mainly through contact points and water diffusion goes through the pores. Contrary to bulk stored grain in silos and warehouses, convection currents do not play a role (18). A representative example of temperature patterns, here for a 1 m deep chaff lined pit (III), is given in table 2. Position [1] was in the middle of the pit at the bottom, position [2] at the north side at half depth, position [5] was in the centre of the grain and position [8] near the top. Ts started around 30 °C and increased during the first 100 to 135 days, reaching everywhere maxima between May and July close to or over 40 °C. Highest maximum Ts were usually reached in the first year of storage for the top (earliest) and the centre. Considerable cooling in the course of the season was only obtained near the top of the grain. Such high Ts contribute to protection against insects, which can't survive such conditions (2).

Table 3 indicates that the mc took 200 days of storage (dos) or more to reach the unsafe level of 13.5% in the middle of the pit at the bottom (position [1]) in the chaff lined pits (R and U), while it took only about 50 dos to reach that value in the unlined pits (P and T). This was at the same, almost always worst behaving bottom position for first year pits in village A. The chaff apparently had a delaying effect on moisture transport. At the north side at half depth (position [2]), the difference in moisture transport rates (215 to 355 days to reach 13.5% mc for chaff linings against 35 to 160 days for unlined conditions) was also clear for those same pits.

Table 2

Temperature at different positions (pos) in pit III (village A, depth of 1 m), with chaff lining, for two years

dos/pos	1	2	5	8
07	31.2	31.0	31.1	32.2
42	34.0	34.5	35.7	37.8
72	36.4	35.6	41.4	42.2
103	37.2	38.5	41.6	41.2
115	38.4	39.6	42.7	40.8
134	38.8	39.9	42.2	41.2
171	38.1	36.9	40.9	39.7
203	37.7	36.7	40.5	37.6
237	37.4	38.0	40.0	38.0
265	37.4	37.3	39.8	37.7
302	35.8	37.5	38.3	34.1
377	36.1	38.8	39.0	38.4
421	37.3	40.3	39.5	38.9
468	37.6	39.7	39.7	38.4
508	37.1	39.4	39.4	36.8
554	36.3	39.7	40.2	37.6
607	37.0	40.9	39.8	39.5
641	37.1	40.6	39.7	38.3
673	37.5	40.1	39.9	37.2

March 2, 1994, is day of storage (dos) 07; December 23, 1994, is dos 302; December 29, 1995, is dos 673.

Table 3

Round off duration, in days of storage (dos), before the moisture content (mc) reaches 13.5% at positions (pos) [1], [2], [5] & [8] in the unlined (ul) and chaff lined (ch) pits in villages A, B and C

pit	lining	dos\pos	1	2	5	8
R	ch	358	200	215	nr	nr
U	ch	1029	240	355	820	nr
III	ch	673	115	470	nr	440
VI	ch	673	345	520	nr	540
XII	ch	320	135	nr	nr	nd
Y	ch	319	200	205	nr	nr
Z	ch	319	nr	nr	nr	nr
C(B)	ch	345	250	275	nr	nr
I(B)	ch	345	250	nr	nr	nr
F(B)	ch	1003	345	425	780	nr
K(C)	ch	1049	250	250	600	nr
P	ul	358	040	160	nr	nr
T	ul	1020	055	035	695	190
IV	ul	673	095	205	nr	nr
VIII	ul	320	060	190	nr	nr
XIV	ul	673	095	205	nr	nr
X	ul	319	080	200	nr	nr
W	ul	319	145	nr	nr	nr
D(B)	ul	345	245	275	nr	nr
G(B)	ul	345	275	nr	nr	nr
B(B)	ul	696	035	075	615	nr
M(C)	ul	705	100	115	nr	nr

nr= never reached 13.5%; nd= no data.

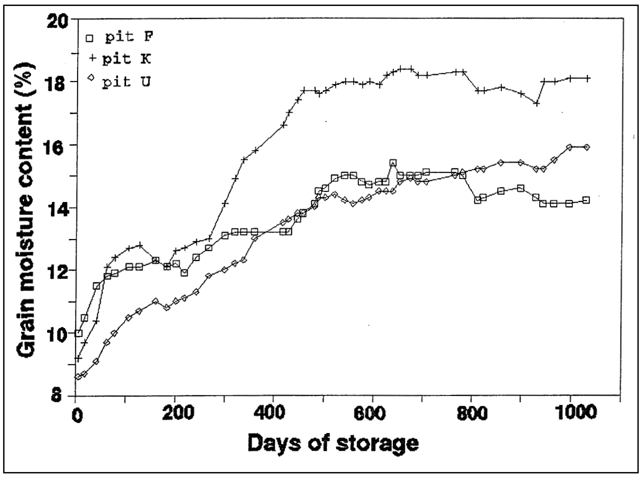

Figure 1: Moisture content (mc) at position [2], north side at half depth, in first year 1.5 m deep pits F (village B, non-cracking clay), K (village C, sandy soil), U (village A, cracking clay soil), all chaff lined and kept for more than 1000 days of storage. Pit F is superior.

Figure 1 shows a comparison for this position [2] between the chaff lined pits kept for more than 1000 dos in the three soil types compared. Pit K (sandy soil in village C) behaved poorly because of high moisture transport in these soils. The others were relatively similar, reaching 13.5% in these deep pits almost simultaneously after about 450 days, which is already much longer than the present storage times. Pit U, in the cracking clay soil of village A, ended at a somewhat higher (unsafe) moisture content than pit F in the non-cracking clay of village B. The final disparity between the last two pits occurred only in the third year of storage. This can only be due to the presence of soil cracks, that come into existence during the dry season, and that get filled with water in the rainy season. Unfortunately non-cracking clays are relatively rare and most grain must therefore be stored in cracking clays.

The already less deep second year pits of table 3 show also again the delaying effect of moisture diffusion through the chaff layers in the pits III, VI & XII

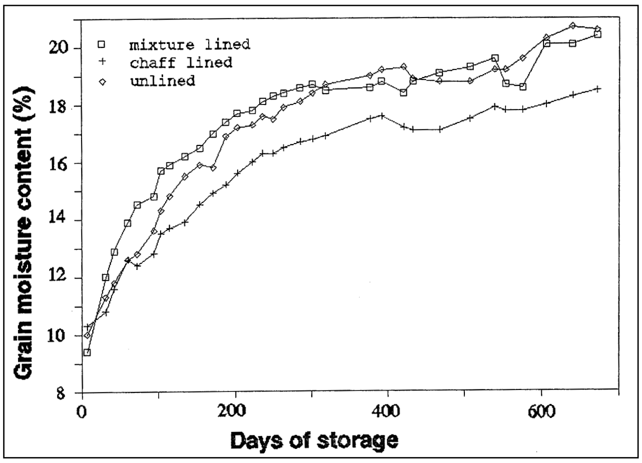

Figure 2: Moisture content (mc) at position [1], middle of the pit at the bottom, in three 1m deep differently lined pits from the second year in village A, kept for more than 600 days of storage. Unlined pit IV and mixture lined pit XIII behave worse than chaff lined pit III.

compared to the unlined pits VI, VIII & XIV at both, positions [1] and [2]. Comparing, for position [1], the three different linings of these pits kept for two years in the cracking clay soil, figure 2 shows the same. However, figure 2 also demonstrates that this delaying effect comes into being only slowly, because of the smaller amounts of chaff used in this second year. The unsafe level of 13.5% is reached much earlier than for the chaff lined pit U of figure 1 in the same cracking clay soil.

This effect is again built up faster in figure 3, in the example of shallow wide capped pit Z, where abundant chaff was applied and sorghum remained in very good quality over nearly 350 days. With respect to these third year chaff lined pits (Y, Z), unfortunately Y, that did not have a widened surface cap, suffered from a crack that opened at one side, making some water seeping into the stored sorghum. Pit Z, with an improved wide cap (50 cm high and for 1 m beyond the rim all around), was far out superior because none of the positions reached the hazardous limit of 13.5% during the first year (4). As for the unlined pits it was clear that even pit W, with improved wide cap, was superior to pit X with ordinary cap, but the chaff of pit Z made an additional very positive difference. The data for these pits in table 3 show of course the same effects for positions [1] and [2]. The wide caps indeed close off cracks that have their opening at quite some distance but still end up in the walls of the pits.

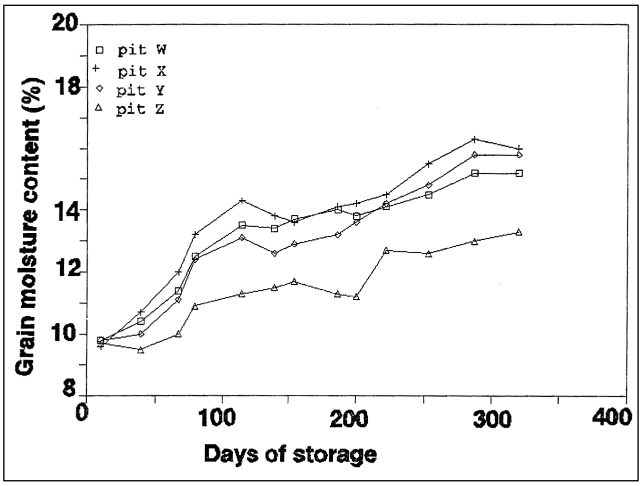

Figure 3: Moisture content (mc) at position [1], middle of the pit at the bottom, in the 0.5 m deep pits of the third year in village A: unlined, with (W) and without (X) improved wide cap, and chaff lined, with (Z) and without (Y) improved wide cap, kept for more than 300 days. Pit Z is clearly superior.

At position [5], the centre of the grain, the delaying effect of the chaff is again shown in the long term storage pits (U and T) in table 3. There were also pits without sensors, which were only analysed by observation at opening (see under 2. below). They confirmed the above results. The unique continuous monitoring of moisture contents and temperatures made it possible to show the superiority and the effectiveness of the innovative measures already designed by some farmers and of the additional improvements introduced by the research.

2. Visual observations

The visual observations, upon opening of all the pits, showed that the sorghum quality from the chaff lined pits was much better than that from the other two types of pit linings in all the villages for the different types of soils. However, the sorghum from village B (non cracking clays, which are least abundantly occurring) was better than in the other two villages (3). Mould damage was particularly noticed at the bottom and sides of the unlined and mixture lined pits. In village C (sandy soil) there was a top layer of moulded sorghum that was not good even as animal feed. Farmers exclude such soils for underground grain storage wherever possible or only use it till the next rainy season starts.

It was also found from the first and second year experiments that the top sorghum in the most abundantly found cracking clay soil was only affected by slight *Tribolium* sp and *Cryptolestes* sp insects attack. The quality of the top sorghum was better than that at the bottom and the chaff lined pits had better quality sorghum in terms of colour, smell, taste and viability, expressed as germination percentage (4). The sorghum quality from the surface treated pits was better in the case of the improved wide cap.

3. Farmers' opinions

From the questionnaire it followed that 90% of the farmers use pits as the only means of storage. Most of the farmers (85%) use pits as precaution against hunger, fire and theft. About 80% thought there is no need for lining material, mainly due to the short storage periods generally in use, 11% thought chaff is appropriate and 9% said cement might be suitable. Good preservation of the sorghum is the best property of the pit for 40% of the farmers, 36% said it is a cheap way of storage and 24% mentioned both. Another very important factor is that 84% of the farmers use no chemicals at all with pits, while 16% said they use some chemicals in powder form. About half the farmers said that in unlined shallow pits sorghum will be still good enough for emergency consumption after two years, nearly 20% think this is only one year and 30% claim a potential of three years or even longer if cracks can be avoided, so in the most suitable soil (3). All the farmers believe that insect damage ranks low in order of importance.

General conclusions from the study

Rainwater seeping through cracks and moisture diffusion through the pores were confirmed to be the most important deterioration factors in underground grain storage. The innovative attempt by farmers to delay moisture movement by lining the pit walls and bottom with chaff showed satisfactory results when monitoring temperature and mc. The use of large amounts of chaff was important. This may be understood from its function as a resistance against water vapour diffusion. The innovative use of shallow wider pits also clearly improved storage conditions. The mc of the sorghum was generally less than in the deeper pits. Also the research innovation of using high wider caps to close the catchment area of the cracks proved effective.

The longer term underground storage of grain in such improved pits is a viable system in dryland farming areas for fighting famine, maintaining food security. It also is an alternative banking systems for farmers producing beyond subsistence, particularly with the observed increasing variability in annual production and the longer sequences of dry and wet years experienced. These developments are a good example of the beneficial use of climate information in agricultural production by low income farmers assisted by contemporary science and research technology.

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Samenvatting

Traditionele ondergrondse graanoslag in kleigrond in Sudan werd met recente innovaties verbeterd

Traditionele boeren in de centrale klei vlakte van Sudan die alleen voor eigen voorziening verbouwen en kleine boeren die daarnaast ook voor lokale markten produceren willen hun gebied zo goed mogelijk zelvoorzienend houden met hun jaarlijkse sorghum produktie en ondergrondse kuilopslag van een deel van de oogst. Met de toenemende klimaatvariabiliteit komt deze voedselveiligheid echter steeds meer in gevaar. Boeren namen recentelijk proeven met innovaties om de doeltreffendheid van de opslag te verbeteren naar meer dan een seizoen. Deze innovaties werden in ons onderzoek in cijfers uitgedrukt en verdere verbeteringen werden voorkomende scheurende kleigronden in dit gebied brede ondiepe kuilen die overvloedig met kaf gevoerd worden en bovengronds een wijdere bedekking hebben, geschikt zijn voor langduriger opslag.

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A.T. Abdalla, Sudanese, M.Sc. (Environm. Sc.), Ph.D. (Agric. Sc.), Associate Professor, Department of Environmental Sciences and Natural Resources, Deputy Academic Dean, University of Gezira, Wad Medani, Sudan.

C.J. Stigter, Dutch, Drs. Exp. Phys., Dr. Agric. Sc., Visiting Professor in Africa and Asia for Wageningen University, Netherlands; Immediate Past President Commission for Agricultural Meteorology (1991-1999), World Meteorological Organization, Geneva, Switserland.

N.I. Bakheit, Sudanese, M.Sc. (Agric. Econ.), Lecturer, University of Sennar, Abu Naama, Sudan.

M.C. Gough, British, Ph.D., former Principal Research Scientist, Natural Resources Institute (UK), private consultant, Chestfield, UK.

H.A. Mohamed, Sudanese, Ph.D. (Agric. Sc.), Professor, Dean Faculty of Agriculture, University of Gezira, Wad Medani, Sudan.

A.E. Mohammed, Sudanese, Ph.D. (Environm. Sc.), Professor, Deputy Vice Chancellor, University of Gezira, Wad Medani, Sudan.

M.A. Ahmed, Sudanese, Ph.D. (Agric. Econ.), Professor and Head of Department, University of Gezira, Wad Medani, Sudan.