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Investigations into the causes and prevention of heating and discoloration ('Stackburn') in bag stored maize

Report No. 1: Quality changes in an outdoor stack of bagged maize

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ACKNOWLEDGMENTS

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SUMMARY

In collaboration with the Grain Marketing Board, Zimbabwe, a study was made of physical and quality changes in maize during food security storage and their economic significance to the Board. Fumigated white dent maize in woven polypropylene sacks was sampled as it was built into a stack in a moist subtropical climatic zone. Grain temperatures and moisture contents at selected points were monitored for two and a half years and were related to stack management procedures and climatic changes. At the end of the study the stack was systematically broken down and resampled to enable changes in quality to be determined.

Changes in quality parameters were related to patterns of temperature and moisture content within the stack. Much of the grain in the core of the stack became discoloured. The proportion of the more valuable composite A plus B grade dropped from 99% to 53% (Clarke and Orchard, 1993). C grade rose from 1% to 6% and D grade rose from 0% to 30%, whilst 10% became unmarketable due to fungal development.

Germination percentage, a general indicator of grain quality, fell from a mean of 70% to 4%.

Aflatoxin contamination did not rise during storage. Samples tested at the beginning and end of the trial did not exceed 20 parts per billion.

The financial loss, primarily due to downgrading, calculated at 1992 prices was Zimbabwe $213,000 or 13% of the stack value.

Stackburn of maize within the core of a stack was a new problem for the Grain Marketing Board. It has occurred in several stacks since the introduction of woven

polypropylene sacks causing significant downgrading of grain estimated to have cost the Board about Zimbabwe $3 million.

It is concluded that stackburn may arise as a consequence of the interactions of insect and fungal development related to temperature and moisture content. The woven polypropylene sacks may form an environment in which stackburn is potentiated.

Recommendations are made for further studies to identify the causes of stackburn, more certainly, and methods of prevention.

BACKGROUND

1. The Grain Marketing Board (GMB) stores maize in silos and warehouses and, when necessary, in large outdoor stacks. This provides a flexible system of storage management which is required because production fluctuates markedly from year to year. Outdoor stacks of up to 5,000 tonnes are built on plinths and/or dunnage protected with plastic sheets and canvas tarpaulins. A system of management has been developed for maize in jute sacks and this has been used satisfactorily for maintaining maize quality.

2. In 1988 the Board introduced woven polypropylene sacks in place of jute sacks for economic reasons. Subsequently, maize from the interior of some polypropylene stacks was found to be discoloured and had to be downgraded, with a consequent financial loss.

AIM AND OBJECTIVES OF THE STUDY

3. The study was part of the Overseas Development Administration (ODA) natural resources research programme. The aim was to record losses during large-scale storage and evaluate how the losses were measured and accounted for by an experienced organization.

4. The specific objectives of the outdoor stack study were:

(a) to measure changes in maize quality during storage in a moist subtropical climate;

(b) to determine how physical loss of quality can be interpreted as loss within the GMB accounting system;

(c) to measure and record changes in important physical parameters (temperature and moisture content within the stack and temperature and relative humidity outside the stack) in order to recognise any correlation with quality changes.

5. The trial lasted for two and a half years in order to replicate seasonal, climatic effects.

SAMPLING AND MANAGEMENT OF THE TRIAL STACK

Construction, sampling and sample analysis

6. An experimental 1,564 tonne stack (number 16 at Marondera depot) was constructed in 1989 to the standard GMB pattern using 90kg polypropylene sacks of home-grown fresh maize transferred from another stack. The maize was a mixture of white dent hybrid varieties fumigated with methyl bromide to control insects immediately before the transfer. The stack was rectangular in shape with a sloped roofline to shed rain; the dimensions are shown in Figure 1.

7. As the sacks were transferred three spear samples were taken from each sack to accumulate a sample of approximately 20kg per 20 tonnes. This intensive rate of sampling was chosen to provide a sample sufficiently representative for analysis for aflatoxins as well as other qualities. Each sample was sub-divided by coning and quartering to provide sub-samples for:

(a) grading by GMB according to Zimbabwe standards (these test a range of qualities which are integrated to define a grade but which can be examined separately);

(b) germination percentage (viability) by the Government Seed Testing Laboratory, Harare;

(c) analysis for aflatoxins B1, B2, G1 and G2 by NRI;

(d) determination of moisture contents using the oven method ISO 6540 by NRI;

8. During construction, temperature sensors (thermistors) and Reethorpe moisture content sensors were

buried inside sacks (Gough, 1980) at preset positions within the stack and were connected by cables to an external recording station (Appendix 1). Temperature and Reethorpe readings from some positions were monitored manually by GMB research staff every two weeks and other positions were monitored automatically using Grant Squirrel data loggers (Appendix 2).

9. Samples of maize were taken from beside the sensors to establish an accurate baseline for possible future changes in recorded moisture content. The samples were preserved in airtight tins and the moisture content was measured accurately using the International Standard ISO 6540 oven drying method.

10. Climatic records were collected from the Zimbabwe Meteorological Department which operates an automatic recording station four kilometres away.

Management during the trial period

11. During the course of the trial the stack was subject to normal GMB management practices. These included regular aeration by pulling back the covering sheets during fine weather and fumigation with methyl bromide coupled with external spraying of the stack surfaces.

12. However, after an initial cycle of rapid temperature rise followed by cooling (Figure 2), when a second cycle started, an attempt was made to forcibly ventilate the stack using extraction fans. This novel procedure appeared to work well as a rapid decline in temperature was recorded (Figure 3).

Figure 1. Marondera Stack 16; thermistor and Reethorpe sensor positions.

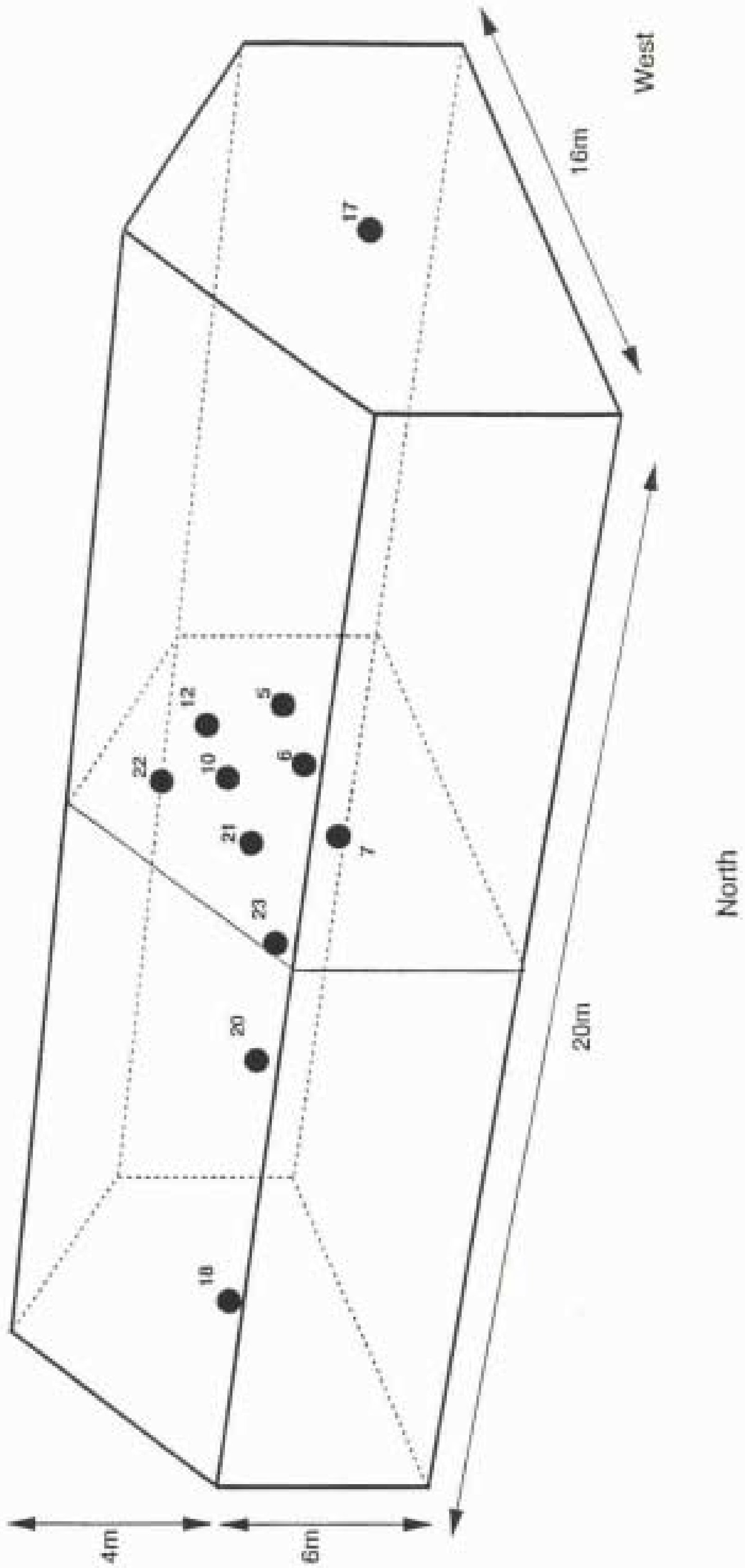


Figure 2. Temperature profiles (20 October 1989 - 31 May 1991).

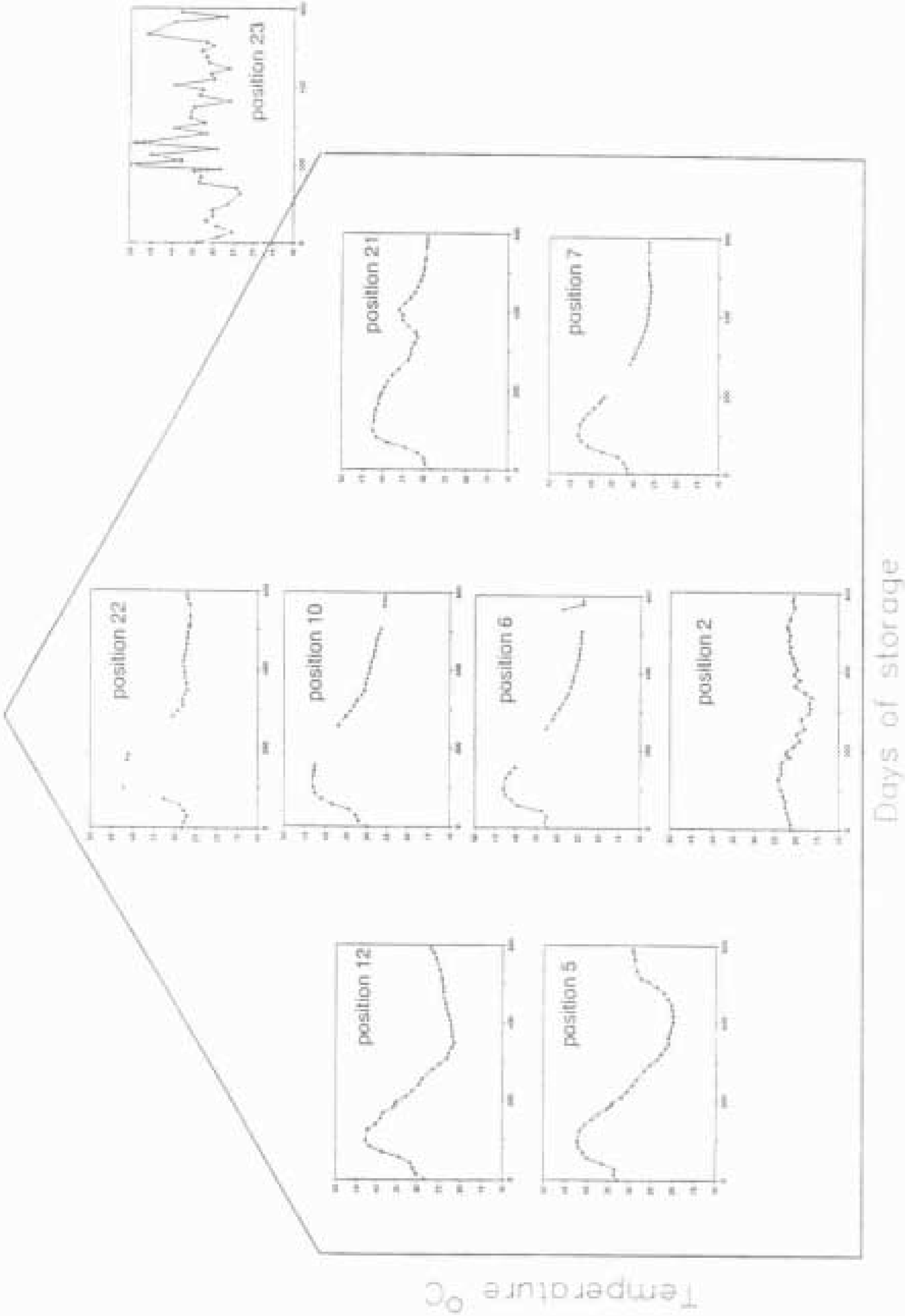
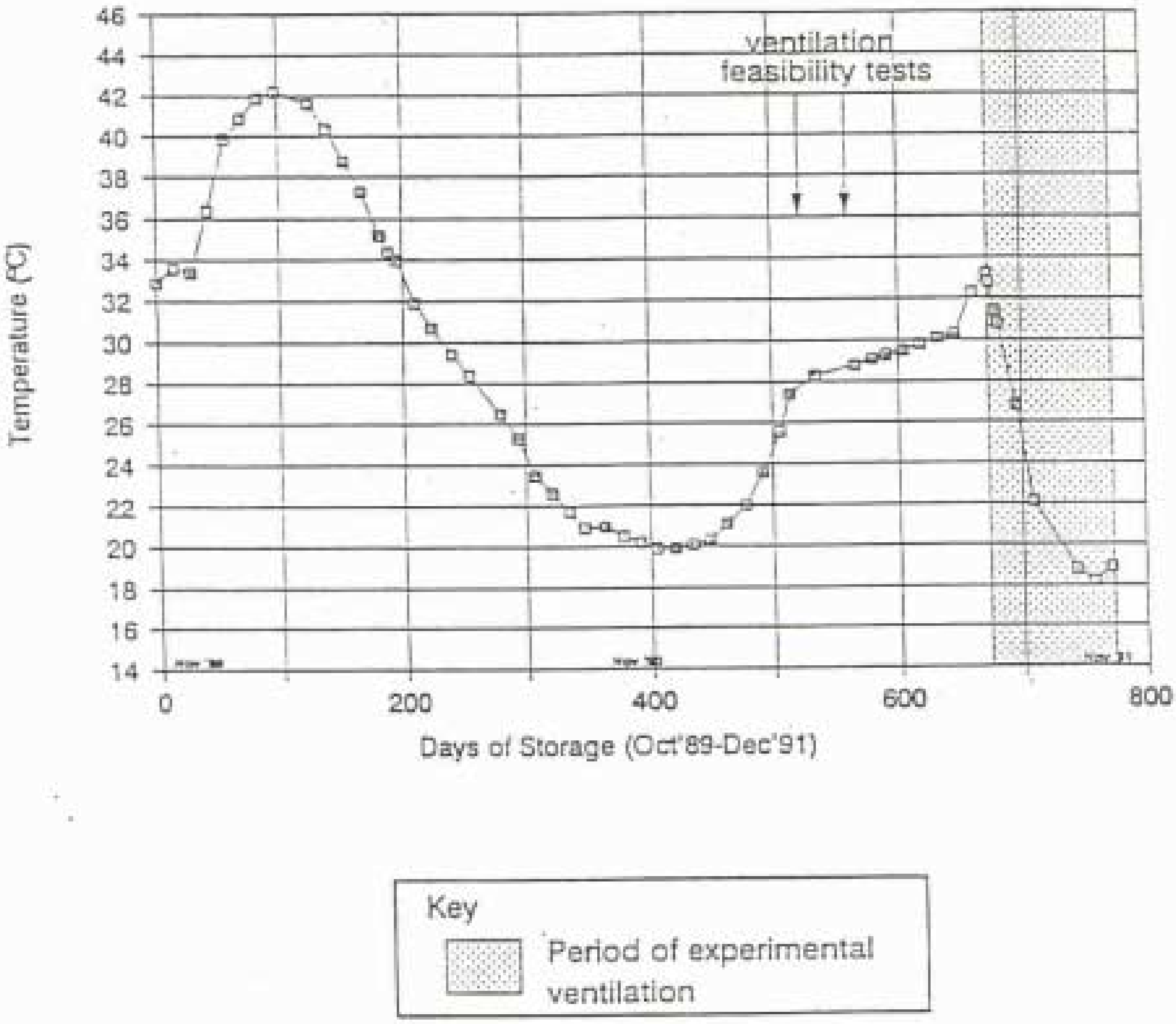


Figure 3. Temperature profile of a central position (October 1989 - December 1991).



Dismantling, sampling and sample analysis

13. The stack was carefully dismantled after 30 months in transects to detect the distribution of internal stackburn. The samples taken related to positions where changes in temperature and moisture content had been observed during the trial. Lines of sacks forming transects across, along and vertically through the stack were removed and the contents sampled in the same way as during construction.

14. Samples were taken as follows:

(a) a moisture content sample was extracted and stored in an airtight tin for oven determination at NRI;

(b) the entire contents of each sack were sieved, the resulting mixture of dust and insects was weighed, and the insects counted, at GMB;

(c) the maize was coned and quartered, and finally divided with a riffle divider to provide samples of approximately 600-1000g for:

(i) grading according to GMB standards by GMB;

(ii) germination testing by the Zimbabwe Government Seed Testing Laboratory;

(iii) measurement of the percentage of insect damaged grains and of weight loss (gravimetric, count and weigh, method) by NRI;

(iv) colour analysis ("L","a" and "b" values), using a HunterLab Colorimeter, by NRI;

(v) breeding-out possible survivors of the fumigation (samples were examined after eight weeks and again after ten months);

(vi) analysis for mycotoxins by NRI.

15. Samples were also taken for further analysis to look for associations between mould damage, insect infestation and stackburn.

RESULTS

16. The results of sample analyses are summarized in Tables 1 to 5.

17. During the storage period the proportion of maize grades A and B decreased from 99% to 53%. C grade increased from 1% to 6%, and D grade (animal feed grade) from 0% to 31%. On despatch, there was also a proportion, 10%, that was unmarketable and this had to be written off (Table 1 and Figure 4).

Table 1. Percentages of sampled maize by grade before and after the trial.

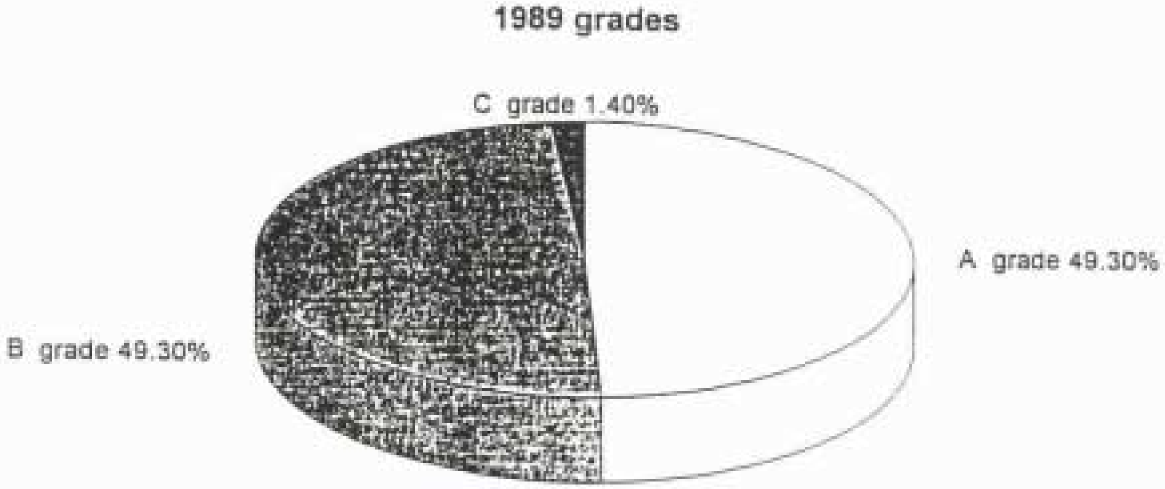
Grade	1989	1992
A	49.3	29.0
B	49.3	24.2
C	1.4	6.4
D	0	30.7
U	0	9.7

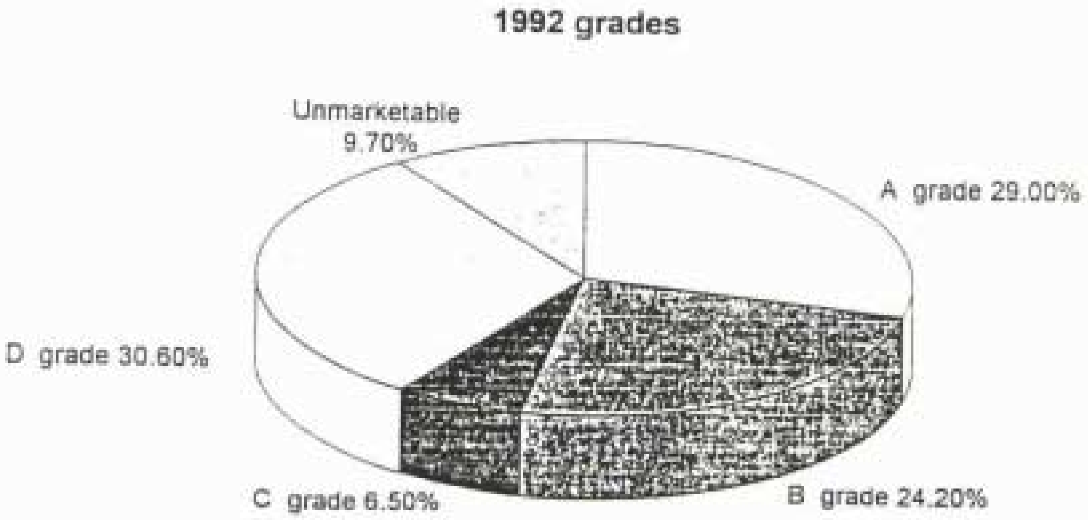
18. There was a marked decline in germination percentage of grains tested at the end of the trial, from 70% initially, to 4% (Table 2).

Table 2. Mean germination percentage (%).

	1989	1992
Live grains	69.9	4.3
Abnormal grains	4.1	0
Dead grains	26.0	95.6

Figure 4. Maize grades (1989 and 1992).





19. The aflatoxin content of maize samples did not show any increase during the trial (Table 3).

Table 3. Maize aflatoxin content (per cent).

	1989	1992
Total aflatoxin (B1,B2,G1,G2)		
> 5 ppb*	5.0	0
>16 ppb*	0	0
Aflatoxin B1		
> 5 ppb*	1.2	0

* - parts per billion

20. The number of insects sieved from whole sacks and counted at the end of the trial was about 2000 adults per sack of *Sitophilus* spp. and *Tribolium* spp. together (Table 4). This figure is considerably less than in an earlier study (Donaldson, 1992). A few live insects were also recorded and these were found in sacks towards the base of the stack. Incubation tests showed that live insects emerged from six samples.

Table 4. Number of adult insects per sack (n=111).

	Live	Dead
Sitophilis spp.	< 1	1,382
Tribolium spp.	0	775

21. Although over ten percent of the grains sampled showed insect damage (Table 5), the loss in weight due to this damage was less than 1% (Appendix 3), as measured by the gravimetric method described by Boxall (1986).

Table 5. Percentage weight loss and grains damaged by insects (n=69).

	Weight loss	Insect damaged
Mean	0.84	10.96

22. HunterLab colour "a" values (green to red spectrum) are shown in Figure 5 illustrating the variation in colour density along transect (a darker shade indicates browner, more stackburnt, maize).

23. Initial moisture contents are illustrated in Figure 6. The maximum moisture content for acceptance of maize by GMB is 12.5% using an electrical resistance meter. When samples were check-tested against the oven method (ISO 6540) about half were below and half were above 12.5%. Because some meters gave very high readings all were subsequently recalibrated.

24. At the end of the trial, 20 samples from beside the Reethorpe sensors were taken for moisture content determination in order to check the sensor calibration. Three quarters of the final moisture contents were below 12.5% and a quarter above (Figure 6).

25. Changes in temperature and moisture content at representative points are illustrated in Figures 2 and 7, respectively. The temperature at a position a few centimetres from the edge of the stack on the northern side (number 23) varied considerably as it responded to solar radiation. Interior positions were insulated from short-term solar effects by the 4-8 metres of maize outside them and did not reflect ambient temperatures (Figure 8).

Figure 5. Colour values of samples from the central transects of the stack.

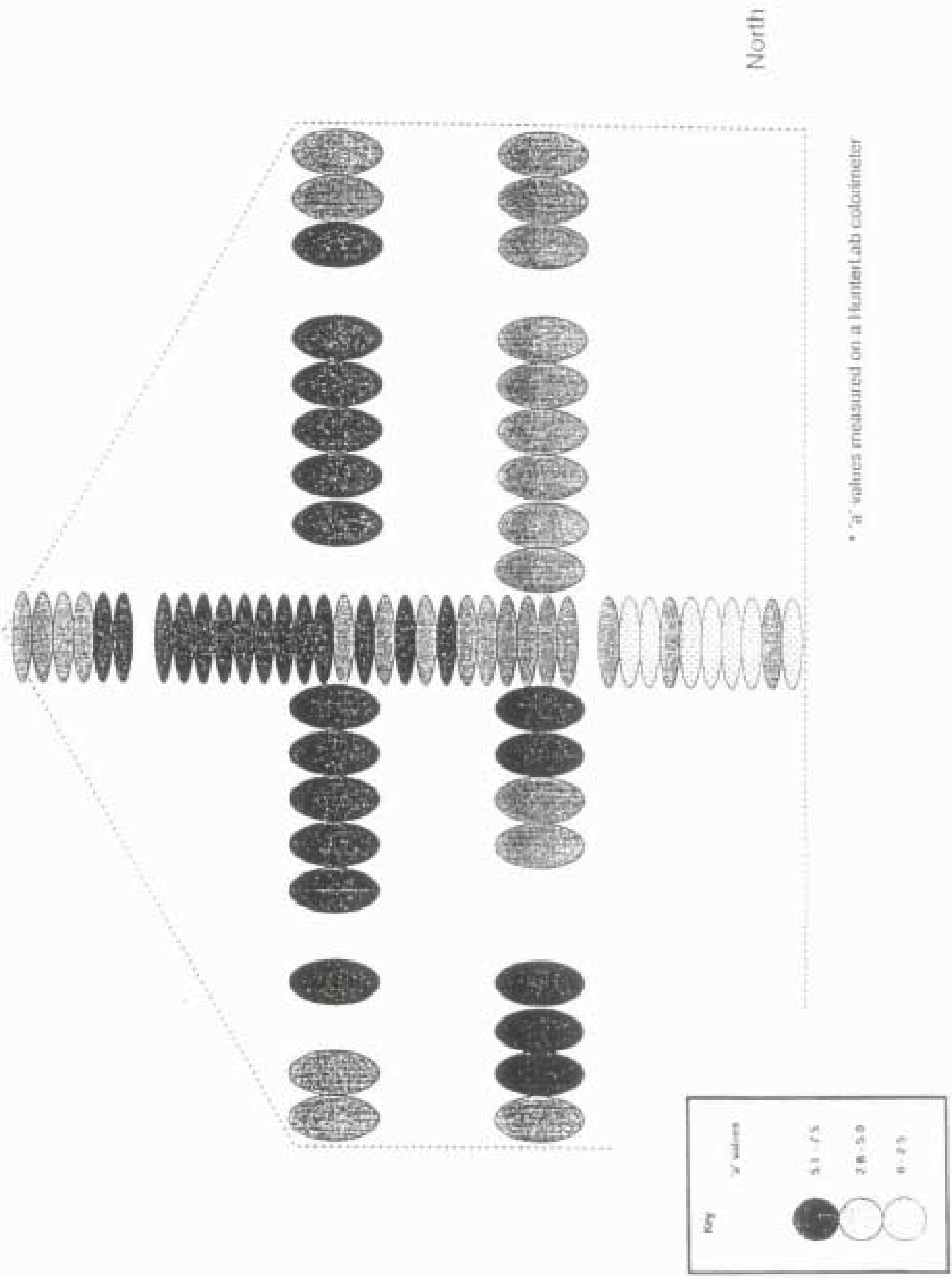
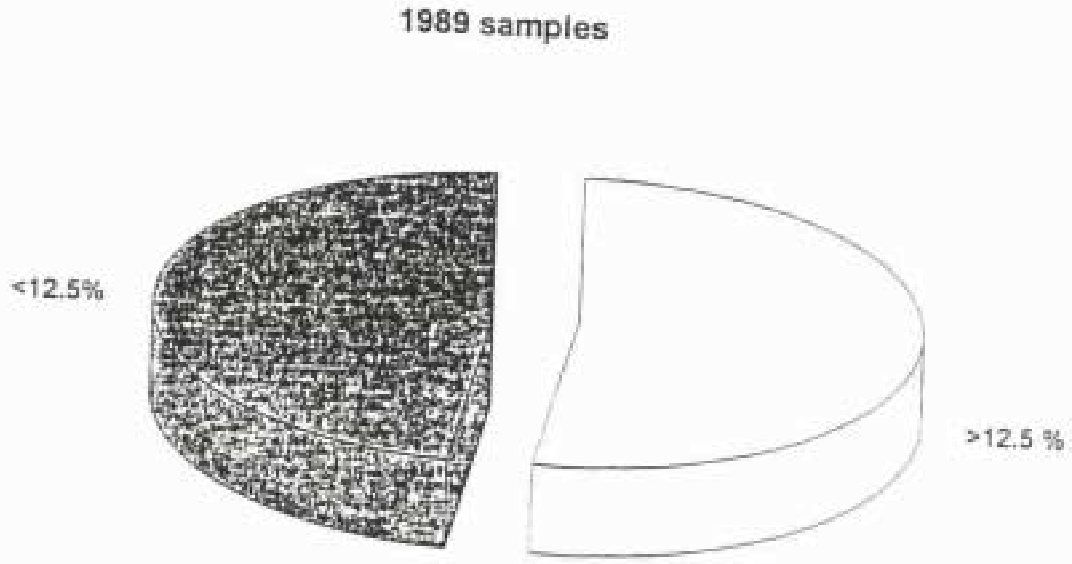


Figure 6. Oven determination of moisture contents sampled from all bags (1989 and 1992).



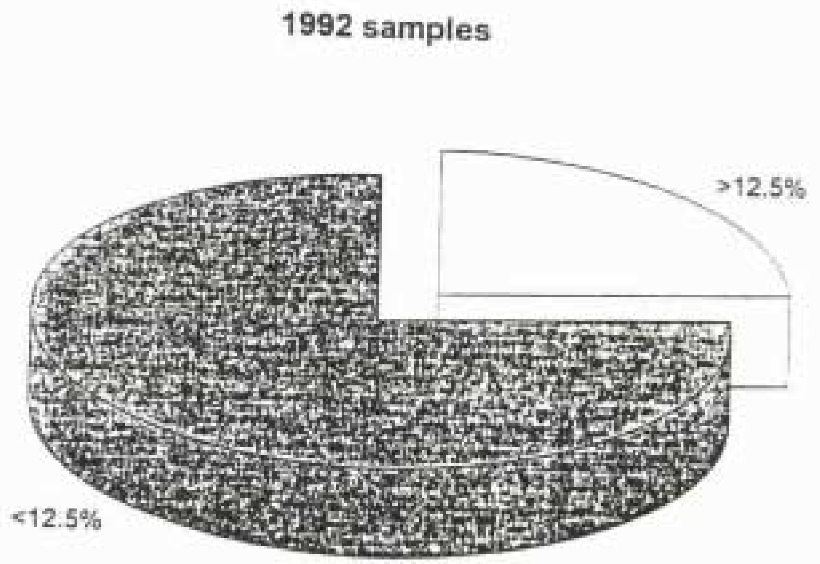


Figure 7. Moisture content changes (20 October 1989 - 31 May 1991).

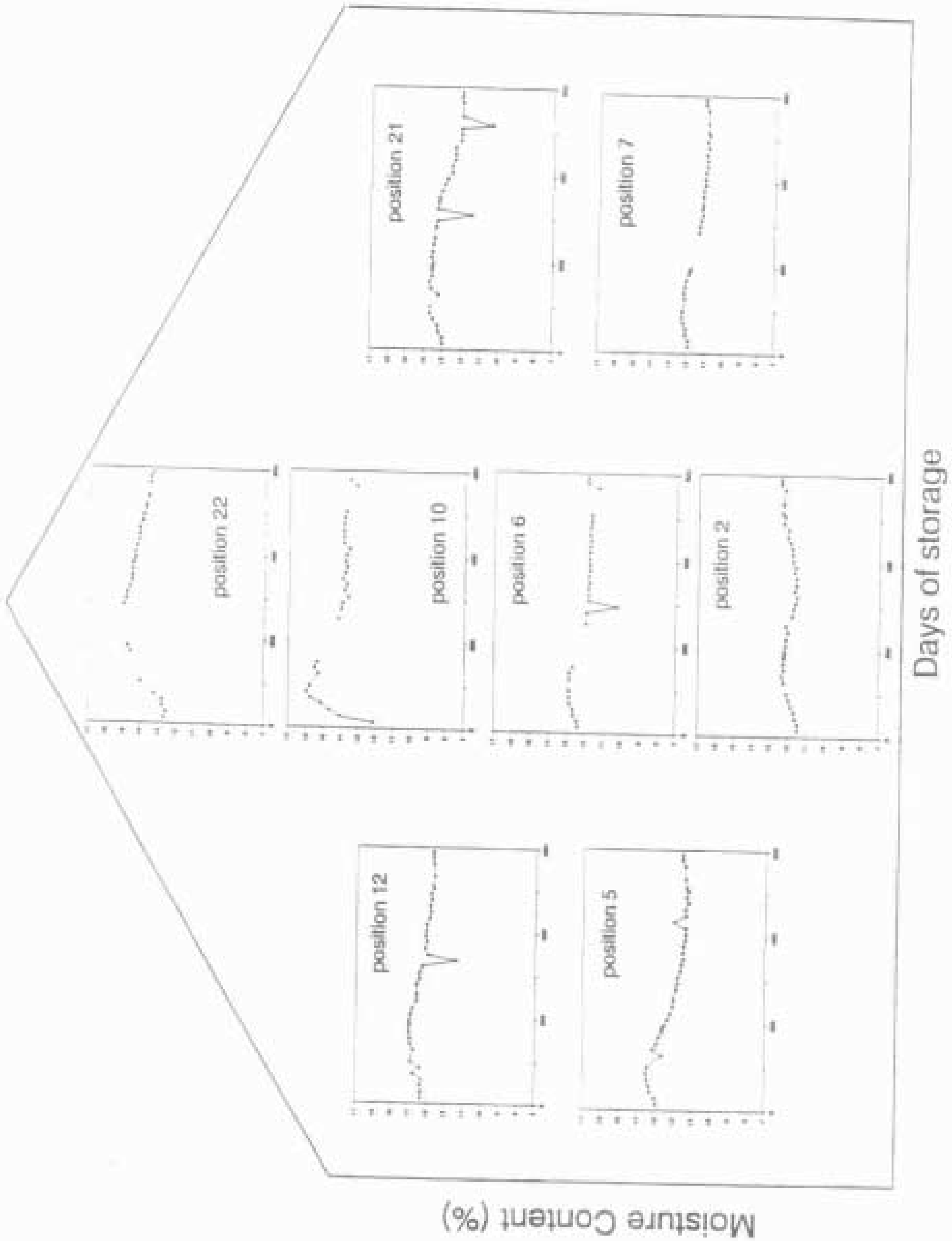
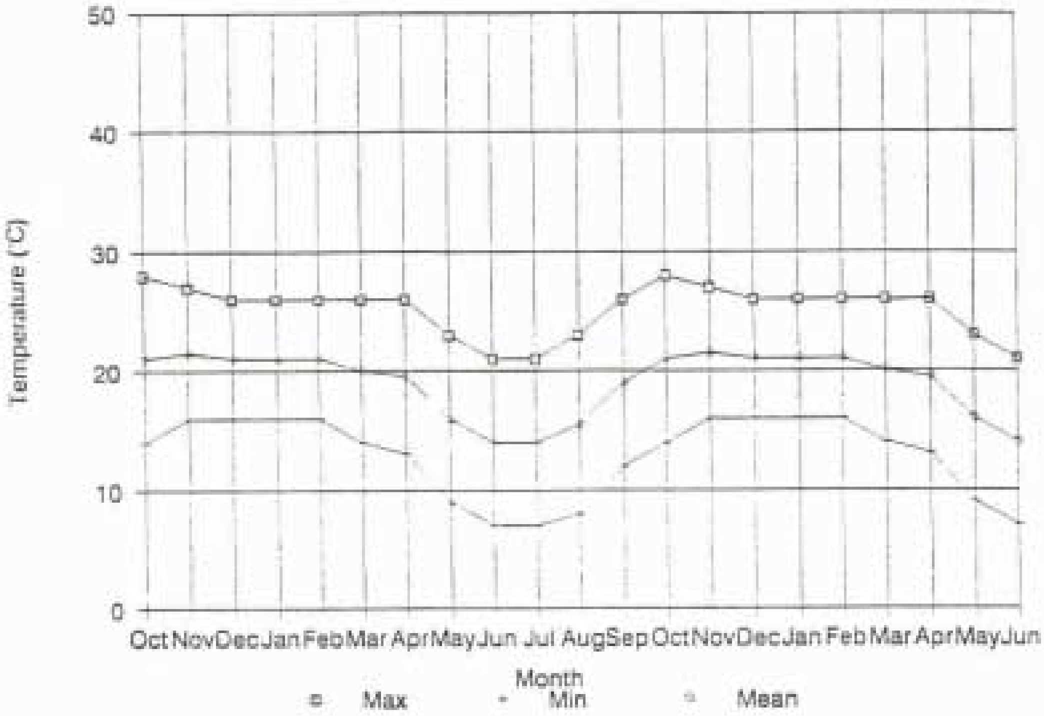


Figure 8. Daily average temperature on the central Zimbabwean plateau.



DISCUSSION

Quality changes

26. There were marked changes in some of the quality parameters measured and these were reflected in the lower grades of maize despatched at the end of the trial.

27. Downgrading of samples to D grade was due to a high proportion of discoloured grains. Discoloration consisted of a change from the original creamy-white to various shades of brown and such maize was classified as stackburnt maize.

28. The distribution of discoloured maize is illustrated in Figure 5. Stackburnt maize was found in the interior of the stack where an early increase in temperatures to around 40°C had been recorded. The darkest (more heavily stackburnt) maize was found in the region where increased temperatures were associated with an increase in moisture content to 16%, illustrated at two positions (10 and 22) in Figure 7. Maize near the outside of the stack was less discoloured; this has been the characteristic pattern found in other stacks (Donaldson, 1992).

Heating

29. The increase in temperature in the interior of the stack cannot be attributed to ambient conditions. The pattern of heating in the stack during this time was characteristic of insect heating of dry grain; maximum temperatures did not exceed 44°C. Above this temperature, metabolic heat production by insects ceases because they are killed by such heat. In all areas of the stack where some heating was measured there was evidence of grain discoloration. Casual evidence would suggest a link.

Fumigation

30. If insects were the cause of the heating during the first 120 days, this implies that fumigation of the maize with methyl bromide, prior to the stack being built, was unsuccessful or that there was significant reinfestation during stack construction.

31. Methyl bromide fumigation of the trial stack after 116 days appeared to be successful, as judged by a fall in temperature of about 25°C during the following 300 days. The timing of fumigations is shown in Figure 9.

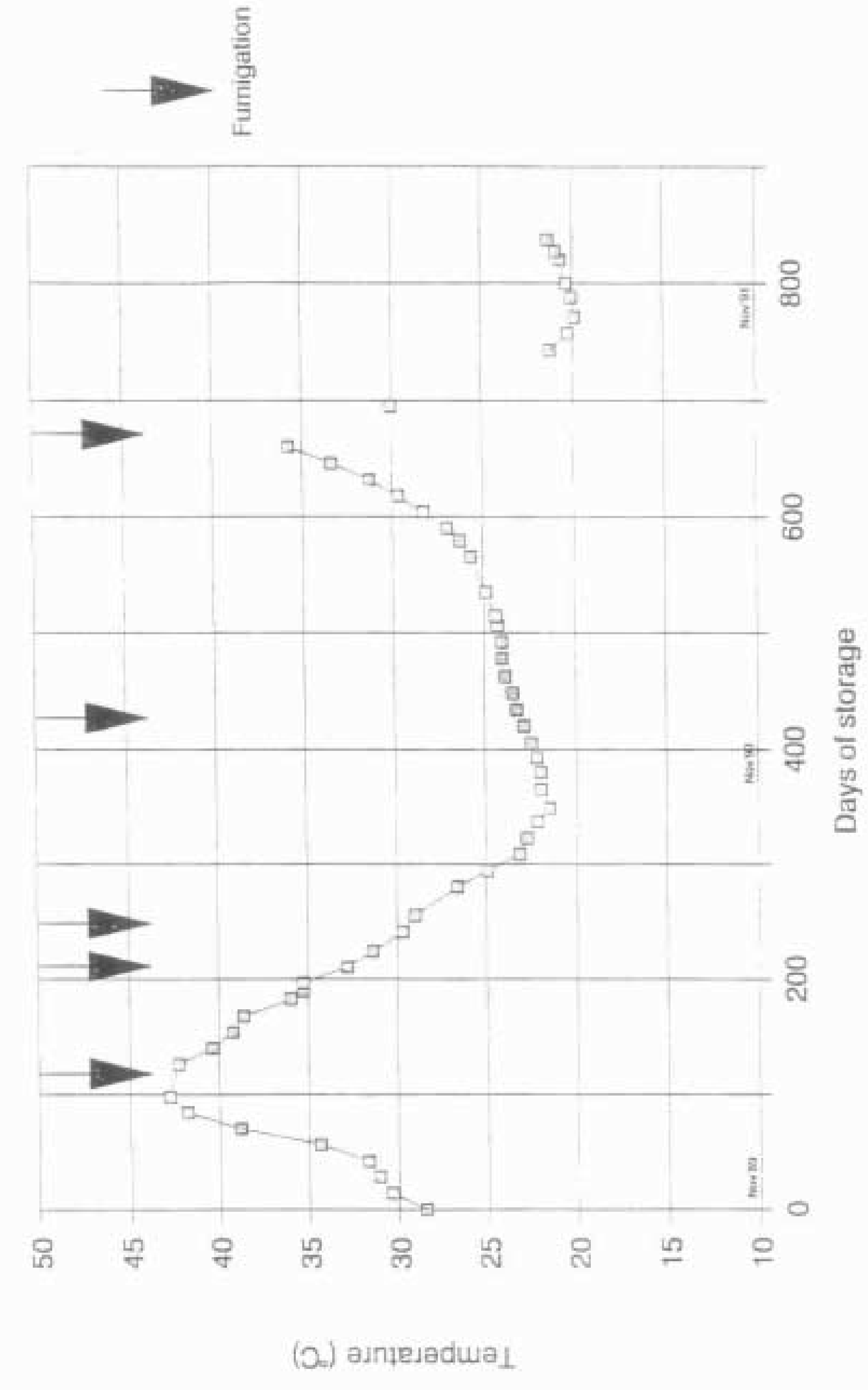
32. It was later found that only partial success may have been achieved, since reheating at some positions could be explained by a small number of survivors breeding (confirmed by the breeding-out trials). However, reinfestation may have occurred.

33. Strains of *Sitophilus zeamais* collected from the stack were tested at NRI for resistance to methyl bromide, but none was detected. Survival is therefore likely to be due to problems of penetration of sufficient gas to all parts of the stack or to gas leakage during the fumigation.

Moisture content and relative humidity

34. In some areas of the stack, heating was accompanied by an increase in moisture content and more severe stackburn. The effect of grain micro-climate on insect and mould activity, and the links to grain discoloration, need further investigation.

Figure 9. Fumigation dates and temperature changes (October 1989 - December 1991).



Properties of polypropylene sacks.

35. A reduction of air permeability in woven polypropylene material has been demonstrated at NRI (New, personal communication) when two layers of polypropylene fabric were pressed together by grain under pressure (similar to that present in the interior of large stacks). Jute sacks did not become similarly less permeable under pressure. The possibility that polypropylene can act as a barrier to the movement of air, and the water vapour it carries, cannot be discounted at this stage.

Climate

36. The weather conditions were near normal during the trial and the findings are therefore applicable in most years.

Losses

37. The mean weight loss due to insect damage was low over the 30-month storage period, at less than 1%. The principal cause of financial loss was in terms of quality, rather than quantity, because of the large quantities of grain that were downgraded.

38. An assessment of the financial losses is shown in Table 6. To eliminate the effects of price fluctuations due to seasonal variations and the drought, all figures are based on 1992 GMB selling prices, which were:

(a)	A and B grade	Zimbabwe	$ 1,070.00;
(b)	C grade	"	$ 1,049.46;
(c)	D grade	"	$ 963.96;
(d)	Unmarketable grade	No value.	

Table 6. Calculated financial loss of the trial stack.

The **potential value** of the stack, if qualities had remained unchanged was:

Grade	Quantity (tonnes)	Value (Zimbabwe $)	
A+B	1,542	1,649,940	
C	21	22,039	
Total	1,563	1,671,979	

The **actual value** of the stack at despatch was:

Grade	Quantity (tonnes)	Value (Zimbabwe $)	
A+B	832	890,240	
C	101	105,995	
D	480	462,700	
Unmarketable	138	0	
Total	1,551	1,458,935	
Difference (estimated loss)		213,044	**(12.7%)**

The loss in weight due to insect damage is estimated at:

	Quantity (tonnes)	Value (Zimbabwe $)	
Insect loss	12	12,840	**(0.8%)**

39. The reduction in grade was almost entirely due to stackburn in those parts of the stack where the recorded temperature changes were characteristic of insect heating of dry grain. The total loss was calculated to be 13.5% of the stack value, or Zimbabwe $225,880 (equivalent US $42,050 at December 1992 exchange rates).

CONCLUSIONS

40. The financial loss was predominantly due to changes in quality of the maize. The principal cause of change in quality was discoloration of grain (stackburn) in the interior of the stack.

41. Microclimatic changes in the stack during the trial period suggest that trapped metabolic heat and moisture produced by developing insect infestations could be the cause of stackburn in maize stored in woven polypropylene sacks.

42. There was some evidence that insects could survive methyl bromide fumigations, due to problems with uneven gas penetration throughout the stack.

RECOMMENDATIONS FOR FUTURE WORK ON STACKBURN

43. Stackburn has now been recognised as a problem in several countries and an EC DGXII project has been developed to investigate its socio-economic impact and the technical improvements necessary to prevent it.

44. Future investigations will need to:

(a) survey the frequency with which heating occurs, using low-cost thermocouples, in the interior of large-scale outdoor and indoor maize and wheat stacks;

(b) conduct small-scale tests of changes in water activity of maize, heated to around 40°C in polypropylene and plastic film sacks, to establish whether heating may potentiate stackburn by increasing water activity;

(c) survey the insect infestation and fungal infection present on maize at intake to large-scale storage to determine the potential for heating caused by insects and fungi;

(d) conduct feeding trials to establish the nutritional value of stackburnt maize and so assess its market value;

(e) consider the design of polypropylene sacks and whether they can be changed to improve air permeability and the rapid penetration of methyl bromide; and,

(f) design and field-test stacks using stacking patterns that allow internal ventilation to dissipate heat.

REFERENCES

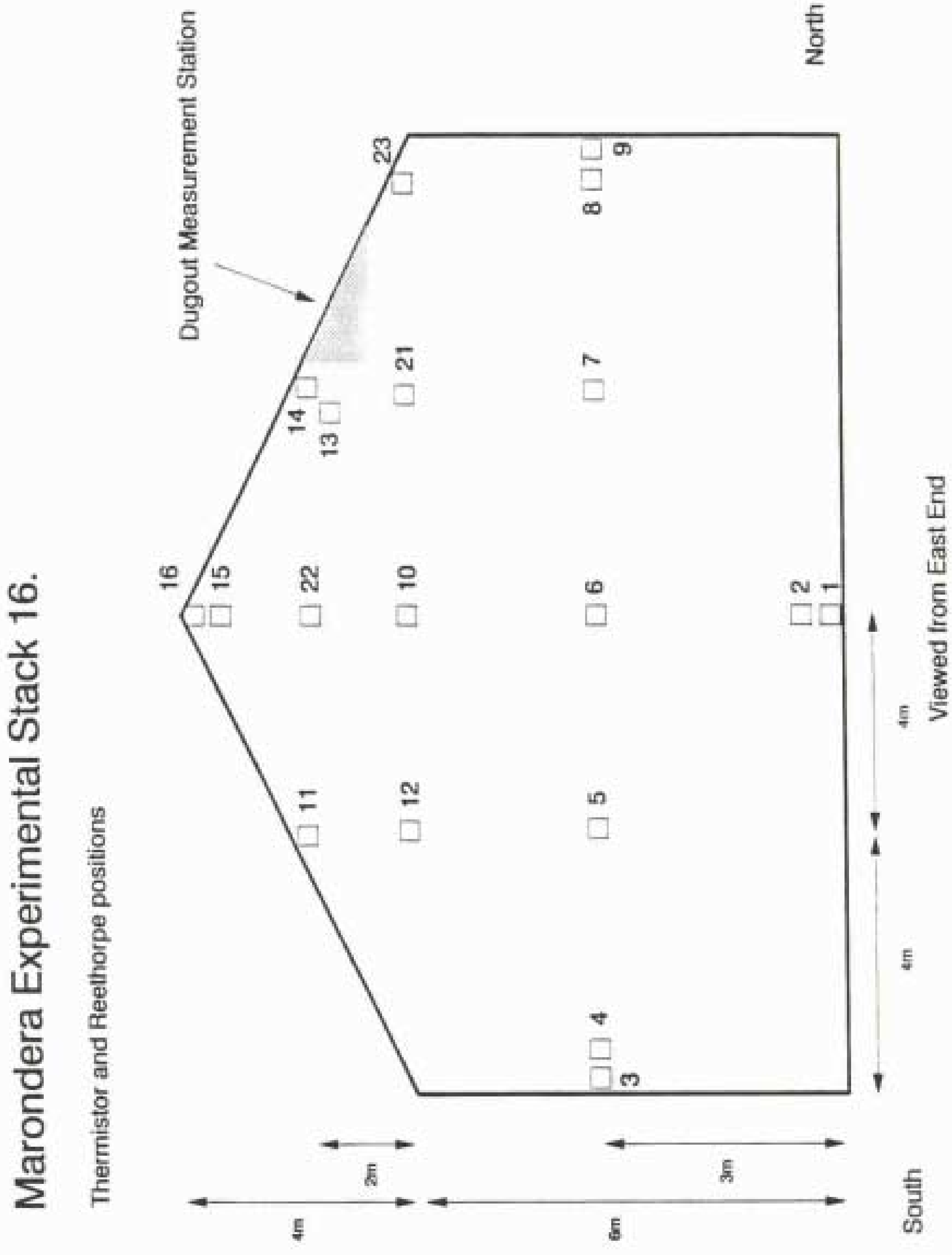
Boxall, R.A., 1986. *A Critical Review of the Methodology for Assessing Farm-Level Grain Losses after Harvest.* TDRI Report G191.

Clarke, P.A. and Orchard, J.E. (1993) *Directory of food grain standards.* ISBN 085954 358-7. Natural Resources Institute, Chatham, Kent, UK.

Donaldson, T.J., 1992. *Assessment of spoilage and loss within stackburned maize.* Report No. R2073(S), Natural Resources Institute, Chatham, Kent, UK.

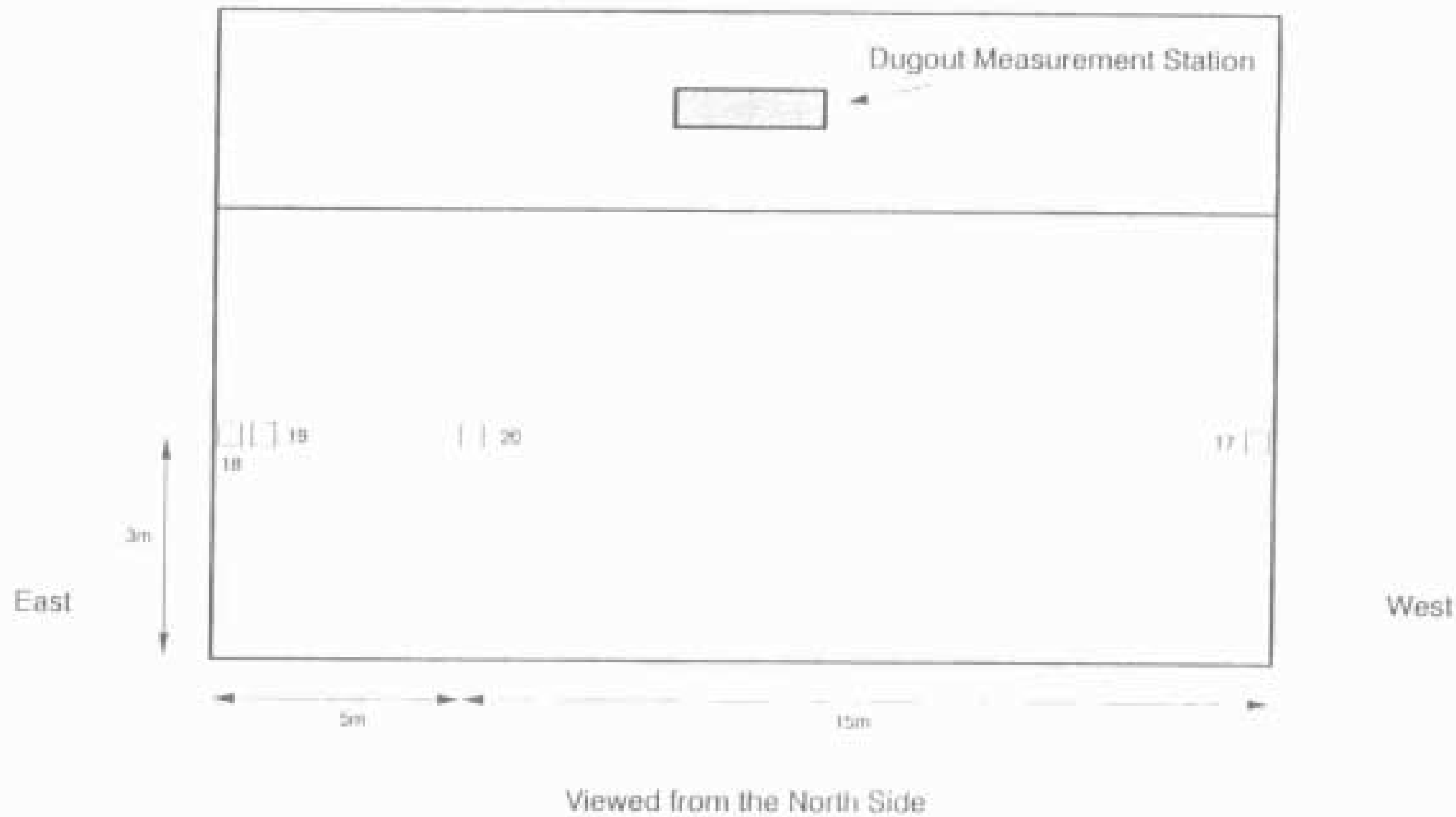
Gough, M.C., 1980. Evaluation of a remote moisture sensor for bulk grain. *Journal of Agricultural Engineering Research* 25, 339-344.

Appendix 1 :   Trial Stack, monitoring positions.



Marondera Experimental Stack 16.

Thermistor and Reethorpe positions



APPENDIX 2: DISTRIBUTION OF SENSORS IN THE BAGSTACK

Most sensors were placed where greatest and least moisture content changes were anticipated (Gough 1985, Gough 1989). In previous storage trials (Gough 1985, Gough *et al.* 1987), the north-south central vertical plane experienced the greatest and least moisture changes, and most sensors were installed in this plane. Taking this and the direction of the prevailing wind into consideration, it was decided to use the same plane in the Marondera trial. Most sensors were installed here - the rest were placed in the east-west plane so that four dispersed regions of the stack were monitored. Most thermistor measurements were recorded with a Grant Squirrel datalogger. An electronic thermometer and a Marconi moisture meter (Gough 1980) were used weekly to obtain readings manually from the rest of the thermistors and all of the Reethorpes respectively.

Ambient temperature and relative humidity were monitored continuously with a Squirrel datalogger placed in a Stevenson's screen located in an unsheltered area about 200m from the stack used in the trial.

References

GOUGH, M.C. (1980) Evaluation of a remote moisture sensor for bulk grain. Journal of Agricultural Engineering Research 25, 339-344.

GOUGH, M.C. (1985) Physical changes in large scale hermetic storage. Journal of Agricultural Engineering Research 31, 55-65.

GOUGH, M.C., CHEIGH, H.S., KIM, S.K. and KWON, T.W. (1987) Physical changes in stored bulk rice. Journal of Agricultural Engineering Research 37, 59-71.

GOUGH, M.C., BISBROWN, A.J.K. and BRUETON, A.C. (1989) The physical effects of tropical humid seasons on bagstacks of grain. Overseas Development Natural Resources Institute Bulletin No. 21.

mar 16/3/6	0.08	(0.06)	10.29	9.63
	(0.20)		8.96	
mar 16/3/7	0.46	0.41	5.71	34.36
	0.35		7.96	
mar 16/3/8	0.46	0.72	3.17	4.41
	0.97		5.65	
mar 16/3/9	0.84	0.38	9.06	7.05
	(0.09)		5.03	
mar 16/3/10	0.47	0.47	5.29	5.29
mar 16/3/11				
mar 16/3/12	0.19	0.62	5.46	5.43
	1.04		5.39	
mar 16/3/13	0.81	0.68	3.35	3.76
	0.55		4.17	
mar 16/3/14	0.39	0.44	3.79	4.02
	0.48		4.25	
mar 16/3/15	1.10	0.73	8.49	6.11
	0.35		3.72	
mar 16/3/16	1.24	0.73	8.00	13.43
	0.22		18.86	
mar 16/3/17	0.81	1.06	3.16	4.69
	1.31		6.21	
mar 16/3/18(Pos7)	1.15	1.15	15.16	15.16
mar 16/3/19	1.99	1.18	18.85	20.07
	0.36		21.29	
mar 16/3/20	2.53	1.24	6.30	47.65
	(0.05)		2.46	
mar 16/3/21	0.04	0.46	4.37	4.65
	0.88		4.92	
mar 16/3/22(Pos8 & 9)	0.62	0.62	3.86	3.86

MEAN	0.84	1.17	10.96	12.73
COUNT	69	20	69	20
MAXIMUM	8.58	8.58	87.15	47.65
MINIMUM	(4.75)	(0.06)	1.07	3.76
STANDARD DEVIATION	1.60	1.61	11.33	12.57
SUM	57.89	35.87	756.17	254.54
VARIANCE	2.55	2.59	128.40	158.08

APPENDIX 3 : MARONDERA STACK 16, LOSS ASSESSMENT DATA

sample coded	wtloss(%)	mean	% dam	mean
mar 16/23/1	(4.75)	(0.80)	87.15	55.46
	3.16		23.77	
mar 16/23/2(sub sample)	3.95	3.66	15.81	16.04
	3.37		16.27	
mar 16/23/3	1.57	1.76	11.35	14.18
	1.94		17.01	
mar 16/23/4	0.67	0.06	9.95	13.49
	(0.55)		17.03	
mar 16/23/5				
mar 16/23/6	(0.14)	0.11	1.07	1.97
	0.35		2.86	
mar 16/23/7	1.52	1.86	19.75	20.38
	2.20		21.00	
mar 16/23/8	0.83	0.48	6.30	11.47
	0.12		5.17	
mar 16/23/9	(0.86)	(0.84)	13.52	19.76
	(0.82)		9.66	
mar 16/23/10	(1.21)	(1.41)	4.30	8.66
	(1.61)		13.02	
mar 16/23/11				
mar 16/23/12	0.35	0.42	3.69	5.79
	0.49		7.89	
mar 16/23/13	(0.37)	(0.36)	9.69	9.78
	(0.34)		9.87	
mar 16/23/14	0.57	1.37	4.15	7.12
	2.17		10.08	
mar 16/23/15	0.64	1.21	6.02	7.50
	1.78		8.97	
mar 16/23/16	1.90	1.39	13.10	9.92
	0.88		6.73	
mar 16/23/17				
mar 16/23/18	(1.69)	(0.30)	16.60	13.03
	1.09		9.45	
mar 16/23/19	2.08	0.80	13.12	13.62
	(0.48)		14.12	
mar 16/23/20	3.02	3.02	20.00	20.00
mar 16/3/1	8.58	8.58	35.54	17.77
mar 16/3/2	2.22	2.14	17.60	35.30
	2.05		17.51	
mar 16/3/3	0.58	0.89	5.46	6.72
	1.19		7.97	
mar 16/3/4	1.71	1.05	6.97	5.22
	0.38		3.47	
mar 16/3/5(Pos5)				