Temperature studies on steel silos in North Africa

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Abstract

The control of physical parameters is a useful means of evaluating the storage quality of grains and legumes. A study was undertaken to assess the performance of storage systems of cereals and legumes in North African climate situations. Bulk storage of three commodities: soft wheat, barley and fava beans in vertical and horizontal silos were investigated. The study involved a multidiscilplinary team and was lead by the Department of Agricultural Engineering, Rabat, Morocco. Four storage units made of different construction materials were investigated and included: one upright 44 t steel unit filled with soft wheat; one 45 t horizontal unit with corrugated aluminium sheet walls containing barley; one 15 t capacity clay straw, naturally ventilated and filled with soft wheat; and a reed silo containing 1.5 t of fava beans. All the units were equiped with a network of temperature and relative humidity sensors that allowed measurement at various time intervals of this data. The temperature and r.h. data were utilised to decide the periods of mechanical ventilation of the steel vertical unit and the aluminium horizontal silo. Ventilation was applied using either ambient or refrigerated air. Sampling was carried out at regular time intervals to assess changes in physical properties and rate loss in terms of storage period. The insect population was monitored using insect traps placed at specific locations in the storage units. The paper presents an analysis of the results obtained.

Introduction

Adequate grain storage is meant to preserve the initial quality and other characteristics the grain had before being stored. North African countries are developing production of grain, a staple food, with the objective of achieving self-sufficiency and reducing imports. Steel silos are being progressively and increasingly used beside other appropriate storage structures by farmers and state controlled sector in order to upgrade grain storage capacity and reduce losses. Given the generally hot climate in the region, stored grain is threatened by excess heating in steel silos, particularly in summer if appropriate aeration is not performed. Ambient air ventilation consists in applying frequent doses to prevent the start of grain heating, or to cool grain by successive steps whenever ambient air temperature is favourable. This requires continuous monitoring of temperature and relative humidity of grain and ambient air to maintain quality of stored product.

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Materials and Methods

An investigation on the behaviour of grain stored in a steel silo was carried out in Meknes, central of Morocco, known for its continental climate. The galvanised steel silo is 44 t capacity, 3.70 m high and 4.3 m in diameter with a conical roof (Fig. 1). The silo is equipped with a fan with 1.3 m^3/second airflow, 1.5 Kw power and total pressure of 55 mm of water gauge. Grain handling is carried out mechanically by an auger equipped for a 6 t/hour filling and emptying rate. The study involved storing soft wheat for one year from January 1989 to December 1990 and monitoring temperature and relative humidity in specific locations of grain and air.

A computer run network of temperature and humidity sensors hooked to data loggers enabled hourly measurements and storage of data. A total of 13 temperature sensors and 1 relative humidity sensor was placed within the grain and on the structure (Fig.2). The silo is equipped with sampling perforations placed at bottom, mid height and top that made it possible to analyse grain quality at regular intervals, 45 days or 90 days, and whenever necessary during aeration.

Investigation was conducted in an experiment station on grain storage, located in an extension station. Research funds were provided by the Moroccan Ministry of Agriculture.

Aeration of grain was performed mostly at night. Continuous monitoring of grain and air temperatures determined when grain ventilation was necessary and possible, what level of grain cooling could be reached and what is the gain with respect to insect control.

Results and Discussion

Temperature variations

Temperature variations recorded at the centre and outside of the silo over a period of 10 months are presented in Figure 3. Maximum air temperatures are shown to reach upper forties in summer. Minimum temperatures reached a few degrees below zero in winter. Grain temperature variations at the centre of the silo are reduced due to thermal inertia of grain and fluctuate between maximum and minimum air temperatures.

Grain aeration

Over 9 months of storage, 8 aeration interventions took place summarised in Table 1 and Figure 4.

Since most ventilation operations took place at night, grain and air characteristics, particularly temperature and relative humidity, tend to vary. There is a need to make several measurements of the variables and evaluate night means. Therefore, intervals between data measurements and recordings were lowered to 20 minutes during ventilation.

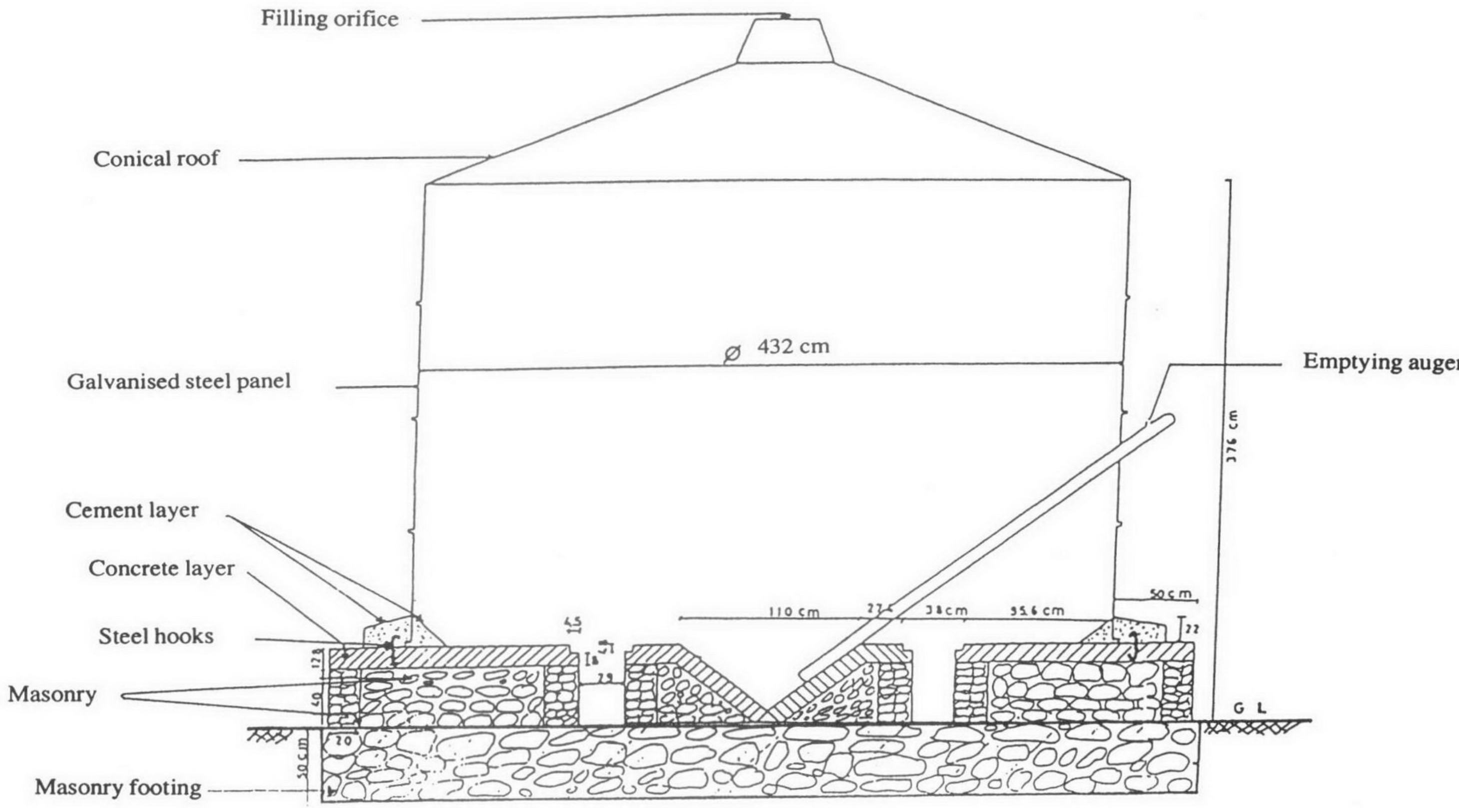

Fig. 1. Steel silo, 44 t capacity.

Table 1. Calendar of aerations and air and grain characteristics.

Ventilation doses	Start	Finish	Duration (hours)	Relative humidity (r.h.) of cooling air (%)	Equilibrium (r.h.) of grain
28/2–1/3/1990	28/2 at 10 pm	1/3 at 6.30 am	8 hours 30 minutes	81	55
14/2-18/3	14/3 at 10 pm	18/3 at 7.00am	27 hours and 30 minutes	79.6	53
22–23/3	22/3 at 12.30 am	23/3 at 6.40 am	11 hours and 30 minutes	80	56
4/4	4/4 at 2.00 am	4/4 at 4.00 am	2 hours	83	54
6–10/9	6/9 at 12.30 am	6/9 at 4.45 am	9 hours and 45 minutes	65	51
27–29/7	27/7 at 8.35 pm	29/7 at 5.00 am	12 hours	45	56
1/11	10.45 pm	6.10 am	7 hours and 25 minutes	73	51
4–9/10	4/10 at 10.40 pm	9/10 at 6.00 am	27 hours	68	52

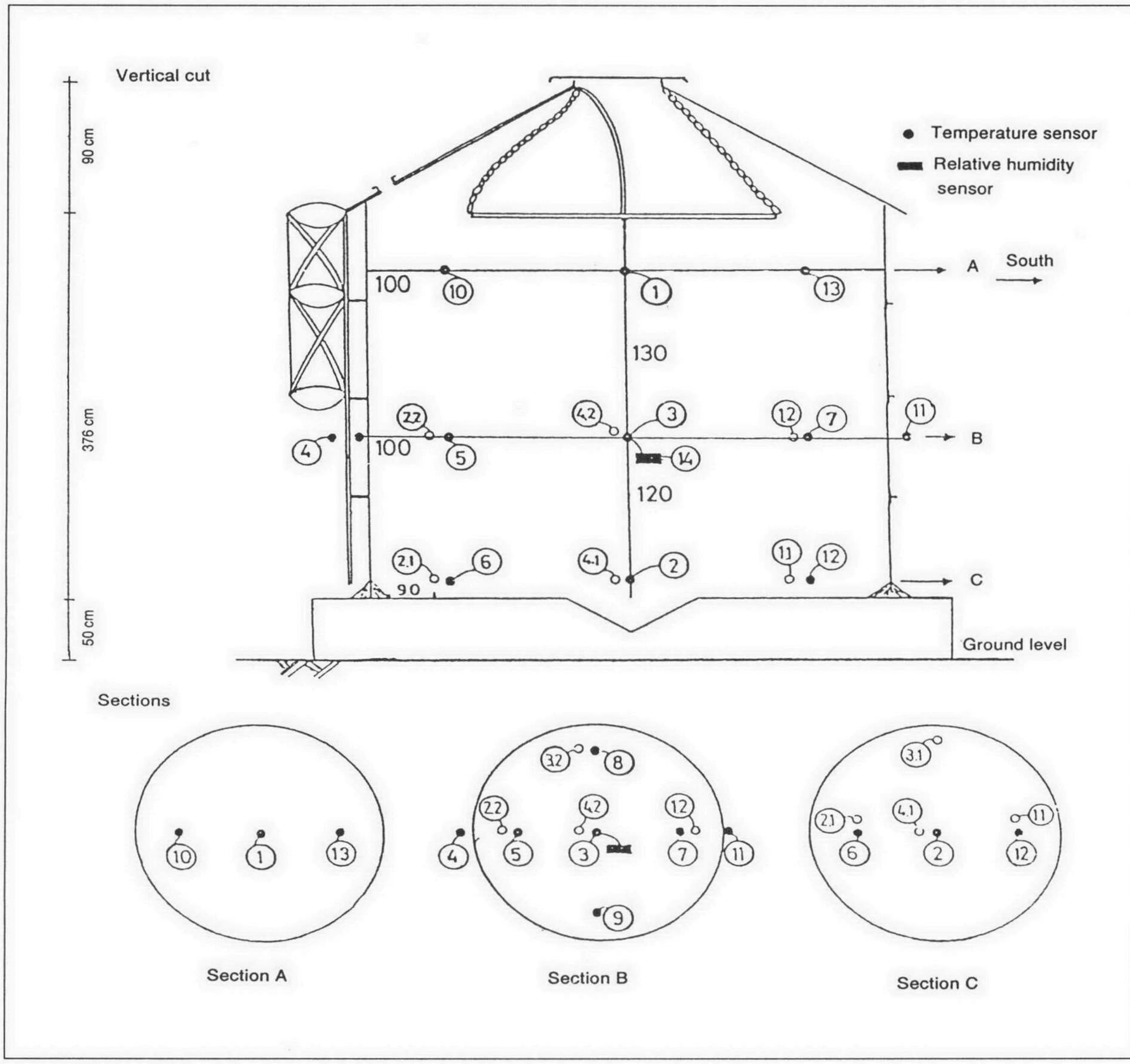

Fig. 2. Locations of temperature and relative humidity sensors in 44 t experimental silo. Measurements are in cm.

Evolution of grain temperature during ventilation

Grain is a poor heat-conducting material. Its temperature changes slowly when ventilation is not applied. However, outside air temperature can undergo rapid and large changes. The storage period outlined in Figure 4 may be divided into three parts.

In the first part, both air and grain temperatures decrease over a 2-month period starting from filling. Grain remains at a temperature close to air temperature. No ventilation was necessary given the safe conservation conditions provided by the low temperatures, as indicated by the conservation diagram.

A second part, that ends in April, is characterised by frequent ventilation interventions due to:

- increases in grain temperature reaching values beyond recommended safe storage figures of the diagram; and
- limited time where air temperature values allow grain cooling, approximately 6 hours per day.

Ventilation has made it possible to decrease grain temperature to 14°C.

A third part, from April–October, corresponds to a progressive increase in grain temperature and more rapidly than in the second part. As indicated in Figure 5, relatively high air temperatures did not allow ventilation at the beginning of this period. During this period a sharp decrease in temperature took place particularly during the eighth ventilation dose where temperature was halved. Analyses carried out by entomologists showed that during this period, development of storage insect species both in number and diversity has increased with temperature.

Detail of a ventilation dose

In order to make detailed observations on the ventilation process, Figures 5 and 6 depict the variation of temperature during ventilation time, along two vertical axes, in the centre and one near the wall of silo.

The eighth ventilation operation that took place in October was selected for this purpose. A high temperature difference between air and grain was noticed –14°C. This temperature difference that happened after a sharp decrease in air temperature in October, could create condensation problems. Such problems were avoided by conducting ventilation over longer periods of time.

At each ventilation, blown air cools the lower layers of grain at the bottom of the silo (sensors #6 and #2) (Figs 5 and 6). A wave of cooling air develops and progresses slowly along air

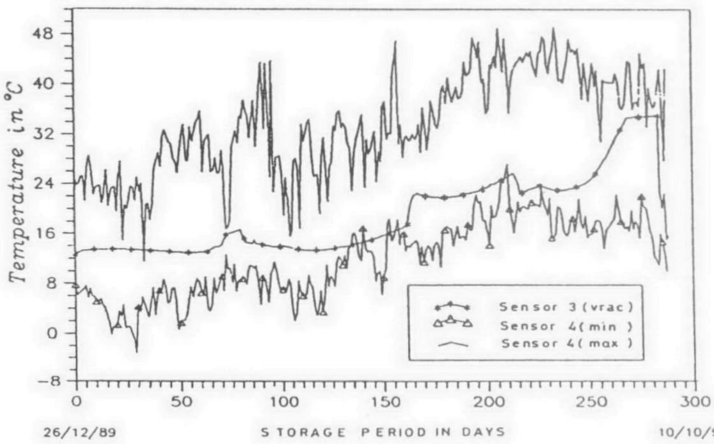

Fig. 3. Maximum and minimum temperatures at the centre of the bulk. See Figure 2 for locations of sensors.

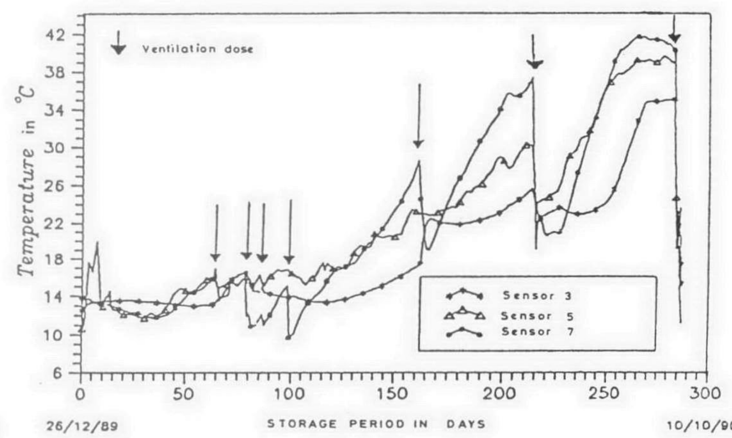

Fig. 4. Effect of ventilation on temperature. See Figure 2 for locations of sensors.

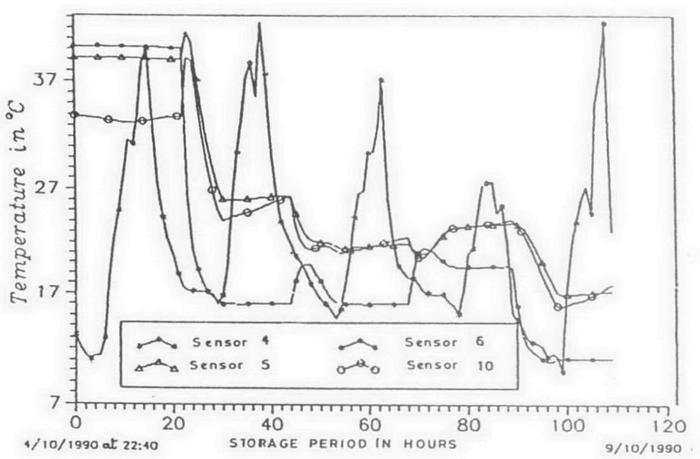

Fig. 5. Sidewall temperature and ventilation doses. See Figure 2 for locations of sensors.

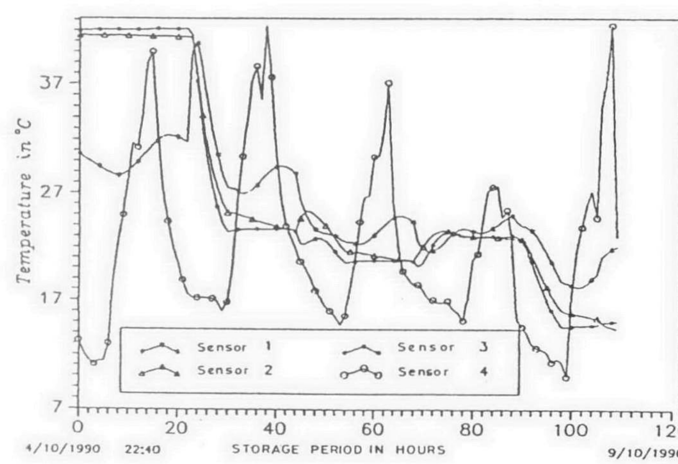

Fig. 6. Central axis temperatures. See Figure 2 for locations of sensors.

stream. All grain layers are then successively cooled from the bottom to the top of the silo, as shown in Figure 6. Lower layers of grain where sensor #6 is placed cools first, followed by middle height layer with sensor #5 and last the upper layer monitored by sensor #10. This upper layer is influenced by changes in ambient air temperature.

Temperatures recorded by sensor #6, located near ventilation conduit, approaches cooling air temperature, after each ventilation whereas temperatures of upper layers often remain higher than external air temperature.

Effect of relative humidity of cooling air

For a given relative humidity of interstitial air within grain mass and a given temperature, there exists an equilibrium moisture content of grain, outside ventilation period.

Table 1 shows relative humidities of cooling air and grain for each ventilation. Relative humidity of cooling air is measured by a psychromèter and of the grain by a relative humidity sensor placed at the centre of grain silo.

Values of the ratio of relative humidity of grain to relative humidity of air are lower than 1, indicating that an under-cooling of grain takes place.

Conclusions

This study conducted on temperature distribution in aerated steel grain bins leads to the conclusion that in hot temperate climates such as the one in continental Morocco, grain aeration is justified and recommended. Although grain moisture content at harvest period is in the range 10–12 %, the grain mass needs be cooled in order to be safely stored. Such cooling by aeration is possible since climatic conditions in this area indicate that 6 hours per day are favourable to carry out ventilation of grain.

The following pattern could be followed for ventialtion of grain stored in a steel bin in the area:

- First cooling of grain whose initial temperature at harvest time is high and ranges from 30–40°C will allow a reduction in grain temperature down to 22°C in July–August.
- Second cooling carried out in October–November will decrease grain temperature to 14°C.
- Third cooling undertaken in December–January will make it possible to reduce grain temperature to approximately 10°C. High thermal inertia of grain will maintain this temperature in spring.

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