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A Comparison of Jute and Woven Polypropylene Sacks for Large Scale Maize Storage

L Kennedy and A D Devereau

Natural Resources Institute, Central Avenue, Chatham Maritime, Kent, United Kingdom, ME4 5NJ

1. Introduction

1.1. Scope.

This paper will present the results of recent and on-going research at the United Kingdom's Natural Resources Institute (NRI) undertaken to compare the performance of jute and woven polypropylene sacks for medium- to long-term storage of cereal grains in Sub-Saharan Africa. A large scale field trial will be described, followed by laboratory work aimed at investigating the results from the field trial. Differences in stacking properties, re-use of sacks and some other considerations will also be described.

1.2. Jute and polypropylene sacks.

Heavy duty shipping sacks made of woven jute are widely used for the storage and transport of agricultural commodities because they are cheap, tough, flexible, have high tensile strength and have good handling and stacking properties (Coveney, 1969). Sacks with a capacity of 60 to 90 kg are typically used and have become the conventional sack around which codes of practice are written. Other natural fibres, e.g. sisal, may also be used for sacks, but the amounts involved are small in comparison.

In the Sub-Saharan Africa (SSA) sub-region, the packaging industry was at one time geared towards locally produced or imported natural fibres, however, production of fibres failed and led to the import of raw fibre or bags from other countries. Producers were also forced to use synthetic fibres produced locally from imported raw materials, with the consequence that natural fibres received diminishing emphasis, e.g. Zambia in 1988, 10 million natural fibre sacks were made compared to 60 million synthetic sacks (FAO, 1992).

Woven polypropylene sack manufacture was developed in Japan in the late 1960's and was quickly taken up in Europe, South Africa, Australia and North America (Paine, 1991). High density polypropylene film is extruded and slit into narrow tapes which are heated, highly stretched and woven into usually plain weave sacks. Sacks produced in this way are lighter than jute but stronger weight-

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for-weight.

Synthetic woven sacks have thus become widespread for the transport and storage of commodities in the developing world at the expense of natural fibres. Little work appears to have been done to investigate the effects of the new sacks on the quality of the stored commodities, but there were seemingly no adverse effects.

1.3 Stackburn.

In recent years, however, the number of cases of stackburn, where bagged maize becomes discoloured during storage in stacks, increased sharply in the SSA region. This was first seen in Zimbabwe, where large quantities of white maize, up to 1.2 million tonnes, are stored outside in tarpaulin covered bagstacks of up to 5000 tonnes each. After the 1990 storage season maize in certain stacks was found to be discoloured by a light tan through to a dark red-brown colour. The discolouration was accompanied by a loss in nutritional value, the maize was consequently downgraded to a lower quality with a loss in monetary value. Jute sacks had recently been replaced by woven polypropylene sacks. Stackburn has also been seen in Ghana and Malawi.

NRI became involved in investigating the causes of the problem (Locke and Phillips, 1992). The discolouration was identified as heat induced non-enzymic browning known as the Malliard reaction. Early investigation of storage in polypropylene bagstacks in Zimbabwe showed that a heating cycle occurred in the interior of the stacks during storage which raised the temperature to approximately 40^{o}C but no higher.

Heating within stored grain can occur for two reasons: a. if the grain is too moist, i.e. its moisture content is too high, mould will grow and cause heating due to its chemical processes, in the same way that compost heats during decomposition; b. if large numbers of insects which infest stored products develop they respire and cause heating. In both cases the grain acts as an effective insulator, keeping the heat within the stack. There were no signs of excessive moisture in the stacks investigated and no signs of mould when they were dismantled; insect counts however showed 300 or more insects per kilogram of maize in some cases. This suggested that insect heating was to blame, but it was not clear why it should have become a particular problem in recent years and whether it was a result of the change to polypropylene sacks. A detailed investigation was therefore undertaken to compare the conditions within identical stacks of polypropylene and jute sacks.

2. Field trial: polypropylene and jute comparison

2.1 Objectives and methods.

The objective of the trial was to compare temperature, moisture and insect development in identical stacks of jute and polypropylene sacks during storage. It was undertaken approximately 40 km north of Harare, Zimbabwe over a nine month period starting in August 1991. Two 1500 tonne stacks of white maize were built on adjacent earth plinths; one stack was built of 50 kg woven polypropylene sacks, the other was built of 90 kg jute sacks. The stacks were approximately 16 m long, 14 m wide and 5.75 m high to eaves. Fumigation to control insect infestations was applied according to standard practice on days 13 (polypropylene only, the jute stack was not complete), 84,170 and 246, by covering the stacks with airtight sheets and applying methyl bromide gas for two days. The day 170 fumigations were part of a training exercise led by NRI aimed at improving fumigation practice.

60 temperature sensors, 13 moisture content sensors and 9 microphones were installed in each stack at identical positions. The microphones were used to detect insect activity by the noises that they produce; this is a system that has been developed at NRI in a previous trial. Most sensors were placed in the interior of the stacks in horizontal planes at 2m, 5m and 8m from the base, with a few placed on the outside faces and on the bottom layer. Maize samples taken from each stack at the start and finish of the trial were analysed accurately for moisture content in the UK by a standard method (ISO 712-1979). They are also to be analysed for colour change but this is not yet complete.

2.2 Results and discussion.

Looking at temperature first, average monthly maximum and minimum ambient temperatures for the trial period from the nearest meteorological station show little deviation from previous years. The mean monthly temperature started at 12°C in August, rose to 22°C by January, then fell to 16°C by the end of the trial.

On the faces of the stacks and at the bases there were few differences between the two stacks; temperatures were higher than the average ambient and tended to rise. In the interior of the stack the temperature trends were largely consistent for each plane, so we can concentrate on two planes from each stack, planes B and F, as representative of the whole.

The lower sensors in the jute stack heated from day 0 until the day 84 fumigation, then cooled sharply for a period of 30 to 60 days. Heating then resumed. In plane B the temperature rose to approximately 40°C by day 130 and stayed roughly level until the fumigation on day 170, after which it fell. In plane F, cooling was greater after the day 84 fumigation and the subsequent heating slower; temperatures therefore did not reach 40°C before the day 170 fumigation, after which they fell. The mid height sensors in the jute stack showed much slower heating from day 0 and did not react to the day 84 fumigation. The temperature reached 40°C just after day 120, stayed roughly constant until the day 170 fumigation, then fell. At the top of the stack the temperature stayed roughly constant throughout the trial until day 160 when it rose sharply to 40°C.

The lower sensors in the polypropylene stack showed little reaction to any fumigation; in plane B they heated to 40°C by day 100 and stayed there until the end of the trial, in plane F two positions did not heat as fast and approached 40°C only by the end of the trial, while the third behaved at those in plane B. All positions showed a slight fall in temperature after the day 170 fumigation. At mid-height the profiles were similar to the lower ones, the temperature rose quite rapidly to 40°C before day 100 and stayed steady until the end of the trial. In many positions there was a small reaction to the day 84 fumigation but there was no reaction to the day 170 fumigation. At the top of the stack the temperature rose slightly but there was no dramatic rise as in the jute.

The points to note then from the results are:

a. there was heating for most of the time at all positions, especially the lower and mid-height ones, which caused the temperature to rise well above ambient;

b. there was some variation in the rate of heating between positions but there was a general consistency between position on the same levels;

c. at all positions, if the temperature reached 40°C it stopped rising;

d. lower jute positions reacted to fumigations on day 84 and 170 by cooling significantly, mid-height positions reacted only to the day 170 fumigation;

e. polypropylene positions showed only a slight cooling reaction after fumigation, far less significant than that in the jute stack;

f. at mid-height the polypropylene positions heated more rapidly than the jute so were hotter for longer;

g. at the lower positions, heating was similar in the jute and polypropylene stacks until fumigation caused the jute to cool for a period leaving the polypropylene hotter, though some polypropylene positions heated more slowly and so were cooler than jute for most of the period.

The first question to answer is why there was a temperature rise throughout each stack. As discussed previously, grain heating occurs either through over-moist grain becoming mouldy, or through insect infestation. As in previous trials, the samples analysed for moisture content and the moisture sensors in the stacks showed that the grain was mostly between 12% and 13% moisture content (wet basis), too dry to become mouldy, so insect infestation must have been to blame. The temperature limit of 40^{o}C also points to insects as this is the temperature limit of the species present; at this temperature they will migrate to cooler areas or the population will decline. Finally, the cooling reaction to fumigations seen especially in the jute stack also points to insect heating.

The significant cooling seen after fumigation in the lower layers of the jute stack suggests that, either the fumigation only controlled insects significantly in this portion of the jute stack, or that insects were controlled effectively in both stacks but the different sack materials reacted differently to the loss of heating, i.e. the polypropylene stack retained heat while the jute cooled. It could be the case that both of these are partially true: there could be differences in the distribution of fumigant gas between the two stacks and also within each stack, i.e. it may be more concentrated at the bottom, and there could also be differences in the way that heat is retained in the different stacks. It is certainly true that, even when there was significant cooling after a fumigation, it was relatively short lived; heating generally resumed after one month. The greater reaction to fumigation on day 170 in the jute stack mid layer could be due to a more rigourous fumigation applied as part of the NRI training programme.

The results from the microphone sensors show that insects were present in each stack during the trial. Immediately after each fumigation the number of positions giving positive insect detections fell sharply but there were always one or two positions in each stack which still showed detections, showing that the fumigations were not 100% successful. In the weeks after the fumigations, more widespread infestations were detected, suggesting that the insects were becoming re-established. There were no pronounced differences between either stack, though the polypropylene stack showed slightly more detections than the jute towards the end of the trial. The insect species present were most likely *Sitophilus* spp. and *Tribolium* spp., these insect were seen on the outside of sacks during building.

The microphone evidence supports the conclusions that insects were to blame for heating and that fumigations were failing. The slightly higher incidence of insect detections in the polypropylene stack supports the idea that fumigation was less effective in this stack, though the microphone technique is still under development and few were used in this trial so these results cannot be taken as conclusive proof.

The polypropylene stack was seen to be on the whole hotter than the jute stack during storage. The reason for this was different in different portions of the stack; at the lower layer the reaction to fumigation caused the jute to be cooler for periods, while at the mid layer the jute simply heated more slowly. This again suggests that the two sack materials cause a difference in the way the stacks are fumigated and in the way they respond to heating and cooling. The reasons for the sudden rise in temperature at the top layer of the jute stack and the slow cooling rate at some positions at the lower level of the polypropylene stack are not clear.

Finally, it has been suggested from anecdotal evidence that the polypropylene sacks present a more effective barrier to insect movement than jute. It is not clear what the full implications of this would be on fumigation and insect heating if it was true, though it could mean that insects can move away from hot areas more easily in the jute stack thus reducing the heating effect more quickly.

2.3 Conclusions

a. heating occurred in each stack and could only be attributed to insect heating;

b. the two stacks heated at different rates at the middle layer;

c. there was marked cooling following fumigation in the jute stack, especially in the lower layer

d. the two sacks types had therefore given rise to different temperatures and different responses to fumigation;

e. fumigation was only partially successful in each stack;

f. the polypropylene stack was on the whole hotter than the jute stack.

In order to investigate the effect of the sack type on fumigation and heating we followed the field trial with laboratory experiments, which are still in progress, to investigate the permeability of the sack materials to air flow and the response to temperature changes of stacks built of different sack types. The flow of air through the sacks is important as it will affect the heating and cooling of sacks by convective air currents and may indicate differences in the movement of fumigant gases through the sacks.

3. Laboratory work

3.1 Properties of polypropylene and jute sacks.

Polypropylene and jute sacks have been compared for their storage performance before. Odamtten and Kampelmacher (1986) compared the sorption and desorption of moisture by commodities in the two types of sack and found those in jute absorbed and desorbed moisture to a greater extent than polypropylene. Grains in polypropylene also had lower mould and yeast counts. They concluded that woven polypropylene offers better moisture and mould protection than jute and should therefore be used for storage of grain in tropical areas.

Guritno, Haque and Chung (1991) also compared the two fabrics, this time they placed stacks of bags in high humidities for 90 days and found that grain in the jute sacks absorbed moisture more readily than that in the polypropylene.

These pieces of work tested moisture vapour transfer through the sack materials and found them to be different. As no moisture problems were found in the field trial, while air permeability is of great importance as mentioned above, we designed an experiment to compare the air permeability of the two sack materials under simulated stack conditions.

3.2 Permeability of sack fabrics

Transmission of air and water vapour through sack fabric is measured conventionally using a single sheet of fabric. In the water vapour permeability test the polypropylene sack fabric was less permeable than jute, agreeing with the work cited previously. In the air permeability test the polypropylene fabric was comparable to jute.

Testing single, isolated sheets of fabric does not reproduce the conditions experienced in a stack, where two layers of fabric are pressed together by grain under pressures of up to 4 tonnes/m^2. A test simulating these conditions was devised for air permeability (New, 1992). The results showed that the air permeability of the polypropylene fabric was reduced by as much as 70 to 80% as the load on it increased, while the jute remained relatively unchanged.

The difference in air permeability under load and the difference in water vapour permeability for a single layer were the only significant differences found between the two fabrics in these tests; they indicate that, under pressure, the polypropylene sacks offer a more effective barrier to water and air movement than jute.

3.3 Heating and cooling behaviour of sacks

We devised a series of trials that are still in progress using approximately 10 tonne stacks of maize in a large controlled environment chamber at NRI (Da Maia, 1992). The object is to compare the way in which stacks of the different sacks heat and cool.

In the first series of trials, sacks of maize have been conditioned to 40°C then built into stacks to give uniformly hot stacks. The ambient temperature has then been reduced to 15°C and temperature sensors throughout the stacks used to monitor the change in internal temperature. This has been done to date with loose-filled jute sacks, tight-filled jute sacks and loose-filled polypropylene sacks. Tight-filled sacks tend to leave gaps between each other when stacked which allow convective air currents to flow up through the stack, while loose-filled sacks tend to mould together and reduce air flow. The results so far indicate that tight-filled jute cooled faster than loose filled jute, and loose-filled polypropylene is cooling slower than loose filled jute, though this latter trial is still in progress so the results are as yet incomplete.

3.4 Conclusions

a. single layers of polypropylene fabric have similar permeability to air as jute but lower permeability to water vapour;

b. under simulated stack conditions, i.e. with two layers of sack fabric held together under grain pressure, the air permeability of polypropylene fell by 70 to 80% as pressure increased while jute was relatively unaffected. The polypropylene thus became less porous than the jute;

c. stacks of jute sacks appear to cool more quickly than stacks of polypropylene sacks under controlled conditions.

4. Other considerations

There are a number of documented differences between jute and polypropylene sacks which should be considered when comparing their performance.

The ability of the sacks to be built into stable stacks is at first sight different; jute sacks have rough fibrous surfaces which interlock with other sacks to give stability, whereas polypropylene sacks have a flat, shiny surface which will not interlock in this way. The contact of polypropylene sacks under pressure, however, causes adhesion effects which increase the stack stability, so there is in fact little difference between the two types of sack (Coveney, 1969).

Jute sacks are made of an organic material and will therefore rot if they become wet; this can lead to the failure of sacks. They are also somewhat sensitive to the ultra-violet (UV) part of sunlight, which causes exposed fibres to become brittle if they are exposed to bright sunlight for prolonged periods. Polypropylene sacks do not absorb water and will not rot, but they are sensitive to UV rays and can totally fail in strong sunlight if they are not sufficiently stabilised by chemical additives. Other forms of sack failure, by tearing, bursting. etc., are common to both sack types and there are few differences in performance.

Jute sacks are commonly either recycled for grain storage after being emptied or enter the social chain where they are used for a wide variety of uses, including clothing, matting, blankets, etc. Re-use is possible because the closing stitches on jute sacks do not cause damage when they are removed, and sacks can be easily joined and repaired. Polypropylene sacks however are seldom re-used for grain storage because damage to the sacks, often caused by opening, is difficult to repair. There are few other second-hand uses of polypropylene sacks outside grain storage.

The texture of jute makes it easy for insect pests to hide and be retained in sacks to infest future commodities, so it is important that used sacks are disinfested. Both sack types can be treated with insecticides which control insects in the fabric for a reasonable length of time.

Polypropylene sacks do not impart taint or odour to their contents and do not leave hair-like fibres as jute sacks can, however, polypropylene sacks are not suitable for cotton lint.

5. Overall summary and conclusions

In summary, the occurrence of stackburn, or grain discolouration during bagged storage, has increased in the SSA region at a time when polypropylene sacks have been increasing used for grain storage in place of jute. Investigations showed that high temperatures were developing in grain bagstacks.

A field trial was undertaken in which the temperature, moisture content and occurrence of insect infestations were compared in stacks of jute and polypropylene sacks. Heating was found which was attributed to insect infestation, the heating was greater in some areas of the polypropylene stack and fumigation to kill insects only caused temporary cooling in the jute stack. Subsequent laboratory work showed that, under stack conditions, air permeability was lower in the polypropylene stack than in the jute stack. In a separate experiment it appears that stacks of jute sacks cool faster than stacks of polypropylene sacks.

Other considerations between the two types of sack show that jute will rot when wet but polypropylene is more susceptible to UV degradation, and more importantly polypropylene sacks are generally used once while jute can be repaired and can be recycled or used for a wide variety of other uses after storage.

In conclusion, although woven polypropylene stacks have been introduced into the storage systems of many tropical countries as an alternative to jute sack , the implications, particularly in respect to the physical conditions during storage, have not been fully understood. Stackburn, although not caused by using polypropylene sacks, is certainly aggravated by them; this paper has demonstrated some of the research being carried out at NRI to discover the exact causes of the problem.

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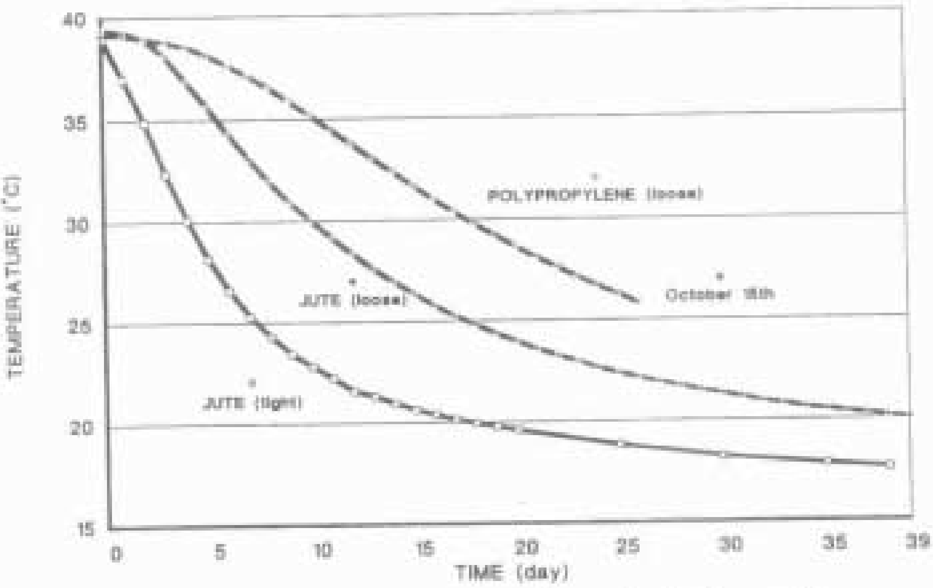
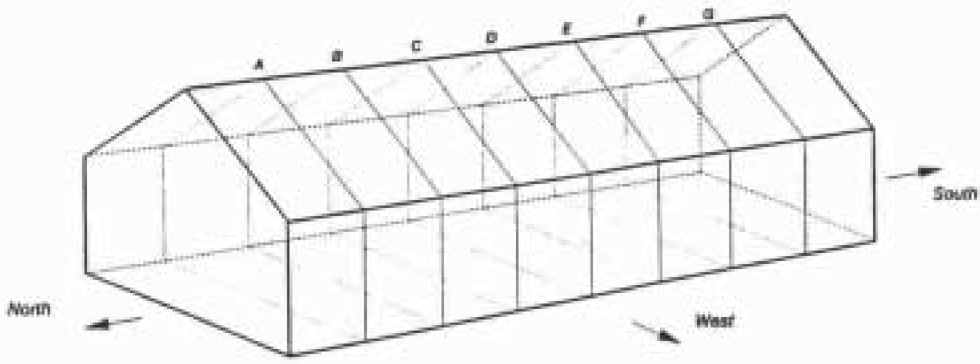
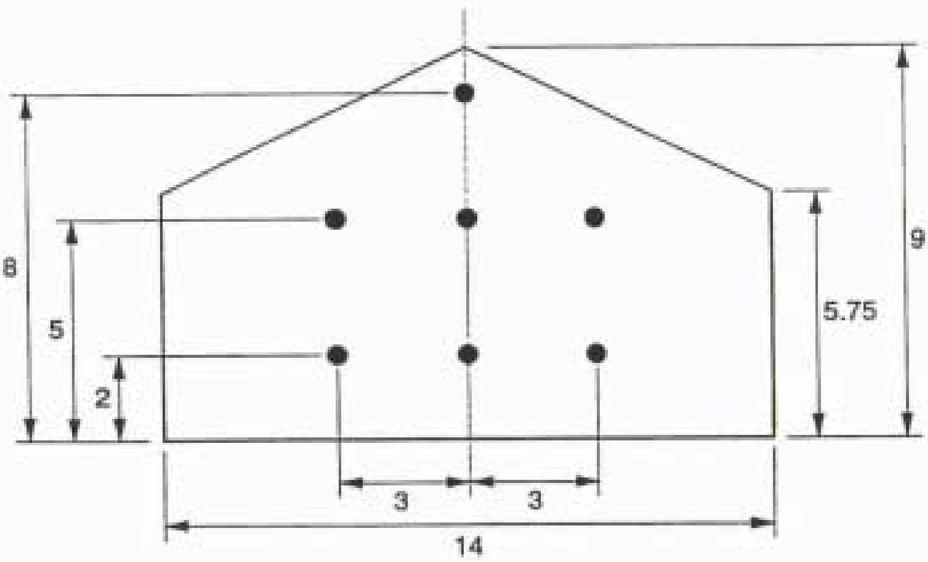


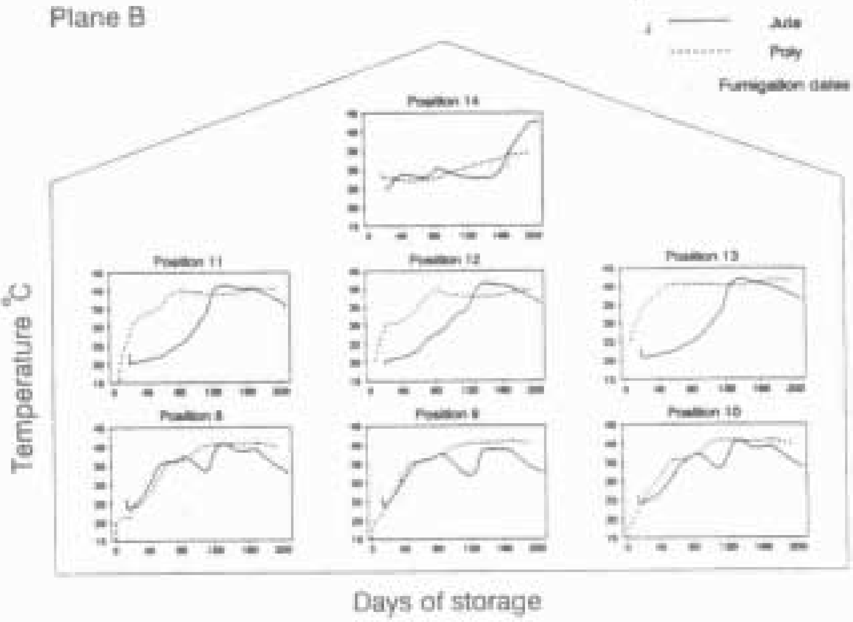
Comparison of cooling of jute and polypropylene sacks. (centre of stack)





● = SENSOR POSITION

Dimensions in metres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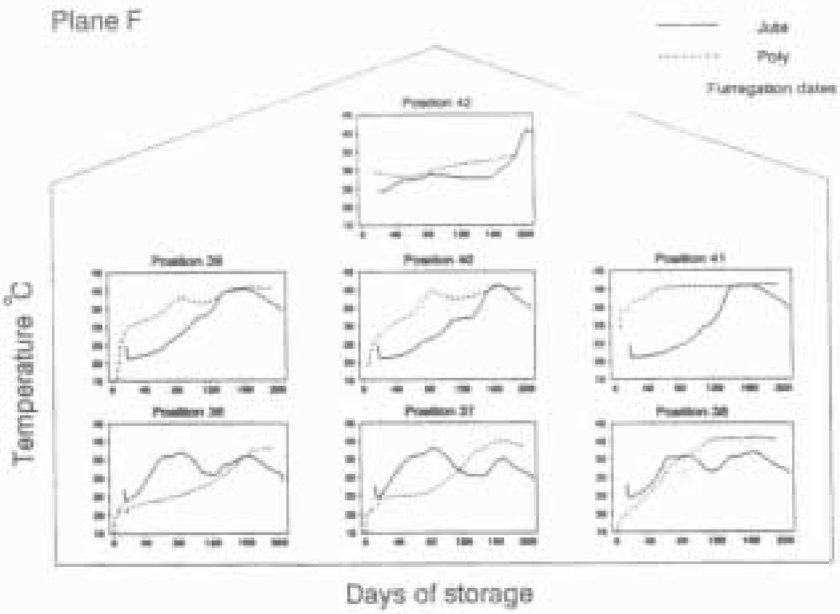
Jute
Poly
Fumigation dates
Position 14
Position 11
Position 12
Position 13
Position 8
Position 9
Position 10
Temperature °C
Days of storage


Plane F
Jute
Poly
Fumigation dates
Position 42
Position 41
Position 37
Temperature °C
Days of storage