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Natural Resources Institute

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R 2231 (S)

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

Report No. 7: Ventilated Bagstack Trial, Zimbabwe, September 1994 to January 1995

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SUMMARY

An experimental trial in Zimbabwe is reported in which the Zimbabwean Grain Marketing Board (GMB) have built an outdoor bagstack ventilated throughout by means of horizontal and vertical tunnels. It is intended that these tunnels will allow excess heat to escape from the bagstack during storage and thus reduce the development of stackburn.

The author visited Concession, the site of the trial, during September 1994 to extract samples and to install instrumentation in the bagstack to monitor conditions during the trial. A further visit was made in January 1995 to collect the first four months of data, which are presented in this report. GMB intend to leave the bagstack for 12 to 18 months before despatch.

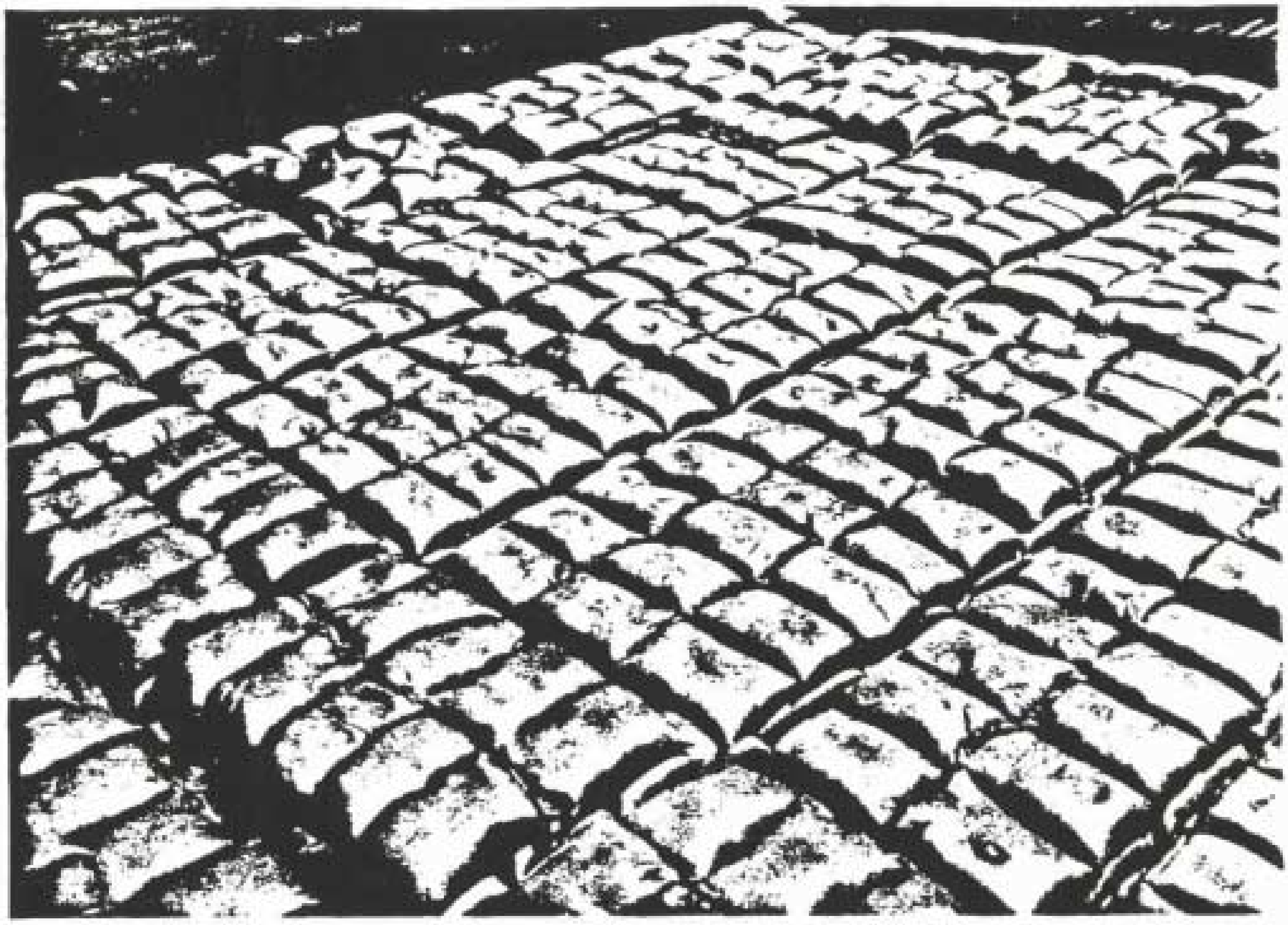
The results to date show that ventilation has continued throughout the first four months of the trial and has reached the centre of the bagstack. The bagstack has remained stable, though there are some signs of settlement. The temperature in the bagstack centre rose initially to a peak of between 33°C and 35°C then fell after fumigation to 29°C. There is a strong correlation between the date of fumigation and the fall in temperature. The peak temperatures are in contrast to sustained temperatures of 41°C seen in previous trials. Moisture contents are all within the safe range for storage.

The following conclusions are drawn:

- the tunnelled bagstack is stable and has experienced cooler storage conditions during the first four months than seen in previous trials;
- fumigation has brought about the fall in temperature;
- the source of heating was within the grain;

- moisture contents were within the safe range for storage;
- there are some drawbacks with the tunnelling method relating to possibly increased time and effort during building and somewhat reduced bagstack capacity.

It is recommended that arrangements be addressed to allow further collection of data from the trials at four month periods, maintenance of the instrumentation and collection of samples at the end of storage .



Top: A section of the stack under construction
Bottom: Channel openings at the side of the stack

ACKNOWLEDGEMENTS

I would like to thank the staff of the Grain Marketing Board in Zimbabwe for allowing and assisting with our participation in the trials, especially Mr Nosenga, Mr Kutukwa, Mrs Tanyongana, Mr Mudzonga and the Concession depot staff. I would also like to thank Professor Giga and Dr Cole at the University of Zimbabwe.

INTRODUCTION

1. This experimental trial was undertaken in collaboration with the Grain Marketing Board (GMB) in Zimbabwe as part of the investigation into the causes and prevention of maize discolouration. Experimental data from NRI has shown that maize discolouration, or stackburn, is a result of moisture and temperature dependent chemical reactions (Phillips and Donaldson, 1994). Previous investigations in Zimbabwe, e.g. Kennedy and Devereau (1994), have revealed sustained temperatures of 40°C or above developing in the centres of bagstacks during storage.

2. GMB suggested the possibility of reducing stackburn by incorporating tunnels into bagstacks to allow excess heat and moisture to be removed by passive (or natural) ventilation. This was first tested on a bagstack in Mutare depot in 1989. In that trial, tunnels ran horizontally across the width of the bagstack and intersected with tunnels running vertically from bottom to top.

3. GMB concluded that the method showed promise and extended it during the 1994/95 intake season to depots in the Concession area. The trial reported here was undertaken at Concession depot and is part of this investigation: GMB provided materials and expertise to build the bagstack, NRI provided equipment and expertise to allow temperatures, moisture contents and airflows to be monitored during the trial. The author visited Concession depot during 6 to 24 September 1994 during bagstack construction to install instruments and returned during 23 to 28 January 1995 to collect data from the first four months of storage.

METHOD

Bagstack design

4. The bagstack was built over the period 1 September to 28 October 1994. It was built in three sections approximately 14 m wide and 14.6 m long each and followed

GMB's normal methods in every way except for the inclusion of tunnels. Figures 1a and 1b show the general bagstack design and dimensions.

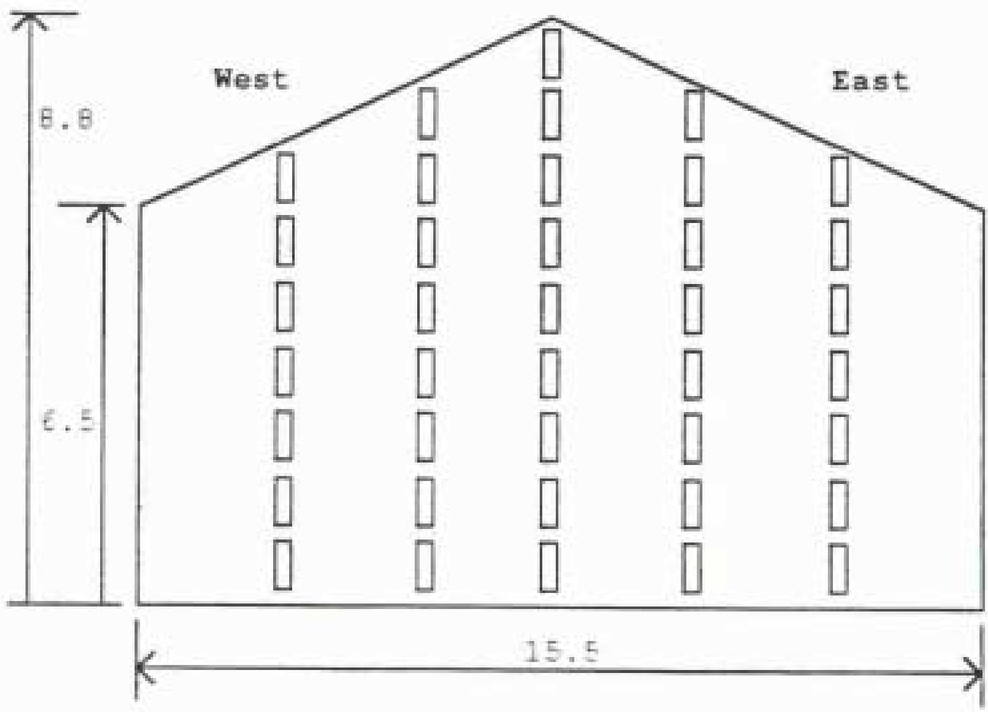


Figure 1a. End elevation of ventilated bagstack. All dimensions are in metres. Tunnel positions are for illustration only and are not exact.

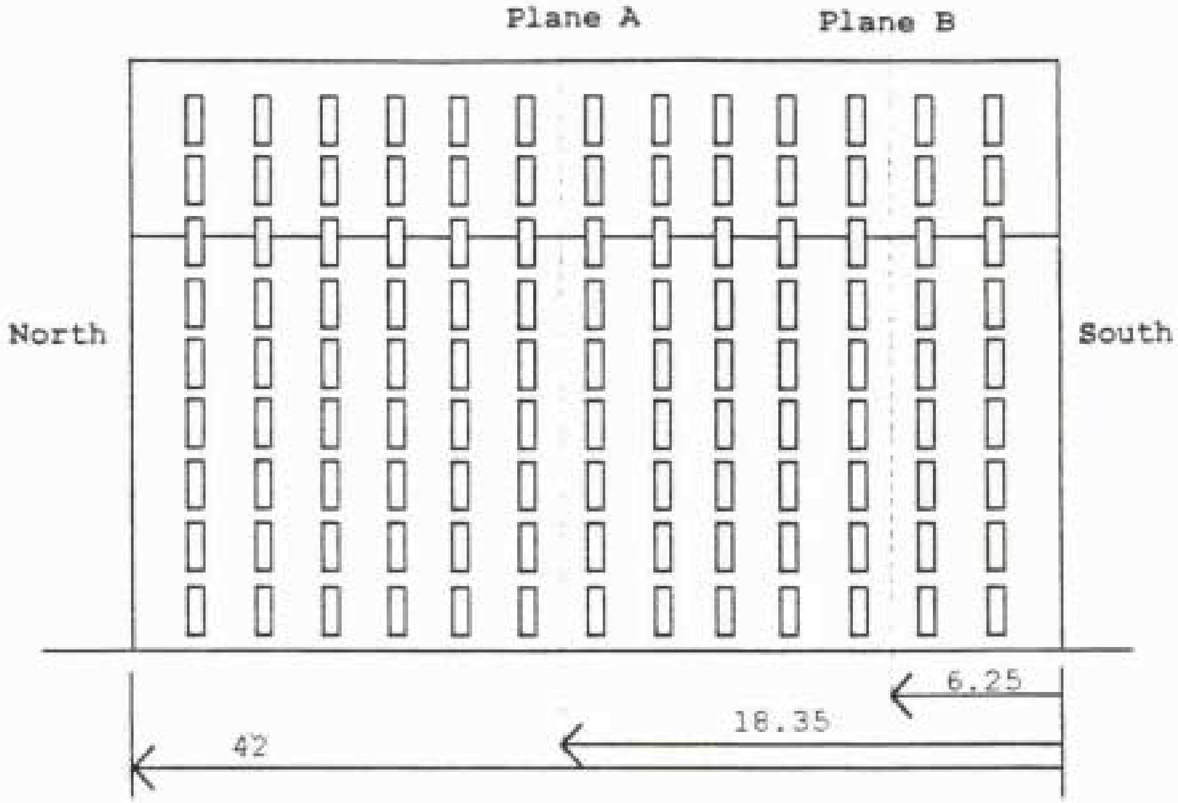


Figure 1b. Side elevation of ventilated bagstack, showing instrumented planes. Tunnel position are for illustration only and are not exact.

5. Figure 2 shows a side view of how the horizontal tunnels, i.e. those across the width and length of the bagstack, were formed. Each tunnel was three layers deep, 100 - 200 mm wide, and separated from tunnels above and below by one layer of sacks. Widthways tunnelling commenced on the second layer of the bagstack and continued to the top of the bagstack, while lengthways tunnelling commenced on the third layer. By thus staggering the layers on which the widthways and lengthways tunnels were built, and by ensuring that the tunnels stayed in line with those above and below up to the top of the bagstack, vertical tunnels were formed inside the bagstack where the horizontal tunnels intersected. Appendix A gives a detailed description of the building method.

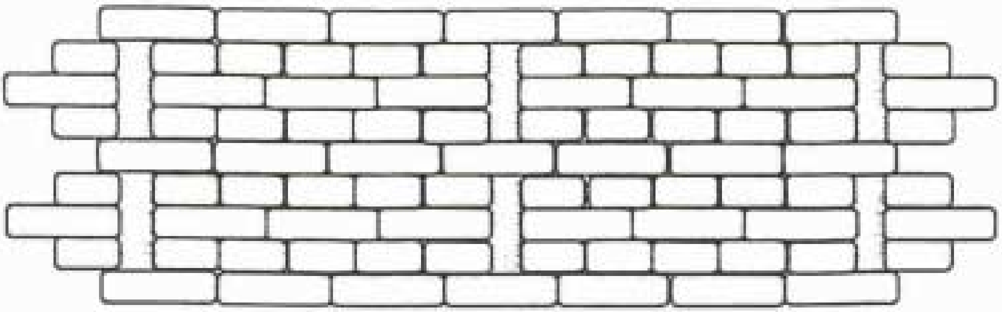


Figure 2. Side view of the horizontal tunnels.

6. The tunnels were spaced five headers (sack widths) or three stretchers (sack lengths) apart both widthways and lengthways as can be seen in Figure 2. This resulted in squares of the same dimensions being formed within the bagstack as shown in appendix A. In all there were thirteen columns of tunnels along the length of the bagstack and five columns across the width, resulting in 65 vertical tunnels being formed within the bagstack.

7. GMB intend to leave the bagstack intact for 12 to 18 months to give full opportunity for stackburn to develop.

8. The drawbacks of tunnelling are that the bagstack takes longer to build, there is extra work for sack carriers in positioning sacks near to the numerous tunnels edges and more semi-skilled bagstack builders are required to place the sacks accurately along the tunnel edges. However, speed of building will increase as experience is gained, and it is hoped that a reduction in stackburn gained through adopting the method, if successful, will compensate for any extra costs involved.

9. The maize used for the trial was recent intake, grade A/B maize of mixed commercial and communal origin held in 50 kg woven polypropylene (wpp) sacks. The finished bagstack contained 58,489 sacks, or nominally 2924 tonnes. A normal bagstack on the size of plinth used might contain 64,000 sacks or 3200 tonnes. The tunnelling has therefore resulted in an approximate 8.5% reduction in bagstack capacity.

Fumigation and airing

10. GMB are treating the stack like any other in regard to fumigation and airing. The bagstack was first fumigated on 4 November 1994 using methyl bromide. A second fumigation was planned for the week 6 - 10 February 1995 following inspections which showed an infestation of *Tribolium* spp. on the bagstack surface.

11. The bagstack is covered in the normal way, i.e. with plastic sheets secured by their top edge only along the long sides and tarpaulins tied over the short sides and top. Airing involves rolling back the tarpaulins on the top of the bagstack during dry periods and this has been practised regularly during the current trial. Appendix B contains a list of airing dates and durations. Because the plastic sheets on the long sides of the bagstack are only secured by their top edge they can billow outwards in the wind and expose these sides directly to the wind. The dunnage underneath the bagstack is also uncovered and therefore open to the wind.

Airflow measurement

12. A method was devised for measuring airflow within the tunnels to give an idea of their performance and possibly to indicate blockages within them. A Solomat 500e meter with a hot-wire anemometer probe was used. The probe was fastened on the end of a pole which could be inserted into the tunnels to a distance of approximately 1.3 m. Airspeeds were averaged over 15 minutes in each tunnel. The direction of airflow was found by placing a cigarette in the tunnel and noting the direction that the smoke travelled. Similar readings, i.e. wind speed and direction, were taken in the open air, using a light thread to determine the wind direction.

13. Airflow measurements are being taken every two weeks by GMB research staff. Because of the large number of tunnels and long time needed for each measurement only a few

readings can be made at each visit. The data gathered in this way is not therefore intended as an accurate record of airflows in the bagstack but as an indication of the scale and trend of airflow.

Temperature and moisture measurement

14. Two planes of temperature and moisture sensors were installed in two sections of the bagstack during building. Figures 3a and b show the positions and numbering of the sensors in plane B: plane A was identical with the exception of position 16 which is illustrated in figure 4. The temperature sensors are thermistors which are connected to dataloggers which measure and record readings automatically every 90 minutes. The moisture sensors are Reethorpes which are read manually and recorded every two weeks. The general positioning of sensors was chosen to mirror that used in other trials in Zimbabwe, allowing direct comparison of results. Appendix C contains a list of datalogger channels and corresponding sensor positions.

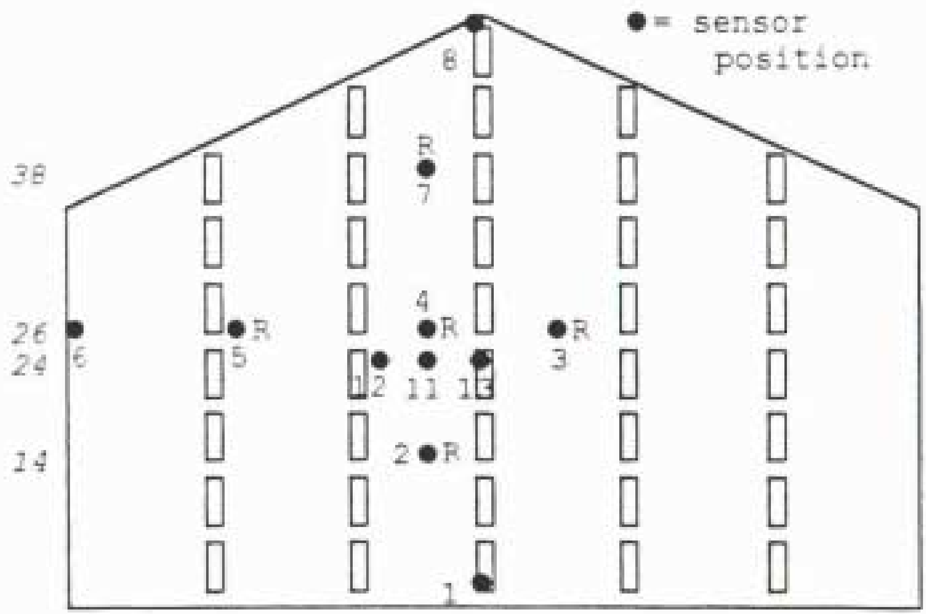


Figure 3a. End elevation (from south) of sensor positions in plane B. Layer numbers in *italics*. R = Reethorpe.

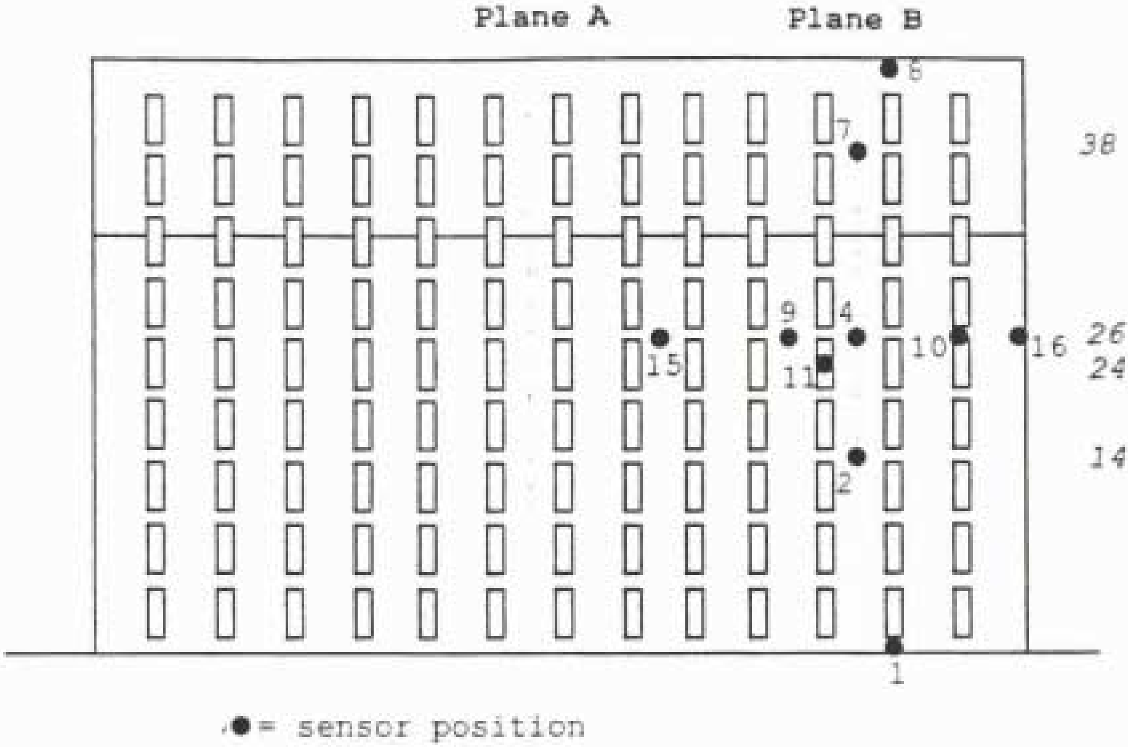


Figure 3b. Side view (from west) of sensor positions in plane B. Layer numbers are in *italics*.

15. The exact positioning of sensors was chosen to take into account the various arrangement of sacks and tunnels in the bagstack. In the bagstack interior there are three types of position which could induce particular environmental conditions in the stored maize:

- at a sack surface in a tunnel;
- inside a sack which has a surface in contact with a tunnel;
- inside a sack which has no surfaces in contact with a tunnel.

16. Temperature sensors were placed at each of these types of position in the bagstack. Note that the maximum distance that a sack can be from a tunnel anywhere in the bagstack is only one stretcher, so the maximum distance of a sensor from a tunnel is 1.5 stretchers or approximately 1.2 m. Further sensor positions covered the exterior sides, bottom and top

of the bagstack as shown in Figure 3. Table 1 shows the percentage of sacks in four layers at mid-height of the bagstack in each of the position types.

Position type	No. of sacks	Percentage
Sack with surface in contact with exterior	344	17
Sack with surface in contact with internal tunnel only	1069	54
Sack with no surfaces in contact with tunnels or exterior	569	29
Total	1982	100

Table 1. Percentages of sacks in different position types in four layers at mid-height of the bagstack.

17. In plane A of the bagstack, sensor position 16 was placed in the same sack as position 12, with position 16 in the centre of the sack and position 12 on the sack edge in a tunnel. The sack was next to the one holding position 4 in its centre. Figure 4 shows the arrangement. This arrangement was designed to study the behaviour of temperature across individual and adjacent sacks near a tunnel at the centre of the bagstack.

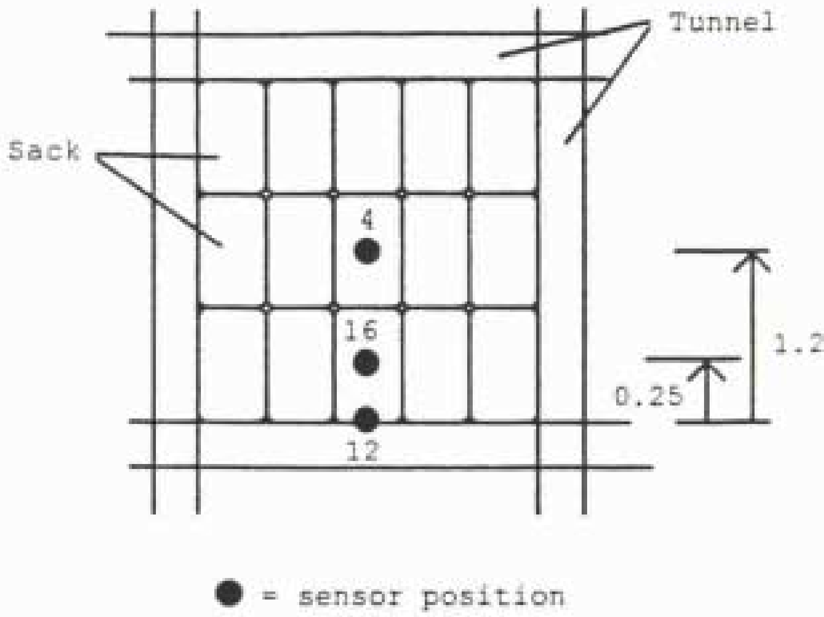


Figure 4. Sensors at positions 12, 16 and 4 in plane A

18. Some sack temperatures were measured during building. Maize on lorries before off-loading was at 28°C inside the sacks and approximately 35°C on the surfaces in the sun. During building the sack surface temperature at entrances to tunnels was approximately 24°C in the shade and 33°C in the sun.

19. After four months the data were collected from the dataloggers, and analysed by averaging the readings over 24 hour periods and plotting the results. Certain positions were also plotted unaveraged to investigate diurnal variations in temperature. Reethorpe values were converted to moisture contents and plotted.

Sampling and analysis

20. Samples of maize from all sensor positions were taken and submitted for analysis according to the methodology presented by Phillips and Donaldson (1994). Moisture content (m.c.) analysis was carried out at the GMB laboratory at Aspindale. The results of the other analyses are attached as Appendix G.

21. Gas sampling tubes were put in the bagstack at the position indicated in Appendix C. These are to allow volatiles to be withdrawn from the interior of the bagstack and returned to NRI for analysis using a novel technique. The analysis of volatiles may be able to indicate the formation of stackburn. The first volatile samples were taken from the stack in February 1995 and the results are not yet available.

RESULTS

Tunnel stability

22. GMB's experience of bagstack tunnelling indicated that settlement may occur during storage causing the tunnels to become blocked. After four months the lowest widthways tunnels were inspected by lifting the sheets on either side of the bagstack. In five out of thirteen cases light could be seen through the tunnels; in all the other cases the tunnels appeared unblocked though some settlement of the bagstack had clearly occurred. Tunnels higher in the bagstack could not be inspected closely because of the sheeting.

23. At the top surface of the bagstack many of the vertical tunnels and some of the horizontal tunnels were ill defined due to movement of the top layer of sacks and because of the necessity of forming a tunnel along the top ridge for fumigation. However in some positions it was possible to see down into vertical tunnels.

Airflow

24. Appendix D gives a table of airflow readings taken over the first four months of the trial in both m/s and as a percentage of the exterior wind speed. The wind was usually north or north-easterly and resulted in air flowing into the east face and out of the west face, as shown in figure 5. The north and south faces were inaccessible due to sheeting.

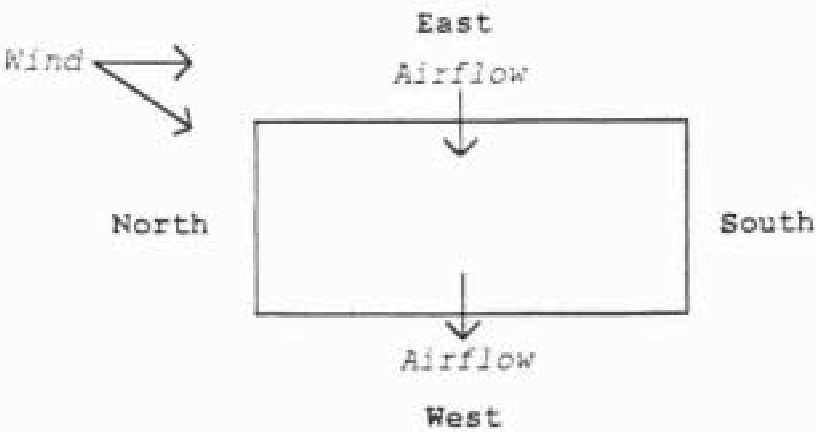


Figure 5. Plan view of airflow into the bagstack.

25. External windspeed was usually in the range 1 to 2 m/s; in the tunnels it was below 1 m/s, usually in the range 20-50% of external wind speed. This, and experience gained when developing the airflow measurement method, tends to confirm what would be expected, i.e. a strong correlation between external windspeed and airflow in the tunnels. The observations show no obvious reduction in airflow in the tunnels as the trial progressed, though the variation in choice of tunnel, and variability of the results, make any quantitative treatment of the results very difficult. Although it is not possible to be certain of the route of airflow in the bagstack, it seems likely that air is blowing into the sides of the bagstack which face the prevailing wind and out of the opposite sides.

26. Airing of the sack appears to have had little effect on airflow when the airflow data is compared with the airing dates (appendix B). This may suggest that the main ventilation effect is gained through airflow into and out of the long sides and bottom of the bagstack rather than the top, though airflow out of the top was measured on a few occasions.

27. The cigarette method of assessing airflow direction has proved effective and reliable at the low airflows involved and is also very cheap.

Temperature

28. Figures E1 to E8 in Appendix E present the first four months of temperature data for the two planes in the bagstack, arranged into external positions, positions in tunnels, positions in sacks next to tunnels and positions in sacks with no contact with tunnels. The fumigation date is marked with an arrow.

29. External positions, Figures E1 and E2, include those at the base, faces and top of the bagstack and in the logger housings. All positions varied significantly from day to day as would be expected. Position 1 (bagstack base) was at approximately 25°C and showed no long term trends. Positions 6 and 8 (west face and top) were similar to the base but were respectively 5°C and 10°C hotter, i.e. 30°C and 35°C. Position 14 (logger housing) was slightly hotter than the base.

30. Figure 6 shows the temperature at positions 4 (sack not near a tunnel, 16 (sack next to a tunnel) and 12 (in a tunnel) for plane A and summarises the data from all the internal positions in this plane. As shown in Figure 4, these positions are in a line and each is progressively further from a tunnel.

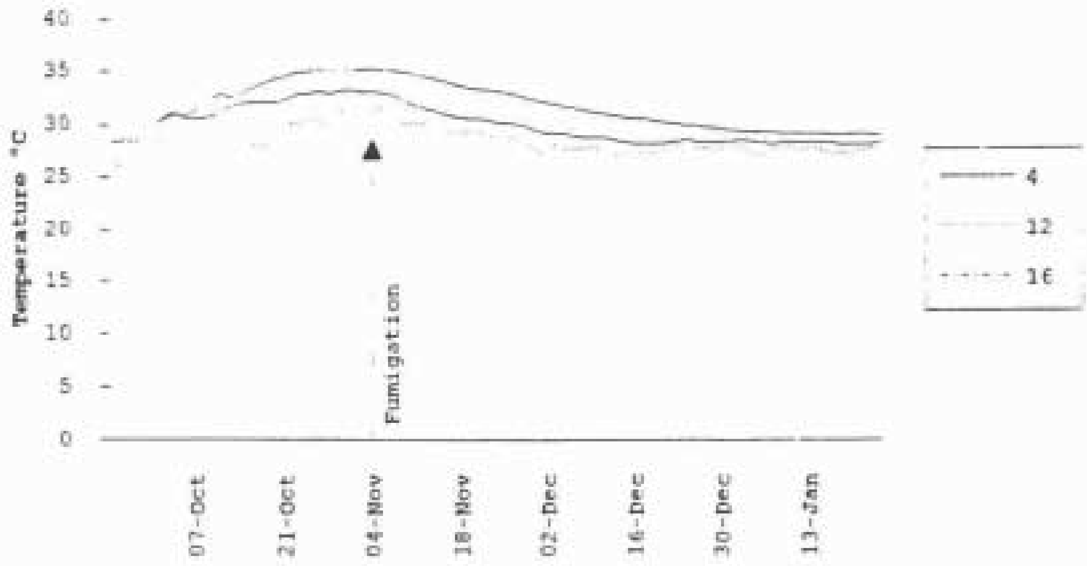


Figure 6. Positions 12, 16 and 4 in plane A of the bagstack, each progressively further from a tunnel.

31. The temperature at all internal positions followed a pattern of rising from the start of the trial until the fumigation then falling until the end of the period. At the day of fumigation position 12 was at 31°C, position 16 was at 33°C and position 4 was at 35°C. During the period of falling temperature after fumigation these differences were reduced until all the positions were within 1°C of each other at approximately 29°C. Positions 4 and 16 appeared to have reached steady temperatures before the fumigation and at the end of the period.

32. Analysis of the non-averaged data from positions 4, 12 and 16 showed that the temperature varied diurnally in the tunnel by 1°C to 2°C peak-to-peak but did not vary at positions in the sacks. This suggests that the tunnels are allowing ventilation to occur throughout the centre of the bagstack.

33. The results from plane B (Figures E2, E4, E6, E8) show few differences from those in plane A. Position 2 (Figure E4) in plane B rose rather more sharply than other positions, reached a peak of 35°C one month before

fumigation and then fell by approximately 1°C and had started to rise again by the time of fumigation. It was the only position to form two temperature peaks in this way, but there were a number of other positions where the temperature was still rising at the time of fumigation. This may be a significant point. In plane A, the temperature rise appeared to have finished by the time of the fumigation and this would suggest that the stacking pattern rather than the fumigation had reduced the peak temperature in the bagstack from the limits of 40°C plus seen in bagstacks on this site in the past (Kennedy and Devereau, 1994), see Figure 7. However, in plane B, the temperature was still rising in some positions, albeit very slowly at the time of fumigation. Past trials (Kennedy and Devereau, 1994) showed no reduction in temperature after fumigation in wpp bagstacks, as shown in Figure 7.

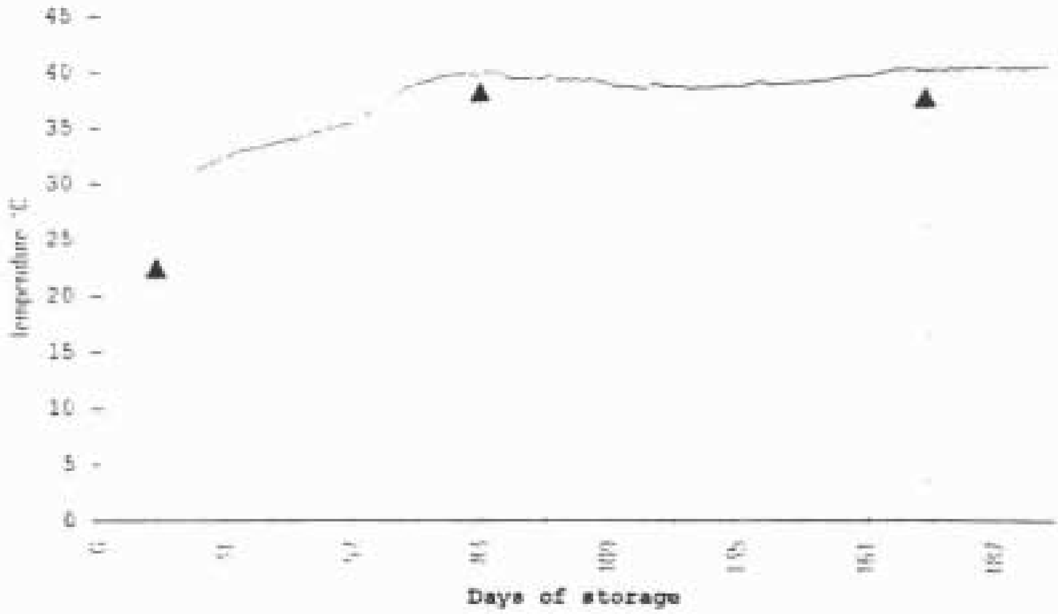


Figure 7. Temperature in a central position in a wpp bagstack at Concession.

34. The following summarises the temperature results to date:

- the temperature in all internal positions rose and then fell;
- the highest temperatures were 35°C in sacks not in contact with tunnels (≈29% of the bagstack);
- sacks in contact with tunnels (≈54% of the bagstack) were cooler than sacks not in contact with tunnels but were hotter than the tunnels, showing that heating must be occurring inside the sacks;
- there are diurnal temperature fluctuations in the tunnels, showing that ventilation is occurring;
- temperature rises stopped in some positions and cooling commenced in all positions from the date of fumigation onwards;
- towards the end of the period all positions had converged to approximately 29°C;
- the temperature at the outside of the bagstack showed no trend to match the pattern of temperature change within the stack.

Moisture

35. The safe m.c. for storage of the maize used by GMB is 12.5% (wet basis). Oven m.c. determinations by GMB are given in appendix F. All were within the safe range. Figures 8 and 9 show the changes from these initial m.c.s recorded by the Reethorpe sensors. They show no rises above the unsafe limit with the exception of position 7, plane B, at the end of the period, which is almost certainly an erroneous reading.

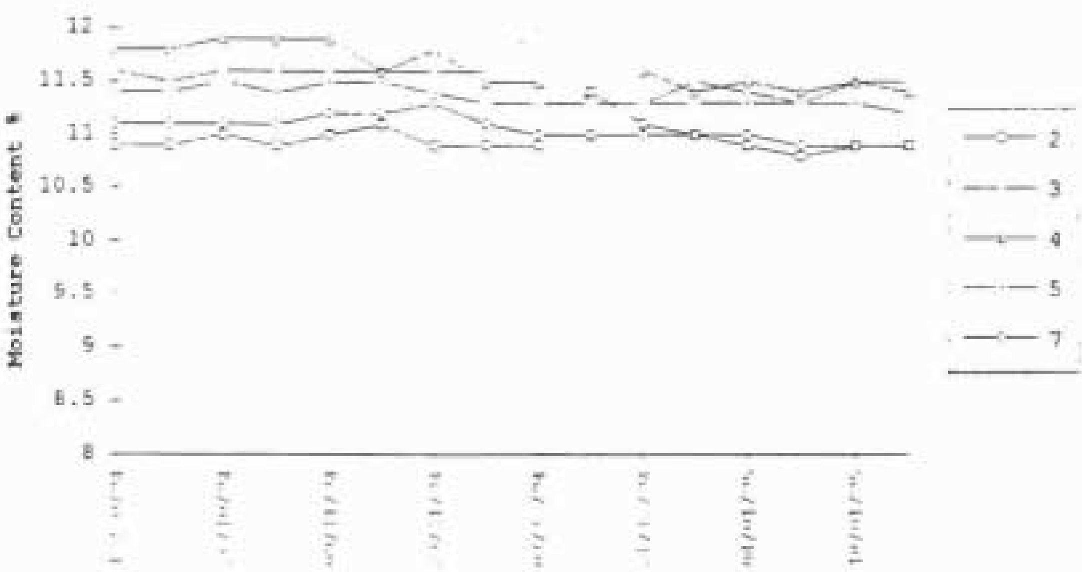
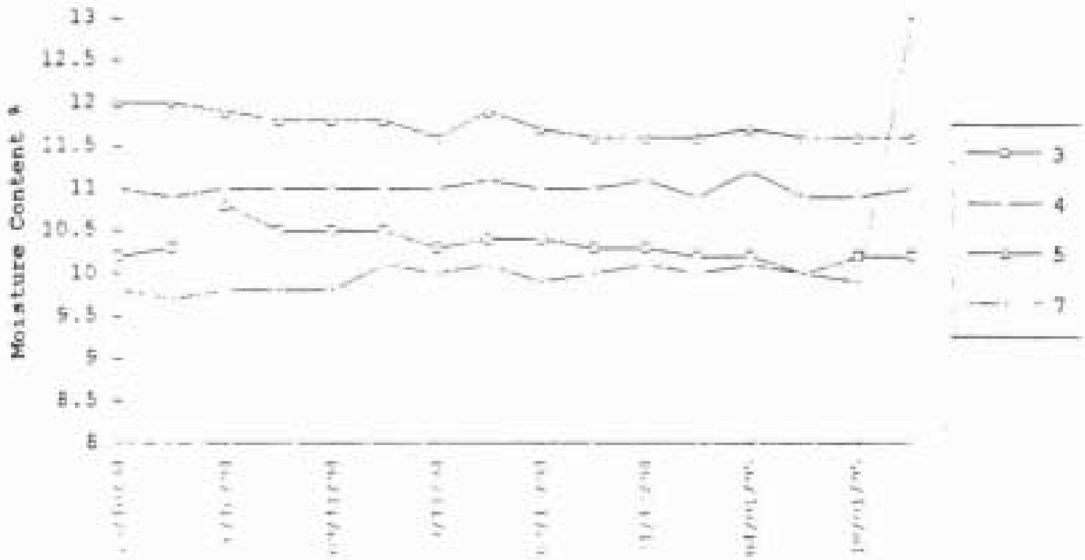


Figure 8. Moisture content changes in plane A.



Figures 9: Moisture content changes in plane B

CONCLUSIONS

36. The ventilated bagstack built at Concession depot has proven stable over the first four months of storage. The ventilation tunnels have remained open as far as can be seen and are allowing ventilation into the centre of the

bagstack. The basic design of the bagstack therefore seems sound.

37. The temperature rise throughout the bagstack is similar to those seen previously in Zimbabwe but differs in having a peak temperature of 35°C in sacks not in contact with tunnels and 33°C in sacks in contact with tunnels, falling to 31°C on the surfaces of sacks in tunnels. Sacks next to tunnels make up approximately 54% of the bagstack. These temperatures may be compared with the 41°C peaks seen previously. It may therefore be concluded that the ventilated bagstack has to date experienced lower temperature rises than previously seen.

38. The fall in temperature to 29°C at the end of the period, started at almost exactly the same date as the fumigation and did not correspond to any ambient temperature change. It may thus be concluded that the fumigation brought about the fall in temperature. This again differs from previous investigations where fumigations of woven polypropylene bagstacks have produced negligible effect on high temperatures.

39. As many positions in the bagstack had reached a steady peak temperature just before fumigation it may be concluded that the fumigation alone did not result in the lower peak temperatures, though there were some positions where temperature was still rising at the time of the fumigation.

40. The lower temperature rise and the subsequent fall in temperature have resulted in significantly cooler storage conditions in this bagstack over the first four months of storage than seen previously.

41. The temperature rise in sacks to levels above those in the tunnels, and cooling to a uniform temperature throughout the bagstack, show that the source of heating was within the stored grain. Moisture contents were below those necessary for mould growth.

42. The drawbacks of the ventilated bagstack are the longer building time, greater work and requirement for more semi-skilled labour, though these will improve with experience. Tunnelling also results in a somewhat reduced storage capacity, approximately 8.5% in this case.

RECOMMENDATIONS

43. The ventilated bagstack is intended to remain in place for 12 to 18 months before despatch. Given the encouraging results to date it is important that data collection continues so that a complete set of data from building to despatch is gathered. This will require collection of data from the dataloggers at further four month periods as they become full, i.e. by the ends of May 1995, September 1995, January 1996 and May 1996 or time of despatch. Datalogger batteries also need to be monitored and changed as necessary to ensure that no data is lost. These actions require only a brief visit to the site and should be easy to incorporate into another visit. As the project under which this work has been carried out will finish in April 1995 it is recommended that arrangements to fund collection of data from the trials are addressed. Beyond this it will be necessary to collect samples from the bagstack at despatch to complement those taken for insect and colour analysis etc. at the start of the trial.

REFERENCES

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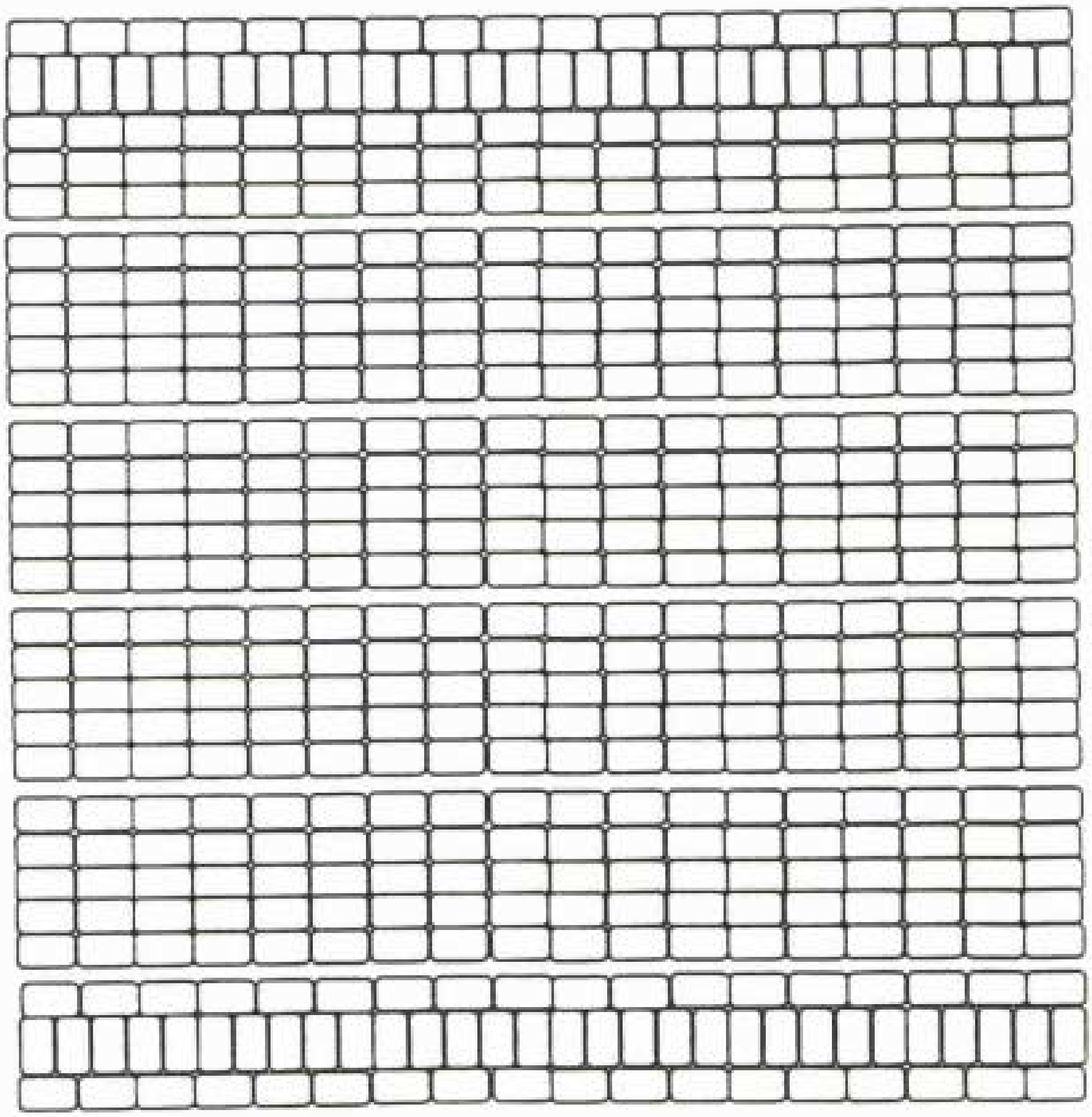
PHILLIPS S I AND DONALDSON T J (1994). *EC DGXII Research Project Workshop, Harare, Zimbabwe, 6-10 June 1994*. Investigations into the causes and prevention of heating and discolouration ('Stackburn') in bag stored maize: Report No.5. NRI Report No. R2140(S). Chatham, UK: Natural Resources Institute.

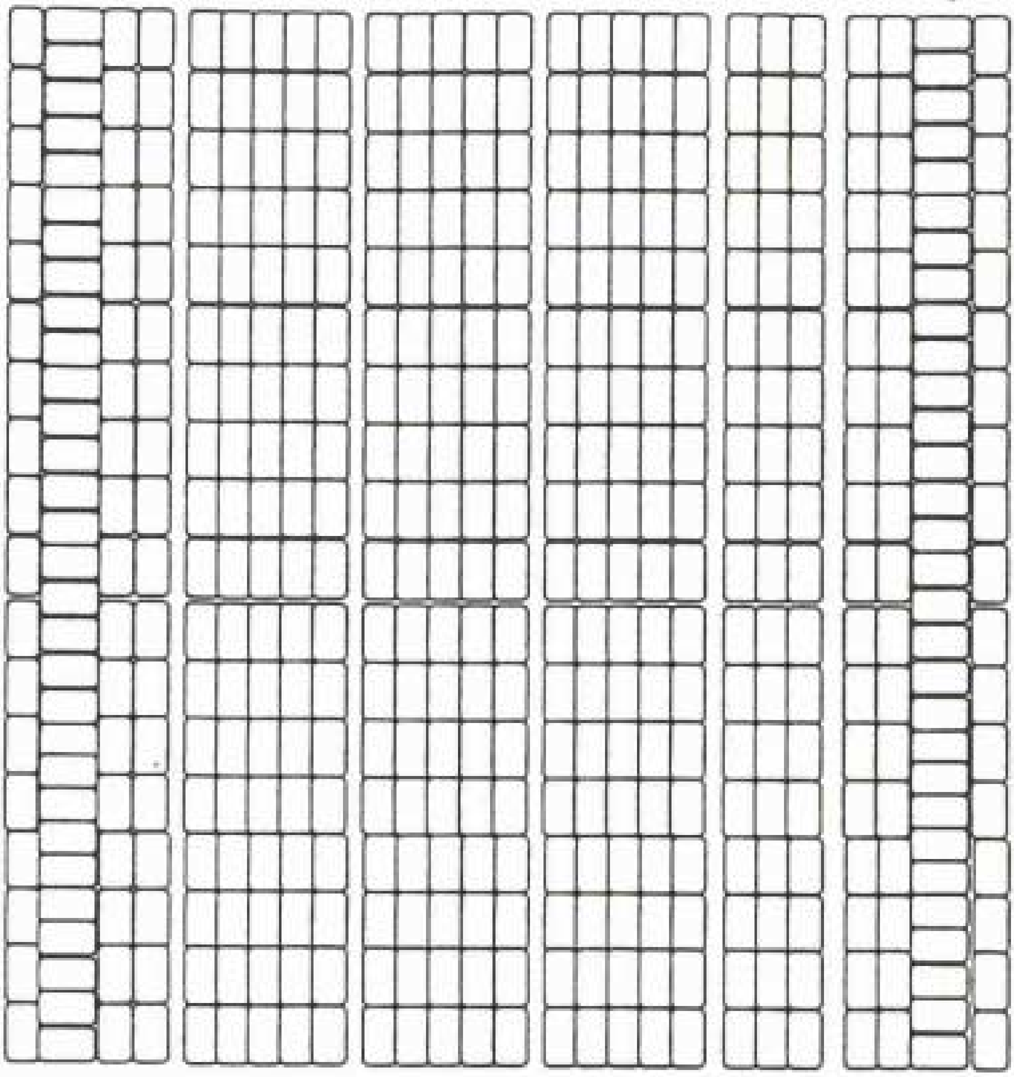
APPENDIX A. DETAILS OF VENTILATED BAGSTACK CONSTRUCTION

The bagstack is based on a unit of four layers which is repeated to the top of the stack. As the bagstack gets higher it gets narrower, and the top layers form a pitched roof shape, so the exact layer patterns vary. The following diagrams give an example of the sack layouts in layers 13 to 16 in one of the three sections of the bagstack.



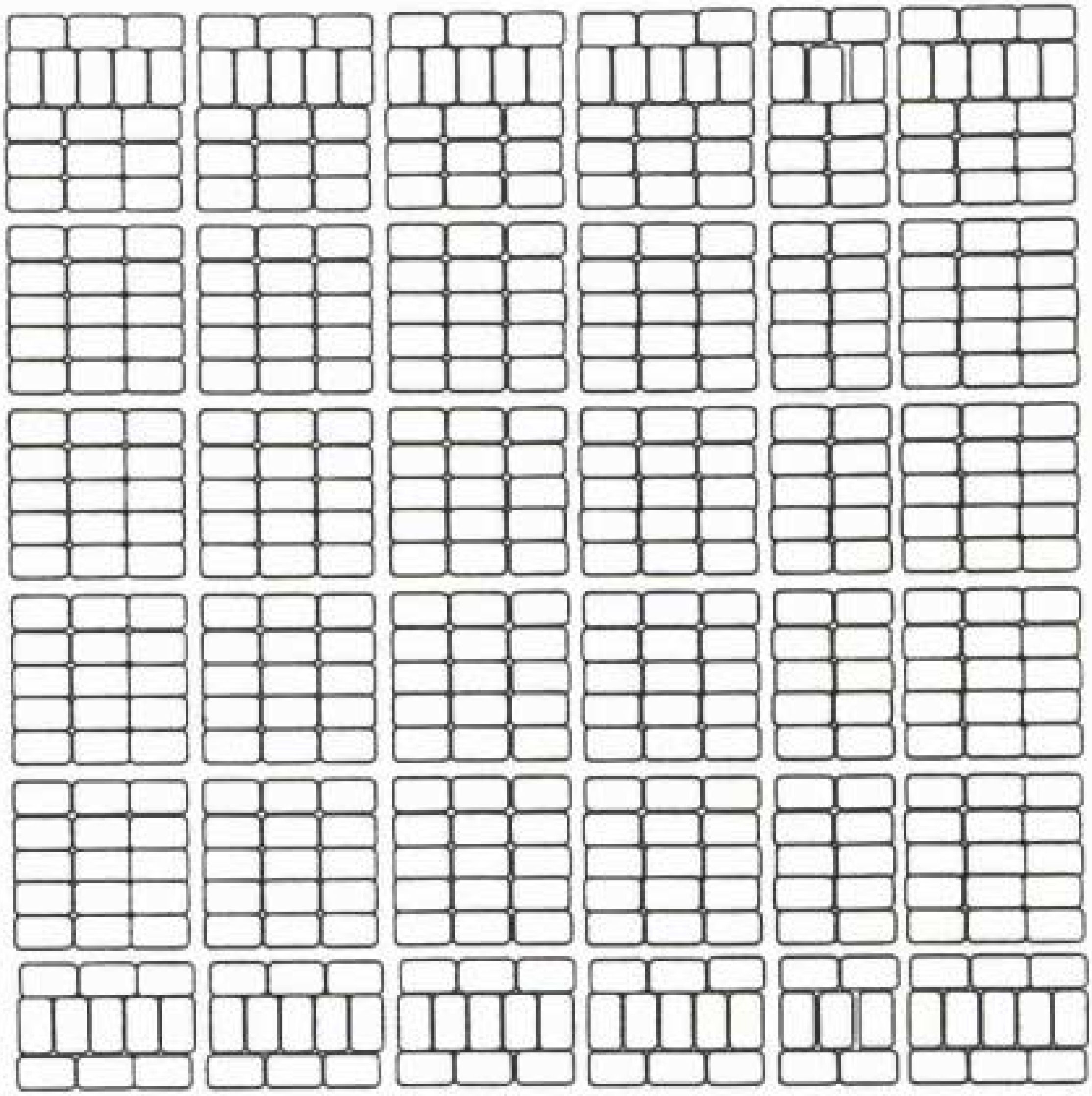
Layer 13: Widthways tunnels only.

The lengthways tunnels in the layer below are covered first. Sacks are then placed carefully to form the edges of the widthways tunnels using strings as guides. The gaps between tunnels are then filled starting from the side farthest from the sack conveyor. As the layer approaches completion the edges of the 14th layer are formed.



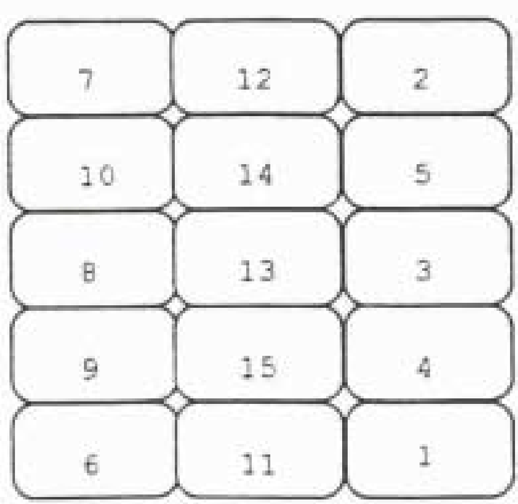
Layer 14: Lengthways tunnels only.

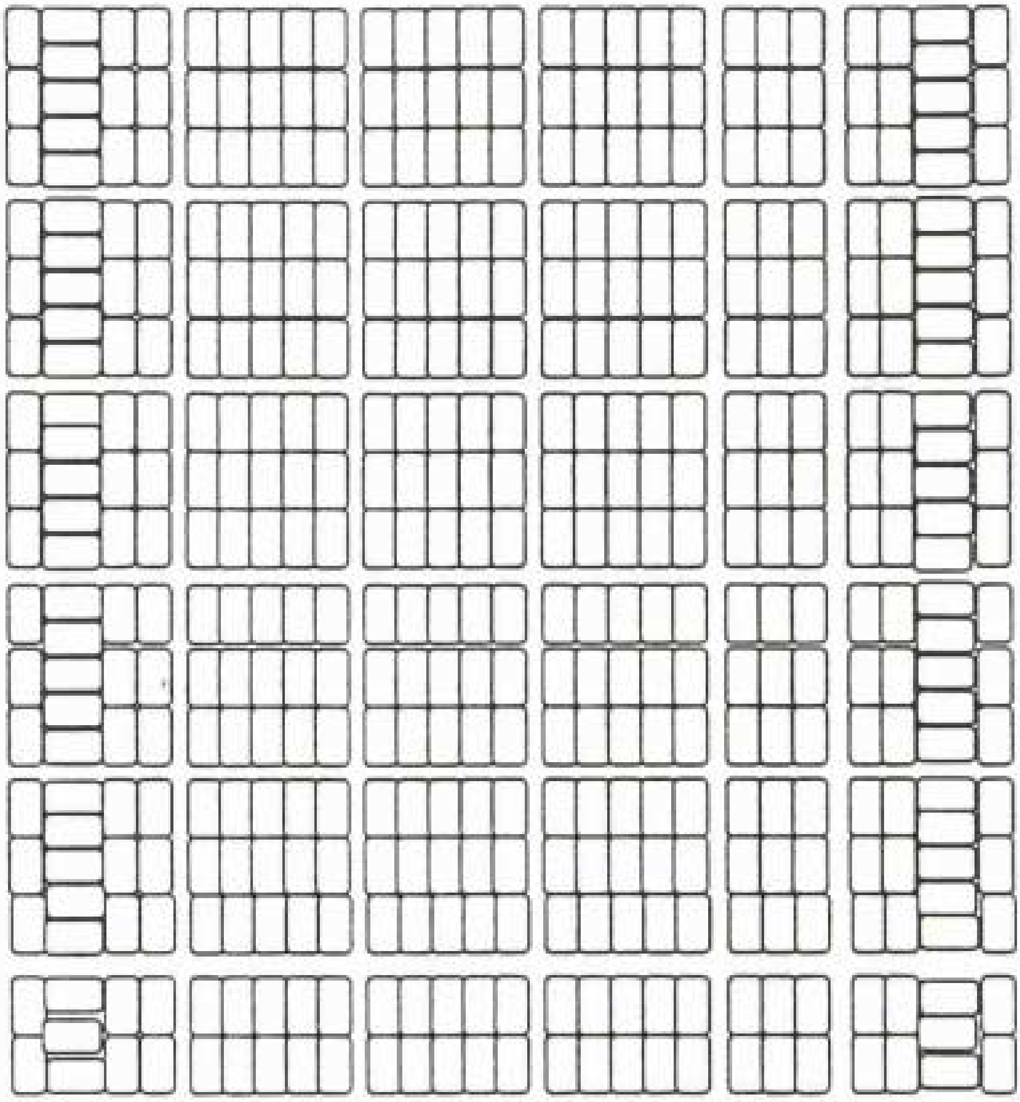
Building progresses in a similar order to layer 13. As the layer nears completion layers 15 and 16 are started on the edge farthest from the sack conveyor and progress across the bagstack one widthways tunnel at a time.



Layer 15: Tunnels in both directions.

In the following two layers the tunnels are in both directions and therefore form squares of sacks. A typical order of laying sacks in a square is shown below.





Layer 16: Tunnels in both directions.

APPENDIX B. AIRING RECORDS FOR THE VENTILATED BAGSTACK

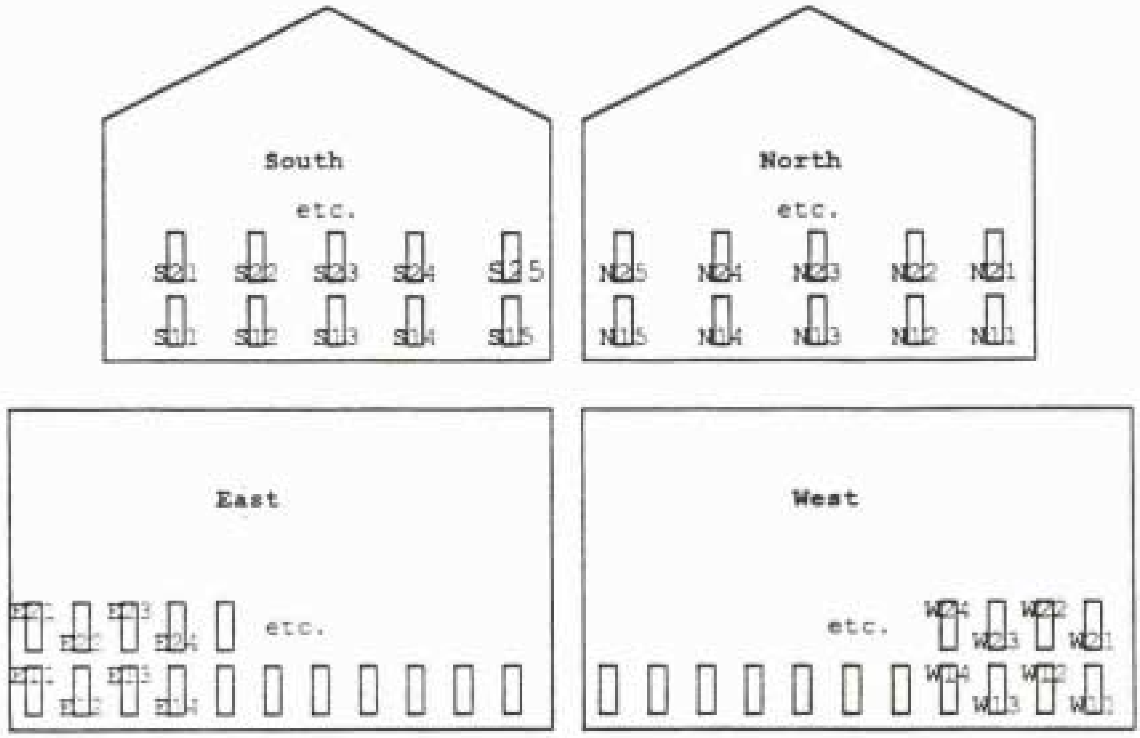
Date	Duration/comments
19 September 1994	5 days
26	5 days
3 October	5 days
10	4 days
17	Closed due to bad weather
18	5 hours
20	6 hours
21	8 hours 30
28	8 hours
29	9 hours 15
2 November	7 hours 20
4	3 hours 30, fumigation
7	6 hours
9	7 hours 40
14	7 hours
15	6 hours 45
16	7 hours 5
18	7 hours 10
21	7 hours 51
23	8 hours
24	7 hours 35
28	8 hours
1 December	5 hours 30
5	8 hours 40
7	8 hours
8	7 hours 2
14	5 hours 10
16	8 hours
19	6 hours
21	5 hours 50, bad weather
4 January 1995	6 hours 30
6	8 hours
15	4 hours 45
17	1 hour 30
18	4 hours 10
25	4 hours 20

APPENDIX C. DATALOGGER CHANNEL NUMBERS AND BAGSTACK SENSOR POSITION NUMBERS

Datalogger serial number and channel	Temperature sensor position	Moisture sensor position	Gas sample tube position
5671: 1	Plane A: 1	Plane A	Plane A
2	2	2	
3	3	3	3
4	4	4	4
5	5	5	
6	6		
7	7	7	
8	8		
9	9		9
10	10		
11	11		
12	12		
13	13		
14	14		
15	15		
16	16		
5670: 1	Plane B: 1	Plane B	Plane B
2	2	2	
3	3	3	3
4	4	4	4
5	5	5	
6	6		
7	7	7	
8	8		
9	9		9
10	10		
11	11		
12	12		
13	13		
14	14		
15	15		
16	16		

APPENDIX D. AIRFLOW RESULTS

The airflow results are shown on the following pages. The tunnel position numbering system is shown below.



Air-flow readings /m/s		+=in -=out														
Channel	13/10/94	19/10/94 covered	26/10/94	02/11/94	09/11/94	16/11/94	23/11/94	30/11/94	07/12/94	14/12/94	21/12/94	28/12/94	04/01/95 airing	11/01/95	18/01/95	25/01/95
Exterior	1.66 N	2.95 NE	1.61 NE				0.69 N	1.9 N		1.23 E		1.48 N	0.93 N	1.68 NE	0.81 S	2.25 N
W11		-0.43														
W12		-0.09								-0.41						
W13							-0.51					0.17			0.25	-0.29
W14										-0.51						
W18			-0.6				-0.39					-0.33				
W19								-0.39								
W21			-0.3					-0.41					-0.36			
W22	-0.34												-0.34			-0.16
W23													-0.28			
W24							-0.76									
W27															0.77	-0.75
W29	-0.68													-0.24		
E11															-0.9	
E12			0.86				0.1	0.1		0.58			0.41			
E14										0.43						
E16			0.6													
E18															-0.41	
E21	0.56							0.61								
E22													0.51			
E24														0.31		
E26	0.55															
S21														-0.39		
S14														-0.45		
pos 8A										-0.85			-0.62		-0.2	
pos 8B							-0.25			-0.71			-0.71		-0.41	

Percentage of exterior																
Exterior	100	100	100				100	100		100		100	100	100	100	100
W10	0	-14.5783	0				0	0		0		0	0	0	0	0
W12	0	-3.05085	0				0	0		-33.3333		0	0	0	0	0
W13	0	0	0				-73.913	0		0		11.48649	0	0	30.8642	-12.8889
W14	0	0	0				0	0		-41.4634		0	0	0	0	0
W18	0	0	-37.2671				-56.5217	0		0		-22.2973	0	0	0	0
W19	0	0	0				0	-20.5263		0		0	0	0	0	0
W21	0	0	-18.6335				0	-21.5789		0		0	-38.7097	0	0	0
W22	-20.4819	0	0				0	0		0		0	-36.5591	0	0	-7.11111
W23	0	0	0				0	0		0		0	-30.1075	0	0	0
W24	0	0	0				-110.145	0		0		0	0	0	0	0
W27	0	0	0				0	0		0		0	0	0	95.06173	-33.3333
W29	-40.9639	0	0				0	0		0		0	0	-14.2857	0	0
E11	0	0	0				0	0		0		0	0	0	-111.111	0
E12	0	0	53.41615				14.49275	5.263158		47.15447		0	44.08602	0	0	0
E14	0	0	0				0	0		34.95935		0	0	0	0	0
E16	0	0	37.26708				0	0		0		0	0	0	0	0
E18	0	0	0				0	0		0		0	0	0	-50.6173	0
E21	33.73494	0	0				0	32.10526		0		0	0	0	0	0
E22	0	0	0				0	0		0		0	54.83871	0	0	0
E24	0	0	0				0	0		0		0	0	18.45238	0	0
E26	33.13253	0	0				0	0		0		0	0	0	0	0
S21	0	0	0				0	0		0		0	0	-23.2143	0	0
S14	0	0	0				0	0		0		0	0	-26.7857	0	0
pos 8A	0	0	0				0	0		-89.1057		0	-66.6667	0	-24.6914	0
pos 8B	0	0	0				-36.2319	0		-57.7236		0	-76.3441	0	-50.6173	0

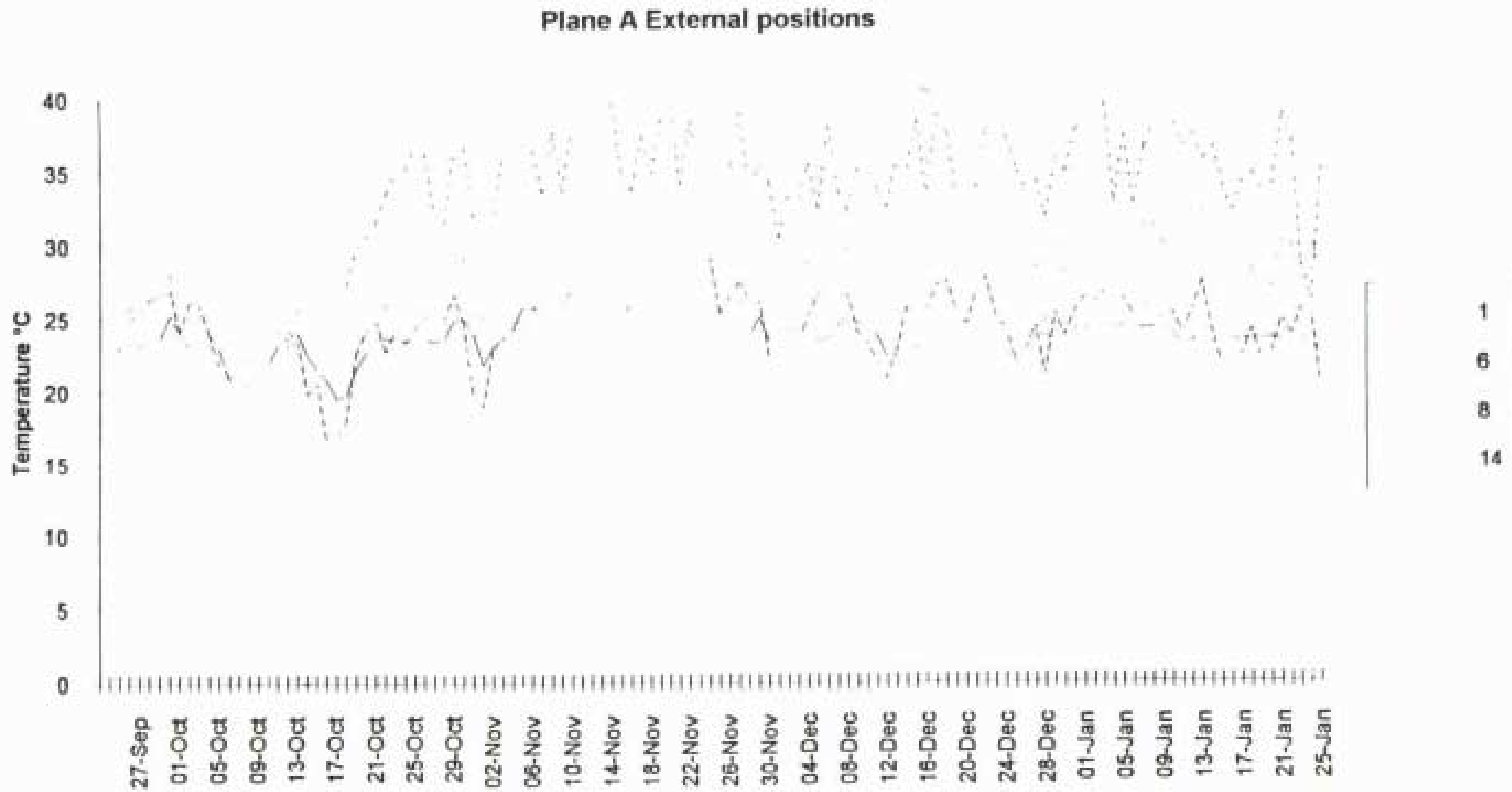

Plane A External positions
Temperature °C
40
35
30
25
20
15
10
5
0
27-Sep
01-Oct
05-Oct
09-Oct
13-Oct
17-Oct
21-Oct
25-Oct
29-Oct
02-Nov
06-Nov
10-Nov
14-Nov
18-Nov
22-Nov
26-Nov
30-Nov
04-Dec
08-Dec
12-Dec
16-Dec
20-Dec
24-Dec
28-Dec
01-Jan
05-Jan
09-Jan
13-Jan
17-Jan
21-Jan
25-Jan
1
6
8
14

Figure E1

Plane B External positions

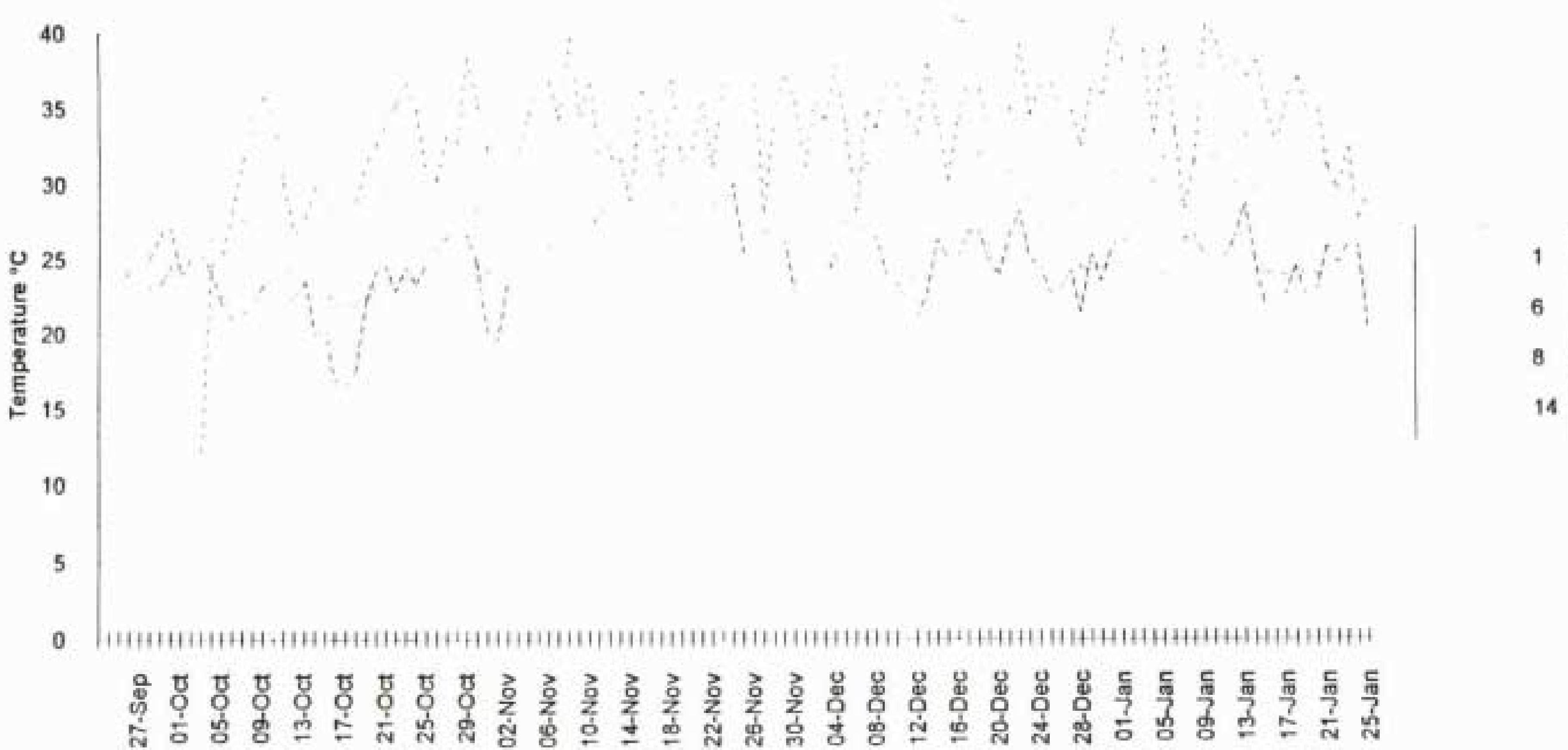


Figure E2

Plane A Internal positions

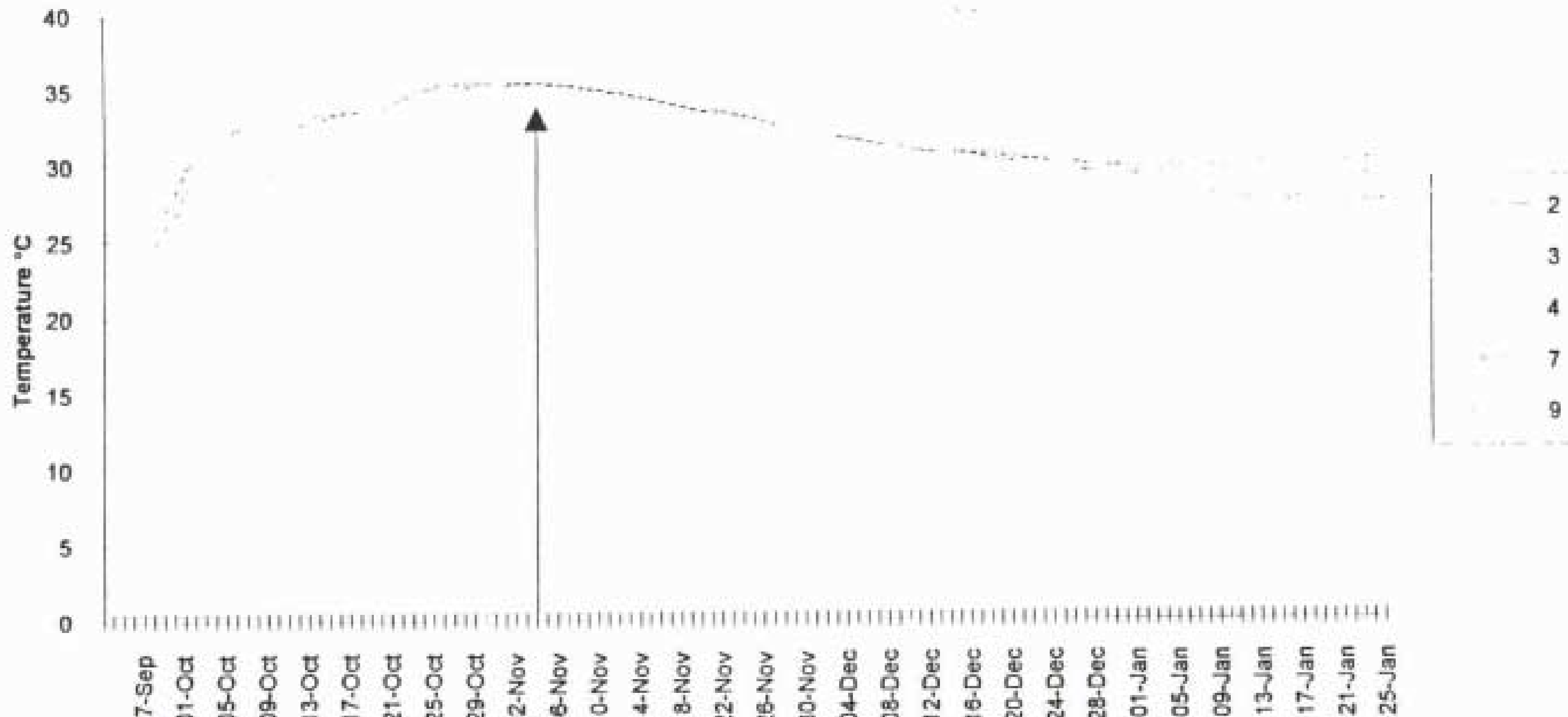


Figure E3

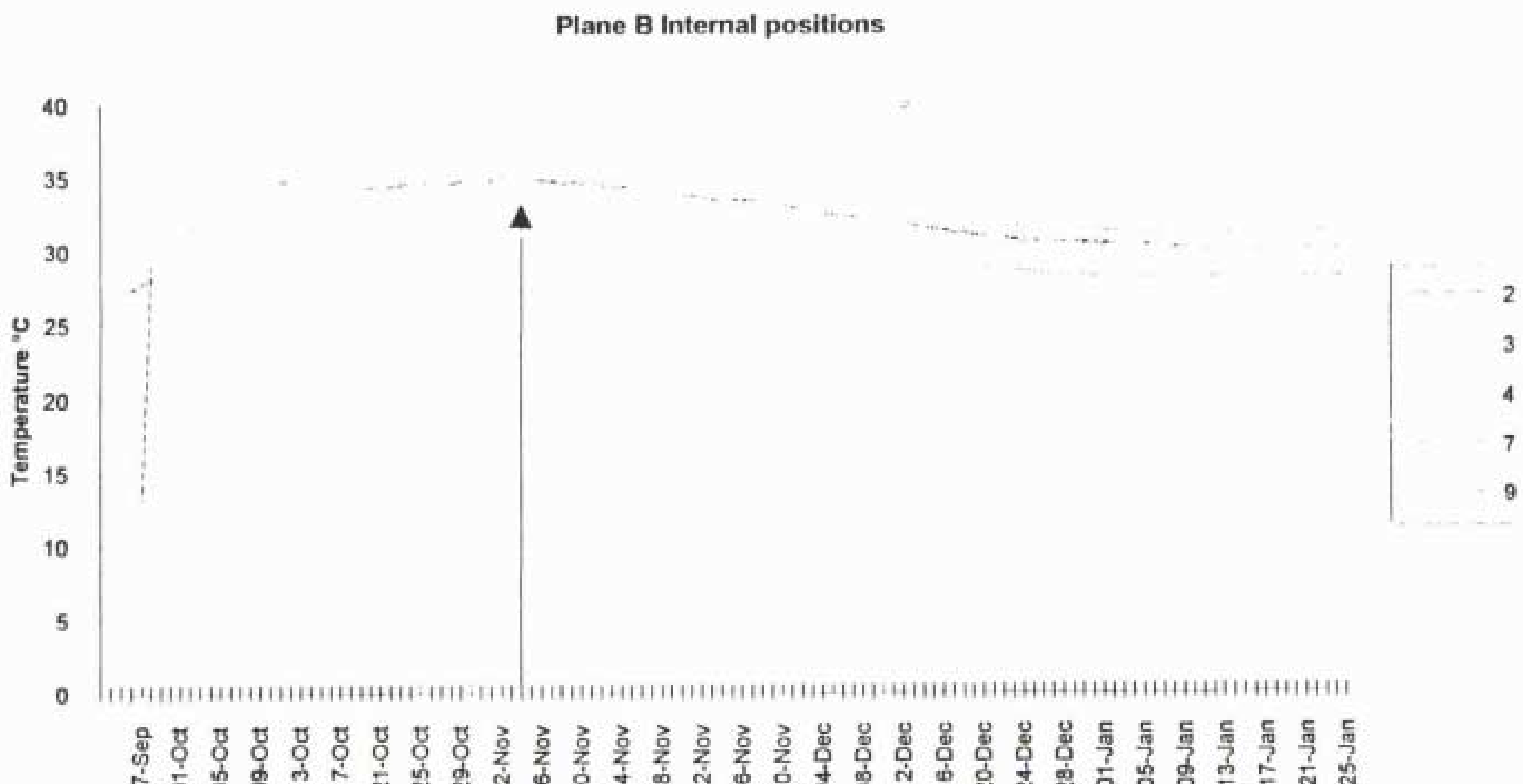

Plane B Internal positions
Temperature °C
40
35
30
25
20
15
10
5
0
27-Sep
01-Oct
05-Oct
09-Oct
13-Oct
17-Oct
21-Oct
25-Oct
29-Oct
02-Nov
06-Nov
10-Nov
14-Nov
18-Nov
22-Nov
26-Nov
30-Nov
04-Dec
08-Dec
12-Dec
16-Dec
20-Dec
24-Dec
28-Dec
01-Jan
05-Jan
09-Jan
13-Jan
17-Jan
21-Jan
25-Jan
2
3
4
7
9

Figure E4

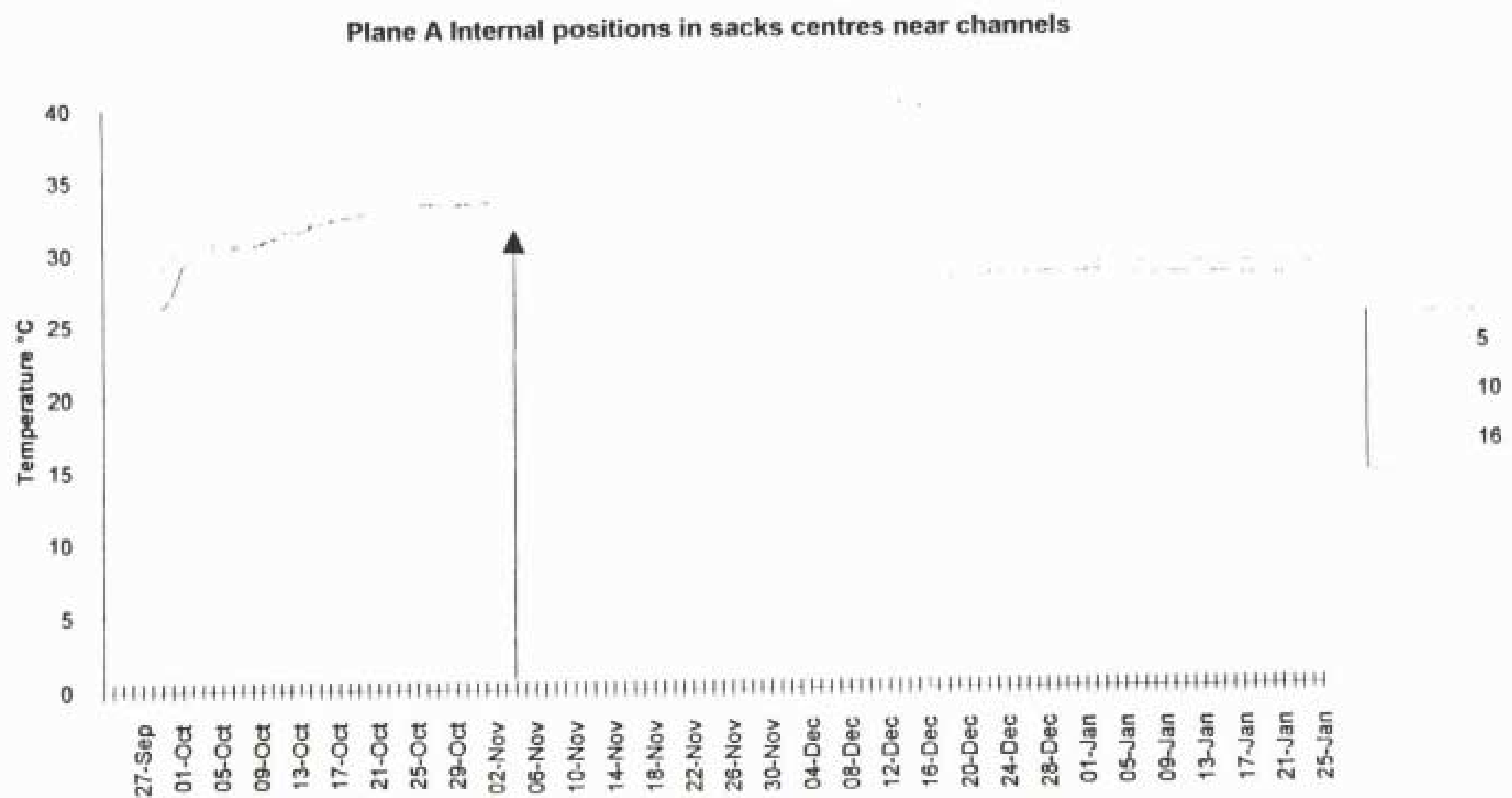

Plane A Internal positions in sacks centres near channels
40
35
30
25
20
15
10
5
0
Temperature °C
27-Sep
01-Oct
05-Oct
09-Oct
13-Oct
17-Oct
21-Oct
25-Oct
29-Oct
02-Nov
06-Nov
10-Nov
14-Nov
18-Nov
22-Nov
26-Nov
30-Nov
04-Dec
08-Dec
12-Dec
16-Dec
20-Dec
24-Dec
28-Dec
01-Jan
05-Jan
09-Jan
13-Jan
17-Jan
21-Jan
25-Jan
5
10
16

Figure E5

Plane B Internal positions sack centres near channels

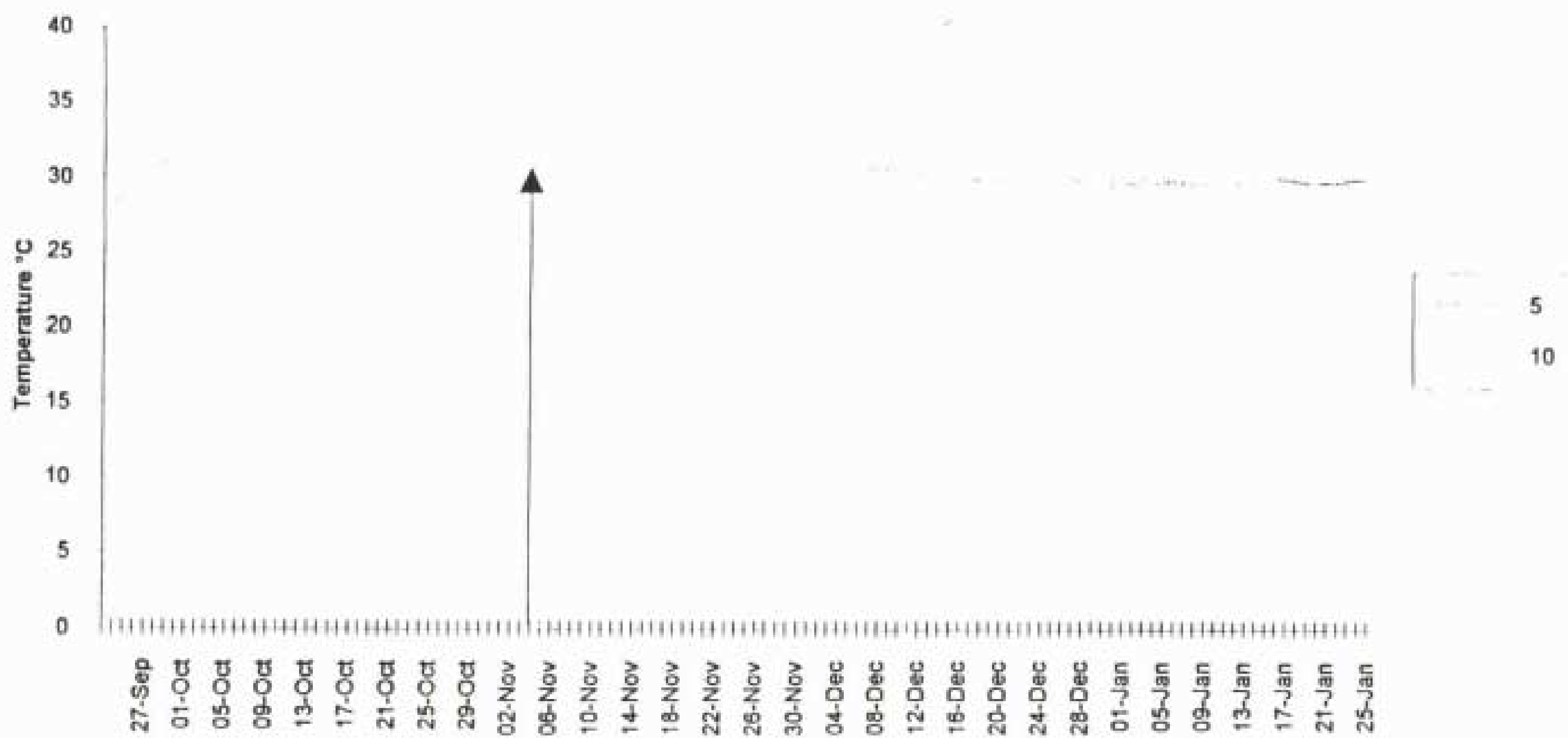


Figure E6

Plane A Internal positions in channels

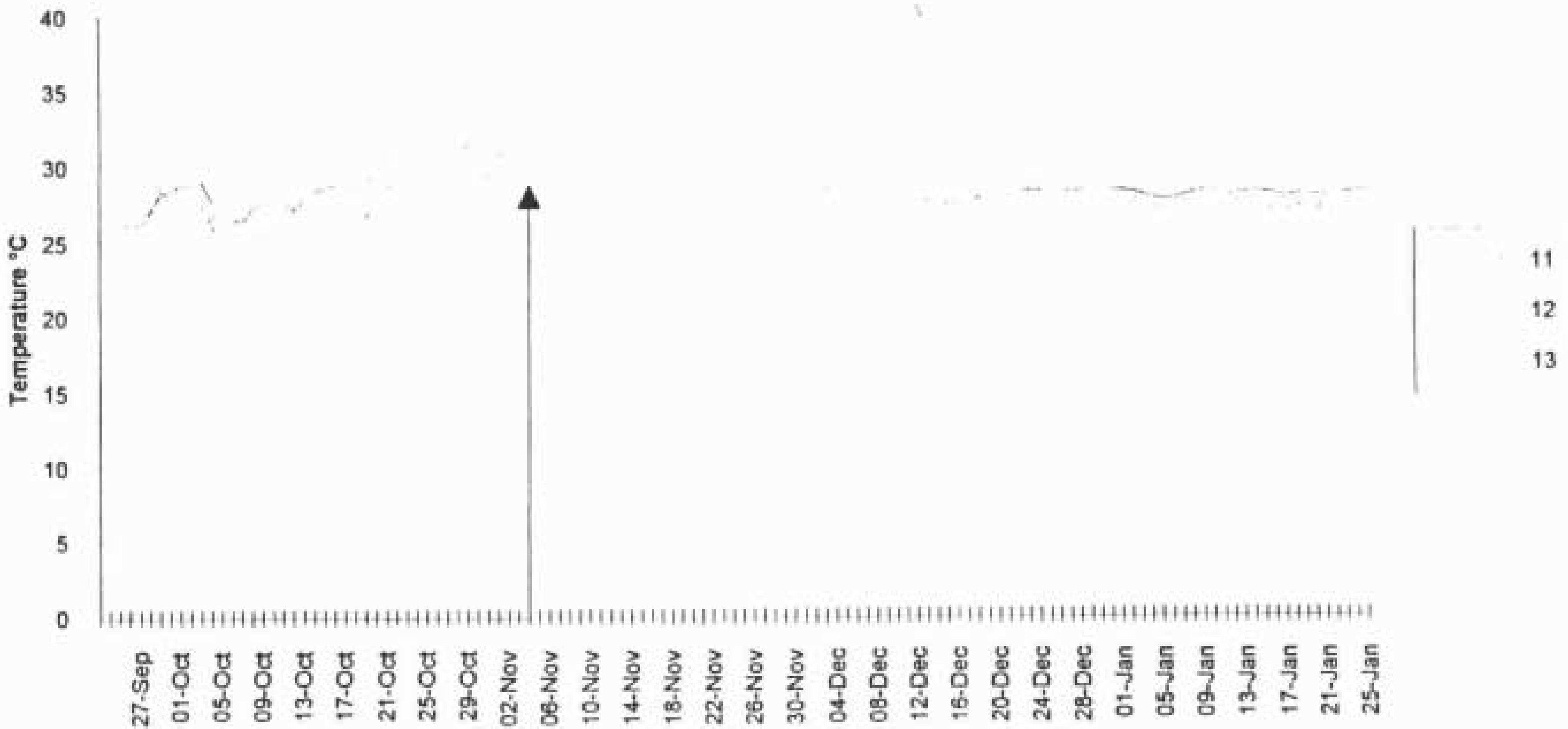


Figure E7

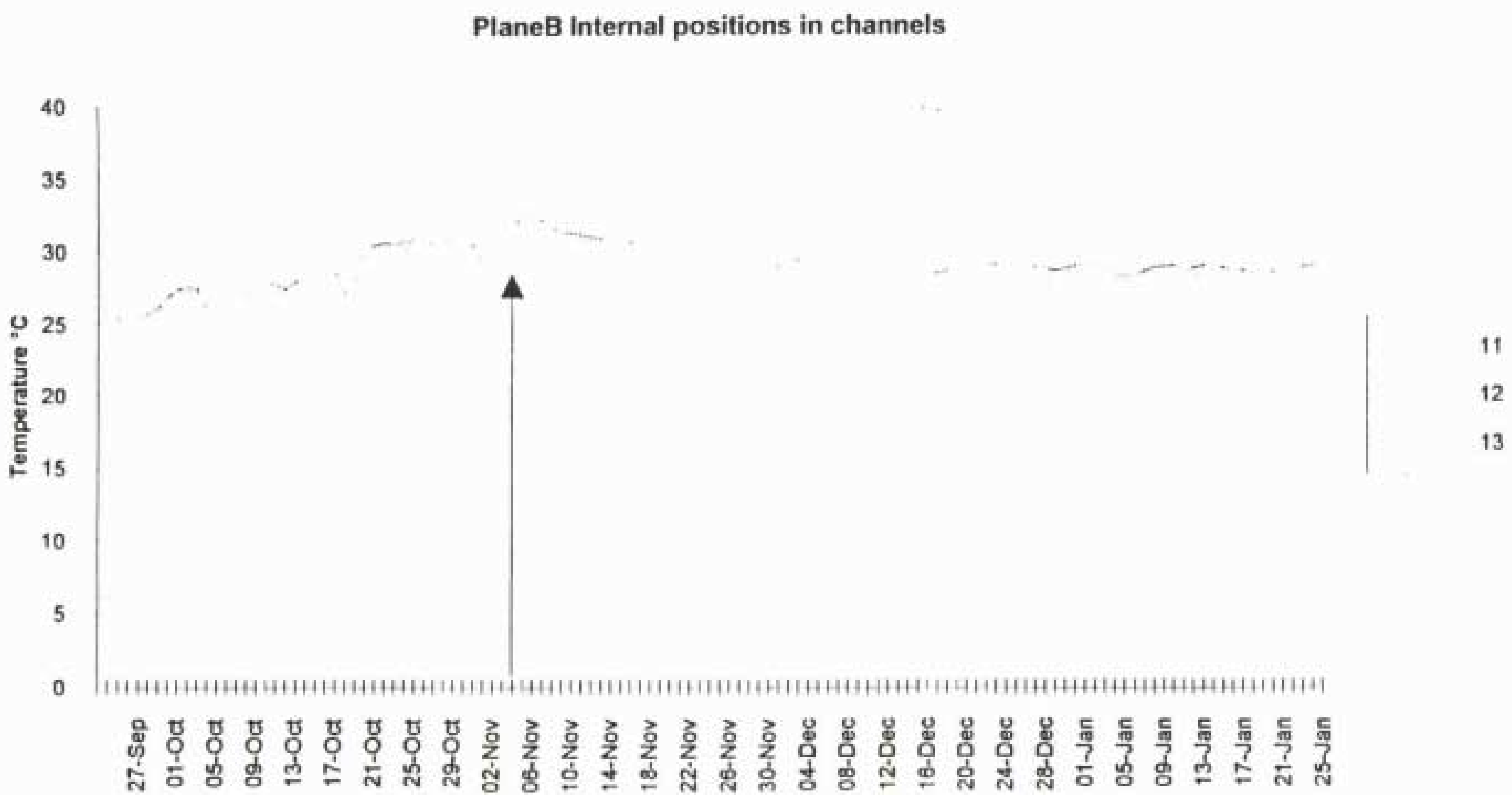

PlaneB Internal positions in channels
Temperature °C
0
5
10
15
20
25
30
35
40
27-Sep
01-Oct
05-Oct
09-Oct
13-Oct
17-Oct
21-Oct
25-Oct
29-Oct
02-Nov
06-Nov
10-Nov
14-Nov
18-Nov
22-Nov
26-Nov
30-Nov
04-Dec
08-Dec
12-Dec
16-Dec
20-Dec
24-Dec
28-Dec
01-Jan
05-Jan
09-Jan
13-Jan
17-Jan
21-Jan
25-Jan
11
12
13

Figure E8

APPENDIX F. MOISTURE CONTENT ANALYSIS RESULTS

The following moisture content were measured by GMB laboratories at Aspindale.

Plane A

Position	% m.c.
1	
2	11.1
3	10.9
4	11.6
5	11.8
6	11.4
7	11.6
8	11.1
9	12
10	12.2
11	11.5
12	11.3
13	12
15	11.5

Plane B

Position	% m.c.
1	
2	12.4
3	11.6
4	10.2
5	11
6	12
7	10.1
8	9.8
9	9.6
10	9.6
11	10.3
12	11
13	11.1
15	10.6
16	11.2

APPENDIX G. DAMAGE AND COLOUR ANALYSIS RESULTS

The following are the results of analyses carried out at the University of Zimbabwe. All percentages are by number of grains unless otherwise stated.

Plane A damage

Position	Insect damage/%	Mechanical damage/%	Discoloured grains/%	Rodent damage/%	Mechanical damage/% by weight
2	0.32	1.17	1.05	0.91	1.33
3	0.59	0.35	1.12	0.70	0.58
4	0.19	0.64	1.03	1.30	0.70
5	0.38	4.67	2.01	0.67	4.09
6	0.13	2.22	0.82	1.28	2.54
7	0.39	2.45	1.07	1.65	2.10
8	0.50	0.84	0.69	0.96	1.06
9	0.24	1.43	0.53	1.30	1.64
10	0.80	1.38	0.55	2.08	1.61
11	0.18	6.32	0.86	2.40	6.27
12	3.35	0.91	1.25	0.80	1.03
13	0.16	5.22	0.66	1.34	5.86
15	0.64	1.03	0.75	1.22	1.12
16	3.35	0.91	1.25	0.00	1.03

Plane B damage

Position	Insect damage/%	Mechanical damage/%	Discoloured grains/%	Rodent damage/%	Mechanical damage/% by weight
2	0.82	0.51	2.47	0.47	0.44
4	0.14	5.59	1.53	1.05	4.67
5	1.37	0.76	1.74	1.32	0.86
6	0.25	2.21	0.94	0.91	2.45
8	0.09	6.05	0.50	0.93	5.82
9	0.19	5.54	0.69	0.74	6.06
10	0.08	4.32	1.13	0.65	4.70
11	0.00	1.30	0.92	1.73	1.13
12	0.27	2.11	3.18	0.91	2.40
13	0.20	0.85	1.37	1.31	0.97
15	0.14	1.02	2.28	1.05	1.12
16	0.23	1.16	0.90	1.31	1.21

Plane A colour

	Mean Chromameter readings			Visual scores	
Position	L	a	b	Grain	Embryo
2	69.88	3.38	24.34	1	1
3	72.59	2.35	24.33	1	1
4	72.17	2.55	23.96	1	1
5	70.81	2.28	23.21	1	1
6	72.12	2.39	24.52	1	1
7	72.04	2.39	22.28	1	1
8	73.31	2.15	23.49	1	1
9	71.60	2.08	22.34	1	1
10	72.54	2.17	23.01	1	1
11	72.22	1.62	21.76	1	1
12	73.44	2.16	22.72	1	1
13	70.99	1.47	21.88	1	1
15	72.45	2.56	24.05	1	1
16	73.44	2.16	22.72	1	1

Plane B colour

	Mean Chromameter readings			Visual scores	
Position	L	a	b	Grain	Embryo
2	70.76	2.97	23.97	1	1
4	72.48	2.45	22.45	2	1
5	72.47	2.46	23.41	1	1
6	71.81	1.51	22.31	1	1
8	71.28	2.49	23.04	1	1
9	72.37	2.50	22.32	1	1
10	71.75	2.56	22.93	1	1
11	71.91	1.81	23.12	1	1
12	73.05	1.54	23.46	1	1
13	71.24	2.21	22.61	1	1
15	73.30	1.74	23.02	1	1
16	71.03	2.31	23.32	1	1