PNEUMATIC PROBE SAMPLING OF KANSAS FARM-STORED SORGHUM

by

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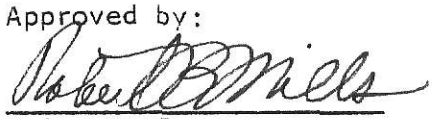

Major Professor

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INTRODUCTION

As a result of the recent government policy that encourages storage of reserve grain on farms, there has been a large increase in farm storage. This has required more and larger farm bins. Many farmers are not aware of the dynamic interactions among the biological and physical factors in the grain mass which can cause deterioration. In Kansas, where seasonal temperatures vary widely, the grain in the larger bins (3,000 bu or more) is especially susceptible to deteriorative changes unless good storage practices are used. As seasonal temperatures change, the insulative quality of grain prevents rapid movement of the temperature changes from the outside to the center of the grain mass. Resulting differences in temperature within the grain cause convection currents of the intergranular air. These may transport moisture from one area of the grain mass to another, sometimes creating areas with enough moisture to permit molding and heating. These areas provide ideal environments for insect populations. Insect access to these environments has been made easier because of the popularity of perforated "false" floors found in nearly all new bins. Little is known about the frequency of intensity of insect or mold problems in the lower parts of these bins.

Recent farm grain surveys in Kansas and in other states indicate that many farmers not only fail to use good storage practices, but often are not aware of problems when they occur (Mills and Pedersen, unpublished report, 1980). This is often due to failure to inspect

the grain, or improper inspection. Common grain depths are 18-20 ft and may be more than 30 ft. A standard manual grain sampling probe usually cannot be forced deeper than 8-12 ft, depending upon type and condition of the grain; thus grain in the lower part of the bin is not sampled for insect infestation, grain moisture content, or other factors affecting grain quality.

During 1980 and 1981, we conducted studies to:

1) gather data from farm bins of sorghum on variables that can influence grain quality (insects, percentage field fungi, percentage storage fungi, moisture content, temperature, and percentage fines),

2) determine relationships among the variables, and which areas in the grain are homogeneous,

3) compare data from pneumatic probe and gravity-fill probe (manual) samples, and

4) develop a "practical" sampling procedure requiring relatively few samples to estimate insect densities in stored grain.

REVIEW OF LITERATURE

Sampling

Investigators have used a variety of sampling devices, such as bait traps, water traps, manual probes, spears, and suction probes, to sample warehouses and grain bulks for insects.

Bait traps may contain either food (Bains et al., 1976) or volatile attractants (Loschiavo and Atkinson, 1967). These traps are used to arrest insect movement and attract other insects of the same or

different species (Pinniger, 1975). Bait traps have been used in dock-side areas, in cargo holds (McFarlane and Warui, 1973), in farms, mills, and in warehouses. One investigator placed traps in garages and car-ports and other nonstorage areas (Strong, 1970). The bait trap is generally used to determine distributions, range, and density levels of several species. Additionally, bait traps can be used as a col-lection tool and as a method for determining effectiveness of insecticide treatments (Pinniger, 1975).

Loschiavo (1974) used an insertion-type bait trap containing rotting wheat. The volatile substances of the decaying wheat attracted the in-sects. This trap included a glass vial, a long cylinder, and a rope for removal of the traps (Loschiavo and Atkinson, 1973). Malathion-treated corrugated paper traps with dermestid (Coleoptera) sex pheromones were effective in capturing target insects (Barak and Burkholder, 1976). Burkholder and Boush (1974) suggested the use of pheromone traps with a pathogen, which might be a feasible method of inoculating a population with entomopathogen.

Water traps have been used for surface collection of insects, psocids, and mites. Watters and Cox (1957) used 6-ounce jars filled with water to within 2.5 cm of the top. The jars were placed in the grain so that the top of the jar was level with the grain. In com-parison to samples taken with a probe, more insects were caught in the water traps. Other experiments related the moisture content of the grain with the movements of insects toward water. The number of insects (Sitophilus granarius and Cryptolestes ferrugineus) collected

in the water traps was inversely related to the moisture content of the grain.

There are various kinds of gravity-fill triers, probes, and spears in use. Special probes have been invented to solve certain problems. For example, in Canada, a probe was needed to sample deep grain masses in terminal grain elevators. A probe with a T-handle at the top and a large auger at the bottom was devised (Andersen and Martin, 1943). Samples were obtained from 80 ft deep, but it took 1 1/4 hrs..

Powered suction probes have been used and may be of 2 types, depending on the delivery system. Burges (1960) found that unlimited size samples could be taken with a domestic vacuum cleaner attached to a lightweight spear and narrow metal pipe. Burges' probe could be inserted in any direction to a depth of 9 m. Burges claimed that his probe did not pick up any more debris than a sampling spear, but Hurburgh et al. (1979) stated that this type of probe (an in-load suction probe) collects more foreign material (fines) than a pneumatic core probe (similar to ours), or a gravity-fill probe.

Various sampling methods and designs have been used to sample grain bulks. Smith (1978) sampled artificially infested granaries (ca. 1,000 bu) of wheat by using a suction probe as did Burges (1960). He sampled on 3 concentric circles, the samples being equidistant from each other. From the same locations samples were taken each month for 7 months, during 4 years. A total of 75 samples was taken on each sampling date. Sinha (1961) sampled "hot spots" (an area of heating grain) in farm granaries by using a gravity-fill torpedo probe. The sampling design

was of concentric circles around the "hot spot." Data on insect and mite species, temperature, and moisture content were collected. Only the selected areas (the hot spots) were sampled, and several were sampled repetitively. This proved to be a good method for collecting large amounts of insects and mites, and for gathering data on temperature and moisture of the grain, but only in localized areas.

In sampling surveys, quick, easy sampling methods are needed. Bell (1972) took 3 samples per bin: a vertical sample in the center, a vertical sample next to the south wall, and a horizontal sample about 7.6 cm below the surface. Mills and Pedersen (unpublished report, 1980) sampled sorghum by taking 6 samples per bin. One vertical sample was taken in each of the cardinal directions near the wall. One vertical sample in the center, and one horizontal or surface sample was taken. Barak and Harein (1981a) sampled shelled corn and wheat in Minnesota with a 1.6-m grain trier and a 265-g capacity deep-bin cup. They took 4 vertical trier samples along a north-south line, one horizontal trier sample slightly below the surface, and a series of deep-bin cup samples at 1-m intervals in the center. None of the surveys sampled the entire depth of the grain bins.

Insects and Fungi

The two most important groups of pests of stored grains are insects and fungi. It was estimated that, "storage losses from insects in the U.S. averaged $471,417,000 for each of the years 1951-1960" (Cotton and Wilbur, 1974). Cryptolestes spp. were the most frequently collected

insects in 2 recent surveys (Mills and Pedersen, unpublished report, 1980); Barak and Harein, 1981a). Lefkovitch (1959, 1962a, 1964, 1965a, 1965b) has done much of the taxonomy of this genus, dividing it down into 6 species that attack stored products.

Cryptolestes ferrugineus can spend their entire life cycle in grain. There are 4 larval instars, and a pupal stage. Larvae may spend some of their developmental period between the pericarp and the kernel (Rilett, 1949). They can develop in relative humidity below 40%, their developmental temperature range is 20-42.5°C, and their optimal conditions are 35°C, 90% r.h. (Currie, 1967). They are coldhardy, being able to acclimate to cold temperatures (-12°C) (Smith, 1970), and are found in the dry tropics and cooler temperature regions (Currie, 1967). They are worldwide in distribution (Howe and Lefkovitch, 1957).

C. turcicus also has 4 larval instars; the last one secretes a tough, silken cocoon. They are limited by dry conditions, not developing in r.h. below 40%. Their developmental temperature range is 17-37°C, and their optimal conditions are 28°C, 90% r.h. (Lefkovitch, 1962b). They are not as coldhardy as C. ferrugineus (Currie, 1967).

The biology of C. pusillus is similar to that of C. turcicus. They too create a tough silken cocoon. They cannot develop in r.h. below 50%, their developmental temperature range is 17.5-37.5°C (Currie, 1967), and their optimal conditions are 30°C, 90% r.h. (Davies, 1949). They are not coldhardy (Currie, 1967).

Fungi "probably rank second only to insects as a cause of deterioration and loss in all kinds of stored products throughout the world" (Christensen and Kaufmann, 1974). Surtees (1965) described patterns of

behavior and dispersion of Cryptolestes ferrugineus to damp and moldy (Aspergillus candidus) wheat. He concluded that oviposition, trophic, and possibly thermokinetic behavior are important in dispersion. Loschiavo and Sinha (1966) observed feeding and oviposition of C. ferrugineus on 24 species of fungi, and studied the aggregation responses to sound and germ-exposed (kernels that had the pericarp scraped from the germ area) wheat. The strongest responses were caused by damp, fungus-infected kernels with exposed germs. Chang and Loschiavo (1971) reared C. turcicus on several different diets, including some with varying concentrations of fungi (Alternaria sp., Cladosporium sp., Aspergillus sp., Penicillium sp.). They found correlations between rate of larval development and fungal concentration. Wright et al. (1980a-c) studied various interactions of Penicillium sp. isolates with Tribolium confusum. These interactions included the nutritional value of the fungi, the preference of the insect for certain isolates, and the effects of some Penicillium sp. mycotoxins on T. confusum.

Alternaria, Cladosporium, Fusarium, and Helminthosporium are representative field fungi genera which attack the grain before harvest. They require a high moisture content to grow (20-23%). Storage fungi attack the grain while it is in storage. They grow at a lower moisture content, some as low as 14.0%. Representative genera include Aspergillus and Penicillium (Christensen and Kaufmann, 1974).

MATERIALS AND METHODS

Location and Access to Farm Bins

Six grain bins were selected by using the data from an earlier grain sorghum survey conducted in 24 counties in Kansas. After studying the data, individual bins were selected on the basis of size (larger than 14 ft diameter), species and numbers of insects (especially Cryptolestes), and the level of the grain relative to the top of the bin (no less than 2' from the eave of the roof). County agents assisted in making arrangements with cooperating farmers (Table 1).

Sampling Procedures

A Cargill Probe-A-Vac®, a commercial pneumatic grain sampler was used to sample the grain bins (Cargill, Inc., Minneapolis, Minnesota). It was powered by a 7/8 h.p. motor, which pulls air carrying the grain up through a 1 1/4" inner tube. Replacement air passes down through the space between this tube and an outer 2" tube. The grain passes into a cyclone collector standing on the grain surface. The probe includes the aluminum double tubes in 2 ft sections, that can be fitted together with special pliers. A flexible hose connects the cyclone with the tubes. The probe point section has a temperature sensor. This system allows a sample and temperature to be taken at any point in the grain bin.

The bins were sampled using the stratified random sampling pattern. The grain surface was stratified with 3 concentric circles; then the

Table 1. Bin size, number of bushels, location, year of harvest, and date sampled for the 6 sorghum bins.

Bin #	Size (diam x ht)	No. of bushels*	Location	Year of harvest	Date sampled
1	18' x 15'	3,045	Wabaunsee Co.	1976	7 Jun 80
2	24' x 21'	7,602	Nemaha Co.	1978	2 Jul 80
3	24' x 13'	4,706	Cloud Co.	1978	1 Aug 80
4	18' x 17'	3,451	Jackson Co.	1978 & 1979	21 Aug 80
5	24' x 22'	7,964	Nemaha Co.	?	31 Oct 80
6	32' x 18'	11,934	Nemaha Co.	?	7 Nov 80

*Calculated using radius of bin and depth of grain (1 cu ft = .8 bu).

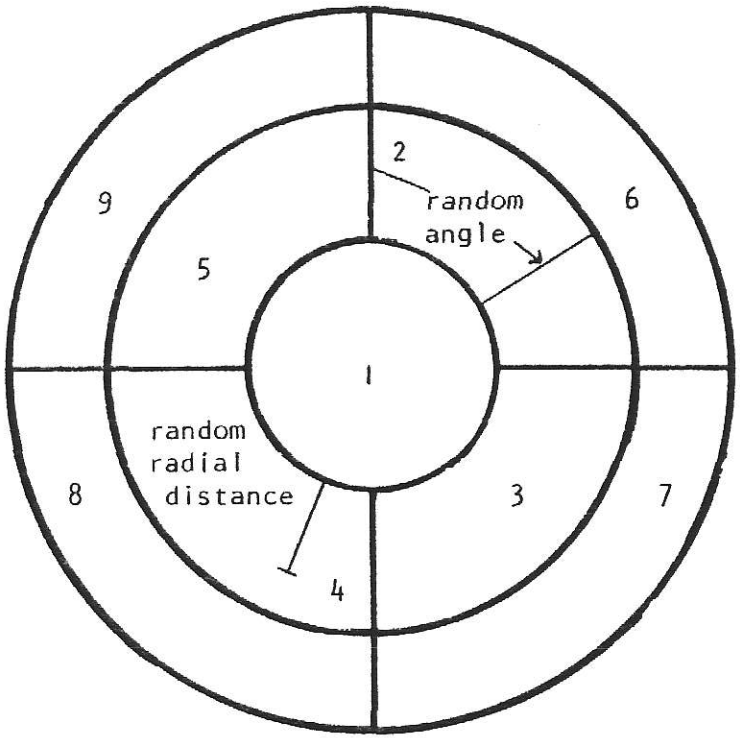
surface was further "divided" by 2 lines (diameters) through the center and perpendicular to each other. These lines pointed toward the cardinal directions. For sampling purposes the center circle was not divided by these lines. The diameter lines served to divide the areas between the concentric circles, which were located so that the central circle and all the "pieces" between the circles were of equal area. There were 9 areas and a vertical probing was done in each, the exact location determined by randomly selecting an angle and a radial distance from the center within each surface section (Fig. 1).

The bins were vertically stratified into 4-ft strata beginning at the bottom and moving toward the top. A "surface" sample was taken from the layer of grain above the last complete 4-ft stratum. Sampling points were identified within each of these 4-ft strata by randomly selecting a depth of 1, 2, 3, or 4 ft within each stratum. A floor sample was also taken.

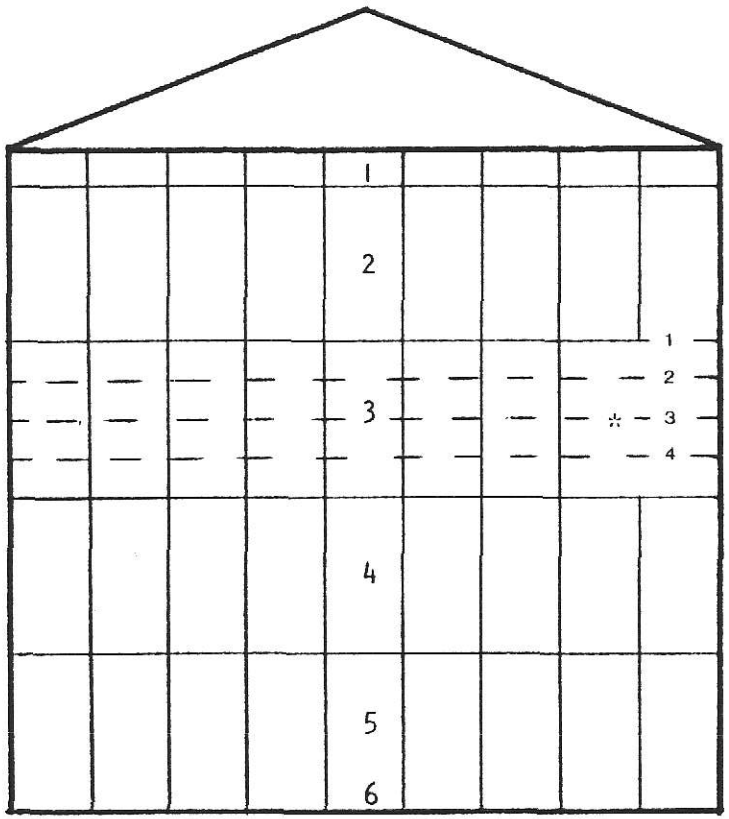
The actual sampling began by lifting the probe, with the necessary extensions, and other materials into the bin using a rope. Surface samples were taken immediately in all 9 areas to minimize disturbance to insects on or near the surface. The center probing was taken next, and the exact depth of the grain determined. By using the roof supports for angle determination, and a cloth tape measure for radial distances, the preselected sample sites were located. The probe was pushed to the desired depth, the cyclone collector emptied, and a sample taken from that point. Each sample was collected in a coffee can to assure equal volumes. The temperature at each sample site was obtained by connecting

Fig. 1. a. Diagram of areas used in calculation of sampling points.

b. Diagram of depths used in calculation of sampling points.



a.



b. *Four levels within each stratum; one of which is randomly selected for sampling.

terminals, one to each tube, then reading temperature on a meter. This procedure was done for each sample in each section for the entire bin. Concurrently, gravity-fill probe samples were taken at the second and third depth for each section.

Each sample was placed in a plastic ziplock bag (6" x 9"), marked, and eventually lowered out of the bin in burlap sacks. The samples were placed in portable coolers to protect live insects from excessively cold or warm temperatures.

Handling and Analysis of Samples

The samples were returned to the lab and kept in a cold room (5.5°C) for 3-4 days. Analytical procedures for the samples included weighing, and sieving using a no. 10, 2mm-opening Tyler Standard® sieve to remove "fines" and insects (W. S. Tyler Inc., Mentor, Ohio). After reweighing, the percentage fines were calculated. Live insects were separated from fines and placed in vials with 70% isopropanol for later identification and counting. The moisture content was measured on a Burrows Digital Moisture Computer 700® (Burrows Equipment Co., Evanston, Ill.). This electronic moisture computer is calibrated for a specific amount of grain (250 g). If a sample contained less than 250 g, as in the case of a few gravity-fill probe samples, the moisture content was measured with an Insto® moisture tester (Insto Inc., Auburn, Ill.).

Identification of Insects and Fungi

Both insect and fungal species were determined in the lab. Insects were identified using a binocular microscope, and most were keyed to species. Cryptolestes spp. were cleared in boiling chloral phenol, placed in Hoyer's medium on a microscope slide, and identified using a low power microscope (Banks, 1979). Fungal invasion of kernels was determined by plating 5% sodium hypochlorite (Chlorox® bleach) surface-sterilized kernels on a malt 4% salt agar plate (Tuite, 1969). Two plates of 25 kernels each were analyzed for each sample. The plates were kept in a rearing room with 27 °C and 67% r.h., for 5 days. On the fifth day, the fungal species were identified using a binocular microscope, to determine morphological and color characteristics.

RESULTS

Six variables were analyzed: insects/1000 g of sorghum, percentage of kernels invaded by field fungi, percentage of kernels invaded by storage fungi, grain moisture content (%), temperature (°C), and percentage fines (material that pass through a 10-mesh sieve, including broken grain, chaff, and insects). The means of the variables were separated by area and depth using Duncan's multiple range test.

Bin 1

Bin 1, sampled June 7, 1980; contained 1976 grain (Table 1). After sampling, we learned that it had recently been fumigated. The grain was originally fumigated in the fall of 1979. Samples were collected during

the sorghum survey January 9, 1980, and the grain was fumigated again during the spring of 1980.

In Bin 1, few live insects (2.3/1000 g sorghum) were present (Table 2), but many dead ones were collected. Density of live insects (5.1/1000 g) was greater at floor level than at any other depth. There were no differences in density of insects from the areas, i.e., areas delineated for probing. The percentage field fungal (0.3) in Bin 1 was low as compared to the other bins, and did not differ by depth. Field fungi were found only in areas 3 and 7. Incidence of storage fungi (2.7%) was slightly higher, and they were found toward the top of the bin. Storage fungi were highest in area 6 (6.5%), and lowest in area 5 (0.4%).

The moisture content was highest at the floor (11.84%), and there were no differences by area. The temperature was highest at the surface (32.2°C), and lowest toward the bottom. Areas 6-9, the outside areas, had higher temperatures ($\bar{x}$ = 30.1°C) than the inside areas 1-5 ($\bar{x}$ = 27.1°C). Percentages of fines were higher in depths 2 and 3 (6.28 and 6.43, respectively), and lower in depths 1 and 5 (3.58 and 3.18, respectively). Percentage fines were similar by area.

To test for relationships between the variables, Spearman correlations were computed. Spearman correlations within depths were computed so that the large differences in insect means would not invalidate the correlations. In Bin 1, percentage field fungi was significantly correlated with percentage storage fungi, and temperature was significantly correlated with percentage fines (both correlation coefficients .33).

Table 2. Mean values[1] for 6 variables pooled for the 9 areas or the 5 depths in Bin 1.

	% Moisture content	Temperature (°C)	% Fines	Insects[2]	Fungi (%)[3] Field	Fungi (%)[3] Storage
A. DEPTH						
1	10.62 c	32.2 a	3.58 b	1.9 b	0.3 a	2.8 ab
2	11.26 b	28.2 b	6.28 a	2.0 b	0 a	6.2 a
3	10.73 c	26.8 c	6.43 a	0.6 b	0.3 a	3.3 ab
4	10.81 c	25.7 c	4.78 ab	2.0 b	0 a	0.4 b
5	11.84 a	26.6 c	3.18 b	5.1 a	0.7 a	0.7 b
B. AREA						
1	11.12 a	26.3 b	3.40 b	1.7 a	0 b	1.5 abc
2	10.96 a	27.6 b	4.60 ab	2.1 a	0 b	0.5 bc
3	10.90 a	27.2 b	4.76 ab	1.3 a	0.4 ab	0.8 bc
4	10.76 a	27.6 b	3.92 ab	4.1 a	0 b	1.0 abc
5	11.10 a	26.9 b	3.80 b	1.3 a	0 b	0.4 c
6	11.02 a	31.1 a	5.94 ab	3.2 a	0 b	6.5 a
7	11.36 a	29.8 a	6.38 a	1.7 a	1.2 a	5.6 ab
8	11.02 a	29.4 a	5.76 ab	4.1 a	0 b	4.5 abc
9	11.24 a	29.9 a	5.08 ab	1.4 a	0 b	4.4 abc

[1] Values followed by the same letter are not significantly different ($p<0.05$) by Duncan's multiple range test.

[2] Number of insects per 1000 g sorghum.

[3] % Fungal-invaded kernels.

Bin 2

Bin 2, sampled July 2, 1980, contained 1978 grain (Table 1). The low numbers of insects (3.1/1000 g sorghum) collected were not significantly different by depth or by area (Table 3). Percentage field fungi was lower (11.7) than percentage storage fungi (48.7). Percentage field fungi was highest at the floor (25.6) than at any other depth. By area, it was highest in area 3 (28.3), and lowest in area 1 (2.3). Percentage storage fungi was highest in the middle (depth 4 = 68.7), and lowest at the floor (19.3). Area 1 had the highest percentage storage fungi (75.7).

The moisture content was lowest at the surface and at the floor (12.60 and 12.38%, respectively), and was statistically similar in the other depths. Areas 1 and 9 had higher moisture contents (13.90 and 14.07%, respectively), while area 8 had the lowest (11.77%). The temperatures were similar by depth; and higher in areas 6 and 8 (26.6 and 27.1°C, respectively), than area 1 (22°C). More percentage fines was at the surface (4.38) than at any other depth. The areas toward the north and center had more fines (areas 1, 2, 5, 6, 9, $\bar{x}$ = 2.26%) than the areas toward the south (3, 4, 7, 8, $\bar{x}$ = 1.27%) (Fig. 2).

In Bin 2, percentage field fungi was negatively correlated with percentage storage fungi (-.34).

A statistical procedure was used to determine which areas in Bins 2-6 were homogeneous, and which areas were outliers. The total numbers of insects found in all samples in the bin were considered the universe, and variance was defined as how much each depth, area, or particular "cell" (specific site of sample collection) differed from the mean. Analysis of variance was first completed on the depths, and

Table 3. Mean values[1] for 6 variables pooled for the 9 areas or the 7 depths in Bin 2.

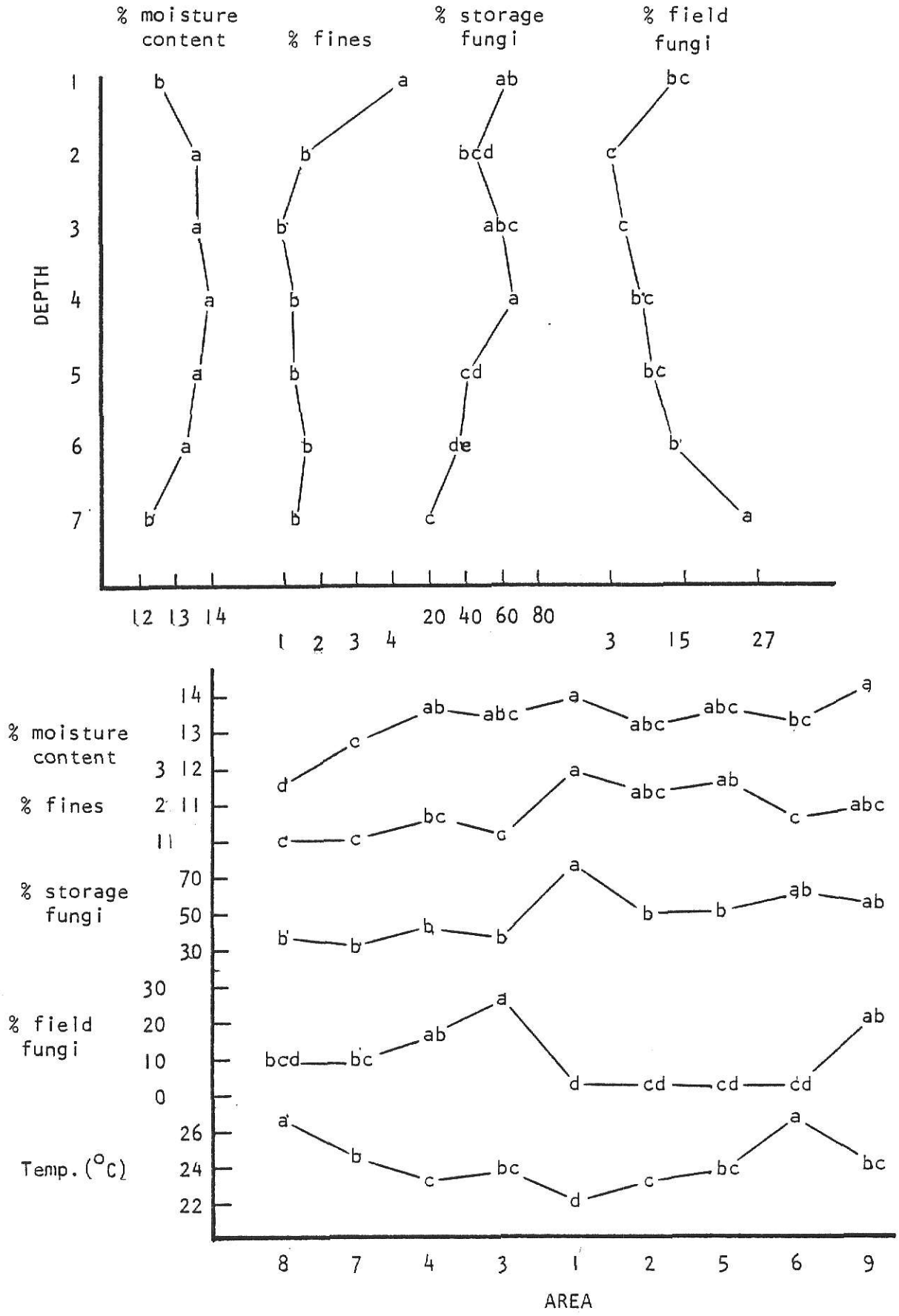
	% Moisture content	Temperature (°C)	% Fines	Insects[2]	Fungi (%)[3] Field	Fungi (%)[3] Storage
A. DEPTH						
1	12.60 b	24.4 a	4.38 a	5.4 a	13.3 bc	65.8 ab
2	13.46 a	24.6 a	1.71 b	4.0 a	3.6 c	46.2 bcd
3	13.74 a	24.4 a	1.12 b	4.1 a	4.2 c	60.0 abc
4	13.94 a	24.1 ab	1.39 b	2.1 a	8.9 bc	68.7 a
5	13.78 a	24.2 ab	1.32 b	1.5 a	11.8 bc	43.3 cd
6	13.29 a	22.8 b	1.52 b	0.8 a	14.4 b	37.3 de
7	12.38 b	25.6 a	1.29 b	3.9 a	25.6 a	19.3 e
B. AREA						
1	13.90 a	22.0 d	2.90 a	7.5 a	2.3 d	75.7 a
2	13.20 abc	23.3 c	2.26 abc	4.2 a	4.3 cd	49.7 b
3	13.66 abc	24.1 bc	1.11 c	0.7 a	28.3 a	35.4 b
4	13.74 ab	23.3 c	1.60 bc	0.4 a	17.7 ab	38.3 b
5	13.66 abc	23.7 bc	2.77 ab	1.9 a	3.4 cd	52.0 b
6	13.00 bc	26.6 a	1.46 c	5.9 a	4.9 cd	58.6 ab
7	12.81 c	24.7 b	1.19 c	2.1 a	13.7 bc	34.3 b
8	11.77 d	27.1 a	1.19 c	1.6 a	10.6 bcd	40.0 b
9	14.07 a	23.9 bc	1.90 abc	3.9 a	20.0 ab	54.0 ab

[1] Values followed by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test.

[2] Number of insects per 1000 g sorghum.

[3] % Fungal-invaded kernels.

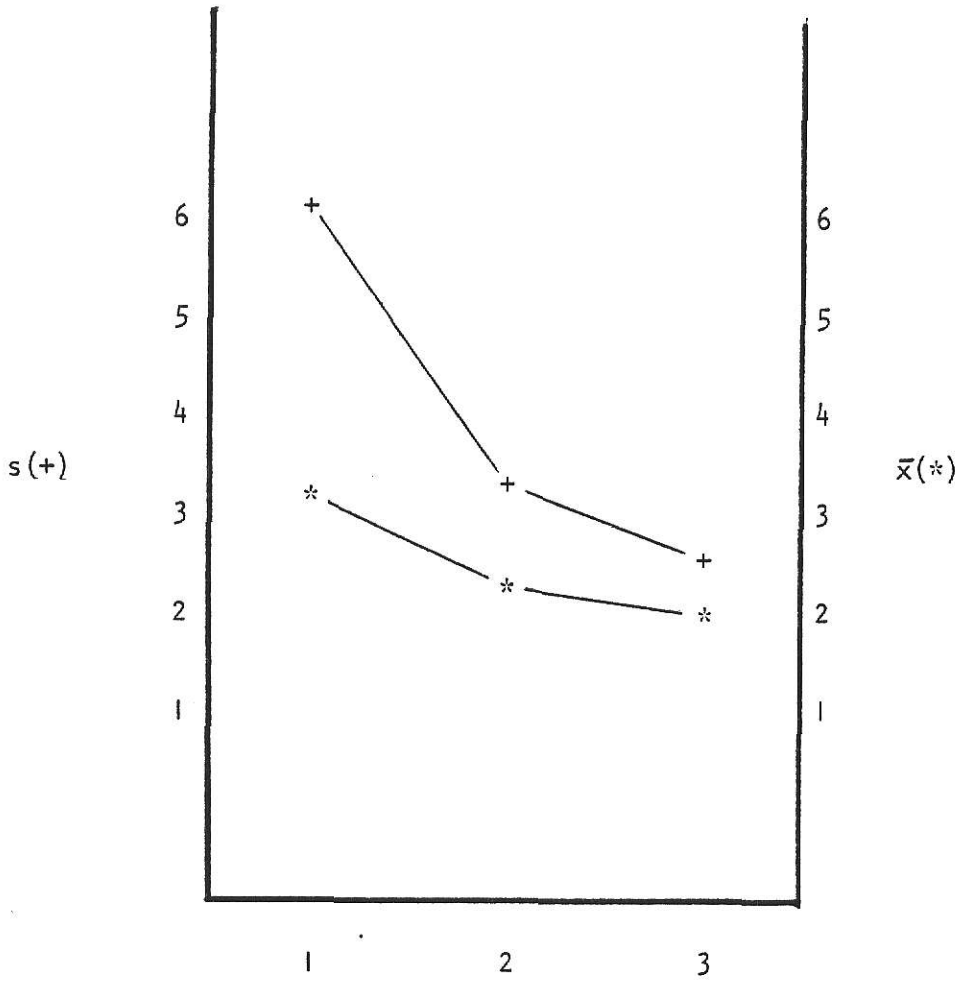
Fig. 2. For variables in Bin 2 showing significant differences in depth and 5 variables showing differences in area. Points represented by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test. Variables exhibiting no significant differences were excluded.


% moisture content
% fines
% storage fungi
% field fungi
DEPTH
1
2
3
4
5
6
7
12 13 14
1 2 3 4
20 40 60 80
3 15 27
% moisture content
% fines
% storage fungi
% field fungi
Temp. (°C)
14
13
12
11
70
50
30
30
20
10
0
26
24
22
8 7 4 3 1 2 5 6 9
AREA

if there was significance, the most extreme depth was removed by using Duncan's multiple range test. The areas were considered next, and if there was significance, the most extreme area was removed. This pattern of removing depths and areas was continued until there were no significant differences among sample means. Next, a plot of depth vs area and area vs depth was completed. Individual cell samples that differed from the overall mean of that bin by more than 3 standard deviations were removed. The depths and areas were considered again, and if there were no significant differences another plot was completed. The variances for depth and area were checked for equality using the Fmax test. This variance procedure was continued until there were no differences in depth or area means, and there were no cells above the 3-standard deviation criterion. Thus, the homogeneous parts of the grain were separated statistically from the outlier parts. This procedure was not performed on Bin 1, because of its low numbers of insects and because of its fumigation record.

In Bin 2, the variance procedure statistically removed 3 cells because of high means. Cells will be designated by their area first, and their depth second. The removed cells in Bin 2 were area 1-depth 1 (37.4 insects/1000 g sorghum), area 6-depth 7 (23.4/1000 g), and area 2-depth 2 (18.3/1000 g). As a result of the removal of these cells, the mean for the entire bin decreased from 3.1/1000 g to 2.0/1000 g, and the standard deviation decreased from 6.2 to 2.6 (Fig. 3).

Fig. 3. Change in standard deviation and in mean of total insects (per 1000 g) in Bin 2 after 3 cells were removed by the variance procedure.



1- original standard deviation and mean
2- after cells area 1-depth 1 and area 6-depth 7 were removed
3- after cell area 2-depth 2 was removed

Bin 3

Bin 3, sampled August 1, 1980, contained 1978 grain (Table 1). More insects were collected from this bin than from the previous bins (41.4/1000 g sorghum) (Table 4). Significantly more insects were at the floor (110.7/1000 g) than at any other depth. There were more insects from area 1 (68.1/100 g) than any other area. Percentage field fungi was lower (6.1) than percentage storage fungi (50.3). Percentage field fungi was much higher at the surface (22.8) than at any other depth, but was similar by area. Percentage storage fungi was similar by depth and by area.

The moisture content was highest at the floor (14.58%), and lowest at the surface (10.76%). It was similar by area. Temperatures were highest at the surface and at the floor (30.1 and 31.1°C, respectively). The outside areas were warmer (areas 6-9, $\bar{x}$ = 32.7°C) than the inside areas (1-5, $\bar{x}$ = 26.3°C). The percentage of fines was similar by depth, but was highest in area 3 (2.96), and lowest in area 6 (1.54) (Fig. 4).

In Bin 3, percentage field fungi was negatively correlated with percentage storage fungi (-.31).

The variance procedure in Bin 3 statistically removed 2 depths because of higher means. They were depth 5 (110.7 insects/1000 g sorghum) and depth 4 (40.7/1000 g). The mean for the entire bin decreased from 41.4/1000 g to 18.5/1000 g, and the standard deviation decreased from 31.0 to 15.7 (Fig. 5).

Table 4. Mean values[1] for 6 variables pooled for the 9 areas or the 5 depths in Bin 3.

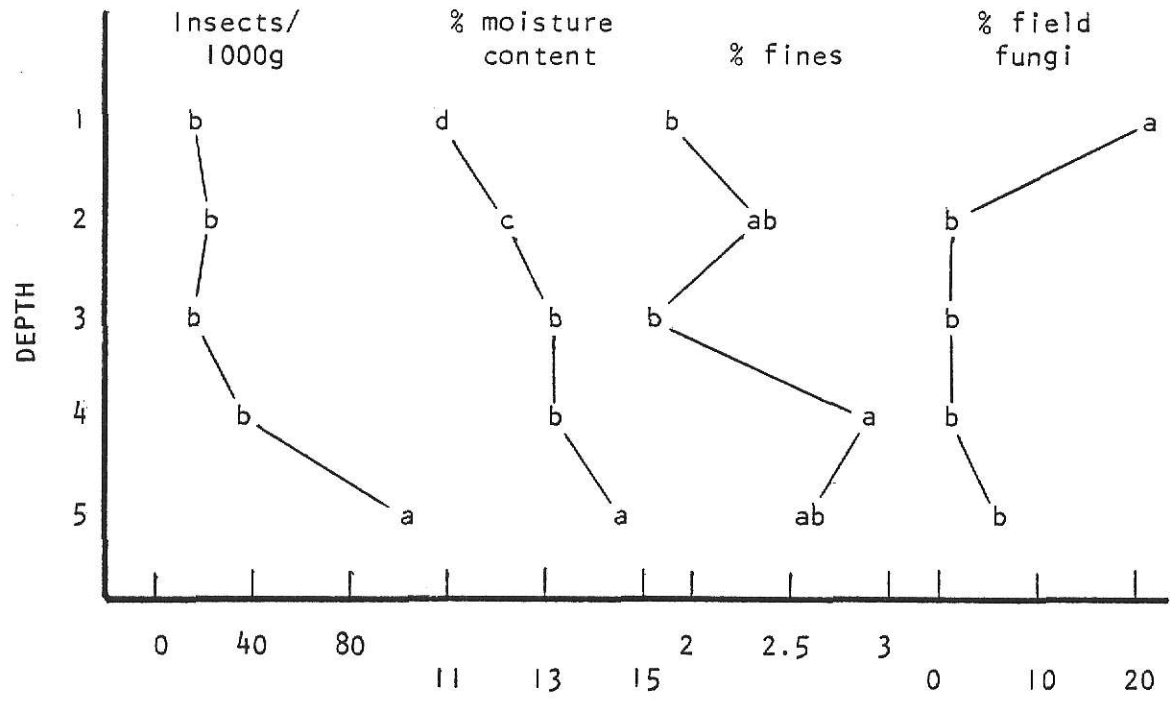
	% Moisture content	Temperature (°C)	% Fines	Insects[2]	Fungi (%)[3] Field	Fungi (%)[3] Storage
A. DEPTH						
1	10.76 d	30.1 a	1.90 b	20.0 b	22.8 a	37.3 a
2	12.22 c	29.4 ab	2.42 ab	21.9 b	1.1 b	54.9 a
3	13.26 b	26.6 b	1.82 b	13.7 b	0 b	56.0 a
4	13.23 b	28.5 ab	2.87 a	40.7 b	0.4 b	61.3 a
5	14.58 a	31.1 a	2.63 ab	110.7 a	6.0 b	41.8 a
B. AREA						
1	13.46 a	26.6 de	2.70 ab	68.1 a	0.8 a	53.2 a
2	12.60 a	24.6 e	2.76 ab	49.5 ab	4.6 a	56.4 a
3	12.80 a	27.4 cde	2.96 a	59.3 ab	0.8 a	33.2 a
4	12.46 a	26.4 de	2.12 ab	22.3 b	6.0 a	55.6 a
5	12.76 a	26.4 de	2.34 ab	27.8 ab	11.6 a	49.6 a
6	13.30 a	33.9 ab	1.54 b	37.9 ab	5.6 a	54.0 a
7	12.58 a	36.0 a	2.44 ab	29.0 ab	1.6 a	62.0 a
8	12.80 a	30.3 bcd	2.10 ab	40.7 ab	10.0 a	31.2 a
9	12.52 a	30.7 bc	2.00 ab	38.1 ab	13.6 a	57.2 a

[1] Values followed by the same letter are not significantly different ($P<0,05$) by Duncan's multiple range test.

[2] Number of insects per 1000 g sorghum.

[3] % Fungal-invaded kernels.

Fig. 4. Four variables in Bin 3 showing significant differences in depth, and 3 variables showing differences in area. Points represented by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test. Variables exhibiting no significant difference were excluded.


Insects/
1000g
% moisture
content
% fines
% field
fungi
DEPTH
1
2
3
4
5
b b b b a
d c b b a
b ab b a ab
a b b b b
0 40 80
11 13 15
2 2.5 3
0 10 20

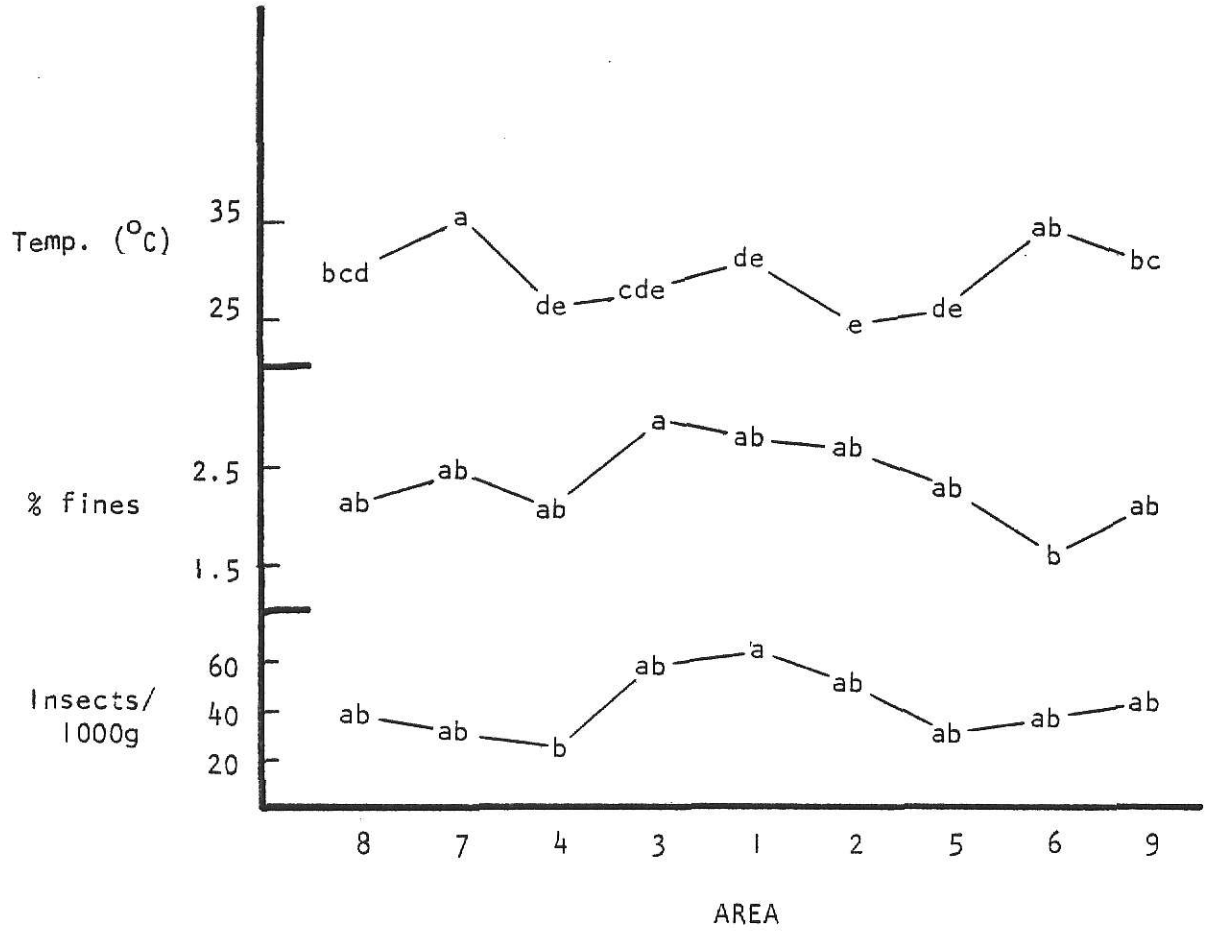
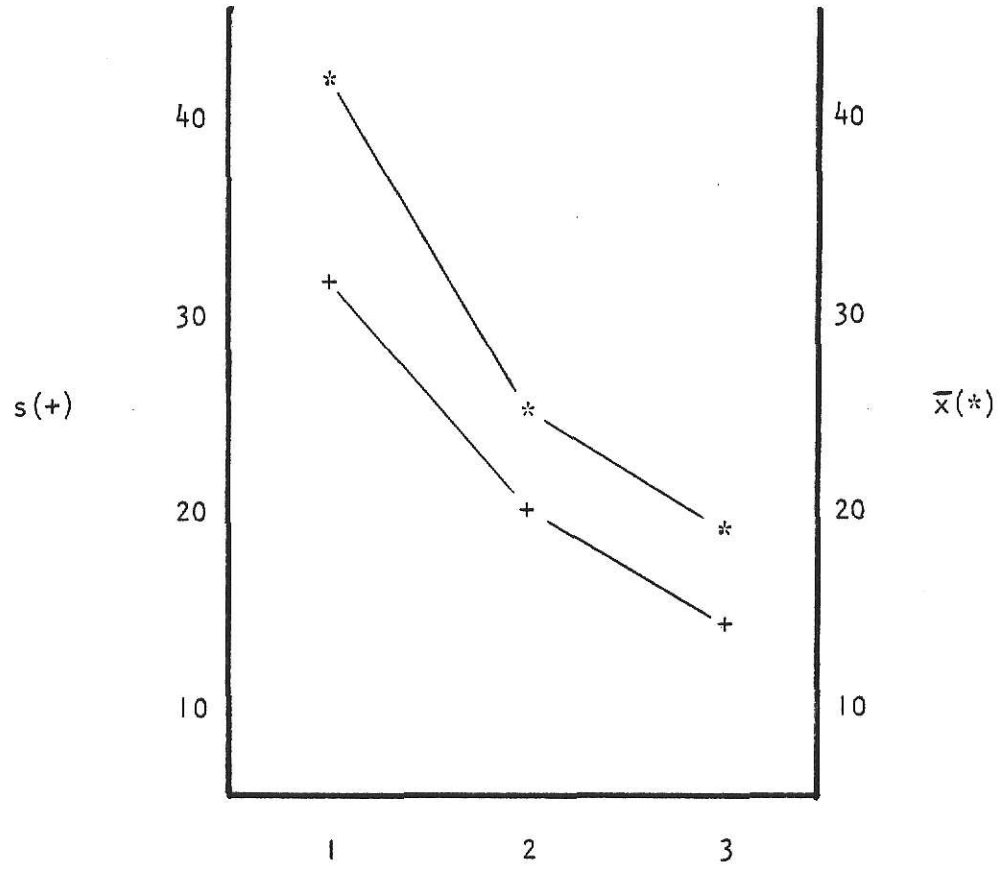

Temp. (°C)
35
25
bcd a de cde de e de ab bc
% fines
2.5
1.5
ab ab ab a ab ab ab b ab
Insects/
1000g
60
40
20
ab ab b ab a ab ab ab ab
8 7 4 3 1 2 5 6 9
AREA

Fig. 5. Change in standard deviation and in mean of total insects (per 1000 g) in Bin 3 after 2 depths were removed by the variance procedure.



1- original standard deviation and mean
2- after depth 5 was removed
3- after depth 4 was removed

Bin 4

Bin 4, sampled August 21, 1980, contained both 1978 and 1979 grain (Table 1). More insects (112.4/1000 g sorghum) were collected from this bin than from any other bin (Table 5). More insects were collected from the floor (246.8/1000 g) than at any other depth. The center area contained more insects (265.9/1000 g) than other areas. Percentage field fungi was much higher (85.1) than percentage storage fungi (0.6). Percentage field fungi was higher in the middle depths (4, 97.3; 3, 95.8) than at the surface (58.4). The center and inner areas had greater percentages of field fungi (areas 1-5, $\bar{x}$ = 91.5) than the outer areas (6-9, $\bar{x}$ = 77.1). Percentage storage fungi was higher at the surface (2.9), and was similar by area (Fig. 6).

The moisture content was highest at the floor (12.59%), but was similar by area. The temperature was lowest at the surface (28.3°C). The inner areas were cooler than the outer areas (29.6°C cf. 34.6°C) (Fig. 9). The percentage of fines was highest in depth 4 (2.4) and lowest in depth 2 (1.26), and was highest in area 6 (2.32) and lowest in area 4 (1.17) (Fig. 7).

In Bin 4, the temperature was negatively correlated with insects, and positively correlated with the moisture content (-.28 and .38, respectively).

The variance procedure statistically removed one depth and 2 cells in Bin 4 because of higher means. They were depth 6 (246.8 insects/1000 g sorghum), and cells area 3-depth 4 (552.0/1000 g) and area 1-depth 5 (627.6/1000 g). The procedure also removed depth 3 (19.1/1000 g), but because of its low mean. After excluding these

Table 5. Mean values[1] for 6 variables pooled for the 9 areas or the 6 depths in Bin 4.

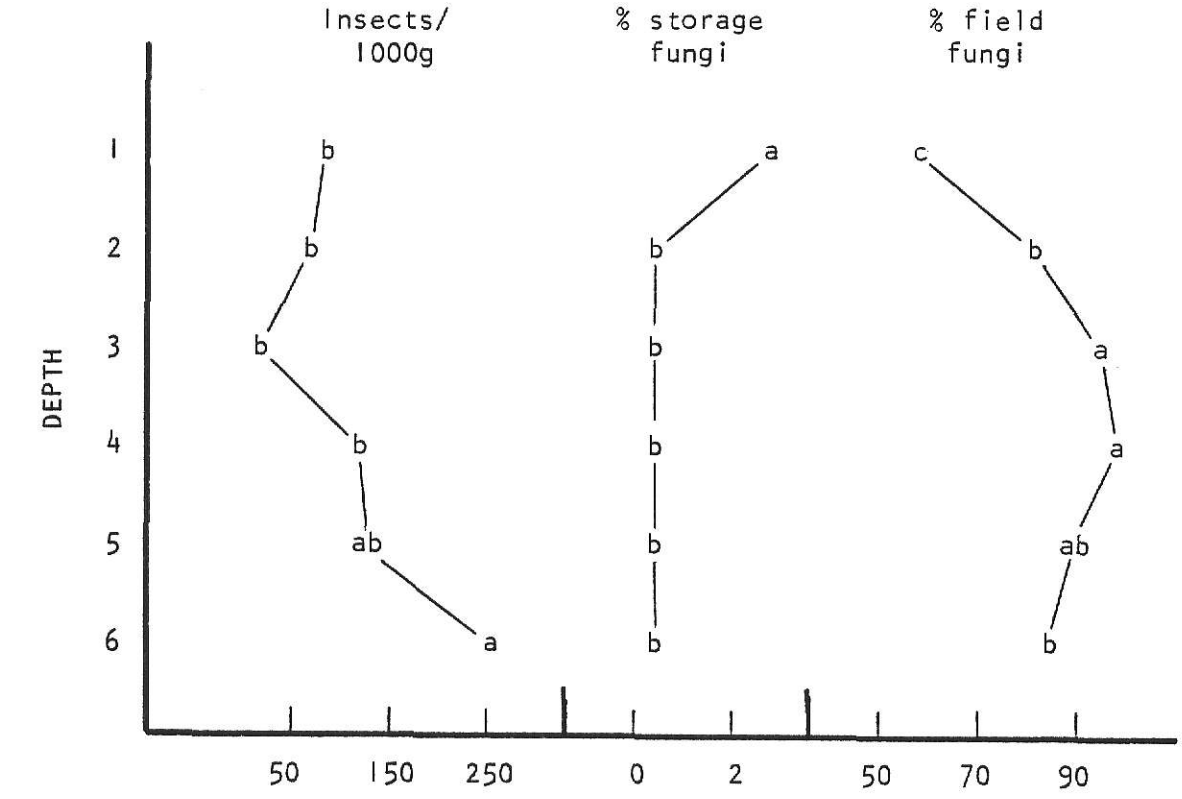
	% Moisture content	Temperature (°C)	% Fines	Insects[2]	Fungi (%)[3] Field	Fungi (%)[3] Storage
A. DEPTH						
1	11.92 c	28.3 b	1.76 abc	89.3 a	58.4 c	2.9 a
2	11.99 bc	33.9 a	1.26 c	73.8 b	83.1 b	0.2 b
3	11.87 c	31.8 a	1.31 bc	19.1 b	95.8 a	0 b
4	11.96 bc	32.1 a	2.40 a	110.3 b	97.3 a	0 b
5	12.26 b	33.7 a	1.98 ab	134.7 ab	91.6 ab	0 b
6	12.59 a	34.2 a	1.86 abc	246.8 a	84.4 b	0.4 b
B. AREA						
1	12.03 abc	26.8 c	1.78 abc	265.9 a	93.3 a	2.3 a
2	12.38 a	29.4 bc	1.68 abc	94.6 b	95.3 a	0.7 a
3	12.15 abc	27.8 c	1.95 abc	194.4 ab	89.0 abc	0.3 a
4	12.12 abc	32.9 a	1.17 c	33.6 b	89.0 abc	0 a
5	12.18 ab	30.9 b	1.80 abc	101.5 b	91.0 ab	0.3 a
6	11.77 c	31.0 b	2.32 a	100.9 b	72.7 d	1.0 a
7	12.02 abc	35.7 a	2.22 ab	84.7 b	77.7 bcd	0 a
8	11.95 bc	36.0 a	1.35 bc	51.5 b	82.0 abcd	0 a
9	12.27 ab	35.7 a	1.57 abc	84.3 b	76.0 cd	0.7 a

[1] Values followed by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test.

[2] Number of insects per 1000 g sorghum.

[3] % Fungal-invaded kernels.

Fig. 6. Three variables in Bin 4 showing significant differences in depth and 2 variables showing differences in area. Points represented by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test. Variables exhibiting no significant differences were excluded.


Insects/
1000g
% storage
fungi
% field
fungi
DEPTH
1
2
3
4
5
6
b
b
b
b
ab
a
a
b
b
b
b
b
c
b
a
a
ab
b
50
150
250
0
2
50
70
90

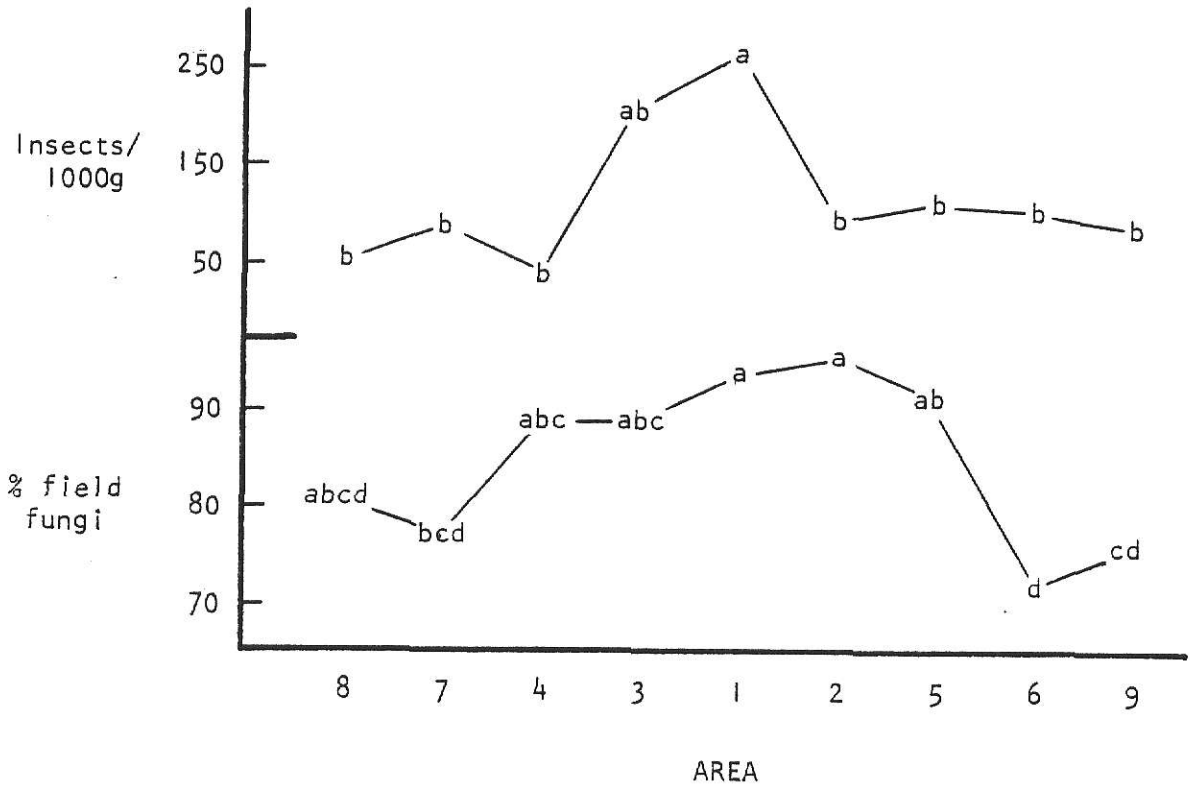
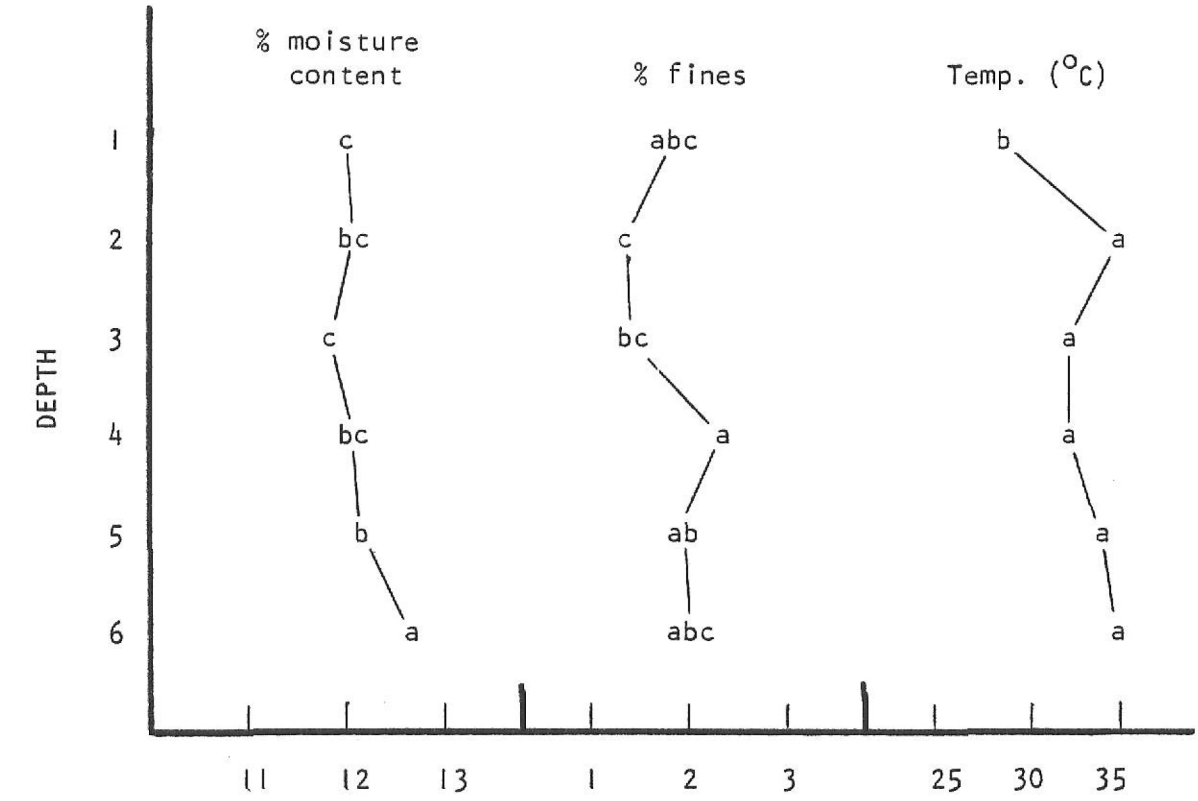
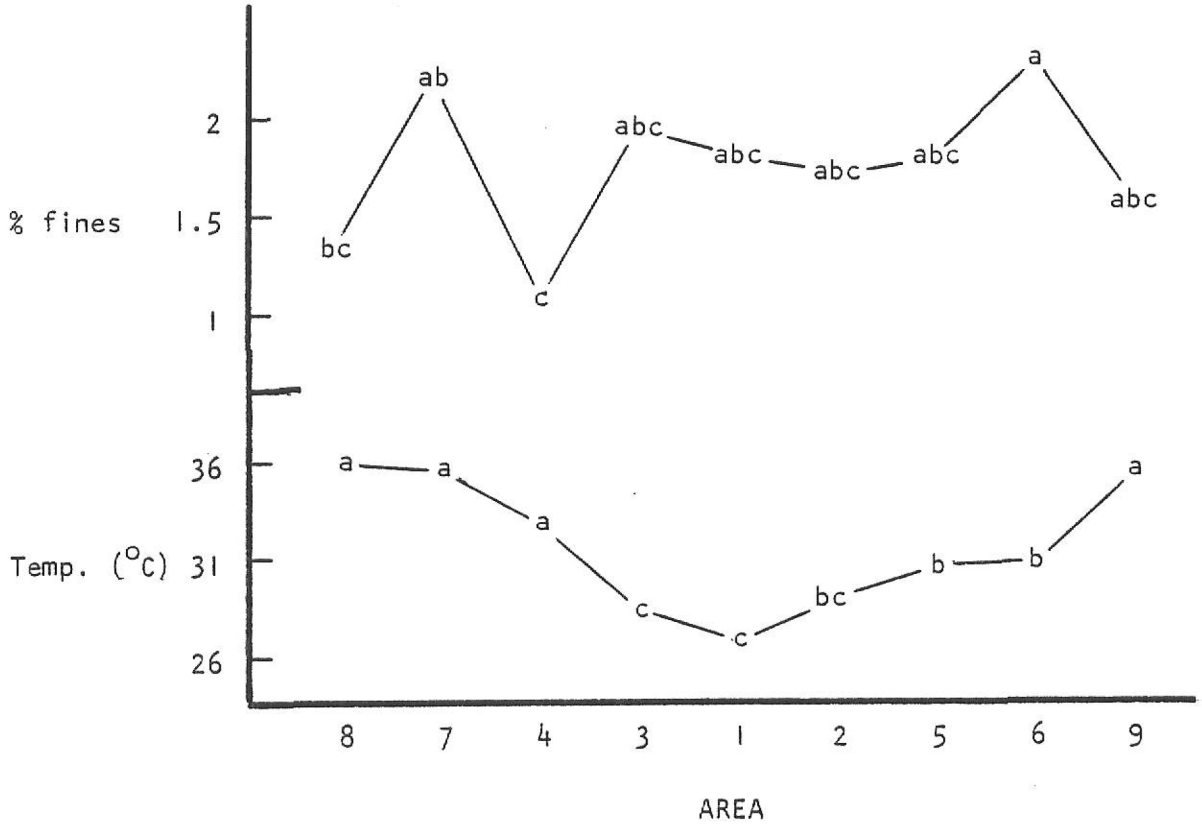

Insects/
1000g
250
150
50
b
b
b
ab
a
b
b
b
b
% field
fungi
90
80
70
abcd
bcd
abc
abc
a
a
ab
d
cd
8
7
4
3
1
2
5
6
9
AREA

Fig. 7. Three variables in Bin 4 showing significant differences in depth and 2 variables showing differences in area. Points represented by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test. Variables exhibiting no significant differences were excluded.


% moisture content
% fines
Temp. (°C)
DEPTH
1
2
3
4
5
6
c
bc
c
bc
b
a
abc
c
bc
a
ab
abc
b
a
a
a
a
a
11
12
13
1
2
3
25
30
35


% fines
2
1.5
1
Temp. (°C)
36
31
26
bc
ab
c
abc
abc
abc
abc
a
abc
a
a
a
c
c
bc
b
b
a
8
7
4
3
1
2
5
6
9
AREA

depths and cells, the mean for the entire bin decreased from 112.4/1000 g to 67.6/1000 g, and the standard deviation decreased from 136.0 to 52.6 (Fig. 8).

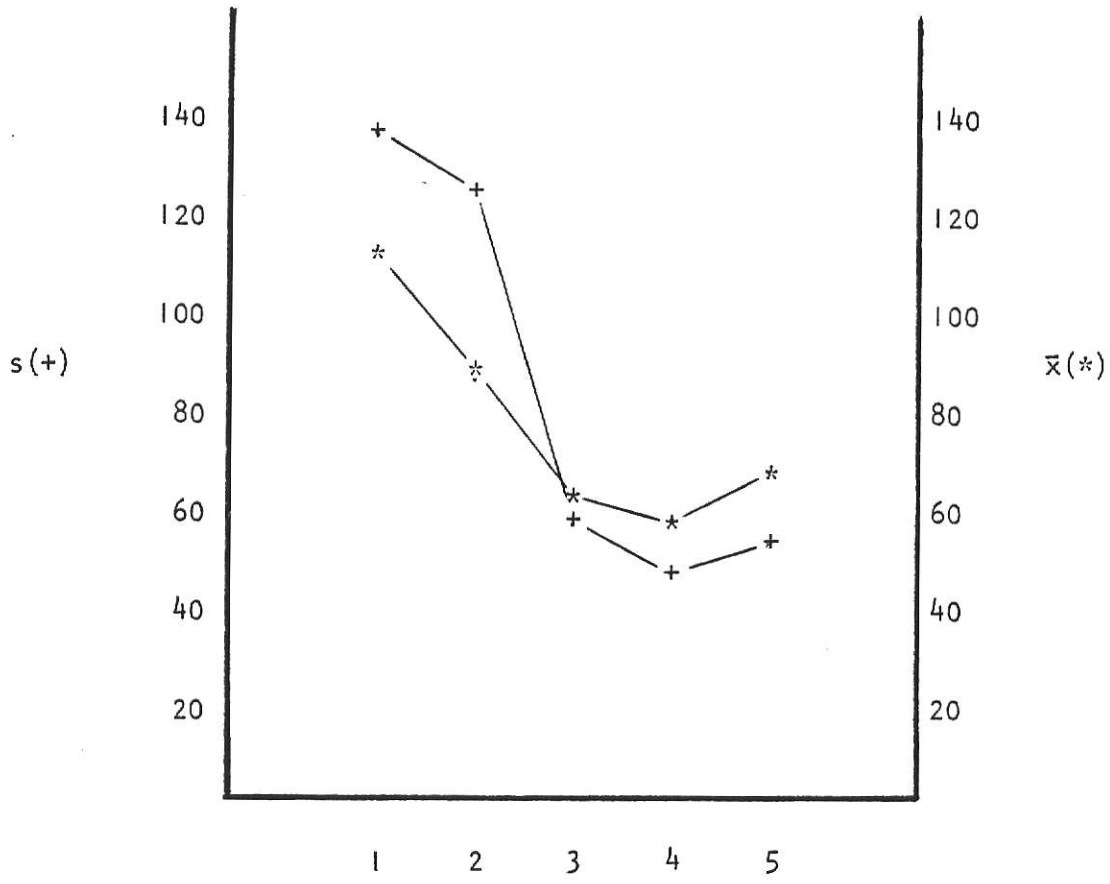
Bin 5

Bin 5 was sampled October 31, 1980; the year of harvest was unknown (Table 1). Large numbers of insects were collected (16.5/1000 g sorghum) (Table 6). Insects were collected in large numbers from the floor (38.6/1000 g) and from the middle depth (depth 4 = 20.0/1000 g). The areas with the most insects were 8, 3, and 9 (39.3/1000 g, 21.9/1000 g, and 16.9/1000 g, respectively). Percentage field fungi was lower (8.1) than percentage storage fungi (22.2). Percentage field fungi was higher in the top 2 depths (depth 1 = 23.6, depth 2 = 20.7). Area 8 had the highest percentage field fungi (16.0), although statistically similar to areas 2, 6, 7, and 9. The floor had the highest, and the surface had the lowest percentage storage fungi (32.2 and 11.8, respectively). It was similar by area (Fig. 9).

The moisture content was highest at the floor (13.27%), and lower toward the top. Area 8 had the lowest moisture content (11.00%). The temperature was lowest at the surface (13.5°C), and highest in the middle (depth 3 = 20.2°C). The temperatures were similar by area. The percentage fines was highest at the surface (3.06), and was lowest in area 9 (1.17) (Fig. 10).

In Bin 5, insects were negatively correlated with the moisture content (-.36), and temperature was positively correlated with percentage fines (.29).

Fig. 8. Change in standard deviation and in mean of total insects (per 1000 g) in Bin 4 after 2 depths and 3 cells were removed by the variance procedure.



1- original standard deviation and mean
2- after depth 6 was removed
3- after cells area 3-depth 4 and area 1-depth 5 were removed
4- after cell area 1-depth 2 was removed
5- after depth 3 was removed

Table 6. Mean values[1] for 6 variables pooled for the 9 areas or the 3 depths in Bin 5.

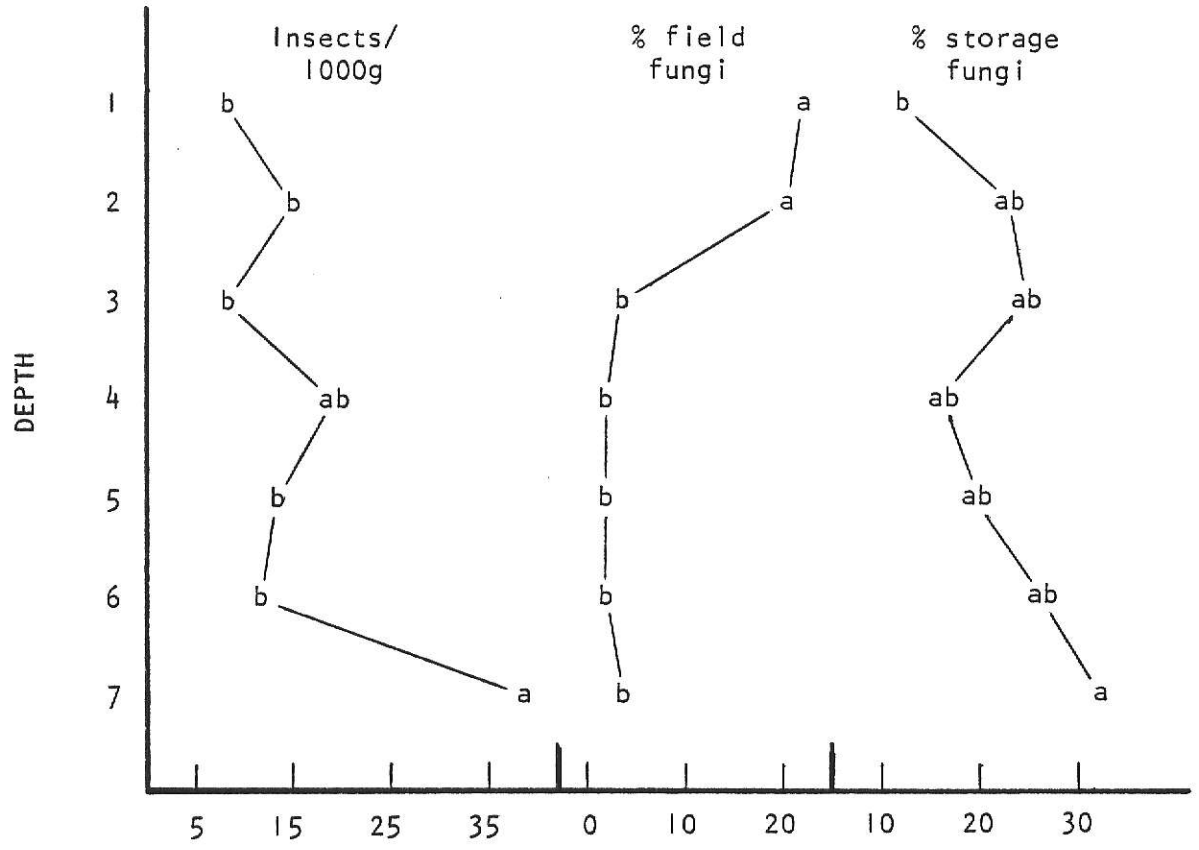
	% Moisture content	Temperature (°C)	% Fines	Insects[2]	Fungi (%)[3] Field	Fungi (%)[3] Storage
A. DEPTH						
1	10.96 d	13.5 d	3.06 a	7.5 b	23.6 a	11.8 b
2	10.79 d	19.0 bc	1.49 bc	14.4 b	20.7 a	24.0 ab
3	11.21 d	20.2 a	1.74 bc	8.8 b	3.6 b	25.1 ab
4	12.11 c	19.8 ab	2.21 b	20.0 ab	0.9 b	16.2 ab
5	12.59 b	18.4 c	1.27 c	14.1 b	2.0 b	20.0 ab
6	12.74 b	18.3 c	1.57 bc	12.4 b	1.6 b	26.4 ab
7	13.27 a	16.7 c	1.74 bc	38.6 a	4.4 b	32.2 a
B. AREA						
1	12.50 a	18.2 abc	2.51 a	7.5 b	5.1 b	23.1 a
2	12.14 ab	18.0 abc	2.47 a	14.6 b	11.7 ab	22.3 a
3	11.90 b	18.9 ab	2.49 a	21.9 ab	4.0 b	19.1 a
4	11.96 b	19.2 a	1.50 b	12.0 b	5.1 b	22.6 a
5	12.49 a	17.9 abc	1.71 ab	12.2 b	4.0 b	24.9 a
6	11.93 b	17.4 bc	1.73 ab	10.5 b	8.6 ab	20.3 a
7	11.96 b	19.3 a	2.04 ab	13.8 b	10.3 ab	20.9 a
8	11.00 c	17.1 c	1.19 b	39.3 a	16.0 a	15.4 a
9	11.70 b	17.2 c	1.17 b	16.9 ab	8.0 ab	31.7 a

[1] Values followed by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test.

[2] Number of insects per 1000 g sorghum.

[3] % Fungal-invaded kernels.

Fig. 9. Three variables in Bin 5 showing significant differences in depth and 2 variables showing differences in area. Points represented by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test. Variables exhibiting no significant differences were excluded.


Insects/
1000g
% field
fungi
% storage
fungi
DEPTH
1
2
3
4
5
6
7
b
b
b
ab
b
b
a
a
b
b
b
b
b
a
b
ab
ab
ab
ab
ab
a
5
15
25
35
0
10
20
10
20
30

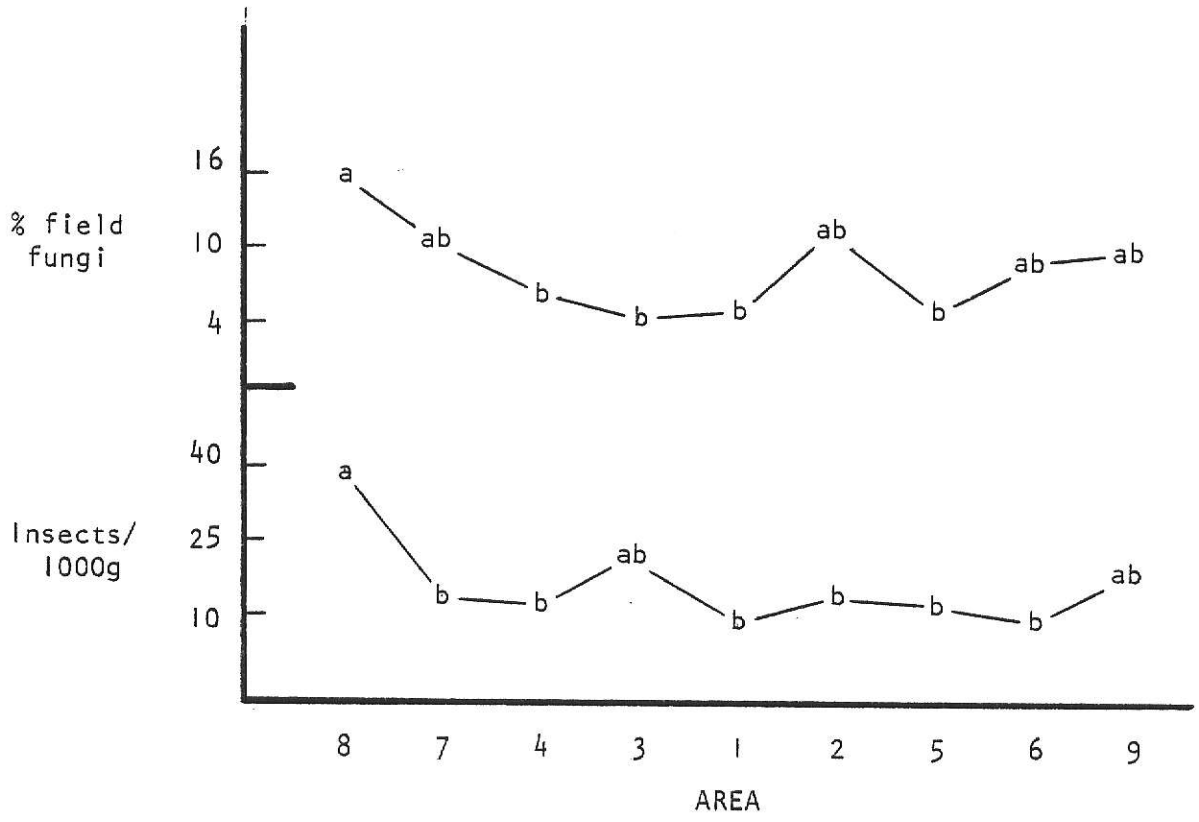
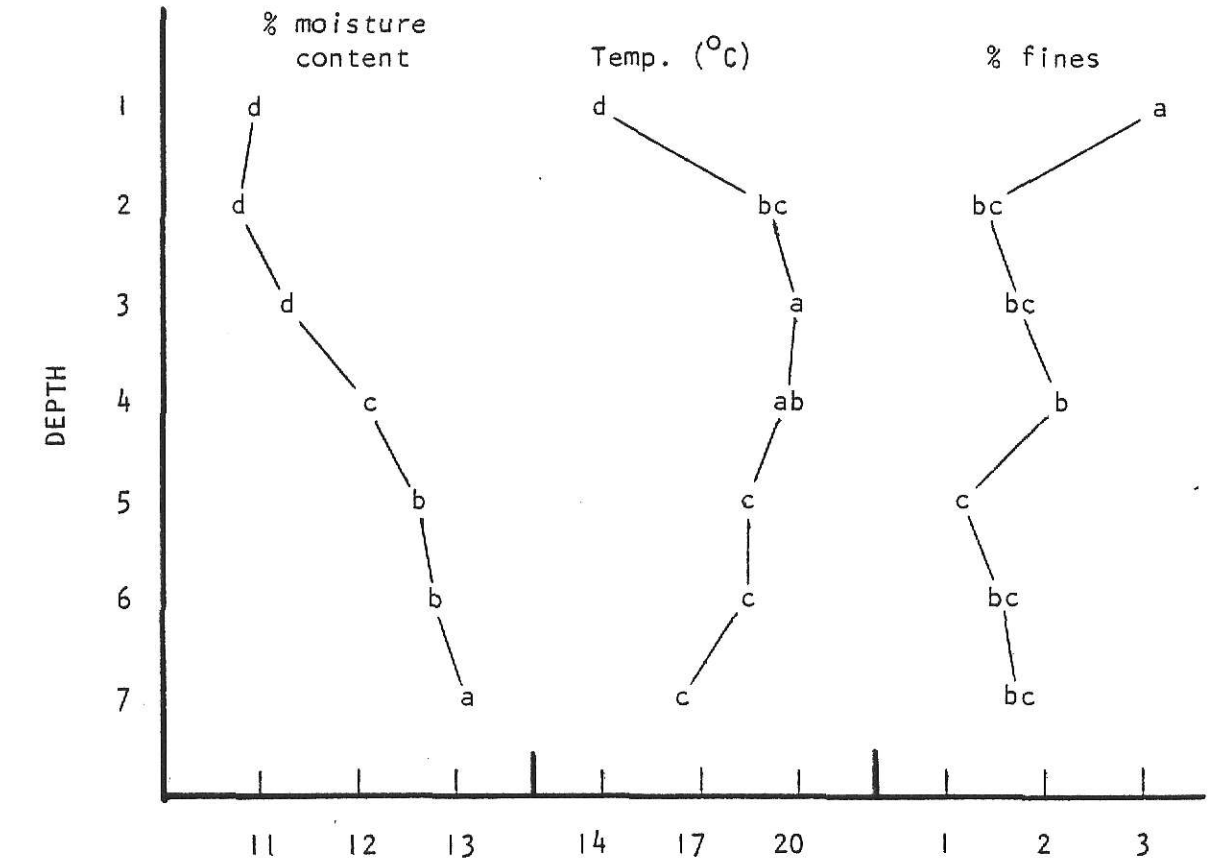
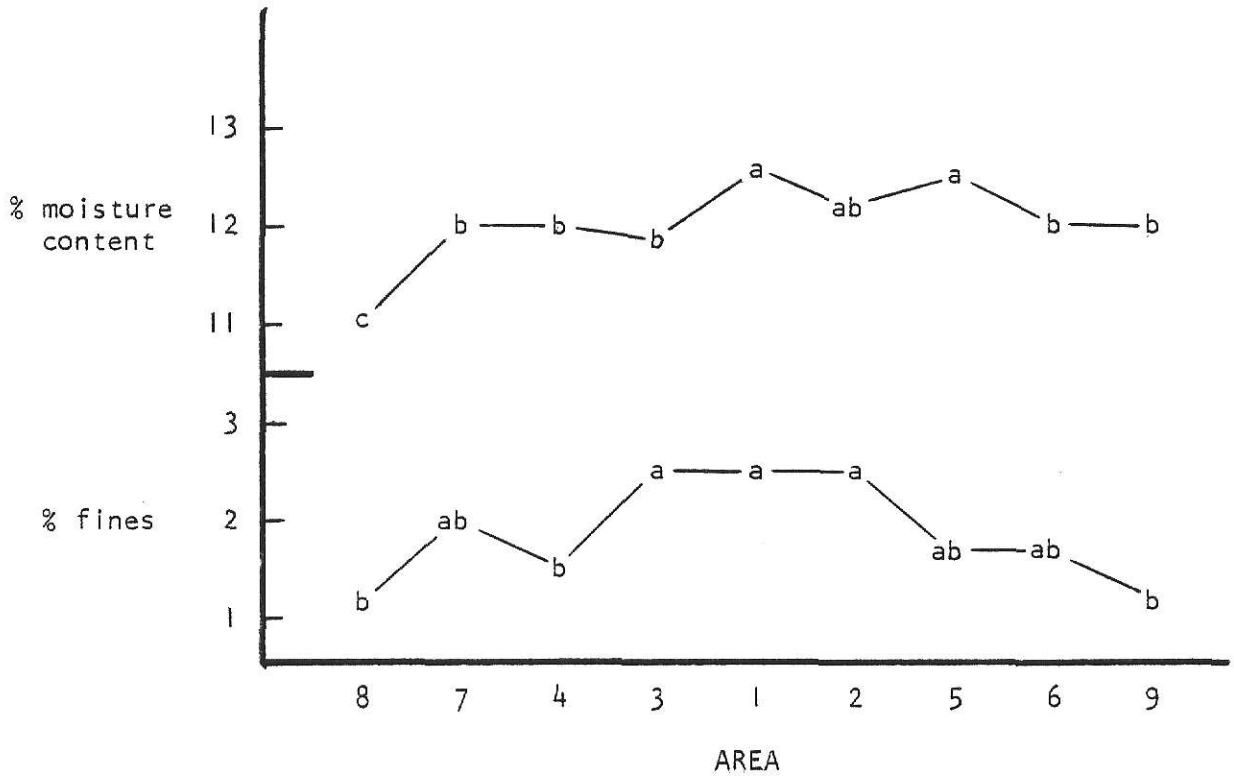

% field
fungi
16
10
4
a
ab
b
b
b
ab
b
ab
ab
Insects/
1000g
40
25
10
a
b
b
ab
b
b
b
b
ab
8
7
4
3
1
2
5
6
9
AREA

Fig. 10. Three variables in Bin 5 showing significant differences in depth and 2 variables showing differences in area. Points represented by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test. Variables exhibiting no significant differences were excluded.


% moisture content
Temp. (°C)
% fines
DEPTH
1
2
3
4
5
6
7
d d d c b b a
d bc a ab c c c
a bc bc b c bc bc
11 12 13 14 17 20 1 2 3


% moisture content
% fines
13
12
11
3
2
1
c b b b a ab a b b
b ab b a a a ab ab b
8 7 4 3 1 2 5 6 9
AREA

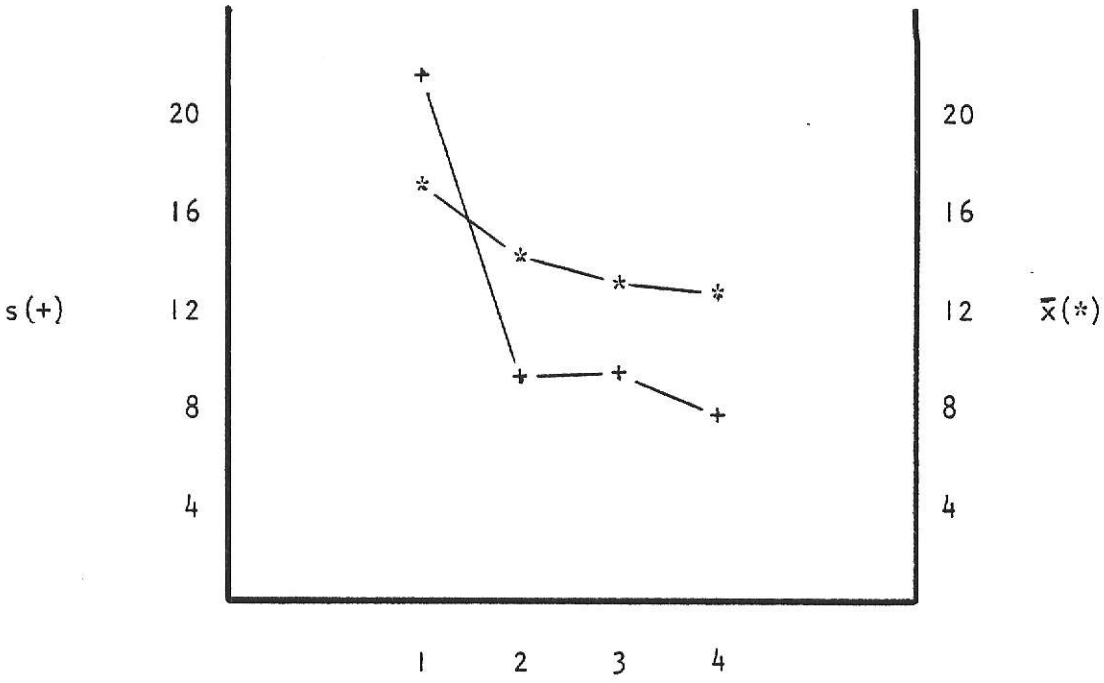
The variance procedure statistically removed one depth and 2 cells because of higher means. They were depth 7 (38.6 insects/1000 g sorghum), and cells area 8-depth 7 (175.6/1000 g) and area 3-depth 4 (45.0/1000 g). As a result, the mean for the entire bin decreased from 16.5/1000 g to 12.2/1000 g, and the standard deviation decreased from 21.4 to 7.7 (Fig. 11).

Bin 6

Bin 6 was sampled November 7, 1980; the year of harvest was unknown (Table 1). Low numbers of insects were collected (4.9/1000 g sorghum) (Table 7). More insects were collected at the floor than at any other depth (9.7/1000 g). Statistically similar mean numbers of insects were collected from areas 1, 3, and 7 (7.9, 7.7, and 8.4/1000 g, respectively). Percentage field fungi was higher (42.1) than percentage storage fungi (28.8). Percentage field fungi was lowest at the surface (14.0), and higher toward the bottom. The center area had the lowest percentage field fungi (19.3). Percentage storage fungi was highest at the surface (56.7). Area 7 had the lowest percentage storage fungi (8.3) (Fig. 12).

The moisture content was higher toward the top (depth 2 = 14.22%), and lowest at the floor (12.41%). Area 7 had the lowest moisture content (12.75%). The temperature, like the moisture content, was higher toward the top (depth 1 = 16.6°C, depth 2 = 16.1°C), and lowest at the floor (14.7°C). Area 7 had the highest temperature (17.3°C). The percentage fines was lower toward the top and middle (depth 3 =

Fig. 11. Change in standard deviation and in mean of total insects (per 1000 g) in Bin 5 after one depth and 2 cells were removed by the variance procedure.



1- original standard deviation and mean
2- after cell area 8-depth 7 was removed
3- after depth 7 was removed
4- after cell area 3-depth 4 was removed

Table 7. Mean values[1] for 6 variables pooled for the 9 areas or the 6 depths in Bin 6.

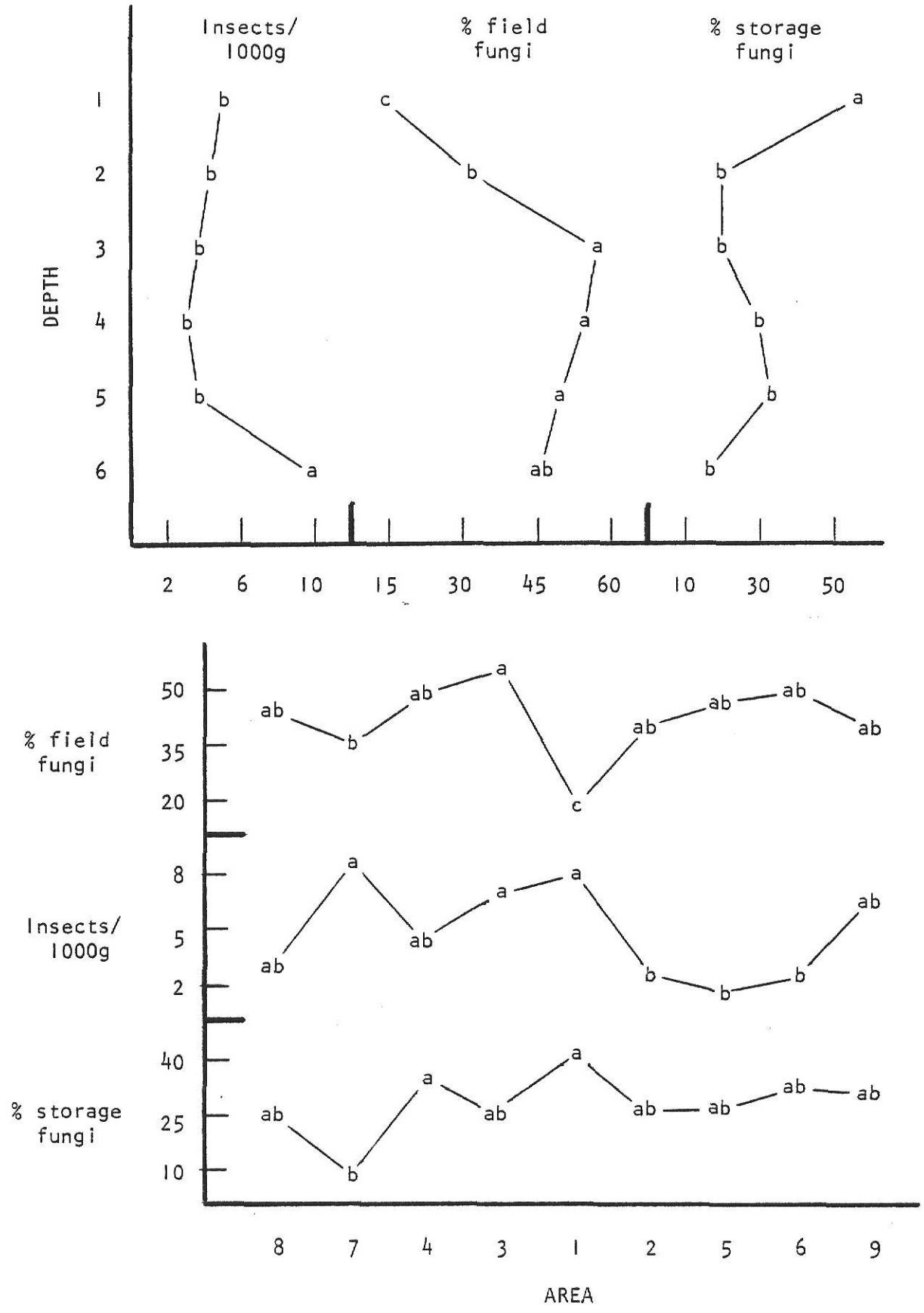
	% Moisture content	Temperature (°C)	% Fines	Insects[2]	Fungi (%)[3] Field	Fungi (%)[3] Storage
A. DEPTH						
1	13.70 ab	16.6 a	0.80 b	4.8 b	14.0 c	56.7 a
2	14.22 a	16.1 ab	0.77 b	4.4 b	34.4 b	18.2 b
3	14.07 a	15.6 b	0.47 b	3.9 b	55.8 a	18.9 b
4	13.37 b	15.5 b	0.86 b	2.9 b	53.6 a	28.9 b
5	12.46 c	15.4 b	1.97 a	3.9 b	49.6 a	34.2 b
6	12.41 c	14.7 c	1.94 a	9.7 a	45.1 ab	16.0 b
B. AREA						
1	12.85 bc	15.4 b	1.38 bc	7.9 a	19.3 c	43.7 a
2	13.38 abc	15.4 b	2.73 a	2.3 b	42.3 ab	26.3 ab
3	13.33 abc	15.3 b	0.87 c	7.7 a	53.3 a	25.0 ab
4	13.62 a	15.9 b	2.28 ab	4.5 ab	47.7 ab	35.0 a
5	13.65 a	15.3 b	1.38 bc	1.7 b	46.0 ab	28.3 ab
6	13.63 a	15.1 b	0.32 c	2.1 b	48.3 ab	33.3 ab
7	12.75 c	17.3 a	0.37 c	8.4 a	36.7 b	8.3 b
8	13.52 ab	15.8 b	0.43 c	3.4 ab	45.0 ab	26.7 ab
9	13.60 a	15.4 b	0.43 c	6.6 ab	40.0 ab	32.7 ab

[1] Values followed by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test.

[2] Number of insects per 1000 g sorghum.

[3] % Fungal-invaded kernels.

Fig. 12. Three variables in Bin 6 showing significant differences in depth and 3 variables showing differences in area. Points represented by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test.


Insects/
1000g
% field
fungi
% storage
fungi
DEPTH
1
2
3
4
5
6
2 6 10 15 30 45 60 10 30 50
% field
fungi
50
35
20
Insects/
1000g
8
5
2
% storage
fungi
40
25
10
8 7 4 3 1 2 5 6 9
AREA

0.47), and higher toward the bottom (depth 5 = 1.97). The inner areas had higher percentage fines (areas 1-5, $\bar{x}$ = 1.73) than the outer areas (6-9, $\bar{x}$ = 0.39) (Fig. 13).

In the correlation analysis, percentage storage fungi was negatively correlated with percentage field fungi (-.31); the moisture content was negatively correlated with insects (-.29) and with the percentage fines (-.27). Insects were positively correlated with temperature (.28).

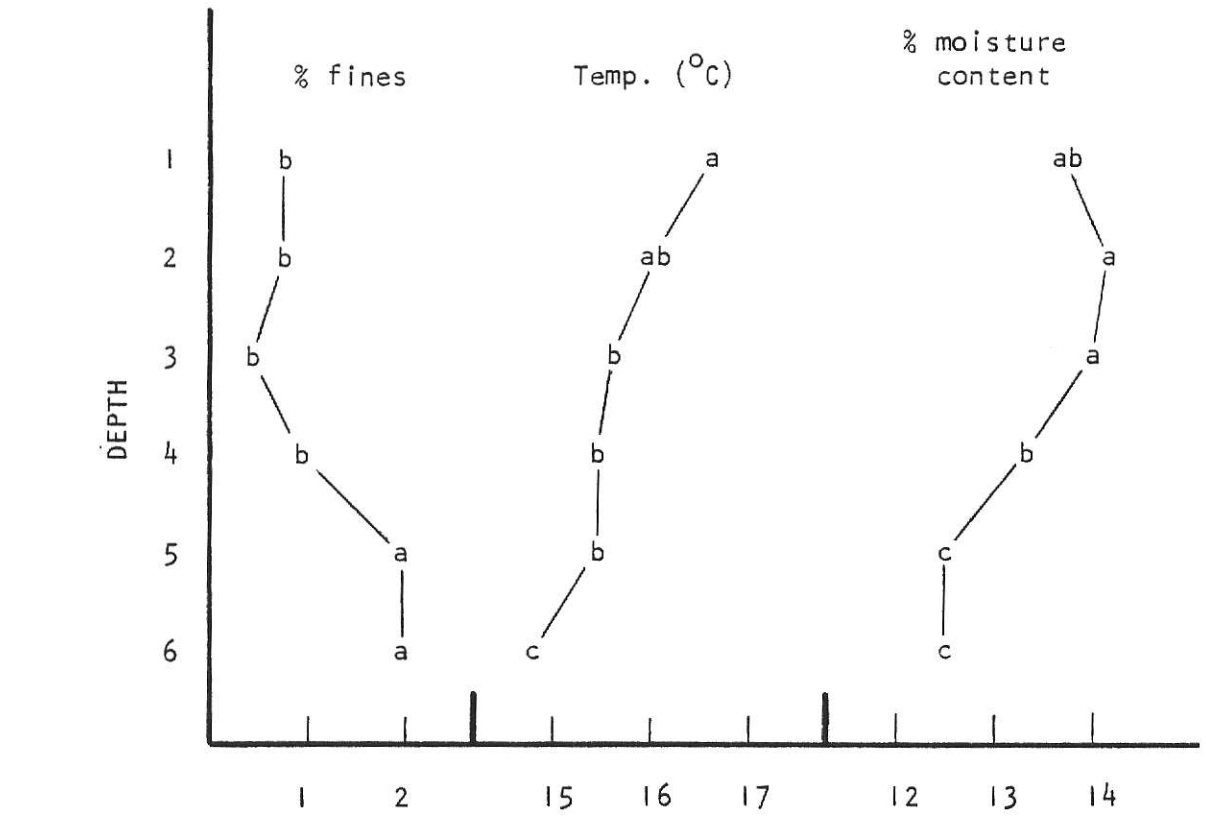
The variance procedure statistically removed one depth, 2 areas, and 3 cells because of higher means. They were depth 6 (9.7 insects/1000 g sorghum), and areas 1 (7.9/1000 g) and 3 (7.7/1000 g). The cells removed were area 9-depth 2 (14.7/1000 g), area 7-depth 3 (11.8/1000 g), and area 7-depth 1 (10.0/1000 g). As a result, the mean for the entire bin decreased from 4.9/1000 g to 2.1/1000 g, and the standard deviation decreased from 4.5 to 2.0 (Fig. 14).

All Bins

To compare the data collected by the gravity-fill probe with that of the pneumatic probe, t-tests were done on 3 variables: insects, Cryptolestes ferrugineus, and percentage fines. This was performed on the data from Bins 2-6. In Bin 4, more C. ferrugineus were collected in the gravity-fill probe, and in Bin 6 more percentage fines was collected in the pneumatic probe. In all other cases, the data were similar.

Regression analysis was used to develop a more practical sampling procedure, i.e., one using fewer samples than were collected from the

Fig. 13. Three variables in Bin 6 showing significant differences in depth and 3 variables showing differences in area. Points represented by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test.


% fines
Temp. (°C)
% moisture content
DEPTH
1
2
3
4
5
6
b b b b a a
a ab b b b c
ab a a b c c
1 2 15 16 17 12 13 14

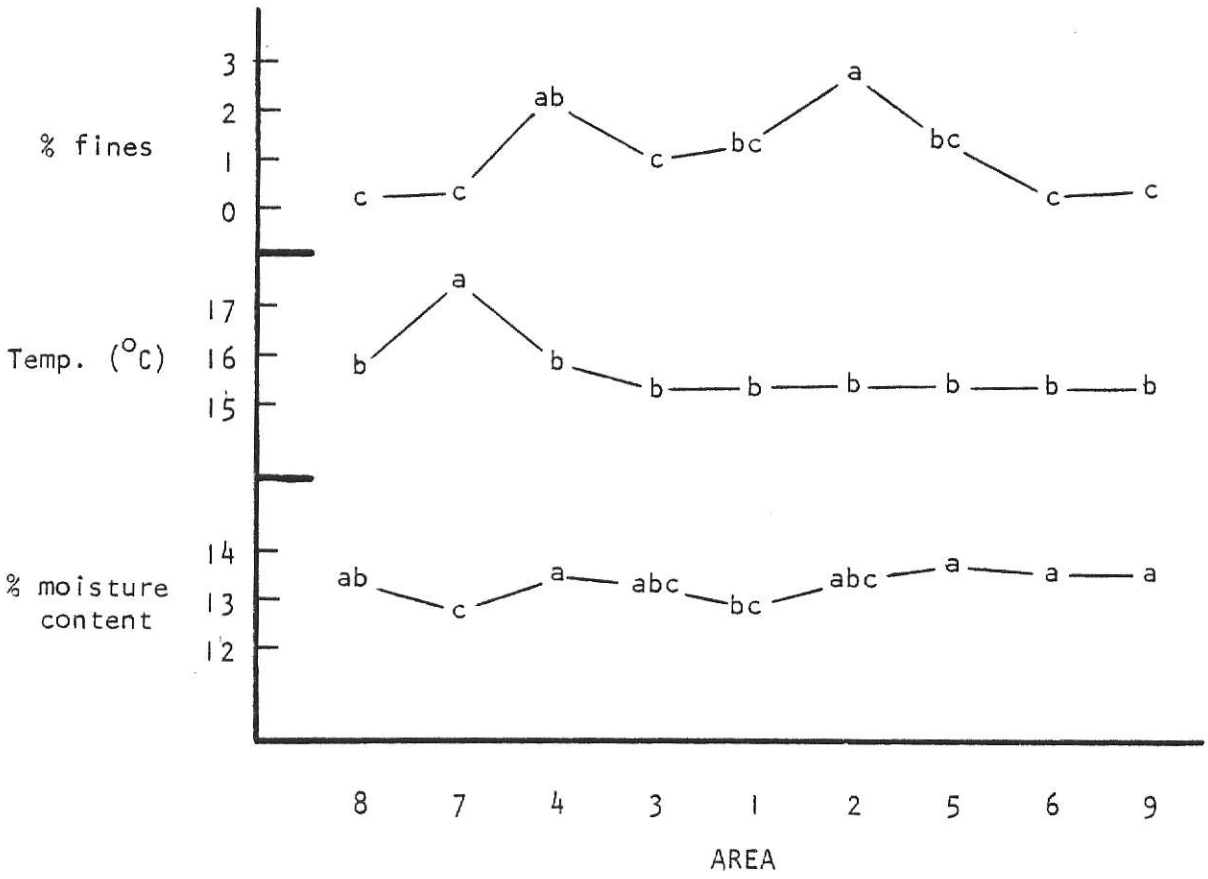
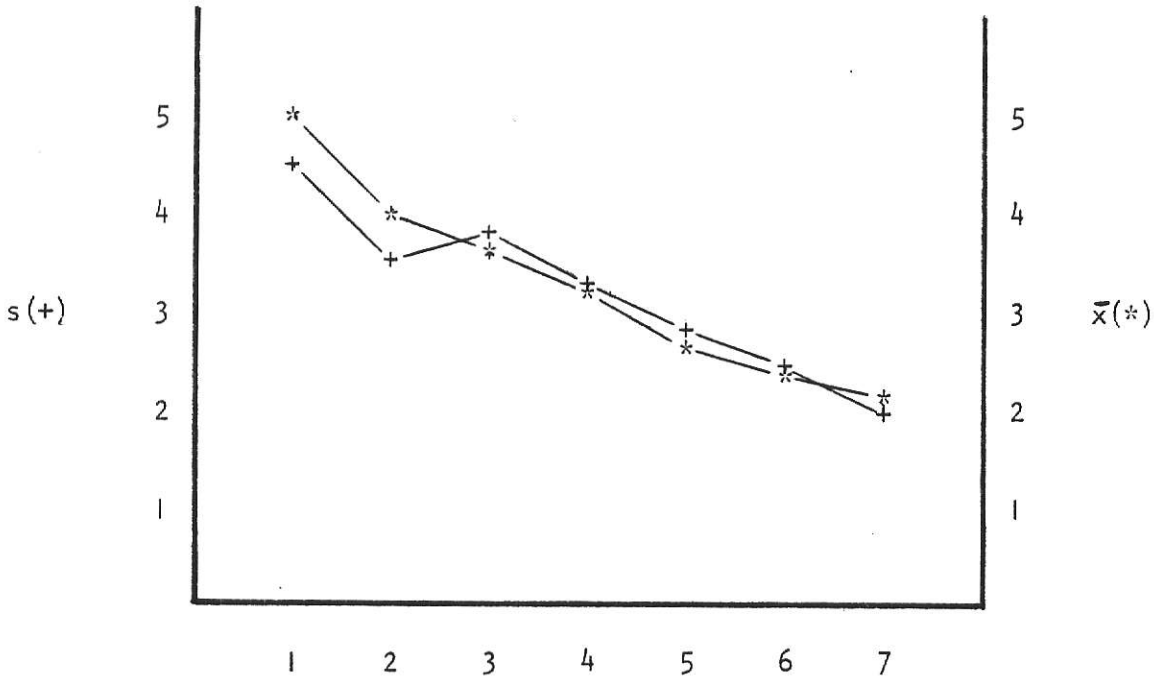

% fines
3
2
1
0
c c ab c bc a bc c c
Temp. (°C)
17
16
15
b a b b b b b b b
% moisture content
14
13
12
ab c a abc bc abc a a a
8 7 4 3 1 2 5 6 9
AREA

Fig. 14. Change in standard deviation and in mean of total insects (per 1000 g) in Bin 6 after one depth, 2 areas, and 3 cells were removed by the variance procedure.



1- original standard deviation and mean
2- after depth 6 was removed
3- after area 1 was removed
4- after cell area 9-depth 2 was removed
5- after area 3 was removed
6- after cell area 7-depth 3 was removed
7- after cell area 7-depth 1 was removed

experimental bins. The analysis regressed the means for total insects in each bin (dependent variable) vs. the means for a selected sampling scheme in each bin (independent variables). This was regressed over all bins (except Bin 1).

Several sampling schemes were tested. One scheme was composed of 15 samples, 12 at depths 1-3, and 3 at the floor level. The exact sample sites were: surface samples from areas 1, 3, 5, 7, 8, 9; depth 2 samples from areas 4, 7, 9; depth 3 samples from areas 2, 6, 8; and floor samples from areas 3, 7, 9. The analysis in this example gave an r^2 = .997, with slope = 1.07 (Fig. 15). Another sampling scheme was composed of 27 samples, one sample from each area of depths 1, 2, and 3. This gave an r^2 = .993, with slope = 1.86 (Fig. 15).

DISCUSSION

Insects

Cryptolestes ferrugineus was the most frequently collected insect species, although when collected, Oryzaephilus surinamensis were more numerous (Table 8). C. ferrugineus were collected in every bin, and were the majority species in 4 of 6 bins. C. pusillus and C. turcicus were also collected; the latter was unexpected because they were collected and identified in only one other Kansas survey (Bell, Partida, and Mills, *unpublished report*, 1972). Bishop (1959) reported C. turcicus in the northern growing areas of the U.S. LeCato (1974) reported C. pusillus as the Cryptolestes sp. of most importance economically in the southern U.S. Thus, it appears that Kansas is in a

Fig. 15. Regression analysis for 4 sampling schemes.

y axis = Mean number of insects (per 1000 g) from all samples of original sampling.

x axis = Mean number of insects (per 1000 g) from samples of selected schemes.

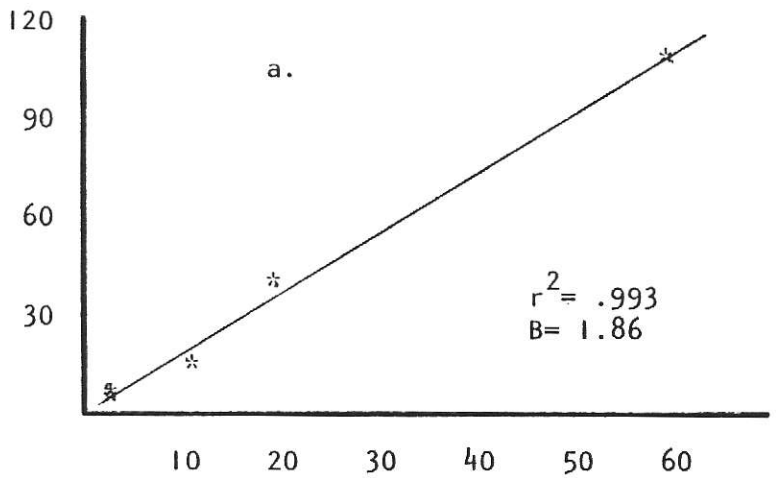
Sampling scheme:

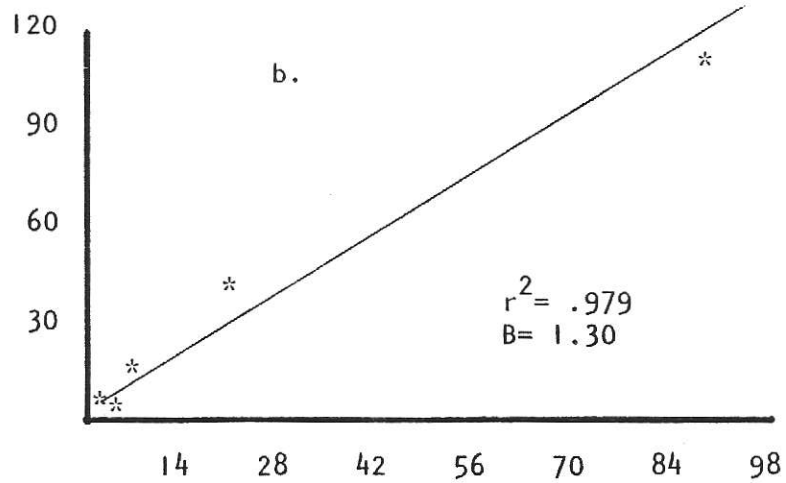
a. Total of 27 samples from areas 1-9, depths 1-3.

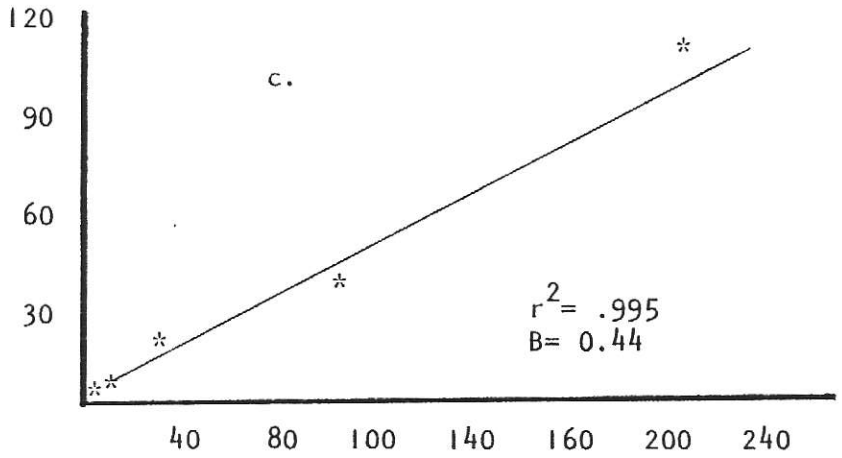
b. Total of 9 samples from areas 1-9 at surface.

c. Total of 9 samples from areas 1-9 at bottom.

d. Total of 15 samples; 12 from depths 1-3, and 3 from bottom.


120
90
60
30
a.
r^2= .993
B= 1.86
10
20
30
40
50
60


120
90
60
30
b.
r^2= .979
B= 1.30
14
28
42
56
70
84
98


120
90
60
30
c.
r^2= .995
B= 0.44
40
80
100
140
160
200
240

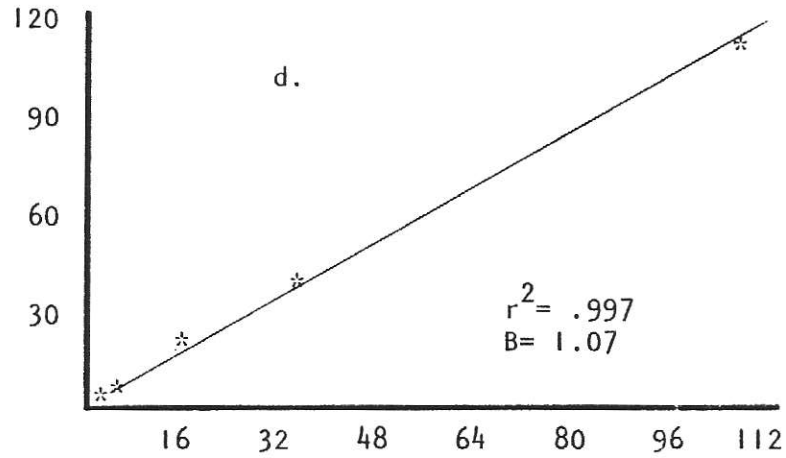

120
90
60
30
d.
r^2= .997
B= 1.07
16
32
48
64
80
96
112

Table 8. Species and actual numbers of insects[1] collected by bin. Other arthropods[2] and the storage fungi[3] collected.

Bins	No. of Samples	C.f.	C.t.	C.p.	O.s.	T.c.	Trog.	Lath.	R.d.	T.s.	TOTALS
1	45	45	0	2	3	0	0	0	0	0	50
2	63	30	32	2	0	0	0	2	0	1	67
3	45	468	265	0	58	0	0	0	0	0	831
4	54	146	2	0	2,733	0	4	0	2	0	2,887
5	63	312	131	10	0	4	0	0	0	0	457
6	54	70	52	0	0	0	0	1	0	1	124
TOTALS	324	1,071	486	14	2,844	4	4	3	2	2	4,416

[1] Insects
- C.f. - Cryptolestes ferrugineus
- C.t. - C. turcicus
- C.p. - C. pusillus
- O.s. - Oryzaephilus surinamensis
- T.c. - Tribolium castaneum
- Trog. - Trogoderma spp.
- Lath. - Lathridiidae
- R.d. - Rhyzopertha dominica
- T.s. - Typhaea stercorea

[2] Arthropods also found, but not included in analysis:
- Bethylidae
- Psocoptera
- Acarina

[3] Species of fungi found:
- Aspergillus glaucus
- A. flavus
- Aspergillus sp.
- Penicillium spp.

transition zone for the 2 species. Lower winter temperatures no doubt influence the distribution, with the more coldhardy C. turcicus (Currie, 1967) better able to survive in the north.

The intensity of direct competition between these very similar species is unknown. Lefkovitch (1965b) divided the genus into 2 groups, based on male antennal length, structure of the mandibles, and relative humidity at which they develop. C. ferrugineus was placed in the first group. He divided the second group into 2 subgroups, based on pupal cocoon structure. C. turcicus and C. pusillus were placed in the same subgroup. Lefkovitch stated, "The species within each group and subgroup tend not to occur together and if more than one species does occur in any one micro-habitat, the two or three are likely to belong to different groups or subgroups." Only 2 bins had both C. turcicus and C. pusillus, and only one sample contained both species. This supports Lefkovitch's conclusion. He does not define, however, the limits of his "micro-habitat."

The dispersion pattern of C. ferrugineus is apparently influenced by several factors. Surtees (1965) noted 3 patterns of behavior for C. ferrugineus: hygrokinesis (movement toward water), oviposition, and trophic. He concludes that oviposition, trophic, and possibly thermokinetic behavior are important, and that hygrokinesis is only a minor factor in influencing dispersion. It is generally believed that areas of higher moisture, with higher percentages of fungi and fines are preferred for oviposition and feeding. Loschiavo and Sinha (1966) showed the importance of fungi and exposed germs of grain in aggregation and feeding responses of C. ferrugineus.

There were no significant correlations between insects and percentage kernels invaded by fungi, or between insects and percentage fines. In Bin 6, the temperature was positively correlated with insects, and in Bin 4 this relationship was negative. In Bins 5 and 6, there was a negative correlation between moisture content and insects. The strongest relationship was numbers of insects and depth, with more insects on or near the floor in 5 of 6 bins. The variance procedure emphasized this in that it removed the floor level in 4 of 5 bins because of higher mean numbers of insects. One explanation of this relationship involves the "false" perforated floors of the bins. This floor is supported above the concrete foundation, and air can be forced or pulled through the floor, thus aerating the grain above. Broken kernels and fines may sift through the perforations, and provide nutritional material underneath for residual insect infestation. Accessibility to these areas is difficult because the false floors are bolted in place; therefore, they are rarely removed for cleaning. Five of 6 bins had this type of arrangement. Bin 3, which had high numbers of insects on the floor, had aeration ducts laying on the concrete floor. There could be broken kernels and nutritional dust inside these ducts, capable of supporting insects.

All of these factors, including moisture content, temperature, fungi, and fines, contribute to the dispersion of C. ferrugineus. But the order of importance of these factors was not determined in this study; more bins need to be sampled to learn more about their interrelationships. This study did not obtain the same results as the other studies, perhaps

because of the larger grain bins, in which the relationships between the variables are more complex. Thus, because of inconsistency in the data, valid conclusions on the importance of these factors on Cryptolestes sp. distribution cannot be made.

Fungi

The age of grain and the type of fungi found were related. Bin 4 contained 1979 grain and had higher percentages of field fungi. Bins 1, 2, and 3 contained grain older than 1979, and had higher percentages of storage fungi. The ages of grain in Bins 5 and 6 were unknown. If the grain is kept dry, the field fungi can survive for several years. When deteriorative changes begin to occur (heating, increase of moisture content), the field fungi percentages decrease rapidly. It took over one year for the storage fungi to invade in large percentages in the bins sampled. It would have occurred sooner if the moisture content had been higher. There was no consistent relationship between grain depth and the occurrence of the two types of fungi. No attempt was made to determine how the grain was inoculated with storage fungi. There could be many sources. It is known that spores of storage fungi are in storage structures. It has been shown that Cryptolestes sp. can carry Aspergillus sp. spores externally (Sikorowski, 1964).

Physical Variables

The moisture content of the grain in 4 of 6 bins was greater on the floor. In one bin, the moisture content was higher at the surface. This can be partially explained by convection currents. During the spring and summer months, the warmer intergranular air near the outside wall will rise, and cool air in the center will sink toward the bottom to replace it. The warmed air along the wall has reduced relative humidity, so it will pick up moisture from the grain. As it is drawn down the center it cools, with concomitant increase in r.h.; thus moisture is given up to grain near the bottom. In the fall and winter months, the convection currents reverse; the moisture collects toward the top, while pockets of moisture may collect at the bottom toward the wall. Insects and fungi can increase moisture by their metabolism. Since the original moisture content was not known, we could not determine such increases, if they occurred.

The surface temperatures were taken at the beginning of sampling, usually in the early morning. The outside area temperatures were taken toward the end of sampling, usually in the afternoon. Both of these are influenced by daily ambient temperatures, the degree depending upon nearness to the outside wall. As noted earlier, inconsistency in the relationship between total insects and temperature makes valid conclusions impossible.

The location in the bins of fine material is influenced by the flow of the incoming grain; the amount is principally influenced by conditions of harvesting and handling, but also by insects. There were more fines

in Bin 1, than in the other bins because of the 2 destructive insect species, Rhyzopertha dominica and Sitophilus oryzae. These species were found dead in the samples of Bin 1. In the other bins, there was no significant correlation between location of insects and location of fines.

Sampling

One objective of this study was to develop a practical sampling scheme. The comparisons between the pneumatic probe and the gravity-fill (manual) probe showed that in most cases (13 of 15) there were no differences. This demonstrated that the pneumatic probe was not picking up more fines or insects due to the air flow. This supports Hurburgh's (1979) conclusion that pneumatic "core probes" do not pick up excess foreign material when compared to manual probes. The pneumatic probe, although capable of sampling at all depths, is expensive and time consuming to use. A "practical" sampling scheme would require the cheaper and more common manual probe, even though samples often cannot be obtained from depths greater than 8-9 ft. As this study has shown, many insects are below this depth.

Selected sets of samples within the original complement of samples were analyzed to determine whether fewer samples from each of the bins would provide similar information. Regression analysis using a sampling scheme of 12 upper samples (in the first 3 depths) and 3 floor samples was completed. It produced a high correlation coefficient (r^2 = .997) and a slope not different from unity (P = 1.07) (Fig. 15).

A set of samples from only the upper 3 depths within the 9 areas (27 samples) using the manual probe, could be a more practical sampling procedure (Fig. 15). If a ratio of 1.86 times the number of insects collected is used, this would give information similar to that from the total of the pneumatic probe samples. Another sampling scheme, consisting of manual probe samples taken at the surface in all 9 areas, would be less accurate (lower r^2), but would be simpler to do. The ratio of 1.3 times the number of insects collected would yield information similar to that from the total of the pneumatic probe samples.

Not all possible combinations of sampling schemes were regressed, and it is possible that there is a better sampling scheme than those suggested; also sampling more bins would have been desirable. Mortality of insects caused by the pneumatic probe was not determined, but in comparing the numbers of insects collected by the two probes, there was no evidence of it.

Bin structures and the way farmers store their grain is important in sampling. It is desirable that the bottom areas be made accessible by bin modification, so they can be sampled. Also, accessibility to areas beneath the false floors when the bin is empty, would permit inspection, cleaning and treating. Some farmers overfill their bins, making sampling, treatment, and uniform aeration difficult, if not impossible.

This study contradicts the common belief that most insects will be found in the upper levels of the grain. More bins should be sampled intensively to gather more data on the relationships between the physical

and biological factors within the large farm bins. Since many features of sampling and grading of grain are not known or are inconsistent (Barak and Harein, 1981b), "better" sampling techniques are needed to assure marketing high quality grain.

REFERENCES CITED

Anderson, J. A., and V. G. Martin. 1943. Probe for sampling deep grain bins. Grain Res. Comm., Dept. of Trade and Commerce, Canada. Bull. 3.

Bains, S. S., G. S. Battu, and A. S. Atwal. 1976. Distribution of Trogoderma granarium Everts and other stored grain insect pests in Punjab and losses caused by them. Bull. Grain Technol. 14(1):18-29.

Banks, H. J. 1979. Identification of stored product Cryptolestes spp. (Coleoptera: Cucujidae): A rapid technique for preparation of suitable mounts. J. Austra. Entomol. Soc. 18:217-222.

Barak, A. V., and W. E. Burkholder. 1976. Trapping studies with Dermestid sex pheromones. Environ. Entomol. 5(1):111-114.

Barak, A. V., and P. K. Harein. 1981a. Insect infestation of farm-stored shelled corn and wheat in Minnesota. J. Econ. Entomol. 74:197-202.

Barak, A. V., and P. K. Harein. 1981b. Unpredictable penalties at time of sale applied to insect-infested, farm-stored grain in Minnesota. Bull. Entomol. Soc. Am. 27(3):166-169.

Bell, K. O. 1972. Kansas Cooperative Economic Insect Survey Report. 19(1).

Bishop, G. W. 1959. The comparative bionomics of American Cryptolestes (Coleoptera: Cucujidae) that infest stored grain. Ann. Entomol. Soc. Am. 52(6):657-665.

Burges, H. D. 1960. A spear for sampling bulk grain by suction. Bull. Entomol. Res. 51(1):1-5.

Burkholder, W. E., and G. M. Boush. 1974. Pheromones in stored product insect trapping and pathogen dissemination. Bull. OEPP 4(4):455-461.

Chang, S. S., and S. R. Loschiavo. 1971. The influence of some fungi in flour, and humidity on the survival and development of Cryptolestes turcicus (Coleoptera: Cucujidae). Can. Entomol. 103(2):261-266.

Christensen, C. M., and H. H. Kaufmann. 1974. Microflora. Chapter 4 in Storage of Cereal Grains and their Products. C. M. Christensen, ed., American Association of Cereal Chemists, St. Paul, Minn.

Cotton, R. T., and D. A. Wilbur. 1974. Insects. Chapter 5 in Storage of Cereal Grains and their Products. C. M. Christensen, ed., American Association of Cereal Chemists, St. Paul, Minn.

Currie, J. E. 1967. Some effects of temperature and humidity on the rates of development, mortality and oviposition of Cryptolestes pusillus (Schonherr) (Coleoptera, Cucujidae). J. Stored Prod. Res. 3:97-108.

Davies, R. G. 1949. The biology of Laemophloeus minutus Oliv. (Col. Cucujidae). Bull. Entomol. Res. 40(1):63-82.

Howe, R. W., and L. P. Lefkovitch. 1957. The distribution of the storage species of Cryptolestes (Col., Cucujidae). Bull. Entomol. Res. 48(4):795-809.

Hurburgh, C. R. 1980. Technical report on grain grading research, project 2320, Iowa State Univ. Agri. and Home Econ. Exp. Sta.

LeCato, G. L. 1974. Increase in populations of Cryptolestes pusillus and C. turcicus on diets of natural products. Florida Entomol. 57(3):309-312.

Lefkovitch, L. P. 1959. A revision of the European Laemophioeinae (Coleoptera: Cucujidae). Trans. Roy. Entomol. Soc. London 111(5): 95-118.

Lefkovitch, L. P. 1962a. A new synonym of Cryptolestes turcicus (Grouvelle) (Coleoptera: Cucujidae) with additional distributional records. Proc. Roy. Entomol. Soc. London 31 (B):71-72.

Lefkovitch, L. P. 1962b. The biology of Cryptolestes turcicus (Grouville) (Coleoptera: Cucujidae), a pest of stored and processed cereals. Proc. Zool. Soc. London 138:23-35.

Lefkovitch, L. P. 1964. A review of Laemophloeinae (Coleoptera: Cucujidae) from Reunion and Mauritius. Proc. Roy. Entomol. Soc. London 33(B):125-130.

Lefkovitch, L. P. 1965a. Arabian Laemophloeinae (Coleoptera: Cucujidae). Proc. Roy. Entomol. Soc. London 34(B):17-19.

Lefkovitch, L. P. 1965b. The Cryptolestes (Gangl.) (Col.: Cucujidae) occurring in stored food. Proc. XII Intern. Congr. Entomol., London.

Loschiavo, S. R. 1974. Laboratory studies of a device to detect insects in grain, and of the distribution of adults of the rusty grain beetle, Cryptolestes ferrugineus (Coleoptera: Cucujidae), in wheat-filled containers. Can. Entomol. 106:1309-1318.

Loschiavo, S. R., and J. M. Atkinson. 1967. A trap for the detection and recovery of insects in stored grain. Can. Entomol. 99:1160-1163.

Loschiavo, S. R., and J. M. Atkinson. 1973. An improved trap to detect beetles (Coleoptera) in stored grain. Can. Entomol. 105:437-440.

Loschiavo, S. R., and R. N. Sinha. 1966. Feeding, oviposition, and aggregation by the rusty grain beetle, Cryptolestes ferrugineus (Coleoptera: Cucujidae) on seed borne fungi. Ann. Entomol. Soc. Am. 59(3):578-585.

McFarlane, J. A., and C. Warui. 1973. A simple technique for stored products infestation surveys. Trop. Stored Prod. Inf. 24:17-24.

Pinniger, D. B. 1975. The use of bait traps for assessment of stored-product insect populations. Crop Insect Rep. 25:49-52.

Rilett, R. O. 1949. The biology of Laemophloeus ferrugineus (Steph.). Can. J. Res. 27(D):112-148.

Sikorowski, P. P. 1964. Interrelation of fungi and insects to deterioration of stored grains. Washington State Univ. Agr. Exp. Sta. Tech. Bull. 42.

Sinha, R. N. 1961. Insects and mites associated with hot spots in farm stored grain. Can. Entomol. 93(8):609-621.

Smith, L. B. 1970. Effects of cold-acclimation on supercooling and survival of the rusty grain beetle, Cryptolestes ferrugineus (Stephens) (Coleoptera: Cucujidae), at subzero temperatures. Can. J. Zool. 48(4):853-858.

Smith, L. B. 1978. Ecology of stored grain in the Canadian provinces. I. The distribution and size of a low density population of Cryptolestes ferrugineus (Coleoptera: Cucujidae). Can. Entomol. 110:1281-1292.

Strong, R. G. 1970. Distribution and relative abundance of stored-product insects in California: A method of obtaining sample populations. J. Econ. Entomol. 63(2):591-596.

Surtees, G. 1965. Laboratory studies on dispersion behavior of adult beetles in grain. XII. The effect of isolated pockets of damp and mouldy wheat on Cryptolestes ferrugineus (Steph.) (Coleoptera: Cucujidae). Bull. Entomol. Res. 55(4):673-680.

Tuite, J. 1969. Plant Pathological Methods, Fungi and Bacteria. Burgess Publ. Co. Minneapolis, MN. 239 pp.

Watters, F. L., and G. A. Cox. 1957. A water-trap for detecting insects in stored grain. Can. Entomol. 89(4):188-192.

Wright, V. F., E. De las Casas, and P. K. Harein. 1980a. The nutritional value and toxicity of Penicillium isolates for Tribolium confusum. Environ. Entomol. 9:204-212.

Wright, V. F., P. K. Harein, and N. A. Collins. 1980b. Preference of the confused flour beetle for certain Penicillium isolates. Environ. Entomol. 9:213-216.

Wright, V. F., E. De las Casas, and P. K. Harein. 1980c. Evaluation of Penicillium mycotoxins for activity in stored-product Coleoptera. Environ. Entomol. 9:217-221.

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PNEUMATIC PROBE SAMPLING OF KANSAS FARM-STORED SORGHUM

by

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AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

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Department of Entomology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1982

Six bins of grain sorghum in Kansas were sampled with a Cargill® Probe-A-Vac pneumatic grain sampler. A stratified random sampling method was used. The surface of the grain was divided into 3 concentric circles and 2 diameter lines with each resulting subdivision of equal area. A vertical probing consisting of from 5 to 7 samples was done in each area. A sample was taken from each 4-ft strata, with an additional surface and a bottom sample. The temperature of each sampling point was recorded, and each sample was analyzed in the lab for percentage of kernels invaded by fungi, percentage of fine material, and species and numbers of insects. The means were separated using Duncan's multiple range test. A regression analysis was used to compare the reliability of selected sets of fewer samples with the complete set of samples taken (45 to 63) in this study. The analysis showed that a sampling scheme with a ratio of 4 top (depths 1-3) samples to 1 bottom-depth sample would gather information similar to that from the complete pneumatic probe sampling.

The most frequently found insect species was Cryptolestes ferrugineus, although Oryzaephilus surinamensis was collected in higher numbers. C. pusillus and C. turcicus were also found. In 5 of the 6 bins, more insects were found near the bottom. In 4 bins, the moisture contents were higher toward the bottom. In a comparison of a manual gravity-fill probe with the pneumatic probe, there were only small differences in the number of total insects, C. ferrugineus, and percentage fines taken with the sample.