Losses Associated with Insect Infestation of Farm Stored Shelled Corn and Wheat in Minnesota

by
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Four common Minnesota stored grain insect pests. (Clockwise from upper left) The flat grain beetle, *Cryptolestes pusillus* (Schönherr); the red flour beetle, *Tribolium castaneum* (Herbst); the larger black flour beetle, *Cynaeus angustus* (LeConte); the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.).

FINAL REPORT

to the

North Central Regional Pesticide Impact Assessment Program

on

Losses Associated with Insect Infestation of Farm Stored Shelled Corn and Wheat in Minnesota [1/] [2/]

by

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INTRODUCTION

The University of Minnesota, Department of Entomology, Fisheries and Wildlife, has conducted a 3 year study of insect infestation in farm stored corn and wheat in Minnesota. The goals of this program were to ascertain (1) the insect species currently infesting farm stored grain, (2) those species responsible for economic loss and the extent and nature of such losses and (3) the justification for continued use (re-registration) of liquid grain fumigants or other pesticides on stored grain to manage insect infestations.

The survey was completed in 3 phases. First, Waseca County, a typical corn production area, was studied during 1977. Second, a Granite Falls area tri-county region was sampled during 1978. Third, a 9 county survey that represented the grain storage areas throughout Minnesota was conducted in 1980. This third phase (statewide expansion) of the survey was supported by a grant from the North Central Region Pesticide Impact Assessment Program.

The 3 phases of the project were completed during separate years. Although the sampling methodology was consistent, the results were considered separately. Data from the 1977 and 1978 phases of the survey were previously reported (Barak and Harein 1981a).

SURVEY METHODOLOGY

Selection of Sampling Sites.

The Minnesota counties in which farm stored grain was sampled are indicated in Fig. 1. Waseca County in South-Central Minnesota, one of the leading corn producing counties in the state, served as the initial survey area. Farm bins which contained shelled corn were sampled there during August and September 1977. Four initial farm sites, selected by the County Extension Director, represented a range of stored grain management expertise. An additional 19 farm sites were selected at random from within the county. A second area in West-Central Minnesota, which included parts of Chippewa, Renville and Yellow Medicine Counties, was sampled during May through October 1978. Farmsites were those of adult Farm Management students at a cooperating Area Vocational-Technical Institute at Granite Falls, Minnesota.

During 1980 the survey was expanded to include other areas of the state. Farmsites in Dakota, Goodhue and Washington Counties in South-East Minnesota were arranged through the Red Wing Area Vocational-Technical Institute. The State Agricultural Stabilization and Conservation Service (ASCS) arranged for farmer-held reserve lots of corn and wheat to be sampled in Becker, Marshall, Pennington, Pipestone, Polk and Stearns Counties. The number of storages of corn and wheat sampled in individual areas is indicated in Table 1. During 1980, storages were first sampled during May (southernmost counties) or June (northernmost counties). The same storages were resampled during August (N) and September (S) if grain remained. This method allowed samples to be collected at the start and end of the summer storage period, at which times aeration management would effect temperature changes consistent with proper storage (Cloud and Morey 1980).

Sampling Equipment Utilized.

The sampling equipment consisted of a 1.6-meter long 10 partition grain trier, a 0.34-liter capacity deep-bin probe (No. 234, Seedburo Equipment Co., Chicago, Ill.) with 1-meter extensions and a thermistor temperature probe (No. TM-2, Delmhorst Instr. Co., Boonton, N.J.) with 1-meter extensions. Waterproof 1-liter polyethylene bottles were used to isolate individual samples of grain gram particular portions sampled. Primary composite grain samples from individual storages were sealed in plastic lined canvas sacks for inspection later.

Sampling Methods.

When possible, uniform grain sampling methods were followed. Bins that were overfilled, had restricted access or were structurally unique required some intuitive variation in sampling techniques.

Figures 2 and 3 illustrate the standard sampling procedures employed. Bins were sampled along a N-S line through the bin center and at ca. 1-meter intervals down the center as deep into the grain as possible. This method took into consideration that the grain adjacent to the N side and S side is usually colder or warmer, respectively, than the remainder of the grain. Sampling down the center of a grain mass provided samples from the spoutline area of a center-loaded bin. The spoutline area usually contains high amounts of dockage (broken kernels, weed seeds and other foreign materials) and may have a higher moisture content than the remainer of the grain. The spoutline, therefore, is relatively susceptible to insect infestation and mold damage. In a flat storage, the volume of grain beneath a loading port or a downspout was considered the equivalent of a spoutline in a center loaded bin. In all storages, a sample of surface grain was also collected from a recently undisturbed area. Figure 3 illustrates the modified grain sampling pattern used in overfilled bins.

At the time of sampling, observations of insects present, temperature, storage practices and pesticide use were recorded for later tabulation.

Laboratory Analysis of Samples.

Grain samples were inspected usually within 1 day after collection except when overnight travel was required. Composite samples of shelled corn were passed through a Boerner Divider 2 or 3 times to reduce the grain quantity to about a 2-liter representative sub-sample. From this sub-sample 250 g was used for a wet basis moisture test using a Motomoco 919 Moisture Tester. The remainder of the sample was used to determine its test weight with a 1 qt (ca. 0.95-l) dry volume test weight bucket and scale. This portion was then sieved over a 12/64 in.(4.76 mm) round hole sieve to remove dockage, foreign material and insects. Live adult insects recovered from the sievings were counted by species. The remaining portions of the original composite sample were sieved also to determine if additional insect species were present.

Wheat samples were passed through the Boerner divider 2 or 3 times to reduce the primary sample to about a 2-liter sub-sample. Insects and dockage were seperated from the wheat samples by sifting over a 1/12 in. (2.12 mm) round hole sieve. Large insects and foreign materials were removed by the 4.76 mm sieve. Insect infestation levels were based on the number of live adult insects, by species, present in a 1 kg divided sub-sample of the original composite sample.

Small portions of corn (100 g) and wheat (25 g) were separated from clean, sieved portions in order to assess the percent by weight of germ damaged and mold damaged kernels.

Figures 4 and 5 are flow charts which depict the sequence of laboratory procedures performed.

Grain Buyer Survey Methods.

Information on policies of grain buyers regarding the economic penalties for infested grain was obtained via a questionnaire survey of elevator personnel attending the 1978 and 1979 University of Minnesota Conferences on Stored Grain Pest Management. These participants responded to questions regarding (1) discounts for infestation, (2) insect thresholds or tolerances, (3) grain inspection and sampling methods, (4) estimated rates of infestation and (5) estimates of pesticide treatments required.

Grain quantities reported by respondees were converted to metric equivalents when necessary.

RESULTS

Waseca County Sampling During 1977.

The frequency of occurrence and number of joint occurrences for 7 major insect species infesting farm stored shelled corn in 40 round steel bins are presented in Table 2. The frequency of joint occurrences as reflected by the Index of Association indicate that a complex of several species existed. Rarely was only a single species detected. As many as 7 species were detected simultaneously within a single bin. The degree of insect infestation, by all species combined, is shown in

Table 3. These data show that ca. 33% (2131.8 metric ton) of the total corn sampled in both round steel bins and flat storages had 15 or more live adult insects detected in 1 qt (0.95-liter) sub-samples taken from each storage. If insect counts of 5 or more live adults per 0.95-liter sub-sample were included, 68% (4400.7 t) of the corn sampled fell into this category. The insect species responsible for sub-samples from 10 round steel bins to contain 15 or more live adults are indicated in Table 4. Such samples would be graded as U.S. Special Grade Weevily by Official Inspectors.

Only one occurrence of Sitophilus oryzae (L.) was documented in grain sampled during 1977. The species was seen on the surface of corn in a flat storage (63.5 t) but was not detected in sub-samples of the corn.

Granite Falls Area Sampling During 1978.

The seasonal frequency of occurrence of several insect species in farm stored corn sampled in Chippewa, Renville and Yellow Medicine Counties during 1978 is shown in Table 5. All major species increased in frequency of occurrence seasonally with the exception of Cynaeus angustus (LeConte).

The seasonal frequency of several species in farm stored wheat in the same counties is shown in Table 6. The only occurrence of Rhyzopertha dominica (F.) was in a 86.1 t lot of wheat from this area. Observations of storage practices and conditions will be discussed later.

Statewide Sampling During 1980.

Occurrence of insect species. A summary of the occurrence of the major insect species in corn and wheat during 2 sampling periods is shown in Tables 7a,b. Table 7a refers to live adult insects present in 0.95-liter (corn) or 1 kg (wheat) sub-samples of grain, whereas Table 7b includes the detection of the species (1) within the sub-samples, (2) in the remainder of the sample or (3) detected in the grain as a whole during inspection. As expected, the trend was for species occurrences to increase later in the season. The data show that the likelihood of detection of a species in a sub-sample was not as great as the actual frequency of the insect in the grain sampled. Therefore, the probability of additional infestation than indicated by sub-sample analysis must be considered. Tables 8a through 11b show the frequency of occurrence and joint occurrence of major species by grain and sampling periods. Tables "a" or "b" refer to the presence of a species in only the test sub-sample portion (a) or detected by all observations (b). The Index of Association is the ratio of total occurrences to joint occurrences with other species. Negative values are the negative inverse values of ratios less than one.

Degree of infestation by species and grain quantity. The numerical levels of infestation in corn and wheat by the major insects, by species, are listed in Tables 12 through 25. The Tables are arranged to show (1) frequency of unique insect counts per 0.95-liter or 1 kg sub-sample, (2) the number of times a species was found in the grain but not found in the sub-sample ("0 values"), (3) the number of times the species was not detected by any method and (4) the total and cumulative quantities of the grain in the storages sampled for each level of infestation. The data are independently for each sample period.

Grain temperatures of storages sampled. Temperature readings (°C) recorded just below the grain surface (0.3 m) and at the center of the grain mass for 2 times of the year are illustrated in Figs. 6 and 7.

Surface temperatures for corn were within a range which would allow insect development. Little change in surface temperatures took place between sampling periods with the exception of 3 bins which had abnormal temperatures due to heating. Mid-grain temperatures during May-June were generally near or above levels which would allow some insect development (above 15°C). During Aug.-Sept. the mid-grain readings were considerably higher, with most bins at temperatures which would allow rapid insect development (above 20°C). Many (14) corn bins were at or above 25°C at their centers and 3 had temperatures near or above the maximum limits for insect survival (about 40°C). These 14 bins contained 33.0% of the corn sampled during this time period. Similar temperature trends were observed for wheat storages (Fig. 7). However, a more northerly location probably resulted in lower average temperatures. Surface temperatures were high enough in wheat to support insect development during the entire summer. Temperatures in the centers of the grain mass were not frequently above 15°C during May-June sampling.

The data of Table 26 summarize surface and mid-grain temperatures for both corn and wheat and indicate the direction and extent of temperature changes between sampling periods.

Insect-temperature relationship. Table 27 shows the relationship between surface and center corn temperatures to the number of insects found in sub-samples of corn from the storages. Storages with 5 or more live adult insects per sub-sample had significantly higher surface corn temperatures than those storages with less than 4 insects. Storages with 10 or more adults per sub-sample of corn had significantly higher center of mass temperatures than the other bins. It is not always possible to separate fungal caused heating from insect caused heating, since the processes are autocatalytic. However, Birch (1946) has stated that grain that appears insect free to most observers can easily contain enough insects to initiate heating. Based on the data of Table 27, we conclude that in the corn storages sampled, insects have caused or contributed to heating. In addition, Howe (1962), Oxley and Howe (1944) and Robertson (1948) have shown that the number of insects per volume of grain needed to cause heating may be below levels considered to be of economic importance by many grain handlers. As few as 1 insect per liter of grain, if uniformly distributed, may initiate heating when such grain is stored in a situation where warm surfaces may cause the insects to aggregate.

Due to equipment failure, it was not possible to gain sufficient temperature data from all wheat storages. However, a comparison of insect numbers in wheat samples shows similar levels of infestation.

Occurrence of damaged corn. Bottle samples (1-liter) of specific "out of condition" corn and damaged corn within storages were taken during the 1980 sampling. A summary of the sub-surface and center-bin temperatures, moisture contents, test weights (grain density) and quantities of grain within these storages is presented in Table 28. Storages which had bottle-sampled damaged areas in May-June (10) and Aug.-Sept. 1980 (12) had higher center of mass temperatures than the remainder of the storages sampled, thus indicating the potential for increased insect and fungal activity. High interior grain temperatures were recorded during Aug.-Sept. sampling in several heating bins. This may cause vertical moisture migration which could result in severe surface and sub-surface moisture and damage increases. For example, during this second sample period surface collected grain samples isolated in bottles had mean moisture contents of 2.8% greater than composite samples of the remainder of the corn in the same storages. Also the test weights of bottle vs. the remainder composite, within the bins, had average test weight reductions of 6.2 ± 2.8 SD kg/hl (4.8 lb/bu). Composite test weights of corn storages which had bottle-sampled damaged areas were, on the average, 1.4 kg/hl (1.1 lb/bu) lighter than for storages which did not have bottle-sampled damage areas. The dry matter loss, based on these differences, amounted to 2.8% for those storages which were sampled during Aug.-Sept. In addition, such conditions are favorable for the development of high insect populations and may, in part, actually be caused by insect activity.

Grain buyer survey findings. Respondees indicated that 45 of 61 grain buyers at country elevators would discount insect infested grain, based on their own standards for infestation. Of these 35 and 26 would discount corn and wheat, respectively. An additional 10 respondees indicated rejection of infested grain or that a prerequisite fumigation or residual insecticide treatment would be required.

The discounts applied to corn averaged 5.3¢/bu (ca. $2.09/t) with a range of 2-10¢/bu and a mode of 5¢/bu (n=24). For wheat the mean discount was 7¢/bu (ca. $2.57/t, range 3-15¢/bu) with modes at 5¢ (n=12) and 10¢ (n=9) per bu.

Obtaining a representative sample of grain from a grain mass is difficult and the variety of sampling methods would affect this likelihood. The sizes of composite grain samples collected for inspection were stated by 56 buyers. The mean was 2.5 kg/sample (range 0.25 to 8.0

kg). The mean portion of the composite sample examined for insects as documented by 55 buyers, was 0.8 kg (range 0.05-4.0 kg).

Insect counts (live adult insects per given sample size) utilized as threshold action levels were specified by 31 buyers (Table 29). Although "USDA" methods were specified by 6 buyers, the adequacy of sampling and inspection must be taken into consideration. When threshold levels were stated in units of insect density, the mean was 5.3 live adult insects per kg of grain (4.4 qt) with a range of 0.5-22.0/kg (.4-17.6/qt). The yearly estimated purchases of corn and wheat by these elevators are summarized in Table 30.

The highly variable estimated percentages of corn and wheat categorized as insect infested appears in Table 31. Some buyers indicated that no grain arrived infested or required an insecticide but others gave estimates as high as 10% infested and 50% treated. We conclude that the higher infestation estimates are based on positive detection and are, therefore, closer to reality than the lower estimates, which may be the result of inadequate inspection and variable threshold levels.

Table 32 and 33 summarize additional quality factors of the corn and wheat samples for both sampling periods in 1980. Determinations were based on a representative sub-sample of the primary composite sample of grain. Based on the mean values, the U.S. Grade No. for the various factors would be as follows for corn:

Factor	U.S. Grade
Moisture	No. 1
Test wt.	No. 2
Dockage (BCFM)	No. 2 or 3
Damage (total)	No. 5

The range of values encountered indicate that considerable amounts of corn sampled could be graded as U.S. No. 5 or "sample grade" unless adequate cleaning and blending were conducted prior to sale. Corn of such quality is highly susceptible to insect infestation if maintained in storage for extended periods, especially under the temperatures reported.

Wheat sampled was also of generally low quality with regards to test weight and damaged kernels (mean values, U.S. No. 3).

Factors Which Contributed to the Problem.

Granite Falls tri-county area, 1978. The data of Tables 34 and 35 indicate that storage practices did not follow generally recommended guidelines. For 35 farm storages of corn, most were precleaned before loading but only 2 were treated with residual insecticide and none had pesticides admixed to the grain. Also, overfilling of bins was common. For wheat, the same trend was evident. This may have contributed to the reported rates of insect infestation detected (also Tables 5,6). On 6 occassions, corn bins were found to be heating at the time of sampling.

Grain spreading during storage filling. As mentioned earlier, the formation of a spoutline or other stratifications while the grain is being loaded will create areas higher in dockage (weed seeds, broken kernels, foreign materials) and moisture content. Such areas are conducive to insect and mold development and also offer resistance to aeration and fumigant penetration. The use of spreaders to more evenly distribute the dockage portion may be beneficial. The data in Table 36 indicate that most corn and all wheat was loaded without the use of spreading equipment. Hand spreading was not common. The cleaning of grain, especially corn, before loading was not practiced by any of the

the surveyed farmers.

Manner in which storages were filled. The method of filling a storage may affect the storability and ease of grain inspection. The data of Table 37 indicate the type of storage filling procedure used for corn and wheat sampled during 1980. The recommended practice of leveling grain was followed for most corn bins and about half the wheat bins sampled. However the practice of leaving a peak and/or overfilling was also common. This may result in inefficient aeration of the peak area and subsequent moisture migration to the grain in the peak. Overfilled, peaked storages may have reduced headspace for adequate sampling. Also, peaked areas expose greater quantities of grain to warm summer temperatures and therefore greater rates of insect development for insects present in that specific volume of grain.

The category of "other" in Table 37 refers to grain bulks which are slanted towards a door or with a conical depression due to center unloading. Such practices decrease the efficiency of aeration systems.

Granary area sanitation. Conditions of sanitation in the immediate granary areas for storages sampled during 1980 are shown in Table 38. Spilled and residual grain was found to be fairly common (about 25% occurrence). Also various combinations of ground cover existed which would make efficient cleanup of spilled grain difficult. Concrete aprons in grain loading areas were encountered only once.

Postharvest treatments to storage or grain. Various treatments applied to the storage structure or grain for grain sampled during 1980, are listed in Tables 39 and 40. Cleaning of the storages before introducing new grain was common (56-85%), but there was little use of residual insecticides on the storage structure, to surface grain or as admixtures to the grain during loading. The data show that later use of pesticides was infrequent, considering the quantity and occurrence of infested grain found.

Aeration management and temperature control. The use of aeration to manage grain in storage, the primary objective of which is temperature control, can be an important factor in limiting insect development. Data from corn bins with and without aeration systems is presented in Table 41. Only 25% of the round metal bins used for corn storage and sampled during 1980 were equipped with aeration systems. Fig. 8 shows the recommended relationship between mean ambient (outside) temperatures and grain temperatures which can be obtained by use of aeration management (Cloud and Morey 1980). Corn sampled during May-June was at the theoretical beginning of the summer holding period, at which time corn temperatures could be adjusted to about 58°F (14.4°C). This would result in the corn being within 15°F (about 8.3°C) of the maximum summer mean temperature (ca. 73°F or 22.8°C) for southern Minnesota (from Fig. 8). Temperatures recorded in sampled bins (Table 41) indicate a center mean of 14.3°C for May-June. However, considerable variance from the recommended ideal were found to occur in both aerated and unaerated bins (ranges 6-24°C and 1-26°C, respectively). It appears that aeration temperature management was not satisfactory, since some aerated corn bins were as much as 8.3°C (15°F) below, and others as much as 9°C (16°F) above the target summer holding temperature (ca. 15°C). These bins are therefore subject to reverse (inward) moisture migration or the initiation of heating due to insect activity, respectively. The same bins were sampled during early Sept. and were found to have mean center temperatures about 7.5°C (13.5°F) higher than the mean ambient for that time of the year (ca. 19.4°C, 67°F). No significant differences were found to occur between bins with and without aeration capability. Temperatures very suitable for the rapid development of storage insects were commonly found in sampled bins.

Some Losses to Farm Stored Grain Due to Insect Infestation.

Losses to grain due to the presence of granivorous insects may include direct consumption of the seed, loss of nutrient value, decrease in germinability, increased free fatty acids, insect fragment contamination and the initiation of, or contribution to, the heating of grain bulks. In addition, the costs associated with the prevention or control of insect outbreaks must be considered.

Grain moved off the farm for original sale in Minnesota may be subject to only cursory inspection for insect infestation. Although the Grain Standards Act (Anonymous 1978) specifies the factors for the determination "Special Grade Weevily", official inspection is neither required nor available at country elevators in Minnesota. The determination for insect infestation appears arbitrary and at the discretion of management. If grain is determined to be infested, penalties may be levied as a cents per bushel discount, a per-load discount, or indirectly by rejecting the grain. During 1973, Minnesota farmers marketed 89.9 and 91.2% of their corn and wheat, respectively, through local country elevators (Dahl and Liu 1973).

Previous data indicate that the insect species most commonly encountered were those species considered as secondary, or dockage feeders. Therefore, insect damaged kernels and weevil cut or holed kernels due to the presence of internal feeding insect species would not be useful as a means of determining insect damage. Therefore, levels of infestation may be based on the number of live insects in a sample.

Grain sample methods and sample sizes reported were diverse and ranged from thorough probing of a load to filling a "coffee can" from the surface of a truckload. The amount of grain examined to make a determination for infestation was also variable (mean 0.8 kg, range 0.05-4 kg). Insect counts utilized as threshold levels averaged 2.7 live adult insects per sample. However, since this was independent of sample size inspected, the threshold must be stated in terms of insect density. The data in Table 29 indicate a mean insect density of 5.3 insects/kg or 4.4 insects/qt.

The procedure for detecting insects in the samples inspected included casual observation, screening and the use of infra-red lamps to stimulate insect movement. The combined variability in sample methods, sample size, inspected portions, detection methods and insect population tolerances does not allow consistent predictions of infestations. Also, during periods of peak grain movement, when unloading delays may be several hours, it is doubtful that adequate and careful inspections could be conducted even if desired. For services offered at country elevators, Dahl and Liu (1973) reported that efficient grain unloading received the least favorable evaluation (37.2 percent negative) from farmers surveyed.

Data presented in Tables 29 and 31 support our conclusion of unpredictable insect infestation determinations. Means of 5.1% and 2.9% of the corn and wheat, respectively, were estimated to be infested by their determination. This was based on considerable quantities of grain (Table 30). However, the ranges of 1-10% and 0-10% (Table 31) indicate contrasting levels of inspection or differing thresholds. Variable thresholds seems more likely, since the estimated quantity of grain needing treatment was high. Also, our survey did not include grain marketed at all times of the year.

As a reference point, we found that farm stored shelled corn sampled during 1977 in Waseca Co., Minnesota, after 1 year in storage, had insect density counts of 5 or more live adult insects per 1 qt test weight portion (ca. 0.95-liter) for 67% of the bins sampled (Table 3). Also, one buyer serving the area surveyed estimated that 75% of the corn bought during the sample period (Aug.-Sept. 1977) had detectable infestation.

The data of Tables 12-25 are summarized in Tables 42-43. For corn, 6.3% (502.9 t) sampled during May-June 1980 had insect levels of 5 or more per sub-sample. For Aug.-Sept. 1980 the figure was 52.7% (3116.0 t). This would exceed buyer tolerances, as indicated in Table 29. Minnesota on-farm corn stocks for June 1 and Oct. 1, 1980 were 309,060,000 bu (7,850,567 t) and 169,680,000 bu (4,310,115 t), respectively. If these rates of infestation were applied to these quantities, an estimated 19,470,780 bu (494,586 t) for June and 89,421,360 bu (2,271,431 t) for Oct., of the on-farm corn stocks could potentially have been discounted an average of 5.3¢/bu (ca. $2.09/t) if sold at that time. The dollar value of such discounts would have been $1.032 million and $4.739 million for June and Oct. stocks, respectively.

For wheat, the June 1 on-farm stocks for Minnesota were 36,154,000 bu (983,961 t). A 16.6% rate of infestation (5 or more insects/1 kg sub-sample) was found for wheat sampled during May-June 1980. Therefore, using similar comparisons, the potential discount loss to the June 1 on-farm wheat stocks, if sold at that time, would be $420,000 The amount of infested wheat sampled during Aug.-Sept. was considerably higher (Table 43). On-farm old crop wheat stocks for Oct. 1, 1980 are not known.

Considerably quantities of corn and wheat sampled had lesser degrees of infestation (1-4/sub-sample) as shown in Tables 42 and 43. Such grain may also be discounted or rejected by some buyers as it may contain significant numbers of insects distributed throughout the grain mass that may develop into damaging populations if conditions became optimal. Insects may aggregate near localized warm or higher moisture areas (ship bulkheads, beams and leaks) and initiate heating. Also, such grain may be commingled with previously uninfested grain if low level populations go undetected.

Data from Tables 26, 27 and 28 indicate that the problem of grain heating in storage is common. Based on insect-temperature relationships (Table 27) and pertinent data from others (Birch 1946, Howe 1962, Robertson 1948), it is likely that insect infestation has been a contributing factor to grain heating problems in Minnesota. Storages which had samples collected from heating and infested volumes during Aug.-Sept. had mean composite test weight reductions of greater than 2% when compared to the remainder of the storages. These storages had mean mid-grain temperatures of 26.9°C, 2.9°C greater than the remainder of the storages sampled at that time, and would therefore be subject to additional insect related damage if kept in storage under the conditions indicated.

Fourteen corn storages sampled during Aug.-Sept. had mid-grain temperatures of 25°C or more, with a quantity weighted average of 29.7°C. These storages contained 33.0% of the corn sampled during this period.

Temperatures of 25-35°C are considered as optimal for the development of most stored grain insects. An additional 13 storages had temperatures of 20-25°C for mid-grain volumes. Temperatures above 25°C were considerably above 10 yr. average ambient temperatures (Fig. 8) and must be considered in immediate danger of dry matter loss and shrinkage due to heating. The loss would be dependent on how long and to what extent heating was allowed to continue.

The frequency of insect infestation in both corn and wheat (Tables 20, 25) indicate that the potential for more severe insect infestation exists. Subsurface grain heating caused by insects also causes the migration of moisture to the surface grain or at least to the grain above such heating. Such surface grain may also become heavily infested as insects are driven to the surface layer to escape lethal temperatures in the interior of the grain bulk.

Data in Table 28 indicate test weight reductions of from 9.0 to 19.4% for such corn sampled during 1980. The temperature distributions encountered (Table 27 and Fig. 6) indicate that insect caused "dry grain heating" may occur in as many as 30% of shelled corn storages and that most storages will have either endemic infestations and/or temperatures which would be conducive to the development of insect outbreaks and subsequent heating.

Surface damage due to subsurface heating may consume significant quantities of grain. The typical situation encountered is illustrated in Fig. 9. Considerable quantities of grain must be removed from a center unloading bin to remove damaged areas of various sizes (Table 44). When such grain is removed by this method, damage and insects are mixed with sound grain. This surface grain typically had 100% damage levels, with significant test weight reductions. High damage and insect levels in this grain may lead to discounts also. This type of damage was especially evident in peaked grain both in bins and flat storages.

High grain temperatures produced by insects do not always proceed to the extreme in both intensity and grain quantity involved. Localized pockets of heating were common, and care must be taken that one does not consider the most severe cases as the norm in considering loss. During 1980, 39% of corn storages had significant, localized heating areas detected during Aug.-Sept. However, 16.1% (5 storages) were found to be in critical condition with mid-grain temperatures averaging 35.6°C (96.1°F) and heavy infestation and/or surface damage to depths of 1-2 m. During 1977 in Waseca Co., 9.7% (4 storages) were found to have serious dry-grain heating during Sept. The bins with serious insect heating sampled during 1980 contained 9.4% (556.3 t) of the corn sampled during that period. This survey, plus other experience suggest that state-wide, one may speculate that about 12% of corn storages will have serious dry-grain heating, if inspected during the period of highest insect activity (Aug.-Sept.).

Based on observations of insect infested/mold damaged areas, we estimated losses from less than 1% to as much as 10% per bin, depending on size and shape of the storage. These situations occurred in 30% of storages sampled. A frequently observed situation would be an infested-damaged volume of about 6 m (20 ft) diameter extending downward to an average depth of about 1 m (3 ft). Portions of this grain may suffer weight loss of more than 50%. For this volume, weight loss would amount to about 380 bu (9.65 t). This may amount to 7.6% for a 5,000 bu (127 t) storage. Losses of ca. 5% were commonly observed. If this figure (5%)

is applied to 30% of the Oct. 1, 1980 on-farm stocks of corn, we may speculate losses equivalent to 2.55 million bu (64,651 t). Losses which would have occurred to corn sold prior to this time would be additive. In addition, shrinkage of grain due to moisture migration associated with dry-grain heating would occur.

In addition to the actual weight loss of corn in storage, discount penalties for high percentages of mold damaged kernels may be applied. Tables 32 and 33 indicate that mean damage levels (germ damage plus other mold damage) were on the order of 10% and 5% for corn and wheat, respectively. Elevator discounts for mold damaged corn kernels may be on the order of 1-2¢/bu/1% of mold damage.

Severe insect caused heating was not encountered in wheat storages sampled. However, insect counts and damage levels indicate that significant damage has occurred. Also Cryptolestes spp., the most abundant insects, will internally infest wheat causing high fragment counts in milled products, thus causing rejection of grain lots. However this was not investigated further.

Additional Findings.

Trap detection of insects in farm stored grain. A brass, reusable, drop-in type of insect trap was evaluated as a device to supplement sampling data collected by our standard method. The trap is shown in Fig. 10. Corn bins (9) were sampled using the methodology employed in this study. Four days later deep bin probe samples of 0.34-liter capacity were collected at 6 points within each bin, as shown in Fig. 11. Each sample was individually tested for moisture, temperature and insect presence. Immediately after the probe samples were collected a trap was inserted at each sample point. The traps were recovered 5 days later and insects caught were identified and counted.

Data presented in Table 44 show the number of bins in which a species was detected by the 3 methods. Traps were the most efficient method for all species. The data of Table 45 provides a direct comparison of individual trap : probe detections. Traps were 2 to 31 times more likely to detect insects, after 5 days, than a single probe sample. Traps frequently caught insects when probe samples failed to detect the species. These data indicate that the degree of insect infestation may be significantly greater than that described in this report, and that certain species may be more common than previously thought. The performance of the traps is more completely described by Barak and Harein (1981b).

Cynaeus angustus (LeConte) as a major pest of farm stored corn in Minnesota. Data collected over a 4 year period (1977-80) show C. angustus to be a common pest of stored shelled corn in Minnesota (Table 46). Previously, this species has received little or no attention regarding its pest status in publications concerned with stored grain management, pest control or insect survey. Therefore, we must assume that it is increasing in both occurrence and abundance in stored shelled corn in Minnesota and probably other states as well (Barak et al., In Press).

Cynaeus angustus is capable of attacking the germ of sound corn kernels and one larva will attack several kernels (Krall and Decker 1946). The insect was more successful on cracked corn. Since shelled corn in a bin has a high percentage of broken corn and foreign materials, it is possible that sound kernels need not be attacked before large populations develop. Krall and Decker (1946) also demonstrated that the insect was successful on barley and oats and that reproduction and survival was greatest on corn of 14.1% moisture content (vs. 9.8, 17.8 and 20.9%).

Cynaeus angustus apparently overwinters within a corn bin. The data in Fig. 12 illustrates that the incidence of adults increased with length of storage time in grain sampled during May-June. New corn probably became infested during the first summer of storage since the incidence of C. angustus was higher during the later sampling period.

Sinha (1971) reported that C. angustus was moderate to highly successful on potato-sugar agar cultures of Aspergillus flavus Link, Cladosporidium cladosporoides (Fresenius) deVries, Nigrospora sphaeric (Sacardo) Mason and Stemphylium botryosum Wallroth, all seed-borne micro-organisms. Aspergillus flavus is common in stored shelled corn and perhaps a mutualistic relationship exists between C. angustus and A. flavus or other storage fungi.

Cynaeus angustus may be capable of causing or contributing to dry grain heating within a grain mass (Table 47). Of 3 bins which contained numbers of larvae in the 0.95-liter samples collected during the later sampling period, the mid-grain temperatures were 39, 30 and 27°C (bins 4,5 and 6). The samples also contained, respectively, 15, 5 and 5 live adult insects of other species in the 0.95-liter samples. The mean mid-grain temperature of 14 storages not found to contain C. angustus adults or larvae was 22.4°C (± 3.9 SD) during the same sampling period.

Barak and Harein (1981a) reported that C. angustus was detected in 14.8% of corn samples determined to be infested by a local elevator serving one survey area. Additional data (A.V. Barak and P.K. Harein, unpublished data) indicated that the detection of a single live insect in a grain sample may cause some country elevators to penalize the seller by applying discounts to the price paid for the grain. Also, the large and active C. angustus is relatively easy to detect in grain being inspected, thus increasing the likelihood for discount penalties due to insect infestation.

These data support our view that C. angustus has become a pest of stored shelled corn of major significance in Minnesota.

SUMMARY

Farm stored corn and wheat in 13 Minnesota counties was sampled for insect infestation. From 41.5% to 90% of the storages sampled had insects detected in 0.95-liter (corn) or 1 kg (wheat) sub-samples of composite samples. The most common and abundant species were *Cryptolestes* spp., *T. castaneum*, *O. surinamensis*, *P. interpunctella*, *C. angustus*, *A. advena*, and *T. stercorea*. The internally developing species, *Sitophilus* spp. and *R. dominica* were not common. Temperature readings from storages indicate that temperatures favorable for the development of insects were commonly found, even though aeration systems available could have been used to more favorably control those temperatures.

In the absence of kernel damage or insect initiated (or potentiated) heating, a farmer may suffer loss, due to the presence of insects, in the form of discounts to the price paid for the grain. In Minnesota, most country elevator grain buyers would apply discounts to grain if judged to be infested according to their standards. For corn and wheat, respectively, these discounts average 5.3 and 7.0¢/bu if, on the average, insects were present at a density of 5 or more adults per 1 kg of grain inspected. Considerable quantities of farm stored corn and wheat were found to exceed this threshold level.

Insect infestations were found to result from, or cause, the heating of corn in storages sampled during 1980. Center-of-grain temperatures were significantly higher for storages which contained 10 or more live adult insects per 0.95-liter sub-sample. Of 31 bins sampled during Sept. 1980, 8 bins had a mean center temperature of 30.1°C, compared to a mean of 22.4°C for the remainder.

CONCLUSIONS

Insect infestation of farm stored grain is common in Minnesota. Farmers are not usually aware of the indirect losses they suffer due to insects. Unless the more severe manifestations are visible (extensive heating) the null strategy is normally followed. The primary outlet for Minnesota farmer's corn and wheat is the country elevator. Elevator buyers do not apply predictable penalties for delivery of infested grain. Therefore,the farmers may not always perceive the need to follow routine preventive procedures or undertake more costly control measures if sufficient economic benefits are not realized, or if damage is perceived as "normal".

Farmers may not be fairly rewarded for the delivery of insect free grain to local outlets. The potential to reduce expensive losses further along the grain marketing system exists. It is likely that much infested grain goes undetected and is later commingled with sound grain, thus creating greater loss and the need for more expensive and time consuming remedies at a later time.

FOOTNOTES

1/ Research supported by the Minnesota Agricultural Experiment Station and by the North Central Regional Pesticide Impact Assessment Program. We acknowledge the cooperation of the Minnesota State Office of the Agricultural Stabilization and Conservation Service.

2/ Mention of a proprietary product does not constitute an endorsement of that product.

3/ Research Associate and Consultant, and Professor and Extension Entomologist, respectively.

Table 1. Location and number of corn and wheat storages sampled, listed by county, year sampled and grain.

		Number of storages sampled	
County sampled	Year sampled	Corn	Wheat
Waseca	1977	43	0
Chippewa, Renville & Yellow Medicine	1978	37	11
Becker	1980	6	5
Marshall		0	4
Pennington		0	27
Pipestone		19	2
Polk		0	5
Stearns		5	3
Goodhue, Dakota & Washington	1980	11	0

Table 2.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Corn
Crop year 1976
Sampled Aug.-Sept. 1977
Waseca Co. MN

Species present in storage
40 round steel bins sampled

Insect species	% stores found in	Only species found	Times found with species number listed							Index of Association [a/]
			1	2	3	4	5	6	7	
1. *Cryptolestes* spp.	67.5	4	27	20	10	11	9	7	1	+2.1
2. *Ahasverus advena*	65.0	2		26	11	12	10	7	1	+2.3
3. *Plodia interpunctella*	37.5	1			15	8	5	2	1	+2.5
4. *Cynaeus angustus*	35.0	0				14	7	5	0	+3.1
5. *Tribolium castaneum*	27.5	0					11	4	1	+3.3
6. *Typhaea stercorea*	22.5	0						9	0	+2.8
7. *Oryzaephilus surinamensis*	2.5	0							1	+4.0

[a/] Ratio of total joint occurrences to occurrences of the species. For ratios less than 1, the negative inverse was used.

Table 3. Characteristics of samples of shelled corn collected from farm storages in South Central Minnesota during 1977. Bins were segregated by live adult insect count per 0.95-liter (1 qt) test weight portion of the sample. From Barak and Harein 1981a.

		Bin size and contents in metric t		Grade factors ($\bar{x}$ SD)		
Number of insects per 0.95-l sample	No. of storages	Bin size Total	Grain quantity total (mean)	% Moisture Mean±% SD	Test weight mean±kg/hl SD	BCFM[a] mean% ±SD
Round steel bins						
≥15 insects	10	2347.7	1877.7(187.8)	13.80±0.92*	70.8±1.2	1.85±0.97
5-14	15	3785.8	2205.4(147.1)	12.75±1.19	71.9±2.0	1.63±0.95
1-4	9	2230.8	1252.6(139.2)	13.29±0.51	72.1±1.2	1.73±1.01
None	4	1016.3	457.4(114.3)	12.79±1.09	73.1±1.5	1.55±0.65
All bins	(38)	9380.7	6047.2(159.1)	13.15±1.04	71.8±2.0	1.68±0.94
Flat storages						
≥15 insects	1	-	254.1	14.60	72.1	0.69
5-14	1	-	63.5	13.65	71.4	1.53
1-4	1	-	101.6	11.70	72.7	3.37
All storages	(3)		419.2			

[a]BCFM = percent by weight of broken corn and foreign materials

*moisture content higher (P=.05) then other categories of infestation.

Table 4. Insects responsible for year-old shelled corn, stored in 10 farm bins, to be graded as infested (USDA Weevily). Three of the bins were heating at the time of sampling.

	Number of bins		
Insect species	Main[a] insect	Contributed[b] to grade	Present[c] in bin
Ahasverus advena	7	3	10
Cryptolestes spp.	2	5	7
Tribolium castaneum		2	5
Cynaeus angustus		1	5
Typhaea stercorea		1	3
Plodia interpunctella			5

a $\geq$15 in 1-qt sample

b <15 in 1-qt sample, but combined to total over 15 per sample

c present in bin, not in 1-qt sample

Table 5. Occurrences of major stored-grain insects in farm storages which contained shelled corn in Chippewa, Renville and Yellow Medicine Counties during 1978. The same bins were resampled each sampling period unless the grain was removed. All corn was from crop year 1977.

Insect	Percentage of bins infested		
	May 37 bins[a]	July-Aug. 36 bins[b]	Sept.-Oct. 25 bins[c]
Cryptolestes spp.	10.8	41.7	56
Ahasverus advena	5.4	50.0	52
Cynaeus angustus	8.1	55.6	24
Plodia interpunctella	2.7	22.2	48
Tribolium castaneum	2.7	13.9	28
Typhaea stercorea	-	13.9	28
Dermestes lardarius	-	13.9	-
Tenebrio molitor	2.7	5.6	-
Trogoderma variabile	-	2.8	-

[a] 4959 t($\bar{x}$ = 134.7) all bins combined

[b] 4779 t($\bar{x}$ = 132.1) all bins combined

[c] 3882 t($\bar{x}$ = 155.0) all bins combined, 8 lots were combined into 4 lots to reduce number to 25

Table 6. Occurrences of major stored grain insects in farm stored wheat in Chippewa, Renville and Yellow Medicine Counties during 1978. The same bins were resampled unless the grain was removed.

	Storages present in		
Insect	May 11 bins	July-Aug. 10 bins	Sept.-Oct. 7 bins
Cryptolestes spp.	2	3	3
Ahasverus advena	-	2	-
Tribolium castaneum	2	3	1
Oryzaephilus surinamensis	-	1	1
Plodia interpunctella	1	2	1
Cynaeus angustus	-	1	-
Dermestes lardarius	-	2	-
Rhyzopertha dominica	-	-	1
Typhaea stercorea	-	1	-

Table 7a. Occurrence of grain infesting insects in representative sub-samples of farm stored corn and wheat obtained during 1980 from 9 Minnesota counties.

Insect species	Percent of samples in which species was found			
	Shelled corn		Wheat	
	May-June 41 samples	Aug.Sept. 31 samples	May-June 38 samples	Aug.-Sept. 38 samples
Cryptolestes spp.	22.0	51.6	31.6	44.7
Tribolium castaneum	19.5	12.9	10.5	2.6
Oryzaephilus surinamensis	2.4	19.4	15.8	15.8
Plodia interpunctella	0	3.2	0	0
Cynaeus angustus	9.8	6.5	0	0
Ahasverus advena	7.3	35.5	7.9	0
Typhaea stercorea	0	16.1	0	0
Tenebrio molitor	2.4	3.2	0	0
Sitophilus oryzae	0	0	2.6	0
Dermestidae	0	0	0	0
Misc. spp.	9.8	0	5.3	0
Summary, any species	41.5	67.6	44.7	50.0

Table 7b. Occurrence of grain infesting insects in farm stored corn and wheat during 1980 in 9 Minnesota counties.

Insect species	Percent of storages in which species was found			
	Shelled corn		Wheat	
	May-June 41 stores	Aug.-Sept. 31 stores	May-June 38 stores	Aug.-Sept. 38 stores
Cryptolestes spp.	29.3	64.5	52.6	63.2
Tribolium castaneum	24.4	29.0	13.2	18.4
Oryzaephilus surinamensis	7.3	29.0	28.9	26.3
Plodia interpunctella	22.0	64.5	0	7.9
Cynaeus angustus	22.0	51.6	0	5.3
Ahasverus advena	17.1	41.9	10.5	10.5
Typhaea stercorea	9.8	32.3	0	0
Tenebrio molitor	4.9	6.5	7.9	5.3
Sitophilus oryzae	0	0	2.6	0
Dermestidae	7.3	9.7	18.4	5.3
Misc. species	24.4	22.6	21.1	10.5
Summary, any species	56.1	87.1	57.9	71.1

Table 8a.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Corn
Crop years 1977-1979
May-June 1980

Species present in test portion only
41 samples

Insect species	% samples found in	Only species found	Times found with species number listed											Index of Association
			1	2	3	4	5	6	7	8	9	10	11	
1. Cryptolestes spp.	22.0	3	9	1	4	0	2	0	1	0	0	1	1	+1.1
2. Ahasverus advena	7.3	2		3	0	0	0	0	0	0	0	1	0	-1.5
3. Tribolium castaneum	19.5	3			8	0	2	0	1	0	0	0	1	+1.0
4. Plodia interpunctella	0	0				0	0	0	0	0	0	0	0	0
5. Cynaeus angustus	9.8	1					4	0	1	0	0	0	0	+1.3
6. Typhaea stercorea	0	0						0	0	0	0	0	0	0
7. Oryzaephilus surinamensis	2.4	0							1	0	0	0	0	+3.0
8. Sitophilus oryzae	0	0								0	0	0	0	0
9. Dermestidae	0	0									0	0	0	0
10. Tenebrio molitor	2.4	0										1	0	+2.0
11. Misc. species	9.8	3											4	-2.0

Table 8b.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Corn
Crop years 1977-1979
May-June 1980

Species present in storage
41 storages

Insect species	% stores found in	Only species found	Times found with species number listed: 1	2	3	4	5	6	7	8	9	10	11	Index of Association
1. *Cryptolestes* spp.	29.3	2	12	4	5	3	5	2	2	0	3	1	6	+2.6
2. *Ahasverus advena*	17.1	1		7	3	2	3	3	1	0	2	1	2	+3.0
3. *Tribolium castaneum*	24.4	2			10	5	5	3	1	0	2	0	4	+2.8
4. *Plodia interpunctella*	22.0	3				9	4	2	0	0	2	1	5	+2.6
5. *Cynaeus angustus*	22.0	1					9	3	2	0	2	1	5	+3.3
6. *Typhaea stercorea*	9.8	0						4	1	0	1	0	1	+4.0
7. *Oryzaephilus surinamensis*	7.3	0							3	0	0	0	2	+3.0
8. *Sitophilus oryzae*	0	0								0	0	0	0	0
9. Dermestidae	7.3	0									3	1	1	+4.7
10. *Tenebrio molitor*	4.9	0										2	2	+3.5
11. Misc. species	24.4	0											10	+2.7

Table 9a.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Corn
Crop years 1977-1979
August-September 1980

Species present in test portion only
31 samples

Insect species	% samples found in	Only species found	Times found with species number listed											Index of Association
			1	2	3	4	5	6	7	8	9	10	11	
1. *Cryptolestes* spp.	51.6	2	16	9	4	0	1	5	5	0	0	0	0	+1.5
2. *Ahasverus advena*	35.5	1		11	2	0	0	4	2	0	0	0	0	+1.5
3. *Tribolium castaneum*	12.9	0			4	0	1	2	2	0	0	0	0	+2.8
4. *Plodia interpunctella*	3.2	1				1	0	0	0	0	0	0	0	0
5. *Cynaeus angustus*	6.5	1					2	1	1	0	0	0	0	+2.0
6. *Typhaea stercorea*	16.1	0						5	2	0	0	0	0	+2.8
7. *Oryzaephilus surinamensis*	19.4	0							6	0	0	0	0	+2.0
8. *Sitophilus oryzae*	0	0								0	0	0	0	0
9. Dermestidae	0	0									0	0	0	0
10. *Tenebrio molitor*	3.2	1										1	0	0
11. Misc. species	0	0											0	0

Table 9b.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Corn
Crop years 1977-1979
August-September 1980

Species present in storage
31 storages

Insect species	% stores found in	Only species found	Times found with species number listed											Index of Association
			1	2	3	4	5	6	7	8	9	10	11	
1. Cryptolestes spp.	64.5	0	20	11	9	12	13	9	7	0	2	0	4	+3.3
2. Ahasverus advena	41.9	1		13	5	9	7	6	2	0	1	0	3	+3.4
3. Tribolium castaneum	29.0	0			9	6	7	6	4	0	0	0	2	+4.3
4. Plodia interpunctella	64.5	3				20	9	6	5	0	1	1	5	+2.7
5. Cynaeus angustus	51.6	0					16	6	6	0	2	1	5	+3.5
6. Typhaea stercorea	32.3	0						10	5	0	0	0	3	+4.1
7. Oryzaephilus surinamensis	29.0	0							9	0	1	0	2	+3.6
8. Sitophilus oryzae	0	0								0	0	0	0	0
9. Dermestidae	9.7	0									3	1	1	+3.0
10. Tenebrio molitor	6.5	0										2	1	+2.0
11. Misc. species	22.6	0											7	

Table 10a.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Wheat
Crop years 1976-1979
May-June 1980

Species present in test portion only
38 samples

Insect species	% samples found in	Only species found	Times found with species number listed											Index of Association
			1	2	3	4	5	6	7	8	9	10	11	
1. *Cryptolestes* spp.	31.6	6	12	2	2	0	0	0	3	1	0	0	0	-1.5
2. *Ahasverus advena*	7.9	1		3	0	0	0	0	1	0	0	0	0	+1.0
3. *Tribolium castaneum*	10.5	1			4	0	0	0	2	0	0	0	1	+1.3
4. *Plodia interpunctella*	0	0				0	0	0	0	0	0	0	0	0
5. *Cynaeus angustus*	0	0					0	0	0	0	0	0	0	0
6. *Typhaea stercorea*	0	0						0	0	0	0	0	0	0
7. *Oryzaephilus surinamensis*	15.8	2							6	0	0	0	1	+1.2
8. *Sitophilus oryzae*	2.6	0								1	0	0	0	+1.0
9. Dermestidae	0	0									0	0	0	0
10. *Tenebrio molitor*	0	0										0	0	0
11. Misc. species	5.3	1											2	+1.0

Table 10b.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Wheat
Crop years 1976-1979
May-June 1980

Species present in storage
38 storages

Insect species	% stores found in	Only species found	Times found with species number listed											Index of Association
			1	2	3	4	5	6	7	8	9	10	11	
1. Cryptolestes spp.	52.6	5	20	4	3	0	0	0	7	1	7	3	7	+1.6
2. Ahasverus advena	10.5	0		4	0	0	0	0	2	0	2	0	2	+2.5
3. Tribolium castaneum	13.2	1			5	0	0	0	3	0	0	1	1	+1.6
4. Plodia ihterpunctella	0	0				0	0	0	0	0	0	0	0	0
5. Cynaeus angustus	0	0					0	0	0	0	0	0	0	0
6. Typhaea stercorea	0	0						0	0	0	0	0	0	0
7. Oryzaephilus surinamensis	28.9	3							11	0	2	3	2	+1.7
8. Sitophilus oryzae	2.6	0								1	1	0	0	+2.0
9. Dermestidae	18.4	0									7	2	4	+2.6
10. Tenebrio molitor	7.9	0										3	2	+3.7
11. Misc. species	21.1	1											8	+2.3

Table 11a.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Wheat
Crop years 1976-1979
August-September 1980

Species present in test portion only
38 samples

Insect species	% samples found in	Only species found	Times found with species number listed											Index of Association
			1	2	3	4	5	6	7	8	9	10	11	
1. *Cryptolestes* spp.	44.7	13	17	0	1	0	0	0	4	0	0	0	0	-3.4
2. *Ahasverus advena*	0	0		0	0	0	0	0	0	0	0	0	0	0
3. *Tribolium castaneum*	2.6	0			1	0	0	0	0	1	0	0	0	+2.0
4. *Plodia interpunctella*	0	0				0	0	0	0	0	0	0	0	0
5. *Cynaeus angustus*	0	0					0	0	0	0	0	0	0	0
6. *Typhaea stercorea*	0	0						0	0	0	0	0	0	0
7. *Oryzaephilus surinamensis*	15.8	2							6	0	0	0	0	-1.2
8. *Sitophilus oryzae*	0	0								0	0	0	0	0
9. Dermestidae	0	0									0	0	0	0
10. *Tenebrio molitor*	0	0										0	0	0
11. Misc. species	0	0											0	

Table 11b.

JOINT OCCURRENCES OF INSECT SPECIES FOUND

Wheat
Crop years 1976-1979
August-September 1980

Species present in storage
38 storages

Insect species	% stores found in	Only species found	Times found with species number listed											Index of Association
			1	2	3	4	5	6	7	8	9	10	11	
1. *Cryptolestes* spp.	63.2	5	24	4	6	3	2	0	7	0	1	1	3	+1.1
2. *Ahasverus advena*	10.5	0		4	0	0	1	0	1	0	0	0	0	+1.5
3. *Tribolium castaneum*	18.4	0			7	2	0	0	2	0	1	0	1	+1.7
4. *Plodia interpunctella*	7.9	0				3	0	0	0	0	0	0	0	+1.7
5. *Cynaeus angustus*	5.3	0					2	0	0	0	0	0	0	+1.5
6. *Typhaea stercorea*	0	0						0	0	0	0	0	0	0
7. *Oryzaephilus surinamensis*	26.3	3							10	0	0	1	1	+1.2
8. *Sitophilus oryzae*	0	0								0	0	0	0	0
9. Dermestidae	5.3	0									2	0	0	+1.0
10. *Tenebrio molitor*	5.3	1										2	0	+1.0
11. Misc. species	10.5	1											4	+1.3

Table 12.

CORN
Cryptolestes spp.

	Sampling periods					
	May-June			August-September		
Live adult insect count per 0.95-1 sub-sample	Number of samples with same count	Total grain quantity in storages samples mt(1000 bu)	Cumulative grain quantity samples mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	5	1041.5 (41.0)	1041.5 (41.0)	3	220.2 (8.7)	220.2 (8.7)
2	0			4	210.8 (8.3)	431.1 (17.0)
3	1	447.5 (18.8)	1519.0 (59.8)	1	1219.3 (48.0)	1650.3 (65.0)
4	2	188.0 (7.4)	1707.0 (67.2)	0		
5	1	129.5 (5.1)	1836.5 (72.3)	3	492.8 (19.4)	2143.1 (84.4)
7	0			1	106.7 (4.2)	2249.8 (88.6)
10	0			1	477.5 (18.8)	2727.4 (107.4)
12	0			1	78.7 (3.1)	2806.1 (110.5)
27	0			1	254.0 (10.0)	3060.1 (120.5)
41	0			1	226.1 (8.9)	3286.2 (129.4)
0 values	3	543.6 (21.4)	2380.1 (93.7)	4	1056.7 (41.6)	4342.9 (171.0)
Not Present	29	5637.8 (221.9)	8018.0 (315.6)	11	1571.1 (61.9)	5914.0 (232.8)

Table 13.
CORN
Ahasverus advena

	Sampling Periods					
	May-June			August-September		
Live adult insect count per 0.95-1 sub-sample	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	0			6	1470.7 (57.9)	1470.7 (57.9)
2	3	355.6 (14.0)	355.6 (14.0)	2	256.6 (10.1)	1727.3 (68.0)
7	0			1	254.0 (10.0)	1981.3 (78.0)
14	0			1	129.5 (5.1)	2110.9 (83.1)
40	0			1	190.5 (7.5)	2301.4 (90.6)
0 values	4	1902.6 (74.9)	2258.2 (88.9)	2	721.4 (28.4)	3022.8 (119.0)
Not Present	34	5759.8 (226.7)	8018.0 (315.6)	18	2891.2 (113.8)	5914.0 (232.8)

Table 14.
CORN
Tribolium castaneum

Live adult insect count per 0.95-1 sub-sample	Sampling Periods: May-June — Number of samples with same count	May-June — Total grain quantity in storages sampled mt(1000 bu)	May-June — Cumulative grain quantity sampled mt(1000 bu)	August-September — Number of samples with same count	August-September — Total grain quantity in storages sampled mt(1000 bu)	August-September — Cumulative grain quantity sampled mt(1000 bu)
1	3	1385.6 (54.6)	1385.6 (54.6)	4	1742.5 (68.6)	1742.5 (68.6)
2	2	383.6 (15.1)	1769.2 (69.7)	0		
3	1	106.7 (4.2)	1875.9 (73.8)	0		
19	1	147.3 (5.8)	2023.2 (79.7)	0		
23	1	109.2 (4.3)	2132.5 (84.0)	0		
0 values	2	624.9 (24.6)	2757.3 (108.6)	5	707.9 (27.0)	2450.5 (96.5)
Not Present	31	5260.6 (207.1)	8018.0 (315.6)	22	3463.5 (136.3)	5914.0 (232.8)

Table 15.
CORN
Plodia interpunctella

Live adult insect count per 0.95-1 sub-sample	Sampling Periods					
	May-June			August-September		
	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	0			1	177.8 (7.0)	177.8 (7.0)
0 values	9	2651.9 (104.4)	2651.9 (104.4)	19	3831.0 (150.8)	4008.9 (157.8)
Not Present	32	5366.1 (211.2)	8018.0 (315.6)	11	1905.1 (75.0)	5914.0 (232.8)

Table 16.
CORN
Cynaeus angustus (adults)

Live adult insect count per 0.95-1 sub-sample	Sampling Periods: May-June			Sampling Periods: August-September		
	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	3	518.2 (20.4)	518.2 (20.4)	0		
2	1	106.7 (4.2)	624.9 (24.6)	0		
3	0			1	106.7 (4.2)	106.7 (4.2)
4	0			1	116.8 (4.6)	223.5 (8.8)
0 values	5	2113.4 (83.2)	2738.3 (107.8)	14	3370.8 (132.7)	3594.3 (141.5)
Not Present	32	5279.7 (207.8)	8018.0 (315.6)	15	2319.7 (91.3)	5914.0 (232.8)

Table 17.
CORN
Cynaeus angustus (larvae)

	Sampling Periods					
	May-June			August-September		
Live adult insect count per 0.95-1 sub-sample	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
3	0			1	106.7 (4.2)	106.7 (4.2)
4	1	116.8 (4.6)	116.8 (4.6)	1	17.0 (.7)	123.7 (4.9)
12	0			1	50.8 (2.0)	174.5 (6.9)
0 values	1	1219.3 (48.0)	1336.1 (52.6)	2	1440.3 (56.7)	1614.8 (63.6)
Not Present	39	6681.8 (263.0)	8018.0 (315.6)	26	4299.2 (169.2)	5914.0 (232.8)

Table 18.
CORN
Typhaea stercorea

Live adult insect count per 0.95-1 sub-sample	May-June: Number of samples with same count	May-June: Total grain quantity in storages sampled mt(1000 bu)	May-June: Cumulative grain quantity sampled mt(1000 bu)	August-September: Number of samples with same count	August-September: Total grain quantity in storages sampled mt(1000 bu)	August-September: Cumulative grain quantity sampled mt(1000 bu)
1	0			3	381.0 (15.0)	381.0 (15.0)
2	0			1	106.7 (4.2)	487.7 (19.2)
6	0			1	53.3 (2.1)	541.1 (21.3)
0 values	4	1854.3 (73.0)	1854.3 (73.0)	5	599.5 (23.6)	1140.5 (44.9)
Not Present	37	6163.7 (242.6)	8018.0 (315.6)	21	4773.4 (187.9)	5914.0 (232.8)

Sampling Periods

Table 19.
CORN
<u>*Oryzaephilus surinamensis*</u>

	Sampling Periods					
	May-June			August-September		
Live adult insect count per 0.95-l sub-sample	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	1	106.7 (4.2)	106.7 (4.2)	1	254.0 (10.0)	254.0 (10.0)
2	0			3	703.6 (27.7)	957.6 (37.7)
3	0			2	360.7 (14.2)	1318.3 (51.9)
0 values	2	282.0 (11.1)	388.6 (15.3)	3	439.4 (17.3)	1757.8 (69.2)
Not Present	38	7629.3 (300.3)	8018.0 (315.6)	22	4156.2 (163.6)	5914.0 (232.8)

Table 20.

CORN
All species

Live adult insect count per 0.95-1 sub-sample	Sampling Periods: May-June — Number of samples with same count	May-June — Total grain quantity in storages sampled mt(1000 bu)	May-June — Cumulative grain quantity sampled mt(1000 bu)	August-September — Number of samples with same count	August-September — Total grain quantity in storages sampled mt(1000 bu)	August-September — Cumulative grain quantity sampled mt(1000 bu)
1	4	1566.0 (61.7)	1566.0 (61.7)	2	181.6 (7.2)	181.6 (7.2)
2	5	960.2 (37.8)	2526.2 (99.5)	2	203.2 (8.0)	384.8 (15.2)
3	1	162.6 (6.4)	2688.7 (105.9)	1	30.5 (1.2)	415.3 (16.4)
4	2	129.5 (5.1)	2818.3 (111.0)	4	391.2 (15.4)	806.5 (31.8)
5	1	10.2 (.4)	2828.4 (111.4)	2	1236.3 (48.7)	2042.8 (80.4)
7	2	236.2 (9.3)	3064.7 (120.7)	1	109.2 (4.3)	2152.0 (84.7)
9	0			1	53.3 (2.1)	2205.4 (86.8)
12	0			1	477.5 (18.8)	2682.9 (105.6)
14	0			1	78.7 (3.1)	2761.6 (108.7)
17	0			2	360.7 (14.2)	3122.3 (122.9)
19	0			1	129.5 (5.1)	3251.9 (128.0)
20	1	147.3 (5.8)	3212.0 (126.5)	0		
27	1	109.2 (4.3)	3321.2 (130.8)	0		
28	0			1	254.0 (10.0)	3505.9 (138.0)
40	0			1	190.5 (7.5)	3696.4 (145.5)
41	0			1	226.1 (8.9)	3922.5 (154.4)
0 values	6	1000.8 (39.4)	4322.1 (170.2)	6	1254.8 (49.4)	5177.3 (203.8)
Not Present	18	3695.9 (145.5)	8018.0 (315.7)	4	736.6 (29.0)	5914.0 (232.8)

Table 21.

WHEAT
Cryptolestes spp.

Live adult insect count per 1 kg sub-sample	May-June: Number of samples with same count	May-June: Total grain quantity in storages samples mt(1000 bu)	May-June: Cumulative grain quantity samples mt(1000 bu)	August-September: Number of samples with same count	August-September: Total grain quantity in storages samples mt(1000 bu)	August-September: Cumulative grain quantity samples mt(1000 bu)
1	4	269.4 (9.9)	269.4 (9.9)	3	266.7 (9.8)	266.7 (9.8)
2	2	185.1 (6.8)	454.4 (16.7)	5	1317.2 (48.4)	1584.0 (58.2)
3	1	125.2 (4.6)	579.7 (21.3)	2	234.1 (8.6)	1818.0 (72.0)
4	1	89.8 (3.3)	669.5 (24.9)	2	141.5 (5.2)	1959.5 (72.0)
6	1	59.9 (2.2)	729.4 (26.8)	0		
7	0			1	57.2 (2.1)	2016.7 (74.1)
9	0			1	49.0 (1.8)	2065.7 (75.9)
10	2	149.7 (5.5)	879.1 (32.3)	0		
18	1	81.6 (3.0)	960.7 (35.3)	0		
20	0			1	65.3 (2.4)	2131.0 (78.3)
23	0			1	73.5 (2.7)	2204.5 (81.0)
39	0			1	73.5 (2.7)	2278.0 (83.7)
0 values	8	879.1 (32.3)	1839.8 (67.6)	7	560.6 (20.6)	2838.6 (104.3)
Not Present	18	2929.8 (107.7)	4769.6 (175.3)	14	1609.3 (59.1)	4447.9 (163.4)

Table 22.

WHEAT
Oryzaephilus surinamensis

	Sampling Periods					
	May-June			August-September		
Live adult insect count per 1 kg sub-sample	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	1	89.8 (3.3)	89.8 (3.3)	2	119.7 (4.4)	119.7 (4.4)
2	1	138.8 (5.1)	228.6 (8.4)	0		
3	1	92.5 (3.4)	321.1 (11.8)	0		
4	0			1	119.7 (4.4)	239.5 (8.8)
5	0			1	193.2 (7.1)	432.7 (15.9)
13	2	137.4 (5.0)	458.6 (16.9)	0		
16	1	49.0 (1.8)	507.6 (18.6)	0		
18	0			1	6.3 (.2)	439.0 (16.1)
26	0			1	49.0 (1.8)	488.0 (17.9)
0 values	5	1518.6 (55.8)	2026.2 (74.4)	4	291.2 (10.7)	779.2 (28.6)
Not Present	27	2743.4 (100.8)	4769.6 (175.2)	28	3668.7 (134.8)	4447.9 (163.4)

Table 23.
WHEAT
Triboium castaneum

Live adult insect count per 1 kg sub-sample	Sampling Periods					
	May-June			August-September		
	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	2	231.3 (8.5)	231.3 (8.5)	1	193.2 (7.1)	193.2 (7.1)
3	1	68.0 (2.5)	299.4 (11.0)	0		
24	1	57.2 (2.1)	356.5 (13.1)	0		
0 values	1	12.2 (.4)	368.8 (13.6)	6	408.2 (15.0)	601.5 (22.1)
Not Present	33	4400.8 (161.7)	4769.6 (175.3)	31	3846.4 (141.3)	4447.9 (163.4)

Table 24.
WHEAT
<u>Ahasverus advena</u>

Live adult insect count per 1 kg sub-sample	Sampling Periods					
	May-June			August-September		
	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	2	108.9 (4.0)	108.9 (4.0)	0		
2	1	81.6 (3.0)	190.5 (7.0)	0		
0 values	1	43.5 (1.6)	234.1 (8.6)	4	367.4 (13.5)	367.4 (13.5)
Not Present	34	4535.5 (166.6)	4769.6 (175.2)	34	4080.5 (149.9)	4447.9 (163.4)

Table 25.

WHEAT
All species

	Sampling Periods					
	May-June			August-September		
Live adult insect count per 1 kg sub-sample	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)	Number of samples with same count	Total grain quantity in storages sampled mt(1000 bu)	Cumulative grain quantity sampled mt(1000 bu)
1	3	187.8 (6.9)	187.8 (6.9)	3	185.1 (6.8)	185.1 (6.8)
2	4	285.8 (10.5)	473.6 (17.4)	5	1317.2 (48.4)	1502.3 (55.2)
3	1	68.0 (2.5)	541.6 (19.9)	1	40.8 (1.5)	1543.1 (56.7)
4	0			1	59.9 (2.2)	1603.0 (58.9)
5	2	228.6 (8.4)	770.2 (28.3)	2	201.4 (7.4)	1804.4 (66.3)
6	2	149.7 (5.5)	919.9 (33.8)	0		
7	0			1	57.2 (2.1)	1861.6 (68.4)
9	0			1	193.2 (7.1)	2054.8 (75.5)
13	1	12.2 (.4)	932.1 (34.4)	0		
14	1	92.5 (3.4)	1024.7 (37.7)	0		
16	1	125.2 (4.6)	1149.9 (42.3)	0		
18	1	81.6 (3.0)	1231.5 (45.3)	1	6.3 (.2)	2061.1 (75.7)
20	0			1	65.3 (2.4)	2126.4 (78.1)
23	0			1	73.5 (2.7)	2199.9 (80.8)
34	1	57.2 (2.1)	1288.7 (47.3)	0		
35	0			1	49.0 (1.8)	2248.8 (82.6)
39	0			1	73.5 (2.7)	2322.3 (85.3)
0 values	5	1475.1 (54.2)	2763.8 (101.6)	8	476.3 (17.5)	2798.6 (102.8)
Not Present	16	2005.8 (73.7)	4769.6 (175.3)	11	1649.3 (60.6)	4447.9 (163.4)

Table 26. Temperature and change in temperature of surface grain (-0.3 m) and center (of mass) grain of stored corn and wheat during 2 sampling periods during 1980 in 9 Minnesota counties.

	Sample period				May-June to Aug.-Sept. temp. change			
	May-June		Aug.-Sept.		Surface temp.		Center temp.	
CORN	n=41 Surface	Center	n=31 Surface	Center	n=21 t rise	n=8 t drop	n=30 t rise	n=1 t drop
Mean °C	21.3	15.0	25.1	24.4	7.1	3.3	10.5	4
Standard deviation	±4.6	±5.9	±5.6	±6.9	±5.3	±2.5	±7.5	-
Range	8-28	1-26	16-43	14-47	1-23	1-8	1-30	-
WHEAT	n=22 Surface	Center	n=22 Surface	Center	n=8 t rise	n=12 t drop	n=20 t rise	n=0 t drop
Mean °C	24.2	11.1	23.9	17.6	4.9	3.3	7.0	0
Standard Deviation	±3.6	±3.3	±2.7	±4.1	±3.6	±1.8	±3.9	-
Range	12-30	4-20	18-29	12-25	1-10	1-6	2-14	-

Table 27. Temperatures of surface and center corn in storages with various categories of degrees of insect infestation for storages sampled during Aug.-Sept. 1980.

Live adult insect count per 0.95-liter sub-sample. (n samples)	Mean grain temperatures in °C ± S.D.					
	Surface Grain [a]			Center of grain mass		
		Cumulative temperature means			Cumulative temperature means	
	mean	least to most insects	most to least insects	mean	least to most insects	most to least insects
none (10)	24.2±2.7	24.2	25.1±5.6	20.8±3.8	20.8	24.4±6.9
1-4 (9)	22.9±3.9	23.6±3.3	25.5±6.6	23.6±6.5	22.1±5.3	26.1±7.4
5-9 (4)	25.8±3.9	24.0±3.4	27.4±7.6	23.8±4.8	22.4±5.1	28.0±7.7
≥10 (8) (12-41 insects)	28.3±9.1	25.1±5.6	28.3	30.1±8.3	24.4±6.9	30.1

[a] temperature ca. 0.3 m below grain surface.

Table 28. Comparison of factors of corn found in storages and without damaged areas. Damaged areas were sampled seperately from the remainder of the corn in the storage during 2 sampling periods.

	May-June (41 storages)				August-September (31 storages)			
	10 storages with spoilage			Composite, Remainder of storages n=31	12 storages with spoilage			Composite, Remainder of storages n=19
	Composite sample	Bottle sample	Mean differential		Composite sample	Bottle sample	Mean differential	
Center of corn temperature °C(°F) mean ±S.D.	15.8±3.8 (60.4)	-	-	14.8±6.5 (58.6)	26.2±9.4 (79.2)	-	-	23.3±4.6 (73.9)
Moisture content % wet basis mean±S.D.	12.0±1.8	15.6±3.2	+4.7±4.4	12.4±1.5	13.4±0.7	16.2±4.1	+2.8±4.0	12.7±0.9
Test weight kg/hl(lb/bu) mean ±S.D.	70.2±3.5 (54.4±2.7)	56.6±5.9 (44.6±4.6)	-12.7±6.3 (-9.9±4.9)	70.8±3.3 (55.0±2.6)	68.6±3.7 (53.3±2.9)	62.4±4.1 (48.5±3.2)	-6.2±2.8 (-4.8±2.2)	70.0±3.3 (54.4±2.6)
In-bin shelled corn quantity								
mt	2,646.8			5,372.4	2,488.6			3,425.1
(bu x 1,000)	(104.2)			(211.5)	(98.0)			(134.8)
% of total	33.0			67.0	42.1			57.9

Table 29. Economic threshold levels for insect numbers in corn and wheat sold at 31 country elevators in Minnesota surveyed during 1978.

	Insect numbers	
Grain quantity	Mean ± S.D.	Range
In sample quantity stated[a]	2.7 ± 2.6	1-12[b]
Per kg	5.3 ± 5.9	0.5-22
Per 1 qt	4.4 ± 4.9	0.4-17.6
Per kg (n=6)	USDA[c]	

[a]Sample size inspected for insects as stated by the 31 buyers.

[b]The mode was 1-2 insects in 25 cases although sample size varied.

[c]"USDA methods" were specified but no specifics were indicated.

Table 30. Estimated yearly purchases of corn and wheat at elevators surveyed during 1979.

	Estimated yearly purchases x 1,000 t			
	Country elevators		Terminal elevators	
Grain	Total	Mean	Total	Mean
Corn	368.0[a]	30.5(n=12)	5943.9	371.4(n=16)
	(14.5 million bu)	(1.2 million bu)	(234 million bu)	(14.6 million bu)
Wheat	54.4[b]	4.9(n=11)	2631.8	263.2(n=10)
	(2 million bu)	(0.18 million bu)	(96.7 million bu)	(9.67 million bu)

[a] 56 lb. standard conversion.

[b] 60 lb. standard conversion.

Table 31. Estimated percents of infested grain and grain needing treatment for infestation bought at surveyed country and terminal elevators during 1979.

	Country elevators				Terminal elevators			
	Est. infested %		Est. treated %		Est. infested %		Est. treated %	
Grain	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Corn	5.1	1-10(n=12)	9.8	0-50	1.6	0-5(n=16)	0.7	0-5
Wheat	2.9	0-10(n=11)	6.18	0-50	3.1	1-10(n=10)	2.1	0-1

Table 32. Quality factors of farm stored shelled corn sampled during 1980 in 7 Minnesota counties. During May-June, 41 storages (8,019 mt) and during Aug.-Sept., 31 storages (5914 mt) of corn were sampled.

Quality factors	May-June, n=41		Aug.-Sept., n=31	
	Mean±SD	Range	Mean±SD	Range
Moisture content % wet basis	12.3±1.6	8.0-15.4	12.0±0.9	9.9-14.6
Test weight kg/hl (lb/bu)	70.7±3.3 (54.9±2.6)	64.0-77.6 (49.7-60.3)	69.5±3.5 (54.0±2.7)	63.1-76.4 (49.0-59.4)
Dockage[a] % by weight	3.5±3.9	0.4-23.0	2.6±2.1	0.4-8.2
Germ damage[b] % by weight	2.0±4.5	0.0-24.0	4.0±5.8	0.0-26.9
Mold damage	8.4±8.8	0.1-43.0	6.6±11.4	1.0-66.4

[a] Combined broken kernels (to pass 4.76 mm sieve, weed seeds and hand picked foreign materials.

b Blue eye mold and discolored germs.

Table 33. Quality factors of farm stored wheat sampled during 1980 in 6 Minnesota counties. During May-June, 38 storages (4,769.6 mt) and during Aug.-Sept., 38 storages (4,447.9 mt) were sampled.

Quality factors	May-June, n=38		Aug.-Sept., n=38	
	Mean±SD	Range	Mean±SD	Range
Moisture content % wet basis	12.5±0.89	10.6-14.5	12.6±0.92	10.2-14.6
Test weight	73.2±2.6	67.1-77.7	71.0±3.3	61.9-75.7
kg/hl (lb/bu)	(56.9±2.0)	(52.1-60.4)	(55.2±2.6)	(48.1-58.8)
Dockage[a] % by weight	3.1±2.5	0.6-10.4	2.6±2.1	0.6-8.9
Germ damage[b] % by weight	3.1±2.4	0.2-10.4	2.4±1.7	0.1-8.4
Mold damage % by weight	1.3±2.0	0.8-10.0	2.5±2.6	0.0-10.4

[a]Combined broken kernels (to pass 2.12 mm sieve), weed seeds and hand picked foreign materials.

[b]Discolored germs.

Table 34. History of 35 farm bins which contained year-old shelled corn[a] (Granite Falls, Minnesota, Spring-Fall, 1978).

32	Bins were pre-cleaned
2	Bins were pre-treated
0	Bins had grain protectant applied
13	Bins were improperly filled (peaked)
25	Bins had visible mold damage
6	Bins were heating
8	Bins were fumigated (liquid)

[a]Total 4,933 mt (194,200 bu) mean 141 mt (5,550 bu).

Table 35. History of 13 farm storages which contained year-old spring wheat[a] (Granite Falls, Minnesota, Spring-Fall, 1978).

13	Bins were pre-cleaned
1	Bins were pre-treated
0	Bins had grain protectant applied
5	Bins were improperly filled (peaked)
2	Bins had mold damage
9	Bins had insect infestation

[a]Total 1,320 mt (48,500 bu) mean 101 mt (3,700 bu) in 9 bins and 4 granaries.

Table 36. The use of grain spreading devices during the storing of corn and wheat sampled during 1980.

Grain	Spreading method	Number of storages	Grain quantity	
			metric t	bu x 1000
Corn	Power centrifugal	1	137	5.4
	Power centrifugal plus in bin stirring	3	282	11.1
	Hand-spread only	3	371	14.6
	No spreading of any kind	34	7227	284.5
	Total	41	8018	315.7
Wheat	Hand-spread only	7	395	14.5
	No spreading of any kind	41	4923	180.9
	Total	48	5318	195.4

Table 37. Summary of how the grain sampled was lying in the storage structures. Peaked means cones beneath loading point. Overfilled refers to fills above eaves or sideboards of storage. Partial fills refers to grain surface average more than 1 ft. (ca. 0.3 m) below eaves or sideboards.

How storage was filled	May-June 1980			Aug.-Sept. 1980		
	Number of Storages	Quantity in storages		Number of Storages	Quantity in storages	
		mt (bu x 1000)	% of total		mt (bu x 1000)	% of total
CORN						
Level filled	18	2878 (113.3)	35.9	15	2461 (96.9)	41.6
Level-partial fill	6	617 (24.3)	7.7	4	267 (10.5)	4.5
Peaked-overfill	5	2321 (91.4)	28.9	8	2896 (114.0)	49.0
Peaked-partial fill	2	188 (7.4)	2.3	2	221 (8.7)	3.7
Other[a]	10	2014 (79.3)	25.1	2	71 (2.8)	1.2
	41			31		
WHEAT						
Level filled	12	1151 (42.3)	24.1	16	1372 (50.4)	30.8
Level-partial fill	5	321 (11.8)	6.7	4	182 (6.7)	4.1
Peaked-overfill	8	1244 (45.7)	26.1	14	1706 (62.7)	38.4
Peaked-partial fill	10	1843 (67.7)	38.6	2	1124 (41.3)	25.3
Other[a]	3	212 (7.8)	4.4	2	63 (2.3)	1.4
	38			38		

[a]slanted toward door or cone depression from unloading.

Table 38. Conditions of sanitation and storage areas for corn and wheat sampled during 1980.

		Grain in storages	
	Number of storages	mt	bu x 1000
CORN			
Total, by each factor alone:			
residual and spilled grain	15	3874	152.5
granary area mowed grass	9	1529	60.2
granary area uncut weeds	22	4389	172.8
granary area gravel or dirt	25	6094	239.9
storages shaded by trees	7	1450	57.1
corn storages sampled	41	8018	315.7
WHEAT			
Total, by each factor alone:			
residual and spilled grain	12	1657	60.9
granary area mowed grass	26	2651	97.4
granary area uncut weeds	21	2675	98.3
granary area gravel or dirt	7	2117	77.8
storages shaded by trees	7	533	19.6
wheat storages sampled	48	5318	195.4

Table 39. Corn and corn storage treatments for corn sampled during 1980.

	Number of storages	Grain in storages mt	bu x 1000
Treatments to storage structure or corn at loading			
Total, by treatment alone:			
storages cleaned before filling	23	3500	137.8
residual applied to storage	5	866	34.1
surface grain residual applied	3	551	21.7
residual applied during loading	0		
total storages surveyed	40	8018	315.7
Total, by unique combinations:			
storage cleaned only	16	2303	90.7
storage structure cleaned and treated only	5	866	34.1
storage cleaned corn surface residual applied	2	330	13.0
corn surface dressed only	1	221	8.7
storage not cleaned or treated grain not treated	16	4188	164.9
Treatments to corn after loading			
Total, by treatment alone:			
liquid fumigant applied	4	460	18.1
DDVP resin strip(s)	5	1776	69.9
PH_3	3	523	20.6
Total, by unique combinations:			
liquid fumigant only	4	460	18.1
PH_3 only	1	221	8.7
DDVP only	3	1473	58.0
DDVP plus PH_3	2	302	11.9
no treatments	31	5563	219.0

Table 40. Wheat and wheat storage treaments for wheat sampled during 1980.

	Number of storages	Grain in storages mt	Grain in storages bu x 1000
Treatments to storage structure or wheat at loading			
Total, by treatment alone:			
storages cleaned before filling	41	4689	172.3
residual applied to storage	11	1352	49.7
protectant applied at loading	11	1491	54.8
surface wheat residual applied	3	294	10.8
total storages surveyed	48	5318	195.4
Total, by unique combinations:			
storage cleaned only	20	2289	84.1
storage structure cleaned and treated only	7	615	22.6
storage cleaned only, residual mixed at loading	7	754	27.7
storage cleaned only, wheat surface residual applied	3	294	10.8
storage structure cleaned, residual applied to structure and grain	4	738	27.1
no treatments to structure or grain of any kind	7	629	23.1
Treatments to wheat after loading			
Total, by treatment alone:			
liquid fumigant applied	8	776	28.5
DDVP resin strips	3	411	15.1
Total, by unique combinations:			
liquid fumigant only	5	365	13.4
liquid fumigant plus DDVP	3	411	15.1
no treatments	40	4542	166.9

Table 41. Characteristics of corn stored in round steel bins, with or without aeration, sampled during 1980 in 6 Minnesota counties. The same bins were resampled during the second sampling period. No significant differences occurred between aerated and non-aerated bins for any factor listed below.

	Sampling Periods			
	May-June		Aug.-Sept.	
	With aeration 7 bins	No aeration 21 bins	With aeration 4 bins	No aeration 16 bins
Grain quantity in mt				
mean	166.2	180.8	113.7	164.11
total	1163.4	3797.4	454.7	2625.8
range	30.5-431.8	40.6-477.6	30.5-254.0	17.0-477.6
Moisture content % wet basis				
mean	12.9	12.5	13.3	13.2
range	10.9-15.0	8.7-15.4	12.3-13.9	12.5-14.6
Damage[a] % by wt				
mean	12.4	10.9	10.7	13.0
range	3.3-25.0	0.14-37.5	6.1-20.2	3.1-66.4
Surface grain temperatures, °C				
mean	23.6	21.6	27.5	24.9
range	21-26	10-28	24-29	16-43
Center grain temperatures, °C				
mean	14.3	15.3	27.0	25.4
range	6-24	1-26	21-35	14-47
Insect counts[b] per 0.95 liter sub-sample				
mean (n samples)	7.8(4)	2.8(8)	10(2)	15.1(13)
range	2-20	1-7	3-17	2-41
"0" values	1	4	1	2
no detections	2	9	1	1

[a]Combined discolored germ and other mold damage.

[b] Number of live adults per 0.95 liter sub-sample of composite sample - "0" values refers to number of times insects were in remainder of sample or detected in bin but not in 0.95 liter sub-sample. No detection refers to number of times no species was detected by any method.

Table 42. Occurrence of live adult insects in 0.95 liter sub-samples of composite samples of farm stored shelled corn sampled during 1980 in 6 Minnesota counties.

	Sampling Period May-June			Sampling Period Aug.-Sept.		
Number of insects per 0.95-liter sub-sample	Number of storages with that number	Total grain in mt (% of total sampled)	Cumulative Total in mt (cum. % of total sampled)	Number of storages with that number	Total grain in mt (% of total sampled)	Cumulative Total in mt (cum. % of total sampled)
1-4	12	2818.3 (35.1)	2818.3 (35.1)	9	806.5 (13.6)	806.5 (13.6)
5-14	3	246.4 (3.1)	3064.7 (38.2)	6	1955.1 (33.1)	2761.6 (46.7)
≥15	2	256.5 (3.2)	3321.2 (41.4)	6	1160.9 (19.6)	3922.5 (66.3)

Table 43. Occurrence of live adult insects in 1 kg sub-samples of composite samples of farm stored wheat sampled during 1980 in 6 Minnesota counties.

	Sampling Period May-June			Sampling Period Aug.-Sept.		
Number of insects per 1 kg sub-sample	Number of storages with that number	Total grain in mt (% of total sampled)	Cumulative Total in mt (cum. % of total sampled)	Number of storages with that number	Total grain in mt (% of total sampled)	Cumulative Total in mt (cum. % of total sampled)
1-4	8	541.6 (11.4)	541.6 (11.4)	10	1063.0 (36.0)	1603.0 (36.0)
5-14	6	483.0 (10.1)	1024.7 (21.5)	4	451.8 (10.2)	2054.8 (46.2)
≥15	3	264.0 (5.5)	4769.6 (27.0)	5	267.6 (6.0)	2322.3 (52.5)

Table 44. Quantity of grain theoretically contaminated by infested surface grain of several volumes.

Diameter of infested area	Quantity of infested grain[a]	Grain in cone of grain removed[b]	Percent of infested grain in cone	Insect count dilution factor
1.5 m (5 ft)	0.8 t (31.6 bu)	3.4 t (132.3 bu)	23.9	4.2
3.0 m (10 ft)	3.2 t (126.2 bu)	8.3 t (327.5 bu)	38.5	2.6
4.6 m (15 ft)	7.2 t (284.0 bu)	17.0 t (669.5 bu)	42.4	2.4
6.1 m (20 ft)	12.8 t (505.0 bu)	30.0 t (1182.8 bu)	42.7	2.3

[a]Based on 0.6 m (2 ft) depth, 0.803564 bu/cu ft. of 56 lb/bu corn.

[b]Volume of cone removed plus vertical path of auger.

Table 45. Frequency of detection of 9 insect species in 9 bins of shelled corn by 2 probe sampling methods and trapping. Pipestone Co. Minnesota, Sept. 1980. From Barak and Harein 1981b.

	Number of bins out of 9 in which species was detected			Ratio of trap to survey or probe detection	
Insect species	Standard[a] survey methods	Paired[b] probe samples	Paired[c] trap catch	Traps: survey method	Traps: paired probes
Cryptolestes spp.	6	8	9	1.50:1	1.13:1
Typhaea stercorea	1	1	7	7.0 :1	7.0 :1
Tribolium castaneum	2	3	6	3.0 :1	2.0 :1
Cynaeus angustus	1	4	5	5.0 :1	1.25:1
Oryzaephilus surinamensis	3	3	5	1.67:1	1.67:1
Ahasverus advena	2	3	5	2.50:1	1.67:1
Plodia interpunctella	1	1	1	1.0 :1	1.0 :1
Sitophilus oryzae	0	0	1	--	--
Tenebriodes mauritanicus	0	0	1	--	--

[a] Barak and Harein 1981a.

[b] Sum, 6 sites/bin.

[c] Sum, 6 traps for 5 days cont.

Table 46. Frequency of detection of 9 insect species in paired probe/trap samples at 54 sites (6 per bin) in 9 bins of farm stored shelled corn.[a]

Insect species	Detection by paired traps and probes: Probe N	Probe %	Traps N	Traps %	Ratio trap:probe	Detection by one method but not other: By probe: not trap	By trap: not probe
Cryptolestes spp.	15	27.8	43	79.6	2.87:1	2	30
Typhaea stercorea	1	1.9	31	57.4	31.0 :1	0	31
Oryzaephilus surinamensis	4	7.4	27	50.0	6.75:1	2	25
Cynaeus angustus	5	9.3	19	35.2	3.80:1	2	16
Ahasverus advena	4	7.4	18	33.3	4.50:1	3	17
Tribolium castaneum	3	5.6	16	29.6	5.33:1	1	14
Plodia interpunctella	2	3.7	4	7.4	2.0 :1	1	3
Tenebroides mauritanicus	0	-	2	2.7	--	0	2
Sitophilus oryzae	0	-	1	1.9	--	0	1

[a]Barak and Harein 1981b.

Table 47. Incidence of *Cynaeus angustus* (LeConte) in farm stored shelled corn on Minnesota farms sampled during 1977 and 1978. From Barak et al. 1981.

Minnesota county sampled	Year sampled	Storages sampled (% with *C. angustus*)	Corn sampled in t (% with *C. angustus*)	% Moisture of infested and (non-infested) corn ± SD[a]
Waseca	1977	46 (41.3)	7,826.2 (41.4)	13.33 ± 0.83 (13.27 ± 1.12)
Chippewa Renville Yellow Medicine	1978	36 (63.9)	4,887.2 (56.1)	13.08 ± 1.36 (12.83 ± 0.99)

[a]Moisture contents (wet basis) of infested and non-infested corn not significantly different ($P \geq .05$).

Table 48. The abundance of Cynaeus angustus (LeConte) in 6 corn bins in which larval populations were detected. Moisture content is wet basis. From Barak et al. 1981.

	Sampling Periods								
	May-June				Aug.-Sept.				
Bin No.	Stage[a] Present Larvae	Adults	Moisture content (%)	Temp. of surface/ center of bulk grain in °C [b]	Stage Present Larvae	Adults	Moisture content (%)	Temp. of surface/ center of bulk grain in °C	Months in storage and quantity(t) of grain in bin
1	+	+	11.4	25/14	+	+	12.7	30/20	23 (1219.3)
2	4	1	11.9	18/ 4	-	4	12.8	21/23	35 (116.8)
3	-	-	12.3	23/12	+	+	13.0	22/14	21 (221.9)
4	-	2	10.0	24/18	3	3	14.6	38/39	33 (106.7)
5	-	-	13.2	22/24	4	-	13.2	28/30	23 (17.0)
6	-	+	9.9	23/18	12	+	14.3	29/27	33 (50.8)

[a](+,-) = present in bin but not in 0.95-liter (1 qt) representative sub-sample of composite sample (number) = actual count of C. angustus in the 0.95-liter (1 qt) sub-sample

[b]Temperatures recorded at ca 0.3 below grain surface and at estimated center of grain bulk

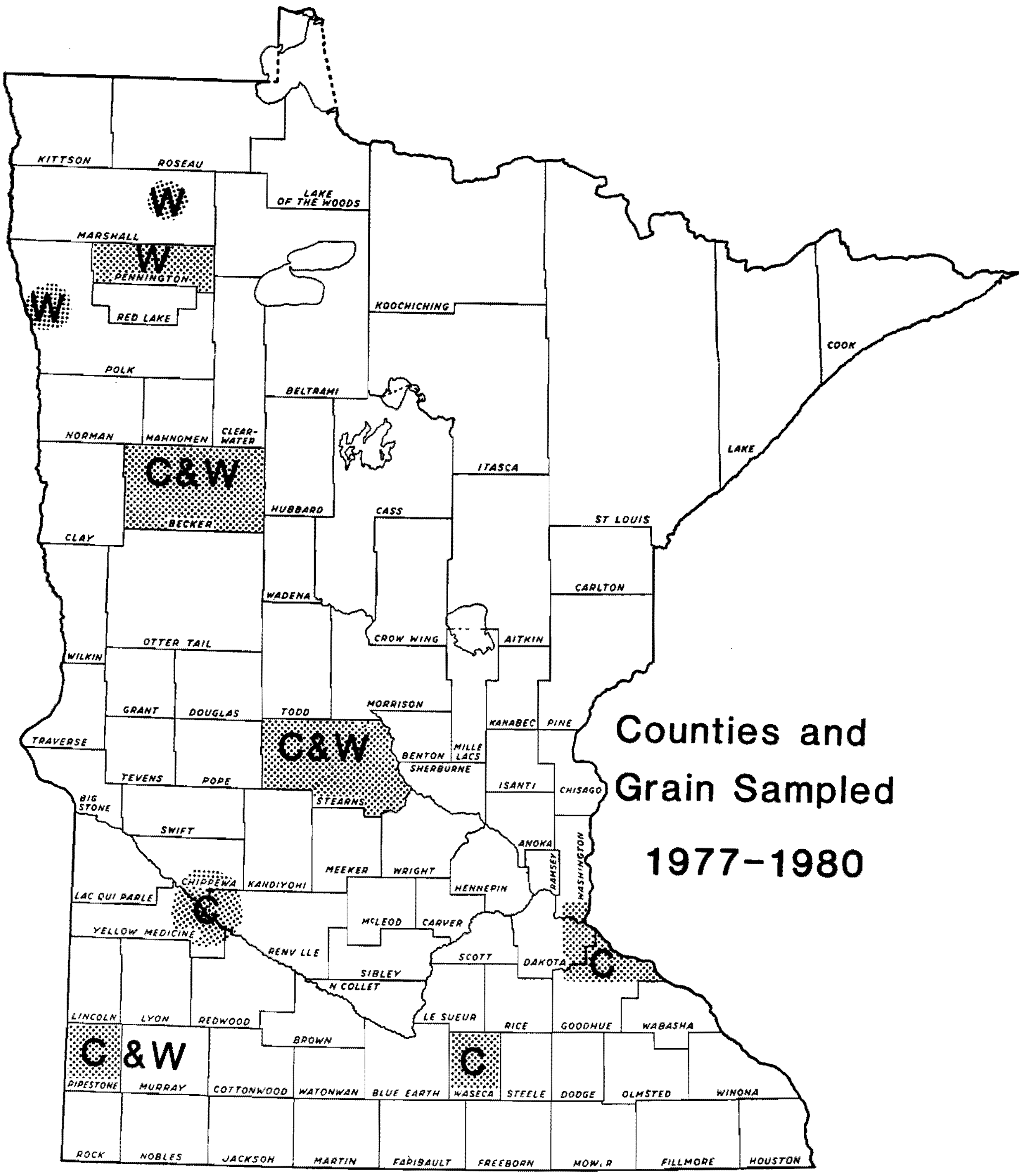

Fig. 1. A map of Minnesota showing the areas sampled during 1977-80. Waseca county was sampled during fall, 1977. The Chippewa, Renville and Yellow Medicine county areas were sampled during May-Sept., 1978. The remainder of the counties were sampled during May-Sept., 1980. From Barak et al. 1981.

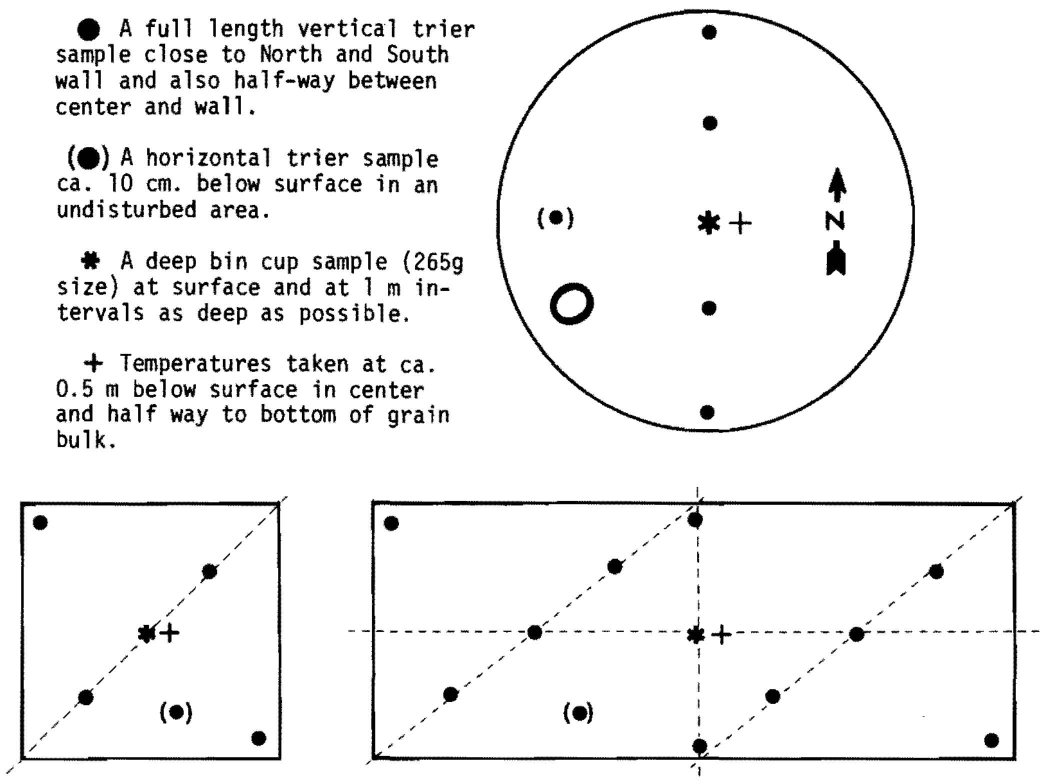

Fig. 2. Sample points in a level filled bin and typical flat storage. In a flat storage the center was considered as the spot beneath the loading port, if present, or the deepest portion of the grain bulk. From Barak and Harein 1981a.

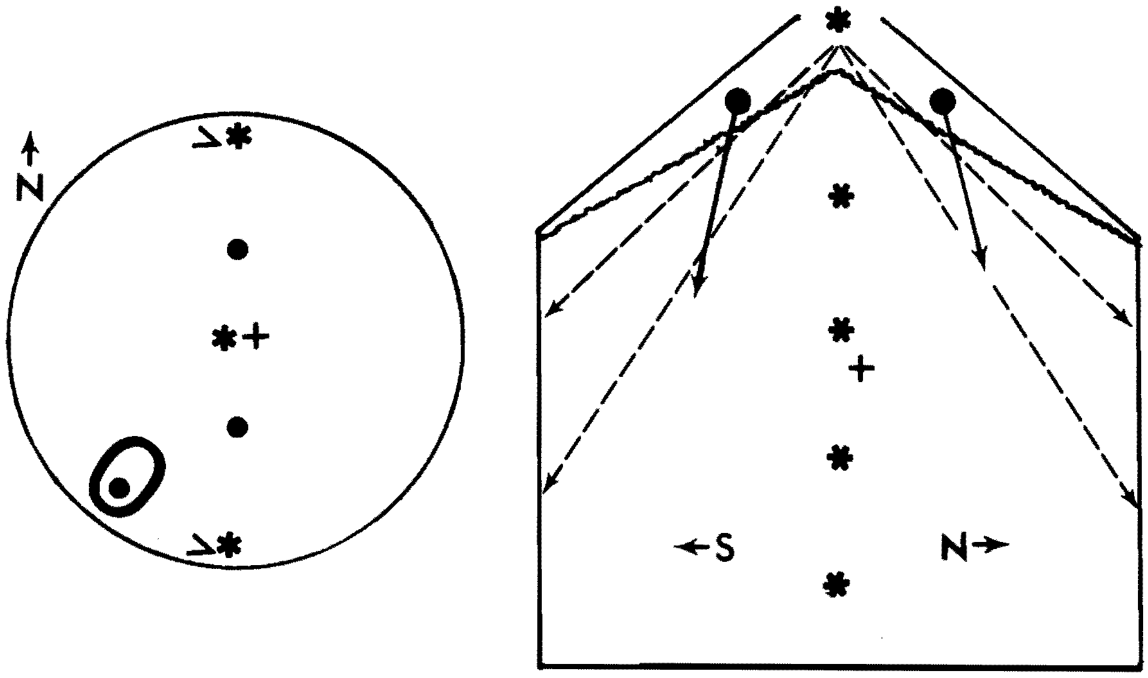

Fig. 3. Sample points in an overfilled bin. Samples were collected near the walls by insertion of the deep-bin probe at appropriate angles. A N-S orientation was maintained. Deep-bin probe sample sites at the center were as those in a level filled bin. From Barak and Harein 1981a.

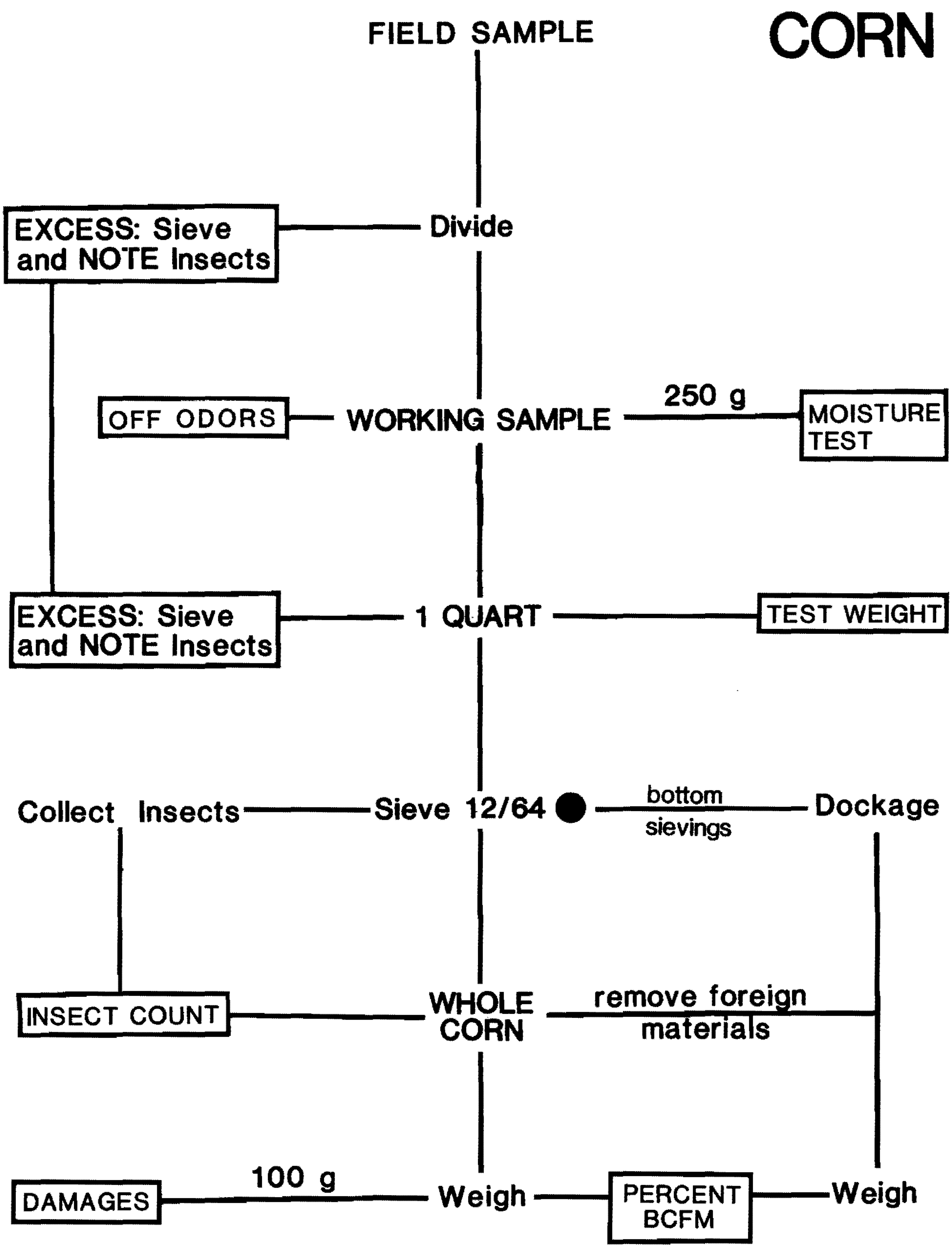

Fig. 4. Flow diagram of the laboratory handling of corn samples. Factors in boxes were recorded as survey data.

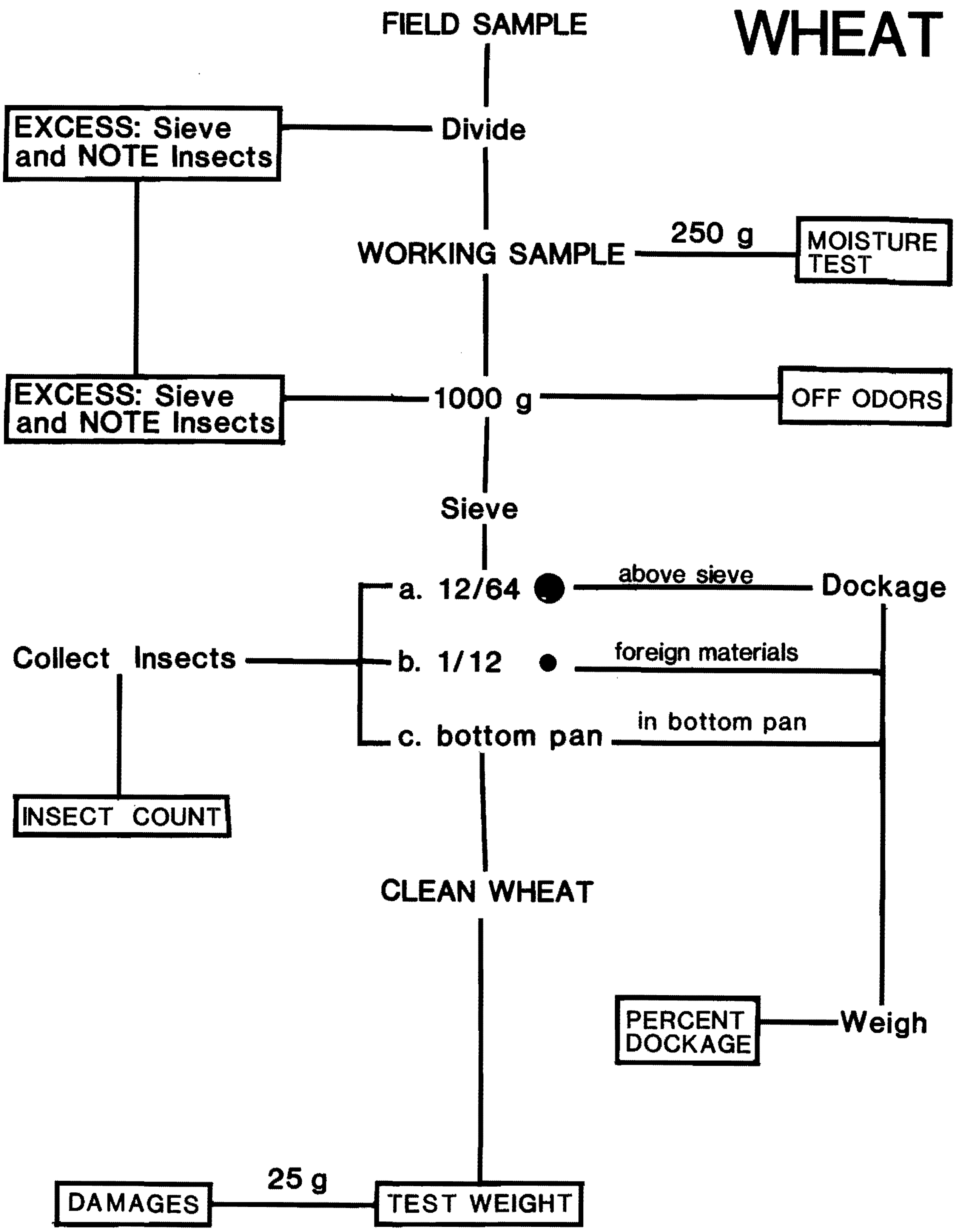

Fig. 5. Flow diagram of the laboratory handling of wheat samples. Factors in boxes were recorded as survey data.

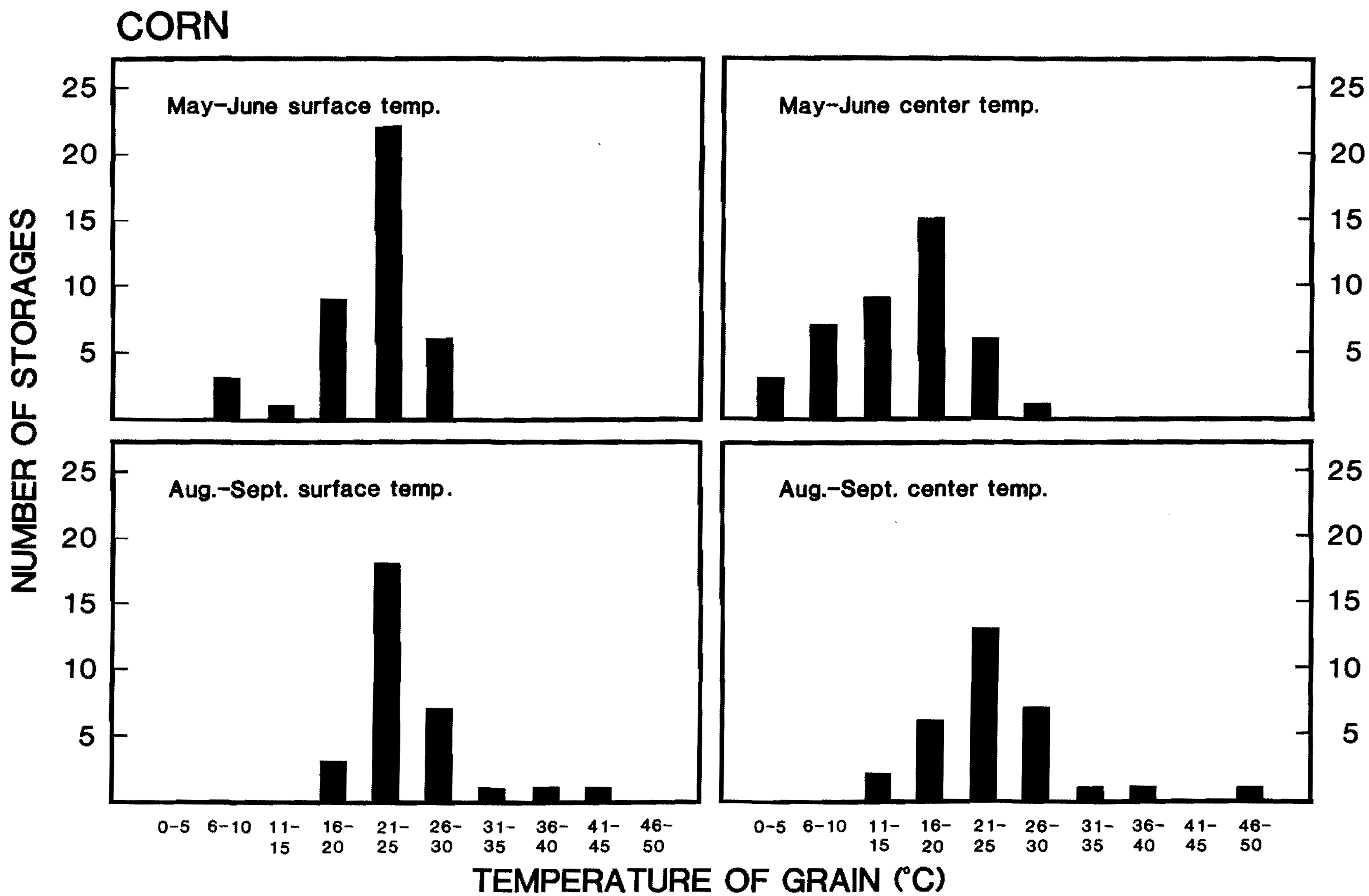

Fig. 6. Histogram presentation of sub-surface (-0.3 m) and center of grain bulk temperatures recorded for stored shelled corn during 2 times of the year.

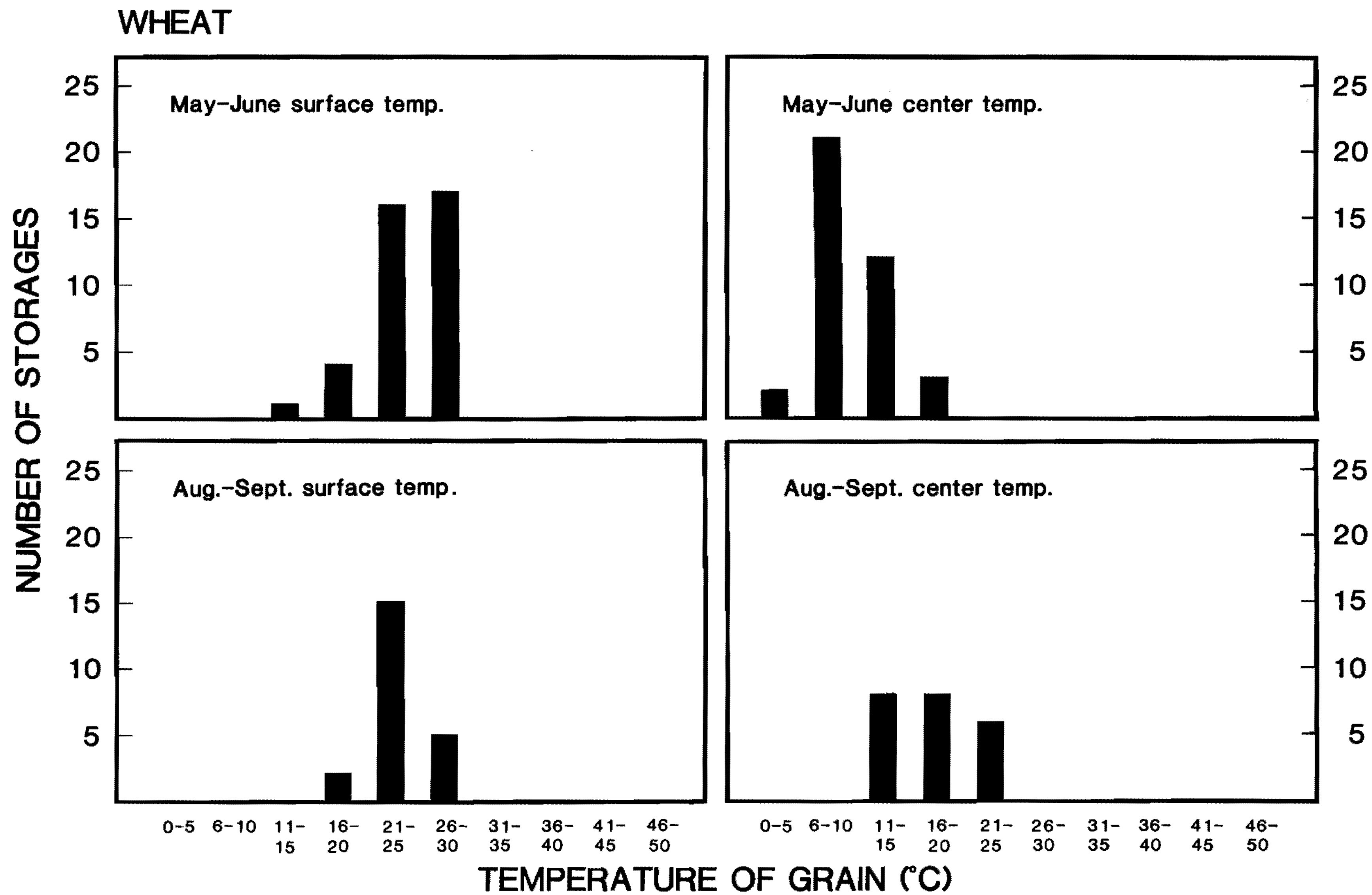

Fig. 7. Histogram presentation of sub-surface (-0.3 m) and center of grain bulk temperatures for stored wheat during 2 times of the year.

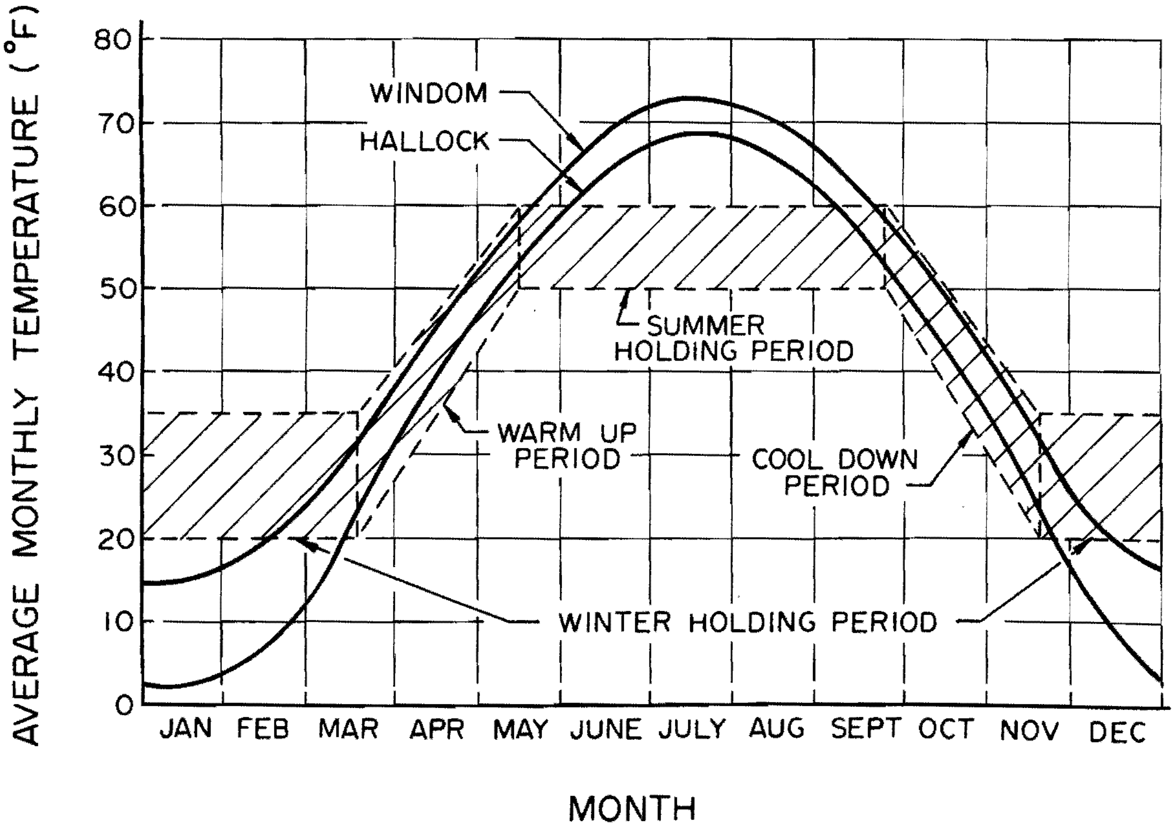

Fig. 8. The relationship of mean ambient temperatures and suggested aeration management periods for 2 locations in Minnesota. From Cloud and Morey 1980.

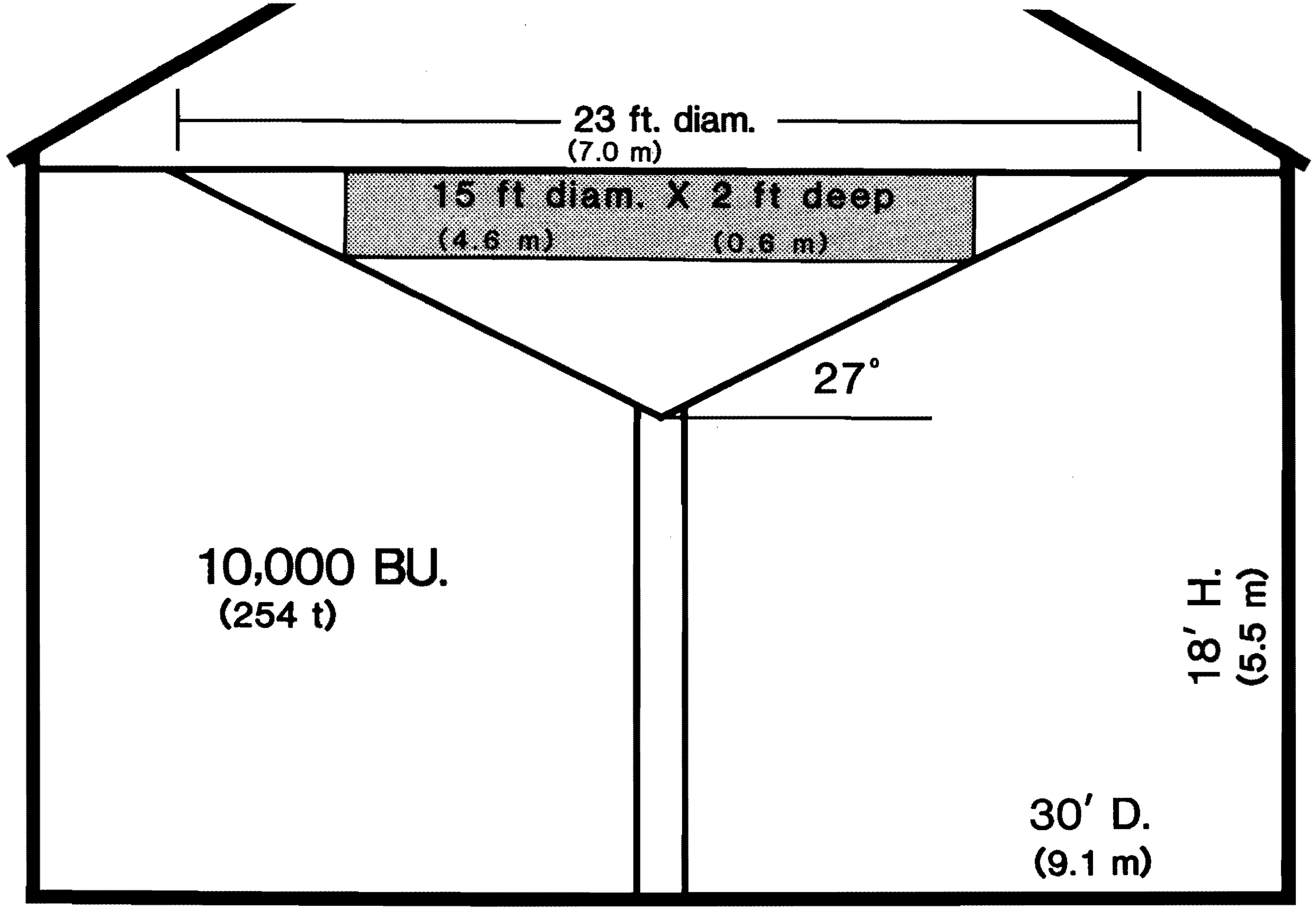

Fig. 9. The relationship of damage/infested surface grain to the remainder of grain in a bin, showing cone of depression caused by removal of damaged volume by center unloading.

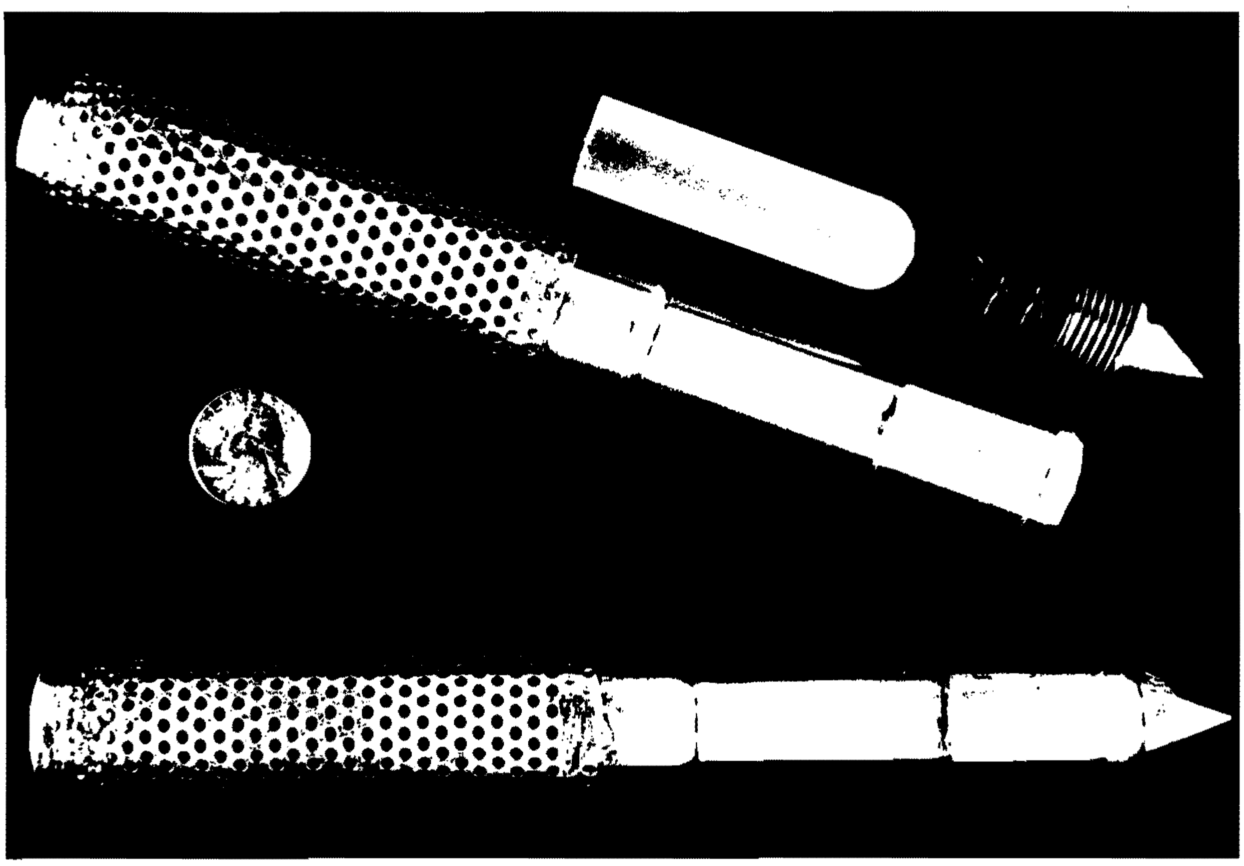

Fig. 10. The perforated brass, drop-in type of insect trap used in this survey. The trap is similar to that described by Loschiavo and Atkinson (1972). From Barak and Harein 1981b.

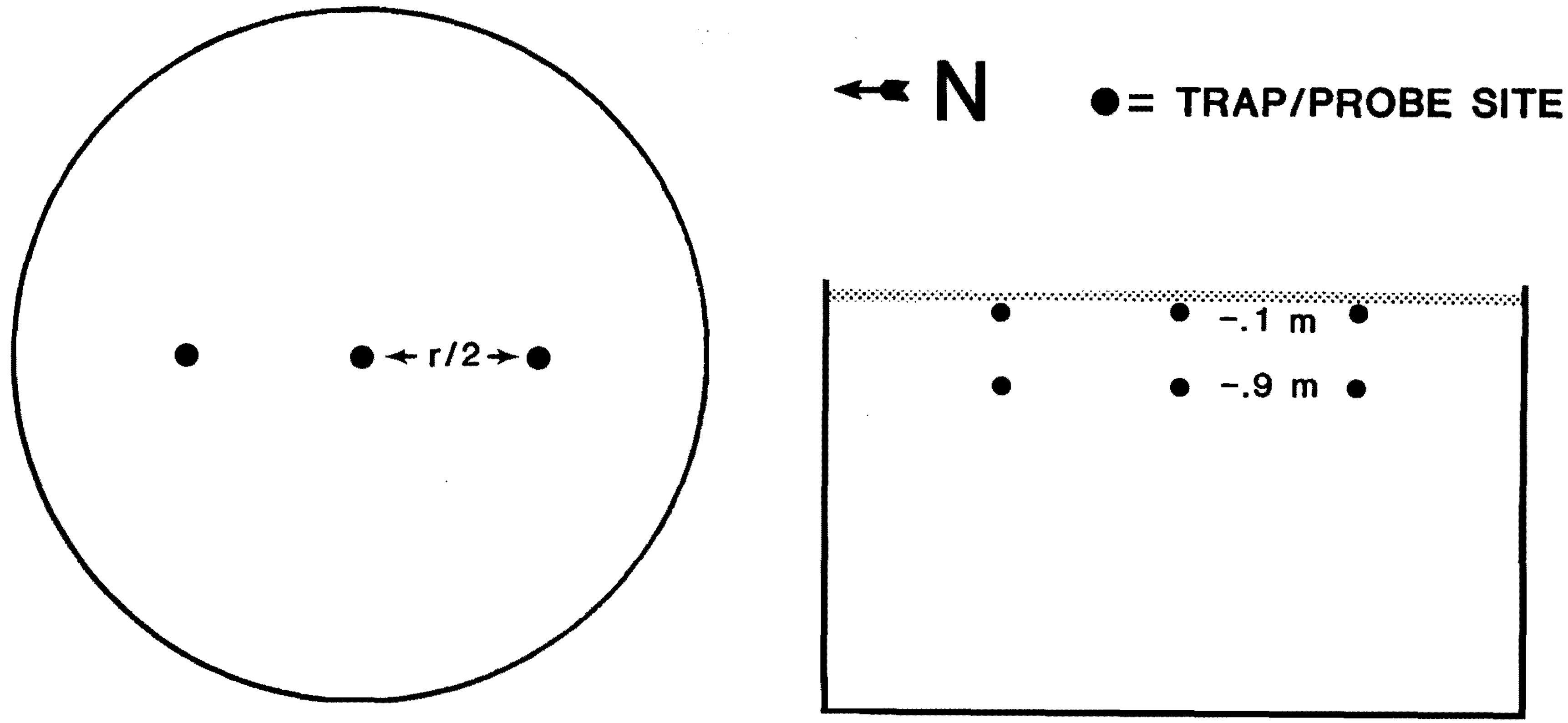

Fig. 11. Probe/trap sample sites as used in 9 bins of shelled corn trapped for insects during Sept. 1980. From Barak and Harein 1981b.

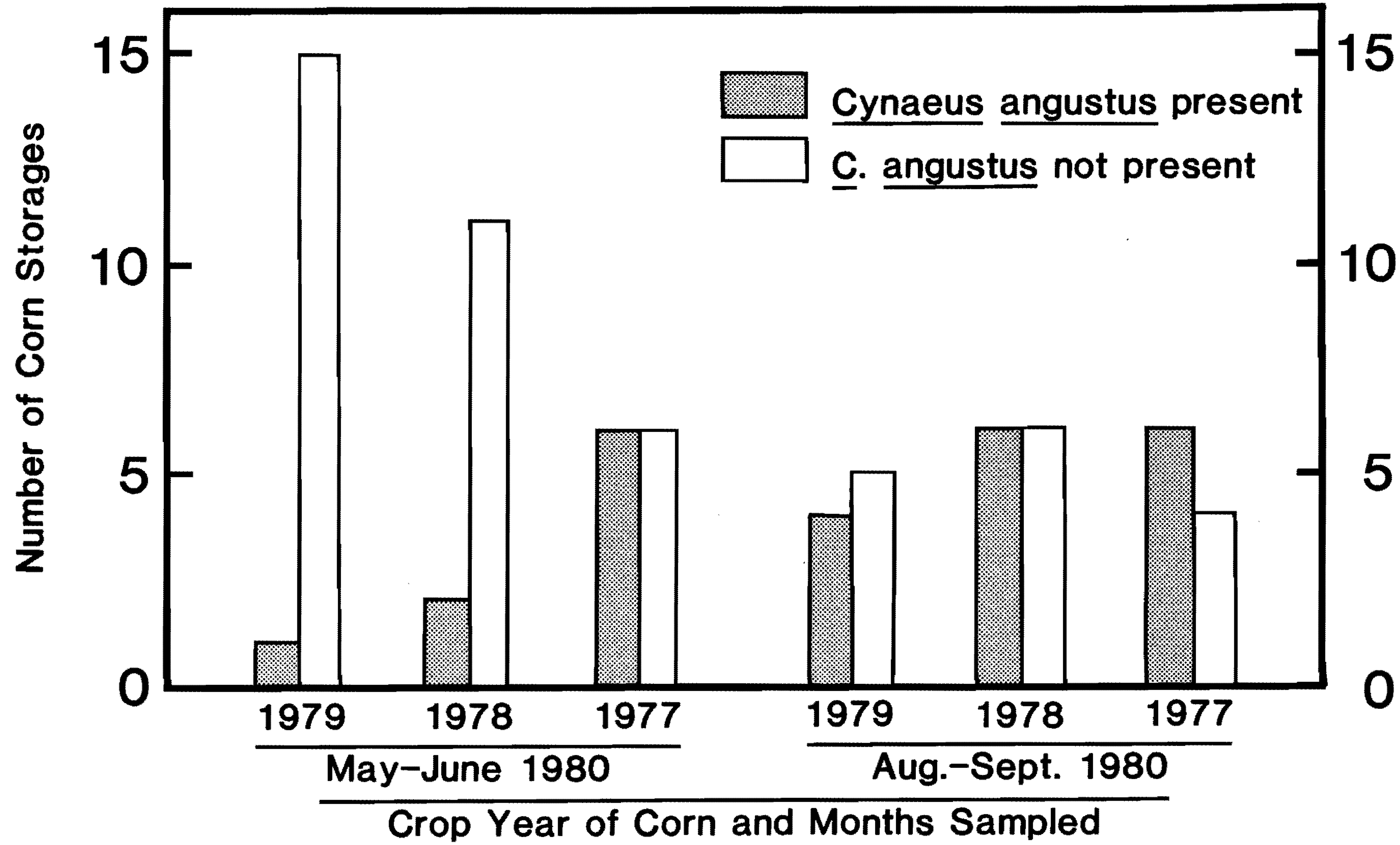

Fig. 12. The presence of Cynaeus angustus (LeConte) in corn bins sampled during 1980 in 6 Minnesota counties. From Barak et al., 1981.

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