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

Report No. 2: Assessment of spoilage and loss within stackburnt maize

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Acknowledgements

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Summary

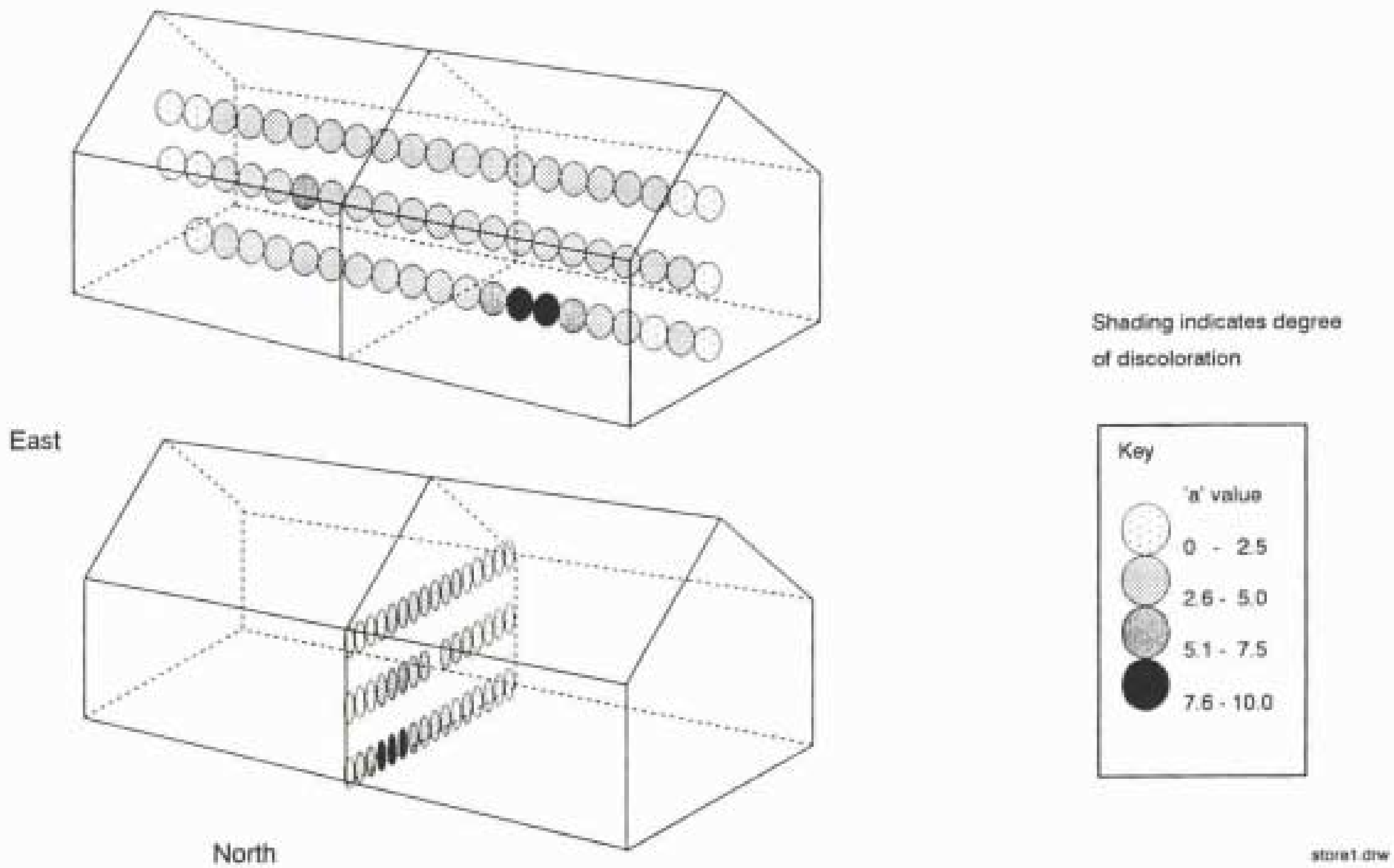
1. As part of a research project into the causes of internal stackburn in large-scale maize bagstacks in Zimbabwe, an experimental stack in which internal heating had been recorded was dismantled and sampled to determine whether maize discoloration (stackburn) had occurred within the stack and its extent. The opportunity was taken to assess the possible differences within adjacent jute and polypropylene bags.

2. During the field study of the stack, a total of 283 bags were sampled and analysed by the Grain Marketing Board (GMB) and NRI. Severe discoloration of the maize was observed in the interior of the stack, being more severe towards the base. The intensity of discoloration was measured using a HunterLab colorimeter and the degree and extent of this discoloration is summarized pictorially in Figure 1.

3. An assessment was made of the loss in weight due to insect damage, and the (financial) loss due to quality changes associated with the discoloration. Weight loss due to visible insect damage was estimated to be 2.3%, with an equivalent value of Zimbabwe $14,200. Downgrading of maize due to discoloration was provisionally/1 estimated to be Zimbabwe $11,600. This gives a combined loss of Zimbabwe $25,800 of the potential value of the stack (or 4.2% of the total). A methodology for future stack examination and recommendations for future trials are outlined.

/1 Nearly half the maize despatched was to another depot on transfer. Its final grade is yet to be determined and, if less than AB grade, will add to the figure given above for 'discoloration loss'.

Figure 1 : Discoloration of maize in the stack



Introduction

1. The GMB of Zimbabwe has experienced severe discoloration of white maize in the interior of large outdoor bagstacks, which they term 'stackburn'. In the past stackburn has been noticed on the surface layers of stacks, immediately below the covering tarpaulins. Its present occurrence has been reported coincidentally with the introduction of polypropylene bags. During despatch of an experimental stack (number 17) at Marondera depot it was possible to sample maize to investigate the incidence of stackburn. The objectives of sampling stack 17 were;

(a) to determine the extent and distribution of discoloured maize, as well as any other associated quality changes;

(b) to identify and measure losses from the stack; and

(c) to develop and determine a methodology for future stack examination.

During the field work the opportunity arose to conduct tests on maize from adjacent jute and polypropylene sacks.

History of the stack

2. Maize used in the construction of the stack was all from the 1989 harvest. Whilst records of variety are not kept by the depot, the common varieties grown in this part of Zimbabwe include hybrids SR52, R215, R200 and R201 (Friis-Hansen, 1991). GMB classifies these hybrids as 'white dent maize'; the majority (approximately 95%) was received through depot transfers from Wedza, and said to be of communal farmer origin. It is likely that this communal maize may have been stored for a short time on the farm, before it was delivered to Wedza. The remainder was restacked from another stack at Marondera.

Table 1: The number of bags of maize by grade, used to construct the sack.

Grade of maize	No bags	% bags
A	8,325	44
B	10,751	56
Total	19,076	100

3. Stack building began on 9 November 1989 and was completed on 5 December 1989, an interval of 27 days. On request of the GMB Research Manager, the stack was built without gum pole dunnage onto a compacted earth floor and covered by 'write-off' tarpaulins and plastic sheets. These were glued together to form a barrier to fumigants and sleepers were placed around the edges. This design was intended to test for any improvement in fumigation effectiveness.

4. The bottom layer of sacks were all placed in the same orientation and the standard GMB stacking pattern was then followed from the 2nd layer upwards. This is shown, together with the location of sample bags, in Appendix 1. All maize delivered to GMB comes in polypropylene bags, but during stack building and despatch some sacks break. Spilled maize was re-bagged into jute sacks both during despatch from Wedza and construction of the stack.

5. Preliminary maize samples (which showed some discolouration) were taken on 21 March 1991 from the eaves level of the stack, and 945 bags removed all together. The stack was then covered until 22 July 1991 when despatch of maize began and continued until 9 August 1991. All the remaining bags of maize were cleared by this date from the site. The grades of maize despatched from the stack are shown in Table 2.

Table 2: The number of bags of maize by grade, despatched from the stack

Grade of maize	No bags	% bags
Export	3,156	17
AB	5,255	27
AB (depot transfer)	8,406	44
DD	2,102	11
Mould damage/1	157	1
Total	19,076	100

Management of the stack

6. As is customary, black plastic sheets were built into the sides at the 14th and 28th layers, and black tarpaulins placed on the top and ends of the stack as protection against rain. The top tarpaulins were pulled back to air the stack occasionally and the airing schedule is given in Appendix 1. At the start and finish of each airing period a sample of maize was taken from a single bag for an on-the-spot moisture content reading using a Marconi meter. These moisture readings are recorded with the airing schedule. After construction the day-to-day management of the stack was the same as for normal stacks.

7. Fumigation of the stack was carried out by covering the entire stack with fumigation sheets, sealing the sheets together by rolling and clamping, and placing sand snakes around the base of the stack. The fumigant used was methyl bromide and the gas was dispersed into the stack through lay-flat tubing, which was placed in a channel along the ridge of the stack. Usual dosage rates of 40g/tonne are used for an

/1 The mould damaged grain was seen to be severely discoloured.

exposure period of 48 hours. The fumigation schedule for the stack is given in Appendix 1 and shows that the maize was fumigated a total of seven times, while it was stored at Marondera.

Methods

8. Sampling was designed to investigate two different situations; firstly, to determine the extent and distribution of maize discoloration and loss of quality from the edges of the stack to the centre point along transects; and secondly, to compare adjacent jute and polypropylene sacks as the opportunity arose.

(a) Transects

A total of six transects were taken across the width and length of the stack. Bags running lengthwise in a row towards the middle of the stack were selected and marked before being put aside for sampling. To do this successfully it was necessary to break down the stack in a orderly fashion, which significantly increased the labour required.

(b) Jute/Polypropylene paired sacks

As the stack was broken down and as jute bags appeared, they were marked together with the adjacent polypropylene bags and put aside for sampling. These sampling pairs were either in a side-by-side or an end-to-end orientation.

Sampling Protocol

9. Marked bags were all sampled in a similar manner according to the following protocol:

(a) a ~1kg scoop of maize was taken from three places in the bag (namely top, middle and bottom) as it was being tipped into a large sieve;

(b) the ~3kg sample was divided down twice, using a riffle divider to obtain a ~750g sample;

(c) from this sub-sample, ~50g was taken for an oven determination of moisture content analysis, and placed in an aluminium screw top tin and sealed with plastic tape;

(d) the remainder was put into plastic bags and labelled;

(e) the sievings from the whole bag were collected and put into a separate plastic bag.

10. Both the sampling methodology and protocol were designed with the assistance of the NRI Statistics Section to ensure that analyses would yield statistically valid results.

Sample analyses

11. Moisture content was determined using the ISO 6540 standard. This method is recommended for accurate measurements (of ±0.1% moisture content); quicker moisture contents can be obtained by using a moisture meter that is calibrated to the ISO 6540 standard for slightly less accurate readings (in the order of ±0.2% moisture content).

12. The method used to determine weight loss due to insects was that described by Boxall (1986) as the gravimetric method. It is a time demanding process but does not require baseline samples. However, this method only measures visible damage and cannot take into account hidden insect infestations. It also assumes that insects attack grains at random, which if not so, can lead to some negative results.

13. Whole grain samples of approximately 200g were measured for colour using a HunterLab Colorimeter. This equipment produces three colour readings for each sample, namely 'L' (black to white spectrum), 'a' (green to red spectrum) and 'b' (blue to yellow spectrum). A large number of samples can easily be measured in a short time, but the equipment is not mobile and unsuitable for field use.

14. The number of dead adult *Sitophilus spp.* and *Tribolium spp.* were counted from the bag sievings. Due to the large numbers found per bag, the sample was divided twice to provide a quarter sub-sample. Nevertheless, this analysis was very time consuming compared to weighing the amount of dust sieved from each bag.

Results - Transects

15. Full results of the analyses are given in Appendix 2 and shown below in Figures 2-9.

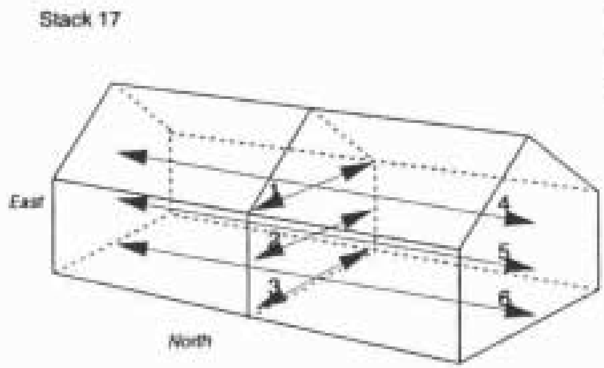
Moisture content

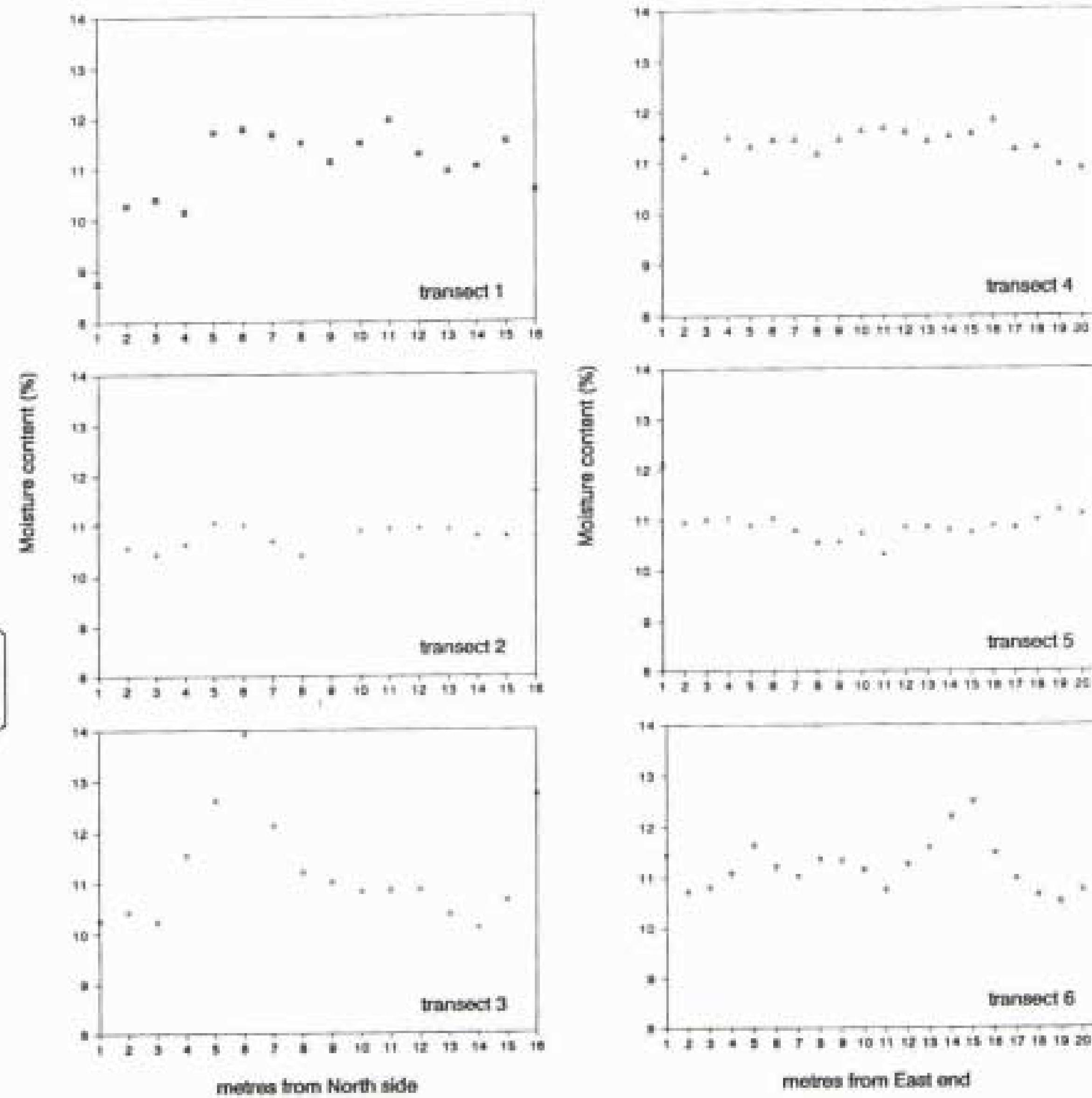
16. Figure 2 shows that moisture contents were uniform throughout the stack and generally below the 12.5% level accepted by the GMB, with an overall mean of 11.1%. These were, however, small peaks in the profiles in the two lower transects, both towards the centre of the stack.

Insect sievings

17. The numbers of dead adult *Sitophilus spp.* and *Tribolium spp.* are illustrated in Figures 3 and 4. The distribution of both species along the transects does not show any clear pattern. Two large counts (one for each species) of over 80,000 insects are omitted from the figures, but were found near the edges of the stack and on the lower transects. The numbers of *Tribolium spp.* tend to increase towards the bottom

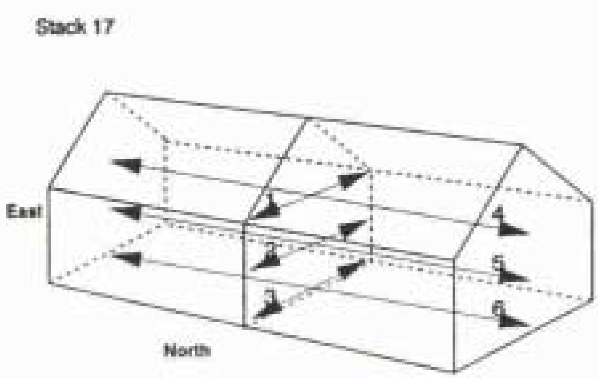
Figure 2 : Moisture content of maize samples taken from transects

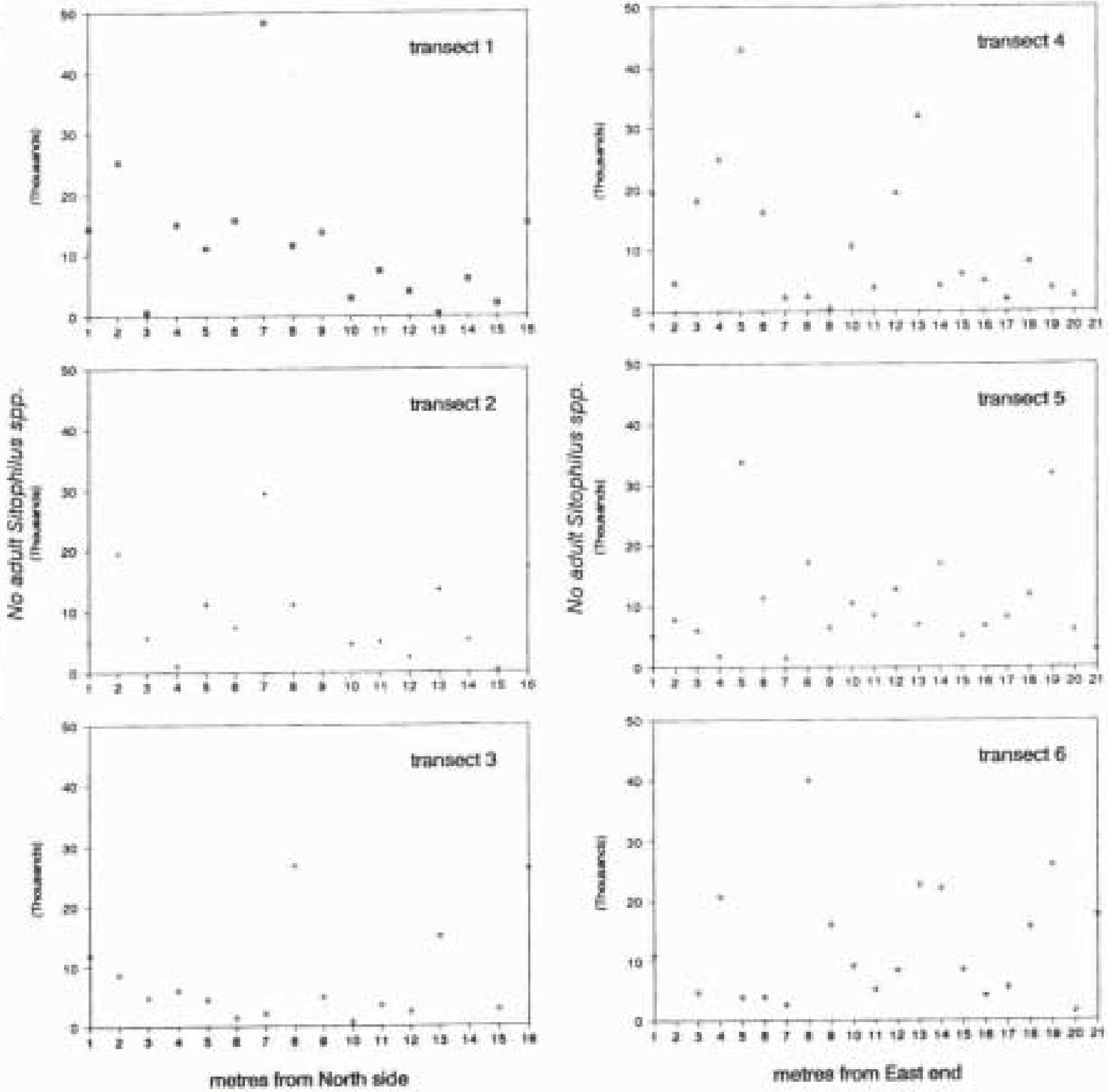




mc.drw

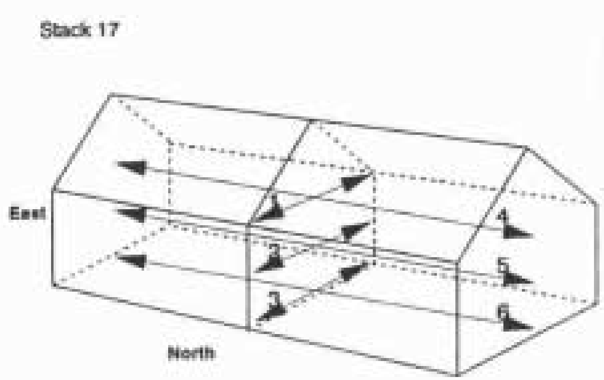
Figure 3 : Numbers of dead adult Sitophilus spp. sieved from whole bags of maize sampled along transects

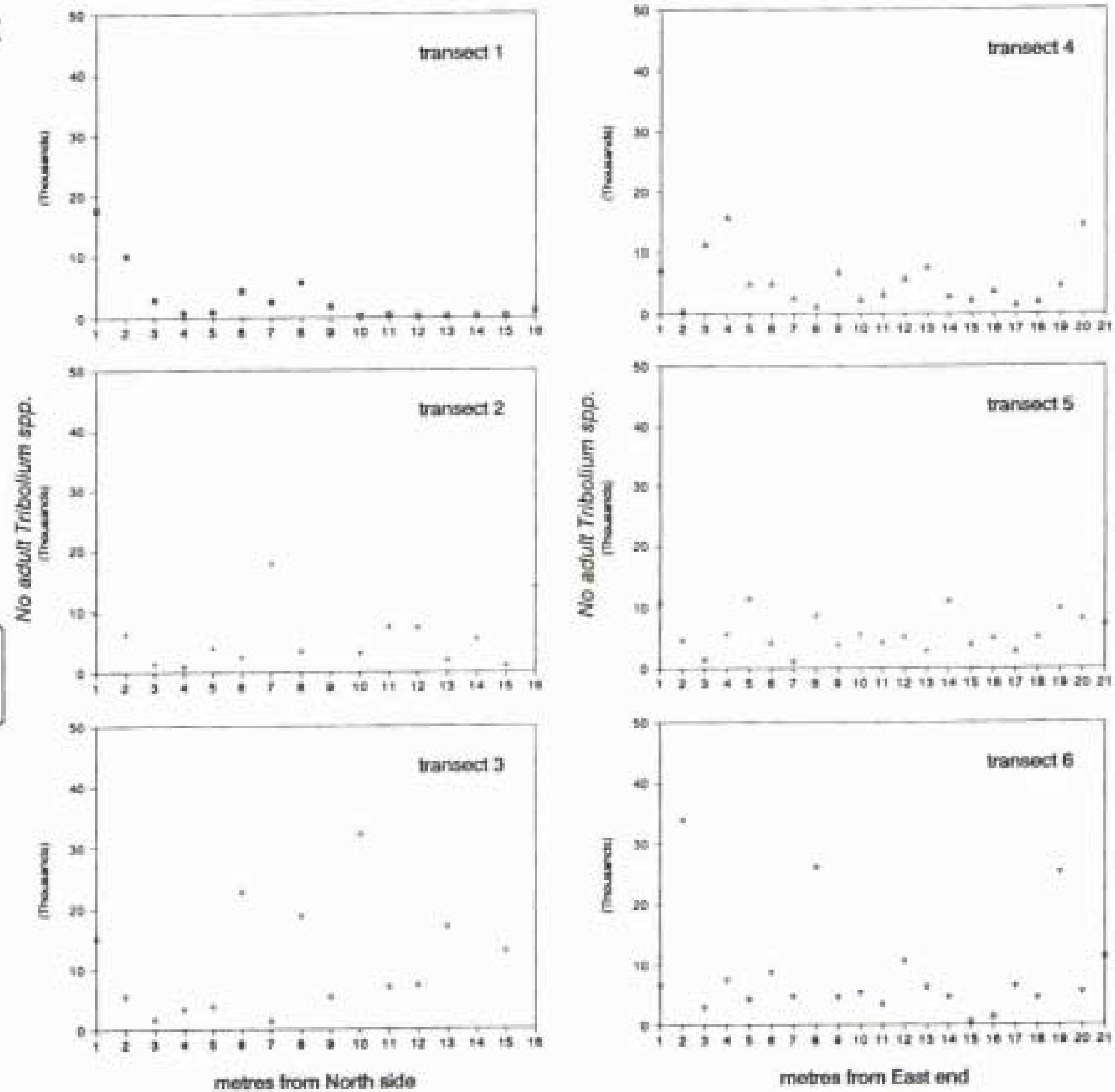




nsit.drw

Figure 4 : Numbers of dead adult Tribolium spp. sieved from whole bags of maize sampled along transects





ntri.drw

of the stack. The means per bag for the transect samples were 11,700 and 7,300 for *Sitophilus spp.* and *Tribolium spp.* respectively and no live insects were found.

Weight loss due to visible insect damage

18. Figure 5 illustrates the weight losses calculated by the gravimetric method along the six transects. Whilst there is no clear trend, it appears that the worst losses are often found within 5-6 metres of the edge of the stack. For all samples, the mean loss was calculated to be 2.3% by weight.

19. Another method of assessing the extent of insect caused damage is to calculate the percentage of maize grains that show visible damage (holes). Using the same data set as for the gravimetric method of loss, the results are illustrated in Figure 6. 17.1% of grains in all the samples showed insect damage, and whilst no clear pattern emerges from Figure 6, the highest figures are often found at the edges of the stack.

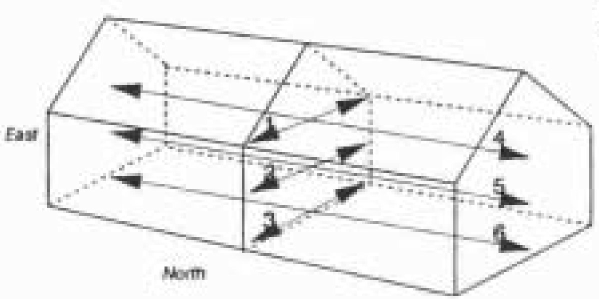
Weight of dust

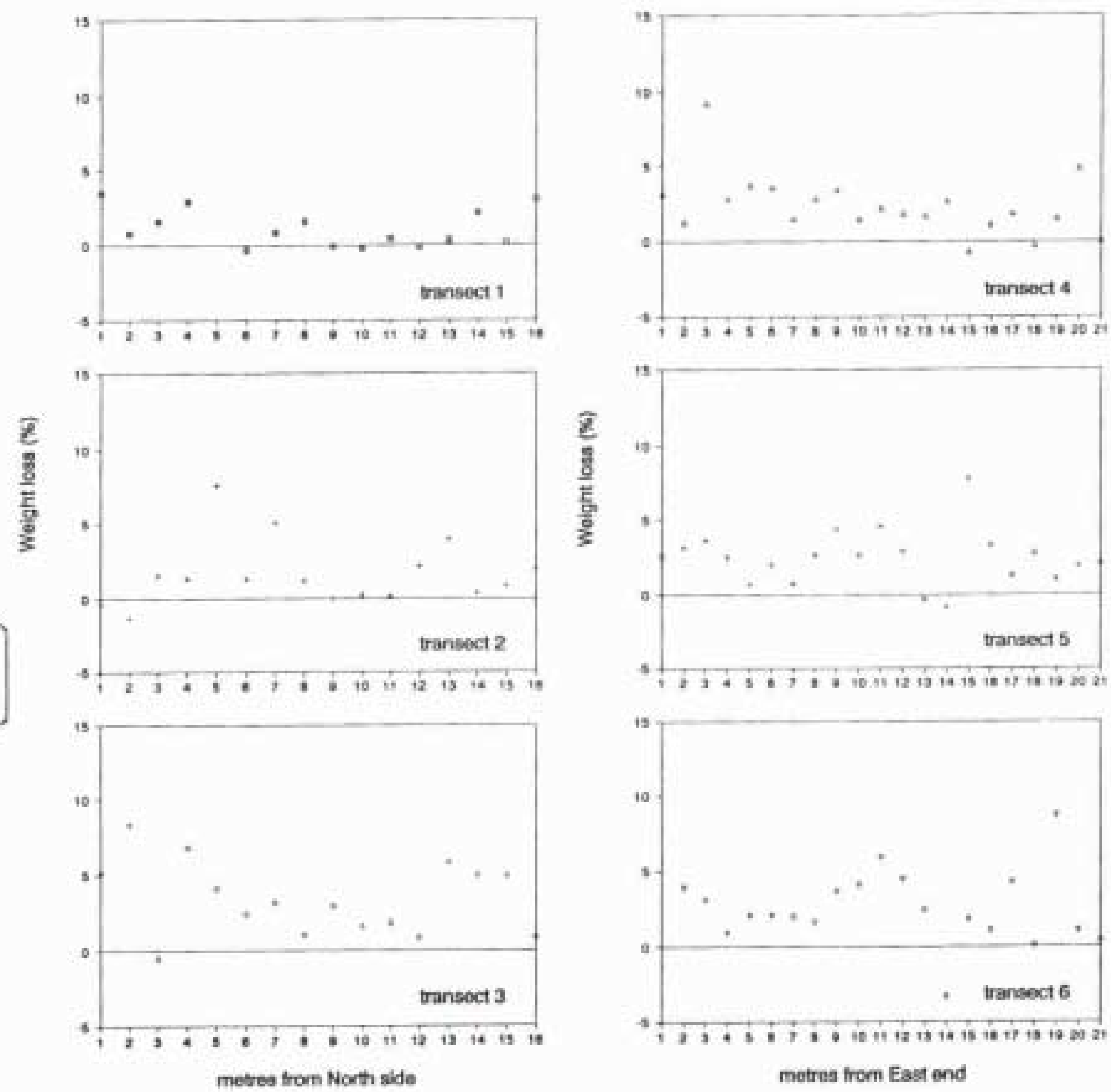
20. The weight of dust retrieved from whole bag sievings averaged 530g. Plotted along the transects in Figure 7 they do not show any clear trend, except to note that the highest values were found in the upper transects.

Colour

21. The large differences obtained from the HunterLab colorimeter could be seen amongst the 'a' and 'L' values and these are illustrated in Figures 8 and 9.

Figure 5 : Weight loss due to visible insect damage of maize samples taken along transects

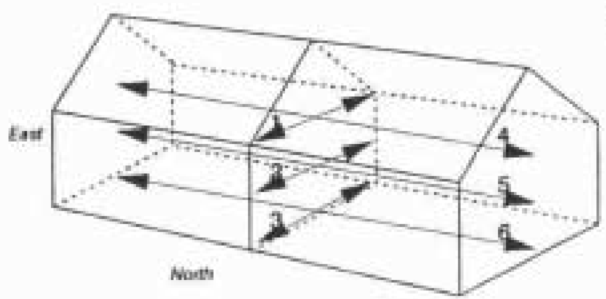


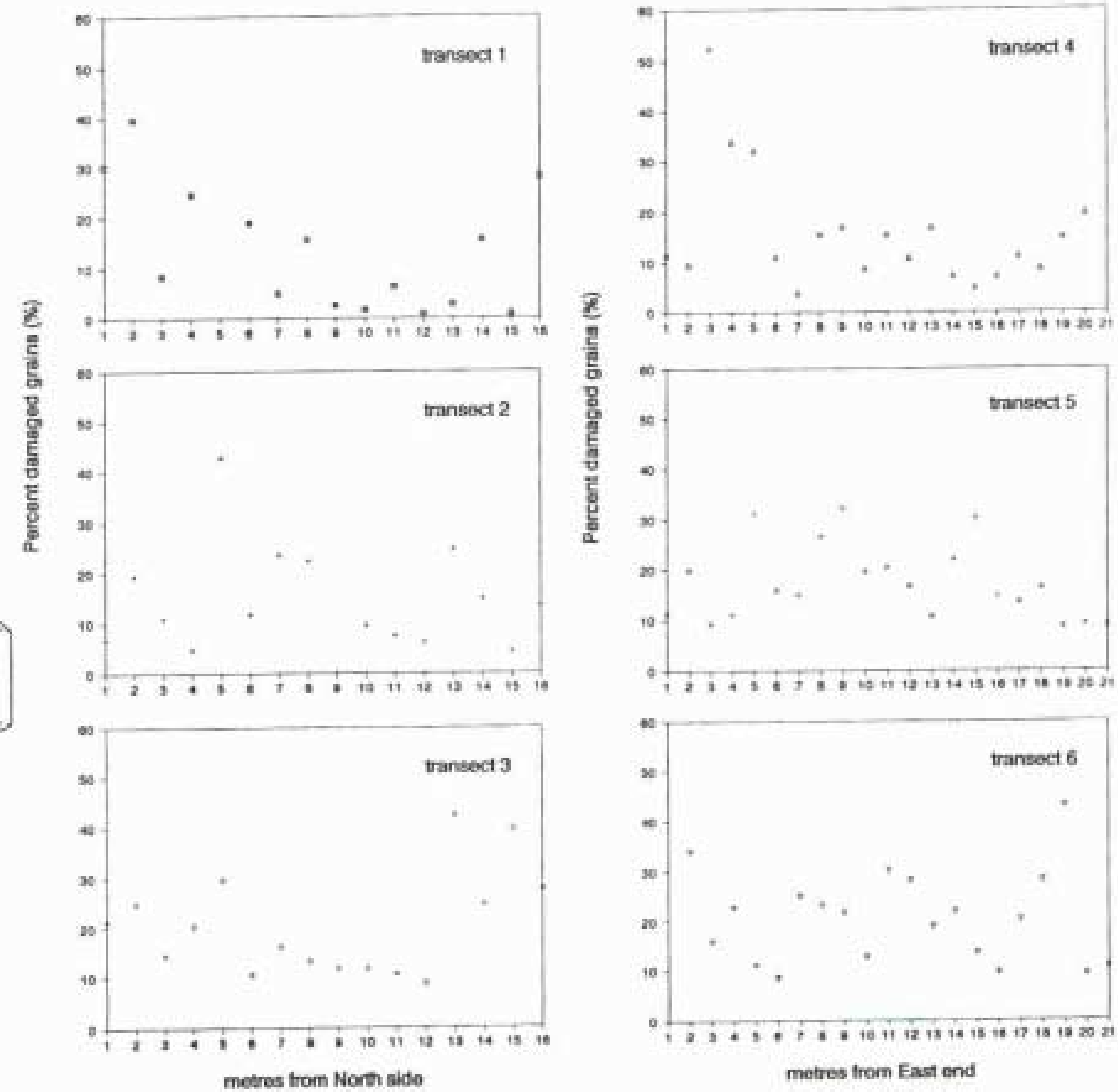


wtlo.drw

Figure 6 : Percentage of grains visibly damaged by insects of maize samples taken along transects

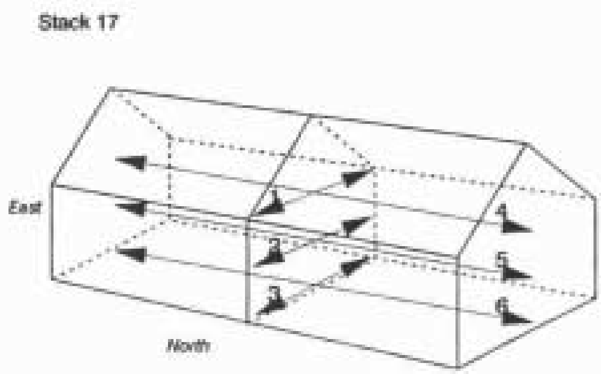
Stack 17

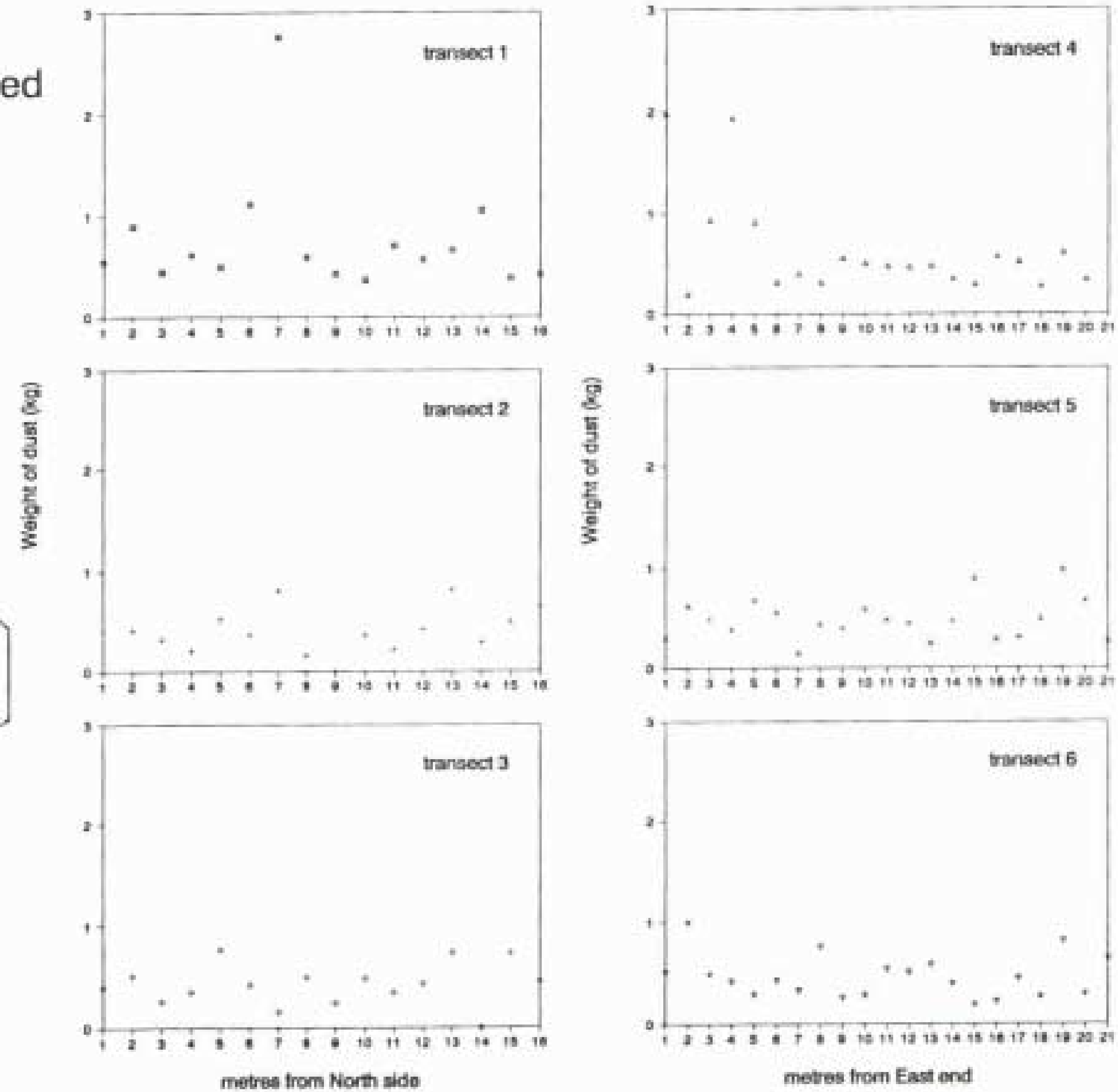




perda.drw

Figure 7 : Weight of dust sieved from whole bags of maize sampled along transects



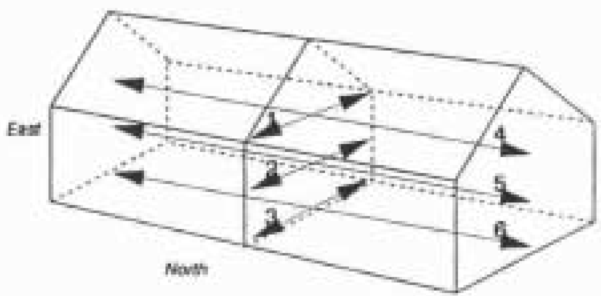


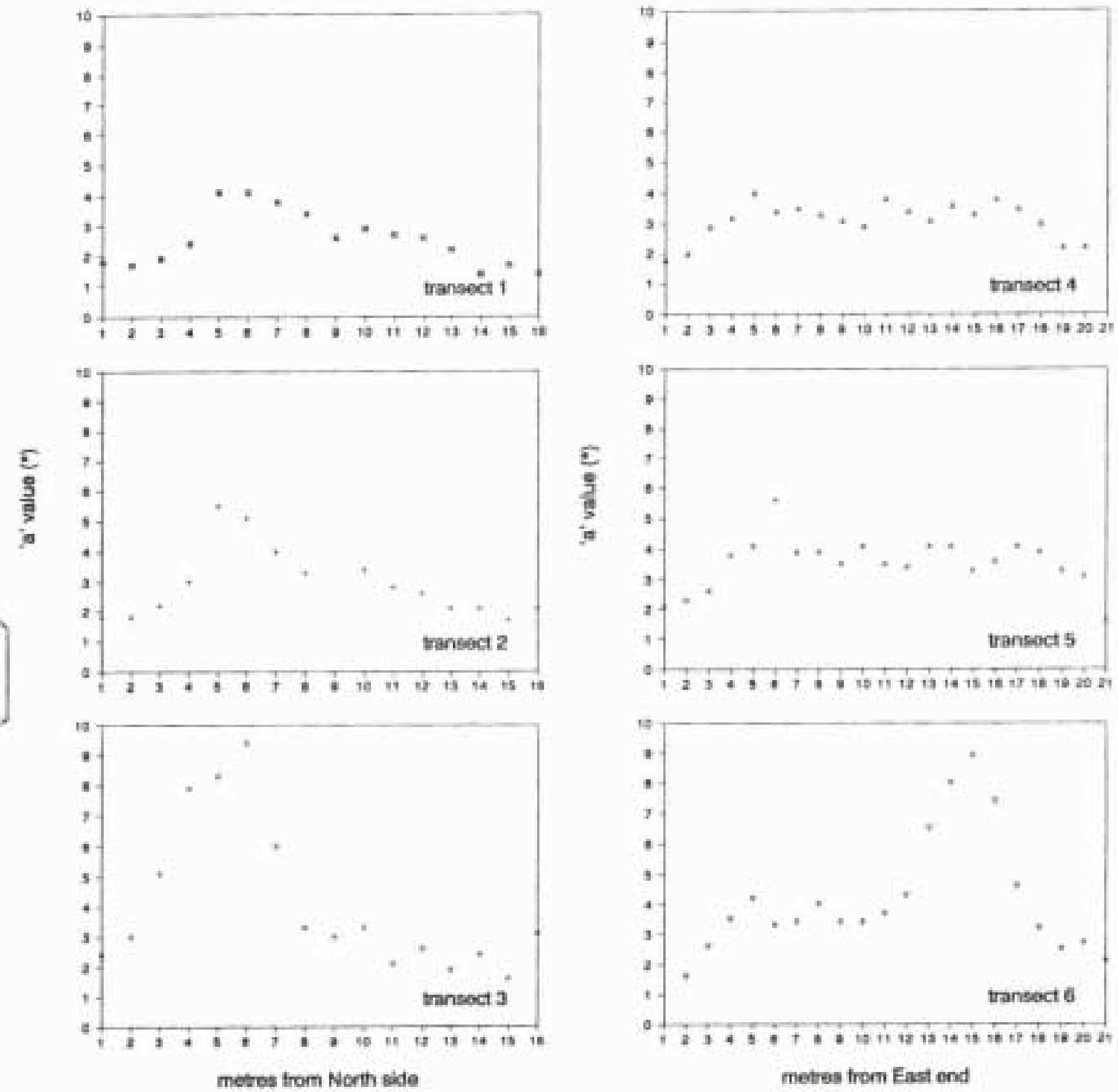
wdust.drw

Figure 8 : 'a' colour values (*) of maize samples taken along transects

(*) the values of 'a' are derived from
a HunterLab colorimeter calibrated to
0 on a black tile and -0.7 on a white tile.
'a' values represent the green to red spectrum
with higher values indicating redness.

Stack 17



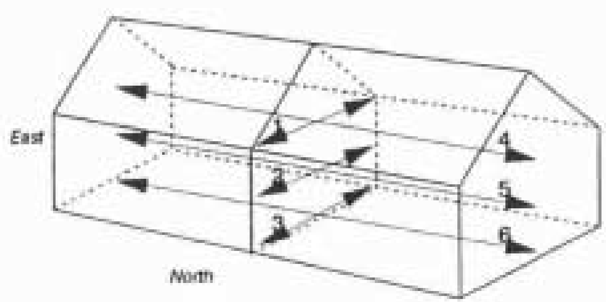


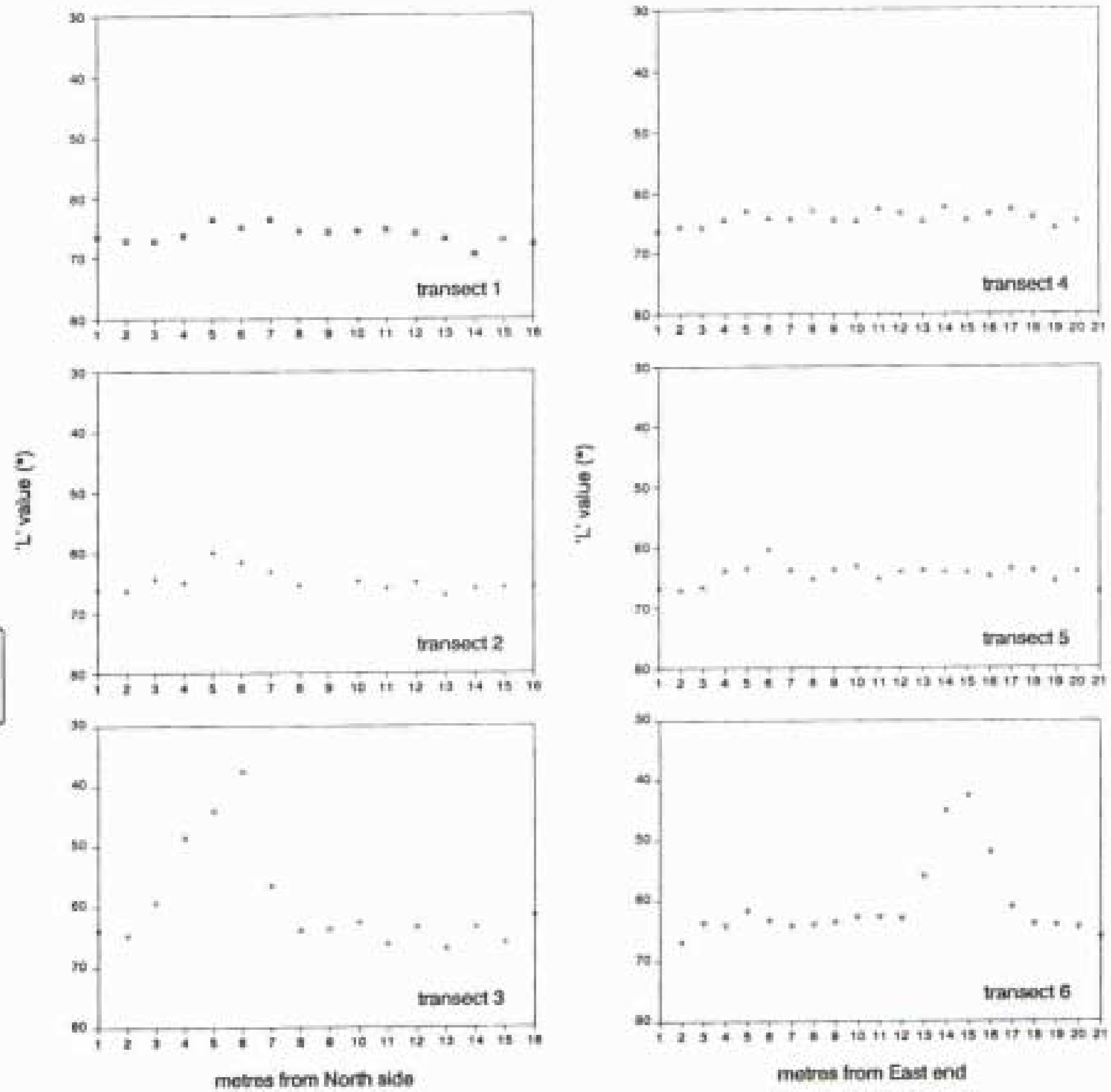
acol.drw

Figure 9 : 'L' colour values (*) of maize samples taken along transects

(*) the values of L are derived from a HunterLab colorimeter calibrated to 0 on a black tile and 90.7 on a white tile.
'L' values represent the white to black spectrum with increasing values along the Y axis indicating blackness.

Stack 17





Lcol.drw

22. Increasing 'a' values, which indicates increasing redness, are found towards the centre of each transect, and this becomes more pronounced towards the base of the stack.

23. This trend is confirmed by the 'L' values, which show a similar though less pronounced pattern (except for extremely discoloured lower samples). Although no baseline maize samples were available for this stack, measurements taken from similar/1 maize give mean readings of 2.4 ('a') and 66.5 ('L').

Results - Jute/Polypropylene Paired Sacks

24. A total of 49 pairs of sacks were tested, which were split into two groups; those pairs that were found lying side-by-side (31 pairs) and those lying end-to-end (18 pairs). Statgraphics 5.0 was used for comparison of jute and polypropylene sacks by multifactorial analysis of variance.

Moisture content

25. The results of the ISO 6540 determination are shown in Table 3.

/1 Maize from the same source which was sampled at stack construction and kept in frozen storage until this study.

Table 3: Moisture contents of paired jute and polypropylene sacks by orientation (standard errors shown in parentheses)

		Moisture Content (%)	
Orientation of sacks	Significance	Jute sacks	Polypropylene sacks
End-to-end	**	**10.8** (0.6)	**11.1** (0.6)
Side-by-side	ns	**10.9** (0.3)	**10.9** (0.3)
All bags	*	**10.9** (0.3)	**11.0** (0.3)

ns - not significant
* - $p<0.05$
** - $p<0.01$

26. Individual moisture content values ranged from 10.03% to 13.05%, with an overall mean of 10.94%. Analysis of variance, in which the sack orientation is considered, shows highly significant difference ($p<0.01$) between the moisture content of the maize in sacks of the two fabrics, when end-to-end, but no significant difference when side-by-side. Ignoring orientation of sacks shows that moisture contents were significantly higher ($p<0.05$) in polypropylene sacks than in jute sacks.

27. The analysis confirms the experimental design in that, taking 'pairs' as a factor of the analysis, showed very high significance ($p<0.001$) throughout. This indicates that there are real moisture content differences between pairs (in different locations in the stack).

28. The small standard errors from the analysis show a homogeneous population that has a small but significant difference in moisture content between maize samples taken from the two types of sack.

Insect sievings

29. The data show that only dead adult *Sitophilus spp.* and *Tribolium spp.* were counted from the bag sievings. The data were transformed for analysis and the results are shown in Tables 4 and 5.

Table 4: Numbers of dead adult *Sitophilus spp.* in paired jute and polypropylene sacks by orientation (standard errors shown in parentheses)

		No of dead adult *Sitophilus spp.*	
Orientation of sacks	Significance/1	Jute sacks	Polypropylene sacks
End-to-end	ns	**9,300** (3900)	**14,700** (4100)
Side-by-side	ns	**10,800** (2400)	**12,000** (2400)
All bags	ns	**10,300** (2000)	**12,800** (2100)

ns - not significant

30. Largely due to the very wide variation in numbers of dead adult *Sitophilus spp.* found (400-77,900 per bag), there were no significant differences between jute and polypropylene sacks in the analysis. However, the polypropylene sacks consistently contained more dead adult insects than the jute samples. Over the whole sample, this was on average, 2,500 more per bag.

/1 Data transformed by a logarithm transformation for analysis of variance

Table 5: Numbers of dead adult *Tribolium spp.* in paired jute and polypropyene sacks by orientation (standard errors shown in parentheses)

Orientation of sacks	Significance/1	No of dead adult *Tribolium spp.*	
		Jute sacks	Polypropylene sacks
End-to-end	ns	**5,000** (900)	**6,100** (900)
Side-by-side	ns	**9,100** (1900)	**6,800** (1900)
All bags	ns	**7,800** (1300)	**6,600** (1400)

ns - not significant

31. A similar large variation in numbers of dead adult *Tribolium spp.* (500-88,300 per bag) did not show there to be any significant differences in insect numbers between the two sack types. One very high value in the data set is the principal cause for the higher mean of jute than polypropylene sacks within the side-by-side orientation and the overall samples.

32. Eliminating this one extreme value, the pattern of insect numbers is similar to that found for *Sitophilus spp.* (with polypropylene containing higher numbers than jute sacks). Almost without exception the numbers of *Tribolium spp.* are less per bag than of *Sitophilus spp.*

Weight loss due to visible insect damage

33. The results of analysis of per cent weight loss by the gravimetric method are shown in Table 6.

/1 Data transformed by a logarithm transformation for analysis of variance.

Table 6: Per cent weight loss of visibly damaged maize in paired jute and polypropylene sacks by orientation (standard errors shown in parentheses)

	% weight loss of visibly damaged maize		
Orientation of sacks	Significance	Jute sacks	Polypropylene sacks
End-to-end	ns	**3.7** (1.1)	**2.5** (1.1)
Side-by-side	ns	**2.3** (0.4)	**1.5** (0.4)
All bags	ns	**2.9** (0.5)	**1.8** (0.4)

ns - not significant

34. Whilst the analysis does not show any significant differences in weight loss between sack type, the loss is consistently higher in jute sacks. This result appears to contradict the above, which shows larger numbers of dead insects in polypropylene than in jute sacks, but might be explained by greater mobility of insects through the fabric of jute sacks.

35. The percentage of visibly damaged grains calculated for the two sack types is shown in Table 7.

Table 7: Per cent visibly damaged maize grains in paired jute and polypropylene sacks by orientation (standard errors shown in parentheses)

		% visibly damaged maize grains	
Orientation of sacks	Significance	Jute sacks	Polypropylene sacks
End-to-end	ns	**23.2** (3.0)	**17.6** (3.0)
Side-by-side	ns	**17.7** (1.9)	**12.9** (1.9)
All bags	*	**19.9** (1.5)	**14.5** (1.5)

ns - not significant   * - p<0.05

36. The analysis reflects the situation shown in Table 6, with maize in jute sacks showing consistently higher levels of insect damage than maize in polypropylene sacks. In the overall sample this difference is significant ($p<0.05$).

Weight of dust

37. This parameter was measured from sievings of whole bags and showed variations of between 200g and 3.8kg. In reality, the 'dust' could be seen to contain dust, dead insects and other organic and inorganic foreign matter (eg. sunflower seeds and stones). The amount of dust from the two different sack types are shown in Table 8.

Table 8: Weight of dust from sievings of paired jute and polypropylene sacks by orientation (standard errors shown in parentheses)

		Weight of dust (g)	
Orientation of sacks	Significance	Jute sacks	Polypropylene sacks
End-to-end	ns	**950** (171)	**530** (180)
Side-by-side	**	**850** (80)	**520** (80)
All bags	**	**880** (80)	**520** (80)

ns - not significant
** - $p<0.01$

38. Jute and polypropylene sacks side-by-side showed highly significant differences ($p<0.01$) in weight of dust, as did the whole sample. Visual observations during sieving saw that jute sacks often contained larger amounts of foreign matter and stones than polypropylene sacks. It looked as though these jute sacks had previously been filled with other commodities, whereas polypropylene sacks would have been new when filled. Furthermore, maize from split bags (spillage) was rebagged into jute bags and this may have introduced some extra dust. Although sweepings are sieved by depot staff before rebagging this cannot remove all the earth coating the maize while it was on the ground. The apparent differences between jute and polypropylene, therefore, may be a reflection of previous sack usage as much as of insect activity.

Colour

39. Tables 9 and 10 show the 'a' and 'L' values recorded for samples from the two sack types.

Table 9: 'a' colour values of paired jute and polypropylene sacks by orientation (standard errors shown in parentheses)

		'a' value	
Orientation of sacks	Significance	Jute sacks	Polypropylene sacks
End-to-end	ns	**2.8** (0.2)	**2.7** (0.1)
Side-by-side	ns	**2.6** (0.0)	**2.5** (0.0)
All bags	ns	**2.6** (0.2)	**2.6** (0.2)

ns - not significant

40. There were no significant differences in 'a' values between sack type, although maize in jute sacks was marginally redder.

Table 10: 'L' colour values of paired jute and polypropylene sacks by orientation (standard errors shown in parentheses)

		'L' value	
Orientation of sacks	Significance	Jute sacks	Polypropylene sacks
End-to-end	ns	**64.7** (0.4)	**65.2** (0.4)
Side-by-side	***	**63.3** (0.4)	**65.4** (0.4)
All bags	*	**63.6** (0.6)	**65.4** (0.6)

ns - not significant
* - $p<0.05$
*** - $p<0.001$

41. The 'L' values recorded for these samples show a very high significant difference ($p<0.001$) when the sack orientation was side-by-side, and a significant difference

(p<0.05) overall. The lower numbers for the jute sack samples indicate a shift towards the black end of this spectrum.

Discussion

42. The relationships of the variables were investigated by the Spearman Rank Correlation function on Statgraphics 5.0. The results of the analysis are shown in Table 11.

Table 11: Spearman Rank Correlations of moisture content, weight loss due to visible insect damage, percentage visible damaged grain, weight of dust, numbers of dead adult *Sitophilus spp.* and *Tribolium spp.* and 'a' and 'L' colour values

	mc	wtloss	perdam	wdust	*nSit*	*nTri*	'a'
% weight loss (wtloss)	-.148 *						
% visibly damaged grains (perdam)	-.209 **	.600 ***					
weight of dust (wdust)	-.080 ns	.315 ***	.373 ***				
No of dead adult *Sitophilus (nSit)*	.034 ns	.196 **	.478 ***	.423 ***			
No of dead adult *Tribolium (nTri)*	-.037 ns	.305 ***	.404 ***	.401 ***	.494 ***		
'a' value	.380 ***	.102 ns	.174 *	-.098 ns	.118 ns	-.056 ns	
'L' value	-.256 ***	-.209 *	-.238 ***	-.041 ns	-.073 ns	.008 ns	-.745 ***

ns - not significant
* - p<0.05
** - p<0.01
*** - p<0.001

43. These correlations consider linear relationships of the measured variables and show that moisture content is significantly correlated with weight loss (p<0.05), visibly damaged grains (p<0.01) and the 'a' and 'L' colour values (p<0.001).

44. Weight loss is not only significantly correlated to per cent damaged grains ($p<0.001$), but also to weight of dust, numbers of dead adult *Tribolium spp.* (both $p<0.001$) and to numbers of dead adult *Sitophilus spp.* ($p<0.01$). 'L' values are correlated to weight loss ($p<0.05$).

45. The correlations to percentage damaged grains are significant for weight of dust ($p<0.001$), numbers of dead adult *Sitophilus spp.* and *Tribolium spp.* (both $p<0.001$), 'a' colour value ($p<0.05$) and 'L' colour value ($p<0.001$).

46. The methods used for all sample analyses were considered appropriate for obtaining thorough baseline data. Further similar analyses are required to make any meaningful correlation coefficients more robust. If this proves possible, subsequent analyses may be dropped (such as the time consuming insect numbers and insect damage techniques) and these parameters estimated from quicker analyses.

Conclusions and Recommendations

47. Although there was only one sensor placed at a central, eave level position in this stack, records show that temperature rose above 40°C for longer than 70 days. This is similar to data obtained from other stacks. Severe discoloration was found in the centre of the stack. **In future trials, extensive heat monitoring layouts within stacks will be important to relate to the extent and degree of any discoloration.**

48. The measured loss due to visible insect damage of 2.3% equates to Zimbabwe $14,200 at GMB, Grade AB 1991 selling prices (Appendix 4). The numbers of bags that were downgraded to Grade DD and the bags that were discarded amounted to a loss of Zimbabwe $11,600 (in both cases due to discoloration). This figure may well rise once the fate of the remaining maize

is known. These two quantified losses total 4.2% of the total potential value of the stack.

49. The discolouration was correlated to visible insect damage and moisture content. The numbers of dead adult insects found in the samples are positively correlated to visible insect damage, and the weight of dust retrieved from the sievings. **The value of experimental methods of acoustic insect detection will help to highlight the role of insects in heat increases within the stack.**

50. The linear correlations are calculated from a total of 210 samples, and whilst showing statistical significance, have only modest coefficients. **Future stack examination should obtain representative samples along transects through stacks.** These may <u>double up</u> along rows of bags that contain heat and moisture content sensors. The minimum number of samples along each transect would be from alternate bags running lengthwise. Sample size will vary from 500g to 10kg depending on analyses required. This should be determined prior to sampling.

51. The factors that may be contributing to maize discolouration include sack type, moisture, temperature, insects, moulds and length of storage. Any trial designed to test these factors will require an experimental design on a large number of stacks. Stack size cannot be reduced sufficiently to counteract the large quantities of maize required; **a large scale trial to test these effects is therefore precluded.**

52. To test precisely the contribution of insects to heat development within maize a **small-scale trial is recommended.** Small quantities of maize (of up to 50kg) will be insulated, monitored for heat and treated as follows:

(a) increasing levels of initial insect infestation; and

(b) increasing levels of initial maize temperature.

The experimental design for this trial would require 32 lots of maize to be tested (assuming 4 levels each of (a) and (b) and 4 replicates of each) in a CTH room at NRI.

53. Since the effect of sack type indirectly influences discoloration, the results of on-going tests on sack type may be applied to the proposed trial outlined above.

54. **It is recommended that a review of results is undertaken on completion of this trial in order to design the layout, treatments and instrumentation of a small number of large outdoor bagstacks.**

55. A large-scale validation trial should then run in at least two countries in sub-Saharan Africa where maize discoloration has been recorded.

References

Boxall, R.A., 1986. *A critical review of the methodology for assessing farm-level grain losses after harvest.* TDRI Report No G191, Natural Resources Institute, Central Avenue, Chatham Maritime, Kent ME4 4TB, UK.

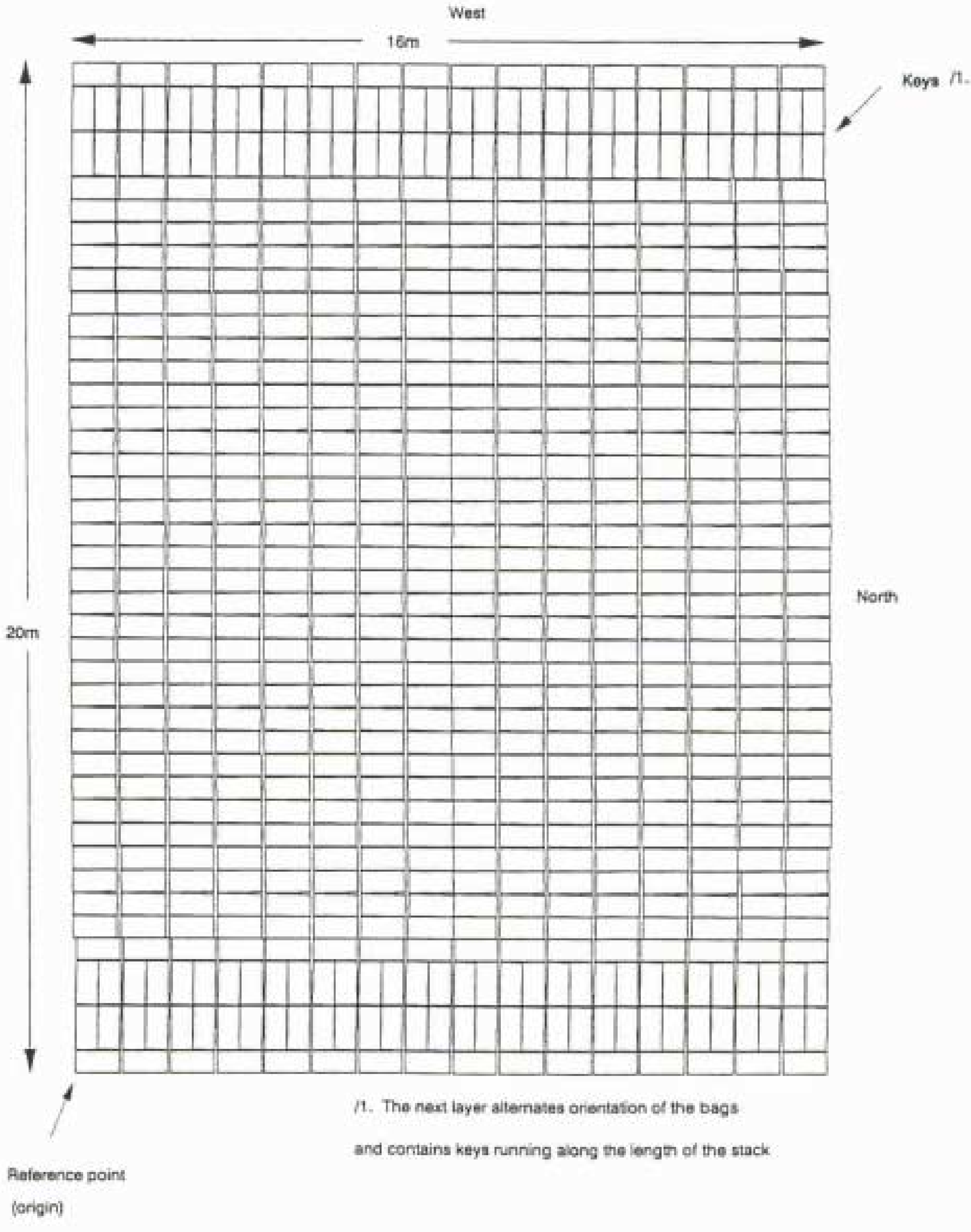
Friis-Hansen, E., 1991. *The performance of the seed sector in Zimbabwe: an analysis of the influence of organisational structure.* Overseas Development Institute, Regent's College, Inner Circle, Regent's Park, London NW1 4NS.

Appendix 1 : Stack information

Annex 1 : Number of bags per layer

Layer No	LXB	Sub Total	«Keys»	Total		Above eave	LXB	Total
1	26x20	520		520		1	20x24	480
2	29x16	464	26x4=105	568		2	34x13	442
3	21x20	420	36x4=144	564		3	22x20	440
4	29x16	464	26x4=104	568		4	34x11	374
5	21x20	420	35x4=140	560		5	19x18	342
6	29x16	464	26x4=104	568		6	34x10	340
7	21x20	420	35x4=140	560		7	19x15	285
8	29x16	464	26x4=104	568		8	34x8	272
9	21x19	399	34x4=136	535		9	19x12	228
10	24x16	384	26x4=104	568		10	34x6	204
11	21x19	399	34x4=136	535		11	19x10	190
12	28x16	448	26x4=104	552		12	34x5	170
13	20x19	380	34x4=136	516		13	19x7	133
14	28x15	420	26x4=104	524		14	34x3	102
15	20x19	380	33x4=132	512		15	33x2	66
16	28x15	420	23x4=100	520		16	19x2	38
17	20x19	380	33x4=132	512		17	19x2	38
18	28x15	420	25x4=100	520		18	17x1	17
19	20x19	380	33x4=132	512				
20	28x15	420	25x4=100	520				
21	20x19	380	33x4=132	512	Base			Peak
22	28x15	420	25x4=100	520	Total= 14915			Total= 7161
23	20x19	380	33x4=132	512				
24	28x15	420	25x4=100	520				
25	20x19	380	35x4=152	512				
26	28x15	420	25x4=100	520				Grand
27	20x19	380	33x4=132	512				Total=19076
28	27x15	405	25x4=100	505				

Annex 2 : Stacking pattern (2nd Layer)



/1. The next layer alternates orientation of the bags and contains keys running along the length of the stack

Annex 3 : Position of jute/polypropylene paired sacks

Code	J/P	Position		
			From reference point	
		Layer	m North	m West
PJ1	J	37	3	3
PJ2	P	37	4	3
PJ3	J	37	5	3
PJ4	P	37	6	3
PJ5	J	32	7	7
PJ6	P	32	7	8
PJ7	J	28	3.5	18.5
PJ8	P	28	4	18.5
PJ9	J	28	3.5	19.5
PJ10	P	28	4	19.5
PJ11	J	29	4.5	0.5
PJ12	P	29	5	0.5
PJ13	J	29	14.5	3
PJ14	P	29	14	3
PJ15	J	27	7	17
PJ16	P	27	7.5	17
PJ17	J	27	8	19
PJ18	P	27	8	18
PJ19	J	27	8.5	19
PJ20	P	27	8.5	18
PJ21	J	27	9	19
PJ22	P	27	9	18
PJ23	J	27	9.5	19
PJ24	P	27	9.5	18
PJ25	J	22	3	8.5
PJ26	J	22	3	9
PJ27	J	22	3	9.5
PJ28	P	22	4	8.5
PJ29	J	23	3.5	9
PJ30	P	23	3.5	10
PJ31	J	23	4	9
PJ32	P	23	4	10
PJ33	J	23	4.5	9
PJ34	P	23	4.5	10
PJ35	P	22	4	9
PJ36	P	22	4	9.5
PJ37	J	22	3	8
PJ38	P	22	4	8
PJ39	J	25	3	7
PJ40	P	25	3	6.5

Code	J/P	Position		
			From reference point	
		Layer	m North	m West
PJ41	J	17	1.5	11
PJ42	P	17	1.5	10.5
PJ43	P	22	5	9.5
PJ44	J	22	5	9
PJ45	J	22	5	8.5
PJ46	P	22	5	8
PJ47	J	16	3	11
PJ48	P	16	3.5	11
PJ49	J	16	3	12
PJ50	P	16	3.5	12
PJ51	J	16	3	13
PJ52	P	16	3.5	13
PJ53	P	16	1	12
PJ54	J	16	1	12.5
PJ55	J	16	1	13
PJ56	P	16	1	13.5
PJ57	J	17	2.5	14
PJ58	P	17	3	14
PJ59	J	24	6	7
PJ60	J	24	6	6
PJ61	P	21	2.5	19
PJ62	P	21	3	19
PJ63	P	19	4	18
PJ64	J	19	4.5	18
PJ65	J	24	6.5	6
PJ66	P	24	6.5	7
PJ67	J	24	7	6
PJ68	P	24	7	7
PJ69	J	24	5.5	5
PJ70	P	24	5	5
PJ71	J	24	6	5
PJ72	J	24	6.5	5
PJ73	J	16	3	7.5
PJ74	P	16	3	8
PJ75	J	24	7	5
PJ76	P	24	7	4
PJ77	J	24	7.5	5
PJ78	P	24	7.5	4
PJ79	J	24	6.5	4
PJ80	J	24	6	4

Code	J/P	Position		
			From reference point	
		Layer	m North	m West
PJ81	J	24	5.5	4
PJ82	J	24	5	4
PJ83	P	24	4.5	4
PJ84	P	19	2.5	19
PJ85	J	19	3	19
PJ86	J	21	3.5	19
PJ87	P	21	4	19
PJ88	J	20	6	19.5
PJ89	P	20	6.5	19.5
PJ90	P	24	5	3
PJ91	P	24	5.5	3
PJ92	P	24	6	3
PJ93	P	19	2.5	2
PJ94	J	19	3	2
PJ95	J	19	3.5	2
PJ96	P	19	4	2
PJ97	J	21	3.5	3
PJ98	P	21	4	3
PJ99	P	24	6.5	3
PJ100	J	24	7.5	6
PJ101	P	24	7.5	7
PJ102	J	14	13	9
PJ103	P	13	13	9.5
PJ104	J	5	12.5	13
PJ105	P	5	12	13
PJ106	P	4	5	10.5
PJ107	J	4	5	10
PJ110	J	3	9.5	14
PJ111	P	3	9	14
PJ112	J	3	5	10
PJ113	P	3	6	10
PJ115	J	2	8	5
PJ116	P	2	8.5	5

Annex 4 : Airing schedule

Date	Opening Time	Moisture	Closing Time	Moisture
04.12.89	07.40	11.6	12.10	11.1
08.12.89	07.50	11.5	15.30	10.9
15.12.89	07.55	11.1	12.10	10.9
20.12.89	08.15	11.4	16.04	10.8
09.01.90	08.00	10.7	15.00	10.6
24.01.90	07.56	11.4	15.30	10.7
01.02.90	07.58	11.2	15.38	10.8
09.02.90	07.56	11.3	16.04	10.7
15.02.90	07.45	11.2	16.28	10.6
26.02.90	08.15	11.0	16.35	10.9
02.03.90	07.54	11.3	16.06	10.6
06.03.90	08.54	11.1	16.52	10.7
08.03.90	08.59	11.2	16.05	10.7
21.03.90	09.30	11.5	15.45	10.5
02.04.90	10.36	11.0	15.50	10.7
09.04.90	10.20	11.5	15.40	11.0
20.04.90	08.03	11.6	15.04	11.1
30.04.90	09.00	11.5	15.15	10.9
07.05.90	09.51	11.0	-	-
11.05.90	-	-	14.56	10.7
14.06.90	11.00	10.9	15.56	10.6
23.05.90	09.40	11.0	14.20	10.7
08.06.90	09.30	11.6	15.35	11.5
18.06.90	10.40	11.4	16.00	11.2
21.06.90	10.45	11.4	15.49	11.0
02.07.90	09.30	11.2	-	-
26.07.90	-	-	15.15	10.7
31.07.90	10.20	10.9	-	-
06.08.90	-	-	19.00	10.7
17.08.90	08.36	10.7	15.44	10.6
20.08.90	07.50	10.7	-	-
31.08.90	-	-	16.05	10.5
03.09.90	09.30	10.9	-	-
10.09.90	-	-	15.16	10.6
21.09.90	11.00	10.9	-	-
28.09.90	-	-	16.20	10.6
08.10.90	08.00	11.0	-	-
11.10.90	-	-	15.45	10.6
29.10.90	08.50	10.9	-	-
02.11.90	-	-	16.00	10.6
05.11.90	09.21	10.7	-	-
06.11.90	-	-	15.50	10.6
12.11.90	08.40	10.8	15.47	10.6
20.11.90	07.56	10.7	16.00	10.5
28.11.90	09.40	10.8	15.45	10.6
07.12.90	10.20	10.9	15.30	10.6
14.12.90	08.00	10.8	15.30	10.6
16.01.91	08.08	10.7	16.46	10.6
25.01.91	10.20	10.7	12.20	10.6
28.01.91	07.40	11.6	16.45	10.6

Date	Opening Time	Moisture	Closing Time	Moisture
04.02.91	07.50	10.9	15.25	10.7
14.02.91	07.41	10.8	16.10	10.6
18.09.91	07.55	10.7	16.55	10.6
26.02.91	08.20	10.6	15.52	10.5
01.03.91	08.55	10.8	16.51	10.4
08.03.91	08.35	11.2	13.55	10.9
16.03.91	07.30	11.0	16.54	10.4
24.03.91	08.15	11.1	16.00	10.8
27.03.91	08.45	11.0	16.30	10.7
08.04.91	08.05	11.0	15.35	10.8
15.04.91	07.40	10.9	15.30	10.6
23.04.91	08.03	10.8	16.40	10.6
30.04.91	09.00	10.8	15.10	10.7
08.05.91	10.45	10.8	15.45	10.6
13.05.91	07.50	10.7	16.45	10.6
20.05.91	07.41	10.6	15.40	10.5
31.05.91	07.45	10.8	16.00	10.6
04.06.91	09.00	10.9	16.05	10.6
11.06.91	09.00	10.8	-	-
14.06.91	-	-	15.30	10.7
21.07.91	09.00	10.7	16.45	10.6
05.07.91	08.50	10.6	16.30	10.3
11.07.91	07.40	10.8	15.50	10.7
15.07.91	07.40	10.7	Opened	

Annex 5 : Fumigation timetable

Date of fumigation	Days in storage	Interval between fumigations (days)
05.02.90	62	-
14.05.90	160	98
12.06.90*	189	29
19.06.90*	196	7
03.12.90	363	167
21.03.91	471	108
19.07.91	591	120

* Experimental fumigations to test fumigant concentration levels. The timing of these fumigations would not be considered 'normal' management practice.

Appendix 2 : Transect sample data

Key to column headings

transect	- number	wdam	- weight of damaged grains (g)	nsit	- number of Sitophilus spp
		ndam	- number of damaged grains	ntri	- number of Tribolium spp
sequence	- north to south (transects 1-3)	wundam	- weight of undamaged grains (g)	NSIT	- number of Sitophilus spp
	- east to west (transects 4-6)	nundam	- number of undamaged grains	NTRI	- number of Tribolium spp
		wtloss	- weight loss (%) by gravimetric method	L	- L colour value from Hunt
		perdam	- percent grains damaged (%)	a	- a colour value from Hunt
mc	- moisture content (%)			b	- b colour value from Hunt
		wdust	- weight of dust (g)		

transect	seq	mc	wdam	ndam	wundam	nundam	ngrain	wtloss	perdam	wdust	nsit	ntri	NSIT	NTRI	L	a	b
1	1	8.74	13.5	53	35.4	123	176	3.46	30.11	549	3599	4385	14396	17540	66.5	1.8	20.1
1	2	10.28	18.2	66	28.4	101	167	.76	39.52	899	6305	2508	25220	10032	67.1	1.7	19.6
1	3	10.40	3.3	16	44.4	175	191	1.57	8.38	448	169	744	676	2976	67.2	1.9	21.1
1	4	10.15	10.1	46	35.0	141	187	2.84	24.60	619	3779	187	15116	748	66.3	2.4	21.0
1	5	11.72								498	2777	217	11108	868	63.6	4.1	23.1
1	6	11.79	9.8	38	40.8	161	199	-.34	19.10	1116	3942	1094	15768	4376	64.9	4.1	23.3
1	7	11.68	2.1	10	48.0	191	201	.82	4.98	2762	12080	642	48320	2568	63.6	3.8	22.8
1	8	11.52	8.1	27	48.2	145	172	1.53	15.70	596	2878	1439	11512	5756	65.5	3.4	22.8
1	9	11.14	4.1	13	159.1	522	535	-.08	2.43	428			13738	1850	65.7	2.6	22.5
1	10	11.51	3.0	9	158.7	548	557	-.24	1.62	365			2981	191	65.6	2.9	23.4
1	11	11.95	8.5	30	136.3	449	479	.42	6.26	709			7387	391	65.3	2.7	21.2
1	12	11.29	1.4	5	134.5	538	543	-.11	.92	572			3978	218	65.9	2.6	21.6
1	13	10.95	3.8	16	155.1	571	587	.34	2.73	666			379	219	66.9	2.2	20.2
1	14	11.04	17.4	85	107.8	456	541	2.11	15.71	1057			5989	284	69.6	1.4	19.0
1	15	11.53	.7	3	125.9	409	412	.18	.73	386			2003	213	67.1	1.7	19.7
1	16	10.58	35.2	109	101.7	281	390	3.01	27.95	420			15229	1045	67.8	1.4	19.1
2	1	11.05	3.6	12	48.4	171	183	-.39	6.56	402	1244	2428	4976	9712	66.2	1.8	20.1
2	2	10.55	10.9	32	42.4	133	165	-1.33	19.39	408	4887	1567	19548	6268	66.3	1.8	21.0
2	3	10.42	4.1	17	39.1	139	156	1.55	10.90	319	1443	361	5772	1444	64.4	2.2	21.8
2	4	10.62	1.8	9	52.4	185	194	1.36	4.64	202	289	244	1156	976	65.0	3.0	23.3
2	5	11.06	17.9	66	29.0	88	154	7.59	42.86	524	2806	988	11224	3952	60.0	5.5	23.6
2	6	11.01	5.8	22	49.0	165	187	1.32	11.76	368	1858	610	7432	2440	61.6	5.1	23.6
2	7	10.68	10.0	46	41.3	149	195	5.09	23.59	806	7358	4439	29432	17756	63.3	4.0	22.9
2	8	10.40	11.4	30	41.7	104	134	1.17	22.39	156	2769	872	11076	3488	65.4	3.3	23.5
2	9																
2	10	10.89	5.2	18	51.3	173	191	.24	9.42	361	1171	790	4684	3160	64.8	3.4	22.9
2	11	10.92	3.9	14	49.1	173	187	.14	7.49	217	1259	1864	5036	7456	65.9	2.8	22.4
2	12	10.93	1.9	11	44.6	168	179	2.15	6.15	421	635	1843	2540	7372	65.0	2.6	21.6
2	13	10.91	11.7	51	42.6	156	207	3.94	24.64	815	3377	491	13508	1964	67.1	2.1	21.4
2	14	10.77	7.4	23	43.5	132	155	.35	14.84	291	1337	1337	5348	5348	66.0	2.1	21.1
2	15	10.76	1.5	6	42.5	136	142	.85	4.23	499	113	263	452	1052	65.9	1.7	20.3
2	16	11.66	5.8	29	44.3	190	219	1.88	13.24	646	4284	3457	17136	13828	65.7	2.1	20.3

3	1	10.26	8.4	30	40.9	111	141	5.11	21.28	398	2974	3785	11896	15140	64.0	2.4	20.9
3	2	10.43	8.9	43	40.4	130	173	8.30	24.86	510	2151	1345	8604	5380	64.8	3.0	21.8
3	3	10.23	9.3	30	53.2	178	208	-.54	14.42	260	1163	408	4652	1632	59.4	5.1	22.5
3	4	11.54	7.1	33	41.6	129	162	6.78	20.37	351	1484	821	5936	3284	48.6	7.9	20.4
3	5	12.62	12.2	48	33.6	114	162	4.08	29.63	765	1096	923	4384	3692	44.2	8.3	17.4
3	6	13.91	4.3	23	47.3	195	218	2.42	10.55	419	348	5655	1392	22620	37.6	9.4	16.1
3	7	12.14	7.4	38	48.0	198	236	3.17	16.10	152	505	333	2020	1332	56.6	6.0	22.3
3	8	11.20	10.0	31	71.5	204	235	1.05	13.19	487	6691	4693	26764	18772	64.0	3.3	23.1
3	9	11.01	4.8	23	47.4	171	194	2.93	11.86	241	1217	1324	4868	5296	63.8	3.0	22.5
3	10	10.82	4.5	14	38.9	105	119	1.56	11.76	480	145	8035	580	32140	62.7	3.3	22.6
3	11	10.85	4.8	20	48.9	169	189	1.80	10.58	344	856	1738	3424	6952	66.2	2.1	22.3
3	12	10.86	4.8	17	55.2	177	194	.83	8.76	427	580	1804	2320	7216	63.5	2.6	21.6
3	13	10.38	18.0	72	28.4	98	170	5.82	42.35	732	3751	4222	15004	16888	67.0	1.9	21.5
3	14	10.11	11.7	47	44.8	144	191	4.92	24.61						63.5	2.4	20.6
3	15	10.65	32.2	110	56.1	168	278	4.88	39.57	727	658	3235	2632	12940	66.1	1.6	21.9
3	16	12.72	15.3	47	41.3	123	170	.84	27.65	451	6528	22065	26112	88260	61.6	3.1	21.3
4	1	11.53	3.9	19	40.7	145	164	3.11	11.59	1975	4916	1788	19664	7152	66.2	1.8	20.2
4	2	11.14	3.9	13	42.7	123	136	1.30	9.56	203	1183	179	4732	716	65.5	2.0	21.0
4	3	10.86	25.9	93	28.4	84	177	9.26	52.54	938	4597	2829	18388	11316	65.7	2.9	20.9
4	4	11.51	12.9	43	27.5	84	127	2.83	33.86	1933	6270	3937	25080	15748	64.4	3.2	21.4
4	5	11.34	22.5	81	54.1	172	253	3.74	32.02	916	10777	1243	43108	4972	62.9	4.0	21.7
4	6	11.47	3.9	18	46.2	144	162	3.61	11.11	318	4107	1249	16428	4996	64.1	3.4	23.7
4	7	11.48	1.4	8	55.7	198	206	1.47	3.88	406	582	643	2328	2572	64.2	3.5	23.1
4	8	11.19	6.2	22	40.9	119	141	2.81	15.60	313	614	307	2456	1228	62.7	3.3	22.8
4	9	11.47	7.0	31	42.3	150	181	3.41	17.13	557	126	1723	504	6892	64.4	3.1	22.5
4	10	11.64	3.7	16	46.6	168	184	1.45	8.70	507	2714	573	10856	2292	64.6	2.9	22.1
4	11	11.69	5.5	19	34.7	103	122	2.19	15.57	483	984	802	3936	3208	62.5	3.8	22.6
4	12	11.61	4.7	18	46.0	147	165	1.81	10.91	471	4865	1456	19460	5824	63.2	3.4	21.7
4	13	11.44	13.6	53	74.1	260	313	1.69	16.93	487	8039	1909	32156	7636	64.6	3.1	22.4
4	14	11.52	2.1	11	42.0	140	151	2.65	7.28	358	1080	729	4320	2916	62.3	3.6	22.4
4	15	11.57	2.4	7	41.0	137	144	-.71	4.86	296	1543	559	6172	2236	64.4	3.3	23.1
4	16	11.84	3.0	14	45.7	180	194	1.13	7.22	579	1265	916	5060	3664	63.3	3.8	23.1
4	17	11.27	4.8	19	45.7	151	170	1.85	11.18	523	513	355	2052	1420	62.6	3.5	22.5
4	18	11.30	4.3	12	43.8	126	138	-.27	8.70	280	2049	486	8196	1944	63.9	3.0	21.9
4	19	10.97	5.8	22	36.4	124	146	1.54	15.07	616	975	1161	3900	4644	65.7	2.2	20.7
4	20	10.89	7.0	36	37.3	145	181	4.86	19.89	347	654	3661	2616	14644	64.6	2.2	19.8
4	21																
5	1	12.11	5.3	22	53.6	172	194	2.57	11.34	298	1302	2691	5208	10764	66.8	2.1	20.4
5	2	10.96	8.6	36	40.8	144	180	3.14	20.00	620	1962	1168	7848	4672	67.1	2.3	21.5
5	3	11.01	2.7	17	43.5	166	183	3.66	9.29	485	1538	366	6152	1464	66.6	2.6	23.6
5	4	11.03	4.0	15	41.4	120	135	2.52	11.11	388	468	1426	1872	5704	63.9	3.8	23.7
5	5	10.88	27.0	88	60.9	194	282	.71	31.21	675	8456	2853	33824	11412	63.6	4.1	23.1
5	6	11.03	7.0	28	42.0	147	175	2.00	16.00	555	2847	1047	11388	4188	60.5	5.6	22.9
5	7	10.78	8.5	25	50.5	141	166	.76	15.06	143	378	270	1512	1080	63.9	3.9	23.2
5	8	10.54	10.2	38	31.3	105	143	2.65	26.57	435	4293	2163	17172	8652	65.3	3.9	23.0
5	9	10.55	26.2	96	64.1	203	299	4.36	32.11	398	1619	959	6476	3836	63.8	3.5	22.0
5	10	10.72	9.4	41	44.5	168	209	2.64	19.62	586	2606	1413	10424	5652	63.2	4.1	22.5
5	11	10.30	7.8	38	39.1	148	186	4.56	20.43	479	2131	1052	8524	4208	65.3	3.5	22.8

5	12	10.85	5.8	27	35.0	135	162	2.86	16.67	444	3181	1273	12724	5092	64.1	3.4	22.3
5	13	10.84	9.1	33	73.7	276	309	-.35	10.68	244	1750	700	7000	2800	63.9	4.1	22.3
5	14	10.78	21.4	77	73.0	273	350	-.87	22.00	469	4242	2742	16968	10968	64.1	4.1	22.6
5	15	10.73	23.3	93	72.4	215	308	7.73	30.19	888	1272	979	5088	3916	64.3	3.3	23.2
5	16	10.87	10.6	56	79.3	325	381	3.30	14.70	281	1673	1230	6692	4920	64.9	3.6	22.8
5	17	10.83	6.4	25	45.3	160	185	1.29	13.51	308	2046	698	8184	2792	63.7	4.1	22.8
5	18	10.99	6.9	28	42.6	144	172	2.72	16.28	488	2941	1287	11764	5148	64.0	3.9	22.1
5	19	11.19	6.4	27	77.8	288	315	1.05	8.57	976	7951	2429	31804	9716	65.7	3.3	22.6
5	20	11.10	3.6	14	44.8	138	152	1.91	9.21	671	1518	2024	6072	8096	64.2	3.1	21.9
5	21	11.74	3.2	13	43.4	135	148	2.06	8.78	259	704	1773	2816	7092	67.4	1.6	21.0
6	1	11.41								508	2680	1608	10720	6432			
6	2	10.71	26.9	99	58.9	192	291	3.89	34.02	991	27349	8444	109396	33776	67.0	1.6	19.3
6	3	10.79	5.4	19	35.6	101	120	3.07	15.83	483	1128	692	4512	2768	63.8	2.6	21.2
6	4	11.07	19.4	73	68.9	249	322	.90	22.67	412	5162	1835	20648	7340	64.3	3.5	21.5
6	5	11.63	3.9	15	38.9	122	137	2.02	10.95	285	946	1032	3784	4128	61.8	4.2	22.8
6	6	11.19	5.0	23	71.5	249	272	2.05	8.46	422	955	2144	3820	8656	63.4	3.3	22.5
6	7	11.02	8.7	30	28.3	90	120	1.94	25.00	323	609	1145	2436	4580	64.3	3.4	23.4
6	8	11.35	9.6	38	34.2	126	164	1.60	23.17	755	9965	6492	39860	25968	64.1	4.0	22.8
6	9	11.32	7.8	30	34.1	109	139	3.65	21.58	253	3988	1126	15952	4504	63.7	3.4	22.6
6	10	11.14	7.8	34	79.4	235	269	4.06	12.64	277	2260	1318	9040	5272	62.9	3.4	22.3
6	11	10.73	19.6	73	56.7	170	243	5.86	30.04	534	1249	806	4996	3224	62.9	3.7	22.8
6	12	11.24	17.5	74	53.3	190	264	4.40	28.03	503	2067	2618	8268	10472	63.1	4.3	23.5
6	13	11.58	14.2	55	70.1	237	292	2.39	18.84	579	5633	1528	22532	6112	56.0	6.5	21.6
6	14	12.19	22.4	64	69.6	230	294	-3.41	21.77	387	5488	1109	21952	4436	45.2	8.0	17.8
6	15	12.48	8.1	31	60.3	200	231	1.79	13.42	182	2087	82	8348	328	42.7	8.9	17.7
6	16	11.47	7.4	28	79.5	267	295	1.07	9.49	216	996	277	3984	1108	52.0	7.4	20.9
6	17	10.96	14.2	54	71.6	215	269	4.22	20.07	442	1333	1567	5332	6268	61.2	4.6	23.3
6	18	10.64	25.6	77	65.6	197	274	.04	28.10	263	3889	1071	15556	4284	64.1	3.2	22.4
6	19	10.50	31.2	126	51.8	167	293	8.67	43.00	807	6451	6268	25804	25072	64.3	2.5	21.2
6	20	10.73	4.9	18	55.5	180	198	1.06	9.09	286	324	1318	1296	5272	64.6	2.7	20.8
6	21	11.35	9.5	33	83.4	281	314	.32	10.51	633	4342	2768	17368	11072	66.3	2.3	20.4

Appendix 3 : Jute and Polypropylene paired sample data

Key to column headings

bag (type) - 1 = jute
2 = polypropylene

orient(ation) - 1 = end-to-end
2 = side by side

mc - moisture content (%)

wdam - weight of damaged grains (g)
ndam - number of damaged grains
wundam - weight of undamaged grains (g)
nundam - number of undamaged grains

wtloss - weight loss (%) by gravimetric method
perdam - percent grains damaged (%)

wdust - weight of dust (g)

nsit - number of Sitophilus spp in sub-sample
ntri - number of Tribolium spp in sub-sample
NSIT - number of Sitophilus spp in whole sample
NTRI - number of Tribolium spp in whole sample

L - L colour value from Hunterlab Colorimeter
a - a colour value from Hunterlab Colorimeter
b - b colour value from Hunterlab Colorimeter

sample	pair	bag	orient	mc	wdam	ndam	wundam	nundam	ngrain	wtloss	perdam	wdust	nsit	ntri	NSIT	NTRI	L	a	b
1	1	1	2	10.66	19.7	104	48.4	203	307	6.96	33.88	1106	9588	8587	38352	34348	66.0	2.0	20.2
2	1	2	2	10.68	4.0	14	67.8	187	201	1.48	6.97	543	4802	8089	19208	32356	67.8	1.6	20.6
3	2	1	2	10.96	10.7	43	80.2	254	297	3.07	14.48	966	1311	1529	5244	6116	65.3	2.1	21.1
4	2	2	2	10.99	4.4	18	63.1	231	249	.76	7.23	767	2257	1562	9028	6248	66.8	2.0	20.8
5	3	1	2	12.00	12.2	42	63.8	195	237	1.99	17.72	1502	1784	1994	7136	7976	59.2	3.9	21.8
6	3	2	2	11.82	7.3	22	56.4	169	191	.07	11.52	222	841	987	3364	3948	65.0	3.3	22.3
7	4	1	2	10.94	14.7	55	68.2	219	274	2.85	20.07	810	998	758	3992	3032	65.8	2.2	20.4
8	4	2	2	10.78	7.5	25	73.3	241	266	.13	9.40	226	3416	828	13664	3312	67.6	2.2	21.0
9	5	1	2	11.00	12.8	49	70.2	236	285	2.09	17.19	555	2564	1268	10256	5072	62.6	1.8	19.4
10	5	2	2	10.70	12.1	51	76.2	263	314	2.94	16.24	425	960	3860	3840	15440	67.4	2.1	20.4
11	6	1	2	11.12								588	2925	1418	11700	5672	65.8	1.8	19.8
12	6	2	2	11.22	13.1	47	81.2	298	345	-.31	13.62	664	2703	3804	10812	15216	67.1	2.0	20.4
13	7	1	2	11.17	12.2	42	60.6	195	237	1.16	17.72	1111	3520	6034	14080	24136	63.3	2.5	21.0
14	7	2	2	10.85	40.3	170	30.6	112	282	7.98	60.28	1252	13695	6137	54780	24548	64.6	2.6	18.8
15	8	1	2	10.94								837	2389	992	9556	3968			
16	8	2	2	10.97	9.0	30	69.9	199	229	1.91	13.10	336	1192	1318	4768	5272	63.9	4.1	23.0
17	34	1	2																
18	34	2	2									280	2049	486	8196	1944			
19	35	1	1	10.63	8.6	33	70.6	235	268	1.63	12.31	1177	3905	1864	15620	7456			
20	35	2	1	11.02	7.7	24	69.8	226	250	0	9.60	868	1244	3732	4976	14928	65.4	2.7	21.8
21	36	1	1	10.54	36.4	164	36.6	152	316	4.06	51.90	1324	2795	4093	11180	16372			
22	36	2	1	11.28	10.9	32	73.1	214	246	.04	13.01	414	2310	2185	9240	8740	68.3	2.3	22.9
23	37	1	1	10.54	10.2	37	71	245	282	.64	13.12	388	1410	1111	5640	4444	65.6	2.1	20.0
24	37	2	1	10.79	9.8	44	66.8	243	287	2.91	15.33	353	1863	878	7452	3512			
25	38	1	1	10.64	32.8	126	48.2	171	297	3.24	42.42								
26	39	1	1	10.71	15.2	59	66.9	238	297	1.66	19.87						66.2	1.8	20.5
27	40	1	1	10.66	8.6	32	75.9	249	281	1.35	11.39	286	1034	1077	4136	4308	67.5	1.7	21.1
28	38	2	1	10.92	11.3	41	71.1	211	252	2.96	16.27						65.4	2.0	22.0
29	41	1	1	10.93	11.9	51	78.5	275	326	2.86	15.64						65.6	2.4	20.8
30	41	2	1	10.86	18.5	85	63.2	233	318	5.28	26.73						67.1	1.9	20.2
31	42	1	1	10.56	6.0	21	72.6	257	278	-.09	7.55	473	1464	500	5856	2000	64.7	2.4	20.9
32	42	2	1	10.72	11.2	51	70.7	227	278	5.41	18.35	1182	3119	1693	12476	6772	63.5	2.8	21.6

33	43	1	1	11.02	5.6	25	85.0	332	357	.88	7.00	385	464	407	1856	1628	65.8	2.1	21.7
34	43	2	1	10.82	7.1	27	85.0	280	307	1.18	8.79	497	675	788	2700	3152	65.5	2.7	22.0
35	39	2	1	10.73	24.3	74	49.6	202	276	1.26	26.81						64.0	2.4	20.9
36	40	2	1	10.46	22.8	74	53.9	154	228	3.88	32.46	493	1637	633	6548	2532	65.9	2.0	21.2
37	44	1	1	10.78	15.8	57	60.9	189	246	3.24	23.17						62.9	2.5	20.6
38	44	2	1	11.10	8.0	29	78.0	253	282	1.08	10.28						66.6	1.9	21.7
39	9	1	2	11.32	8.5	38	65.0	216	254	3.84	14.96	1725	6244	3122	24976	12488	64.6	2.5	20.7
40	9	2	2	11.00	13.8	53	64.0	203	256	3.60	20.70	573	2202	1600	8808	6400	65.6	2.4	21.4
41	10	1	2	10.40	8.6	37	68.7	235	272	2.79	13.60	1090	4358	1809	17432	7236	62.0	1.8	19.4
42	10	2	2	10.68	7.0	33	65.6	273	306	1.26	10.78	549	538	704	2152	2816	67.4	2.1	21.6
43	11	2	2	11.02	1.8	7	80.4	265	272	.39	2.57	335	1337	706	5348	2824	66.7	2.3	21.9
44	11	1	2	10.76	17.6	68	61.4	213	281	2.47	24.20	1393	3151	1891	12604	7564	61.2	2.6	21.2
45	12	1	2	11.11	8.7	40	72.2	251	291	3.35	13.75	1036	3905	2109	15620	8436	61.3	2.5	20.5
46	12	2	2	11.02	4.8	13	79.8	201	214	.43	6.07	194	686	365	2744	1460	65.2	2.7	22.7
47	13	1	2	10.36	8.7	34	68.9	232	266	1.77	12.78	931	2457	1474	9828	5896	62.3	2.7	20.6
48	13	2	2	10.65	2.7	11	77.7	274	285	.52	3.86	354	107	454	428	1816	67.2	2.2	21.2
49	14	1	2	10.24	5.2	16	78.9	245	261	-.06	6.13	564	1318	1276	5272	5104	65.0	2.0	21.0
50	14	2	2	10.36	2.3	11	75.3	249	260	1.31	4.23	377	227	398	908	1592	67.6	2.1	21.3
51	15	1	2	10.30	7.1	35	67.6	242	277	3.46	12.64	520	980	745	3920	2980	63.2	2.7	21.7
52	15	2	2	10.57	15.4	75	54.9	233	308	3.13	24.35	925	19479	1745	77916	6980	65.8	2.5	20.6
53	16	2	2	10.86	4.3	17	79.4	289	306	.44	5.56	484	912	219	3648	876	67.9	1.7	20.6
54	16	1	2	10.75	14.1	57	59.1	222	279	1.45	20.43	780	1942	687	7768	2748	66.4	1.8	20.4
55	17	1	2	10.86	12.8	51	65.8	228	279	2.38	18.28	2400	5912	2724	23648	10096	61.2	1.7	19.4
56	17	2	2	11.04	4.6	19	86.1	346	365	.14	5.21	386	2940	699	11760	2796	67.5	1.6	19.7
57	18	1	2	10.03	7.3	33	75.0	253	286	2.93	11.54	472	2456	998	9824	3992	64.5	2.4	20.6
58	18	2	2	10.08	9.0	32	78.3	225	257	2.39	12.45	419	2180	411	8720	1644	64.8	2.6	21.7
59	45	2	1	11.56	6.6	34	85.5	341	375	2.05	9.07	908	2808	1507	11232	6028	64.3	2.7	22.1
60	45	1	1	10.98	16.9	58	66.9	216	274	1.25	21.17	645	1166	535	4664	2140	65.3	3.0	22.7
61	20	2	2	10.72	10.2	47	87.5	260	307	5.44	15.31	2158	5859	3743	23436	14972	68.3	2.2	20.8
62	20	1	2	10.83	11.9	43	69.6	226	269	1.62	15.99	354	225	184	900	736	63.1	2.0	20.2
63	21	2	2	10.42	2.8	13	85.1	274	287	1.39	4.53	432	195	130	780	520	65.6	2.4	21.9
64	21	1	2	10.66	2.8	12	78.1	270	282	.82	4.26	354	828	507	3312	2028	65.3	2.2	21.8
65	46	1	1	11.18								1323	2096	1896	8384	7584	65.4	2.8	22.1
66	46	2	1	11.07	18.1	71	64.0	210	281	4.13	25.27	467	5534	3132	22136	12528	63.7	3.6	21.4
67	55	1	1		32.1	150	43.3	106	256	27.90	58.59	377	4750	1337	19000	5348	64.3	3.1	22.4
68	55	2	1		9.0	36	78.4	283	319	1.10	11.29						62.1	4.4	22.4
69	19	1	2	11.06	16.8	52	66.9	215	267	-.75	19.48	873	197	856	788	3424	64.5	3.1	22.8
70	19	2	2	11.30	15.8	61	62.0	217	278	2.05	21.94	456	3407	1824	13628	7296	65.9	2.8	21.5
71		1			13.8	53	70.3	234	287	2.46	18.47	2108	1590	1113	6360	4452	63.6	3.2	22.6
72		1			13.6	52	64.0	223	275	1.68	18.91	1320	1194	1592	4776	6368	61.2	3.8	22.5
73	22	1	2	10.42	16.1	57	64.2	205	262	2.13	21.76	1003	1362	757	5448	3028	64.1	1.9	21.1
74	22	2	2	10.90	9.0	35	76.2	262	297	1.37	11.78	327	1235	543	4940	2172	67.1	2.1	21.1
75	47	1	1	10.24	10.7	38	72.4	246	284	.58	13.38	3789	2857	857	11428	3428	60.2	4.5	22.7
76	47	2	1	11.41	10.7	41	67.3	206	247	3.34	16.60	656	3366	1634	13464	6536	63.7	3.5	21.8
77	48	1	1	11.04								652	1328	984	5312	3936	62.6	4.0	21.6
78	48	2	1	11.26	7.6	31	79.9	257	288	2.28	10.76	298	748	334	2992	1336	66.0	2.1	21.4
79	53	1	1																
80	49	1	1	11.02	14.5	50	65.2	190	240	3.23	20.83	691	469	677	1876	2708	64.3	2.9	22.5
81	50	1	1	10.82	9.0	38	65.4	229	267	2.43	14.23	429	388	582	1552	2328	64.7	3.0	21.0

82	51	1	1	11.40								734	1549	553	6196	2212	64.2	2.5	21.5
83					3.0	10	71.2	223	233	.26	4.29	260	626	470	2504	1880	67.8	1.5	21.7
84	27	2	2	10.80	9.6	30	76.8	254	284	-.62	10.56	183	290	331	1160	1324	68.0	1.8	21.2
85	27	1	2	10.66	11.7	36	70.4	207	243	.66	14.81	605	1278	593	5112	2372	65.4	2.4	20.8
86	28	1	2	10.89	11.9	40	70.5	216	256	1.38	15.63	542	1963	941	7852	3764	66.5	2.0	21.8
87	28	2	2	10.92	20.9	70	71.4	224	294	1.51	23.81	532	4939	803	19756	3212	66.0	2.2	20.2
88	26	1	2	11.02	17.0	61	62.9	217	278	.85	21.94	715	1671	1294	6684	5176	64.6	1.9	20.6
89	26	2	2	10.98	7.6	26	81.1	260	286	.57	9.09	315	1164	427	4656	1708	67.6	1.7	21.0
90	51	2	1	11.75	6.6	23	71.5	287	310	-1.13	7.42	353	1386	1173	5544	4692	65.6	2.5	20.8
91	50	2	1	11.01	6.2	28	71.4	230	258	3.11	10.85	348	158	447	632	1788	66.4	2.0	21.8
92	49	2	1	10.99	27.7	87	45.7	120	207	6.89	42.03	848	19119	2558	76476	10232	67.9	2.2	20.2
93	25	2	2	10.89	2.2	9	85.1	283	292	.58	3.08	330	447	298	1788	1192	68.1	1.5	20.5
94	25	1	2	11.14	9.3	32	64.5	222	254	-.00	12.60	457	724	379	2896	1516	65.9	2.0	20.0
95	24	1	2	10.68	6.9	24	70.8	215	239	1.27	10.04	726	3998	931	15992	3724	65.1	1.6	20.0
96	24	2	2	11.20	5.2	23	93.0	308	331	1.75	6.95	473	1034	998	4136	3992	65.2	2.3	20.6
97	23	2	1																
98	23	2	2																
99	53	1	2		13.2	44	61.2	186	230	1.69	19.13	432	1272	1696	5088	6784	63.9	2.6	21.7
100	52	1	1	11.34	12.2	52	60.1	203	255	4.23	20.39	1509	9329	2503	37316	10012	62.4	4.2	21.6
101	52	2	1	11.73	17.8	51	62.1	165	216	1.72	23.61	322	5100	680	20400	2720	61.8	4.8	22.4
102	29	1	2	10.63								1292	3994	487	15976	1948			
103	29	2	2	10.82	5.0	22	77.3	291	313	1.02	7.03	645	2920	1947	11680	7788	65.5	3.3	22.5
104	30																		
105	30																		
106	31	1	2	10.09	36.9	129	57.1	164	293	7.86	44.03	860	4542	4347	18168	17388	66.4	2.4	20.9
107	31	2	2	10.64	14.0	39	64.7	152	191	3.20	20.42	1089	164	3779	656	15116	56.0	2.1	18.4
108																			
109																			
110	32	1	2	13.06	18.1	69	54.6	161	230	6.79	30.00	503	1214	266	4856	1064	39.6	8.7	15.4
111	32	2	2	12.68	15.7	51	73.6	263	314	-1.62	16.24	274	5648	496	22592	1984	42.2	8.4	16.0
112	33	1	2	11.41								508	2680	1608	10720	6432			
113	33	2	2	11.14	11.2	44	65.7	249	293	.53	15.02	710	8626	5461	34504	21844	66.2	3.0	22.6
114	34	1										451	6528	22065	26112	88260			
115	34	2			7.0	17	85.0	266	283	-1.73	6.01	267	1793	2118	7172	8472	67.2	2.1	21.3

Appendix 4 : Assessment of loss of maize in stack 17 due to visible insect damage and maize discolouration

	Grade	Bags	Tonnes	Tonnes (after insect loss)	1991 Price per tonne Zim $	1991 value Zim $	1991 potential value Zim $	1991 Loss in value Zim $	% of total value
Initial (November 1989)	AB	19076	1716.8		360.0		618062.4		
Weight loss due to visible insect damage @ 2.3%			39.5				14215.4	14215.1	2.3
Final (August 1991)	Export	3156	284.0	277.5	360.0	99902.5	99902.5		
	AB	5255	473.0	462.1	360.0	166346.0	166346.0		
	AB (depot transfer)	8406	756.5	739.1	360.0	266090.2	266090.2		
	DD	2102	189.2	184.8	324.3	59945.5	66538.4	6592.8	1.1
	Mould	157	14.1	13.8			4969.8	4969.8	.8
							618062.4	25777.8	4.2