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ATTACHMENT I

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MILLET LOSS ASSESSMENT PROJECT

REGIONAL FOOD CROP PROTECTION

SENEGAL

Report on 1983 Activities

Prepared by

Galen P. Dively
Consulting Entomologist
4720 Ruatan Street
College Park, MD 20740

submitted to

U. S. Agency for International Devel
Management Office
USAID/Senegal
B. P. 49
Dakar, Senegal

REGIONAL FOOD CROP PROTECTION OFFICE
USAID
B.P. 49
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INTRODUCTION

Since 1980, the AID-Regional Crop Protection project in West Africa has been developing methodologies for pest loss assessments in millet. The major reasons for making quantitative loss assessments are (1) to establish the economic status of specific pests, (2) to determine the level of justifiable expenditure on control actions for each pest, and (3) to provide a basis for planning research and making agricultural policy decisions.

Efforts in Senegal, Guinea-Bissau and the Gambia during the first two years were based on a split-block design involving paired, insecticide treated and untreated replicates within farmers' fields. Although this design was statistically valid, results were less than satisfactory for the following reasons. First, the method did not allow for differentiation between types of insect damage and subsequent losses. Secondly, there were experimental errors due to incomplete control of pests in the treated plots, insecticide drift into untreated plots, and complications caused by the direct effects of insecticides on millet growth. And finally, disease and weed pest losses were not assessed.

Therefore in 1982, crop protection consultants from the University of Maryland were asked to design and evaluate a loss assessment procedure that did not involve insecticides. The work was conducted in 10 millet fields in Senegal, with the help of Peace Corps Volunteers. The method involved tagging 100 millet plants in each field and following these plants through the course of the season to determine relative importance of each pest. On the assumption that the proportion of damaged plants or plant parts is directly related to yield loss, losses attributable to each pest group were estimated, provided that each type of damage could be distinguishable at harvest. This approach provided satisfactory estimations of losses due to direct pests, that is, those that attack the grain spikes of millet at later growth stages. Although possible losses caused by indirect pests were not addressed, it was felt that direct pests account for most of the differences between actual and attainable millet yield in the absence of pests.

Although the loss assessment approach used in 1982 provided a relatively simple and precise tool to establish millet loss profiles, it was not without problems. A major one was the lack of consistent and accurate pest activity data throughout the season. Many of the participating Peace Corps Volunteers lacked both a background in pest management and experience in millet. Other problems involved the time lost trying to locate tagged plants at harvest and the inability to breakdown stand reduction losses into specific causes.

To further refine loss assessment methodology, the same basic approach was used in 1983 but with several modifications. A loss assessment team from the University of Maryland surveyed pest losses in 42 millet fields in 8 Senegalese villages during the harvest period in early October. This report presents the results of the 1983 millet loss assessment project.

MATERIALS AND METHODS

Survey Design - The study was conducted in the Sine-Saloum region which contains 35% of Senegal's crop area. Eight villages extending about 100 km south to north from Nioro to Diourbel were contacted for survey. These villages included: Nioro, Dinguirage, Ngapak, Sanghil Serere, Fass, Oudior, Boustane and Ndiebel. Vilages were selected by the sector chiefs as being representative of typical villages and also most willing to cooperate; therefore, they were not selected completely at random.

Seventeen farmers (1-3 per village) with 42 millet fields (1-3 per farmer) participated and were also selected primarily by the sector chiefs. All millet fields grown by each farmer were sampled so that his overall millet production and profile of yield loss factors could be related to certain socioeconomic information about the family unit.

The 1982 study demonstrated that most direct yield losses can be quantified at harvest, even without prior knowledge of the nature and extent of each loss factor. Therefore, assessments of the following yield loss factors were conducted only at harvest on a random sample of plants in each field.

1. Mildew (*Sclerospora graminicola* (Sacc.) Schroet. was assumed to be the primary mildew pathogen)

2. Smut (*Tolyposporium penicillariae* Bref. was assumed to be the primary smut pathogen)

3. Ergot (*Claviceps fusiformis* Loveless)

4. Birds (buffalo weaver - *Bubalornis albirostris*; village weaver - *Ploceus capitalis*; golden sparrow - *Passer luteus*)

5. Flower feeding insects (blister beetles - *Mylabris* and *Psalydoletta* spp; scarab beetles - *Pachnoda* spp.

6. Head borer (*Raghuva albipunctella* De Joannis)

7. Grain feeding insects (grasshoppers - *Oedaleus*, *Kraussaria*, *Cataloipus*, and *Krausella* spp.; *Heliothis armigera* Hbn.)

8. Stem borer (*Acigona ignefusalis* Hmps.)

9. Rodents and other mammals

10. Stand reduction caused by both agronomic and pest-related factors

The nature of these factors and their actual impact on millet yield are discussed by Dively (1983).

Stand Reduction - The initial plant spacing or distance between plants within rows was measured in each field at five locations selected where there was no evidence of stand reduction (or missing plants). The number of plants per 10 meters of row was recorded at each location.

Row width in meters and the final spacing between plants were also measured at five locations selected by following a stratified random pattern. At each location, the final spacing was determined by counting the number of plants per 25 meters of row.

The procedures for estimating stand reduction losses assumed that plants growing adjacent to the spaces left by missing plants do not produce additional yield as a result of less competition. It was also assumed that no yield losses occur if the final plant population is equal to or exceeds 10,000 plants per hectare, even though there is a reduction in the initial plant population. Research has shown that the optimum millet stand is 10,000 plants per hectare, spaced one meter apart within and between rows (personal communication, Bill Settle).

Field Size - The size of each field was determined by scaling the length and coordinates of the perimeter on a grid and then measuring the area using planimetric techniques.

Plant Sampling - Twenty-five plants were sampled per field using a random start and systematic selection of five plants in each of five areas of the field. The term 'plant' herein refers to a plant cluster which normally consists of 1-3 individual plants.

Plant sampling was conducted by teams of three people including a recorder, examiner and cutter. The cutter was usually the son or laboror of the cooperating farmer who was instructed to cut only those spikes that normally would be harvested. The following information was recorded at each plant:

1. The number of the four possible neighboring plants (two adjacent ones in same row and one in each adjacent row) was recorded.

2. Weed density was assessed around each plant and recorded as a percentage of the surface area covered by weed vegetation. Visual ratings were coded as 0 = no weeds present, 1 = 25% of the area covered by weeds, 2 = 50% of surface area covered; 3 = 75% weed cover, and 4 = 100% weed cover. The observational unit was a one square meter area with the plant situated in the center. Weed composition expressed as the grass portion of the weed cover was estimated to nearest 10%. The number of Striga plants around each plant was also recorded.

3. If no spikes were present, it was determined whether the spikeless condition was due to mildew, drought, insects, or unknown causes. The sampling process for spikeless plants was then complete at this point.

4. The numbers of harvestable and unharvestable spikes were recorded. Also, data were collected on the number of spikeless tillers that were more than half the overall height of the plant.

5. The damaged length of unharvestable spikes attributed to each loss factor was measured and adjusted according to the unit diameter of the largest spike. In other words, the damaged length on smaller spikes was scaled down proportionally according to the ratio of their diameter with the unit diameter. The adjusted length of unharvested, immature spikes was also recorded.

All harvestable spikes were removed from each plant, packaged in bundles marked with the plant and field codes, and brought to the village where they were later processed.

Spike Measurements - The weight per plant of harvestable spikes collected from each field was determined. Total spike length per plant was measured and adjusted according to the designated unit spike. Spikes were then examined for damage caused by each yield loss factor. The adjusted damaged length pertaining to each factor was recorded.

A composite sample of undamaged spikes from all fields were individually measured, weighed and threshed by traditional means to determine the relative weights of grain (sack), chaff (glumes and other associated reproductive tissue), and core (rachis). Six samples of 50 disease-free and 50 smutted grain kernels were also weighed to determine the relative weight of smutted grain compared to good grain.

Socioeconomic Information - Each cooperating farmer was interviewed to obtain the following information:

1. Planting date, soil type and rotation system of each field.
2. Distance from field to village.
3. Fertility and pest control inputs.
4. Dates of weeding.
5. Millet yield that is considered "good".
6. Number of women, men and children per family unit.
7. Millet consumption per day per family unit.
8. Number of years out of 5 that millet was in short supply.
9. Means of buying food when the millet is in short supply.
10. Expected cost of buying millet in the market place right after harvest, 6 months later, and just prior to the next harvest.
11. Labor costs to produce millet if people other than family members are hired to work the fields.

DATA ANALYSIS

Actual Yield - The yield in kg/hectare of grain weight (AY) was computed by:

AY = UNDAMWT X FPLTDEN X PGRAIN

where UNDAMWT = the weight of harvestable spikes per plant adjusted to equal the weight of only undamaged spike length
FPLTDEN = the final plant density per hectare
PGRAIN = proportion of grain on the spikes

To correct the spike weight for the damaged portion, the proportions and weighting factors of grain, chaff and core presented in Table 1 were used to generate relative weights of both total and damaged portions of harvestable spikes.

The total relative weight (TOTRELWT) is given by:

TOTRELWT = (TOTLTH X WFCORE) + (LCHAFF X WFCHAFF) + (LSMUT X WFSMUT) + (UNDAMLTH X WFGRAIN)

where TOTLTH = the total adjusted length of harvestable spikes
WFCORE = weighting factor for core
LCHAFF = the adjusted length of chaff
WFCHAFF = the weighting factor of chaff
LSMUT = the adjusted length of smut
WFSMUT = the weighting factor for smut
UNDAMLTH = the adjusted length of undamaged portion of the spikes
WFGRAIN = the weighting factor for grain.

It was assumed that all yield loss factors causing direct damage to the spikes had no effect on the length of core or chaff except Raghuva which removes 50% of the chaff as a result of its feeding behavior. Thus, LCHAFF = TOTLTH - 50% of LRAGH (the adjusted spike length damaged by Raghuva).

The relative weight of the damaged portion of spikes (DAMRELWT) is given by:

DAMRELWT = (DAMLTH X WFCORE) + (DAMLTH X WFCHAFF) (0.5 X LRAGH X WFCHAFF) + (LSMUT X WFSMUT)

where DAMLTH = the adjusted length of spike damage caused by all yield loss factors combined.

The weight of the undamaged portion of spikes (UNDAMWT) is then given as:

UNDAMWT = TOTWT X (1 - (DAMRELWT/TOTRELWT))

where TOTWT = the weight of harvestable spikes including both damaged and undamaged portions.

Stand Reduction - Yield losses as a result of reductions in the plant population (YLF_{STDRED}) were computed as follows:

$$IPLTDEN = \frac{10000}{RW \times ISPACING}$$

$$FPLTDEN = \frac{10000}{RW \times FSPACING}$$

$$\% STDRED = \frac{IPLTDEN - FPLTDEN}{IPLTDEN} \times 100$$

if FPLTDEN $\geq$ 10000 then % STDRED = 0

$$YLF_{STDRED} = \frac{\% STDRED}{100 - \% STDRED} \times ACTUAL\ YIELD$$

where IPLTDEN = the initial plant density per hectare
ISPACING = the initial average spacing in meters between plants
FSPACING = the final average spacing in meters between plants
FPLTDEN = the final plant density per hectare
% STDRED = percentage of stand reduction

Pest Losses - Yield loss attributed to direct pests was determined by:

$$WTLOSSn = UNDAMWT \times DAMLTHn / UNDAMLTH$$

$$YLFn = WTLOSSn \times FPLTDEN \times PGRAIN$$

where WTLOSSn = the loss in spike weight per plant attributable to pest n;
DAMLTHn = the total adjusted length of damage caused by pest n on both harvestable and unharvestable spikes;
YLFn = the yield loss in kg per hectare of grain weight caused by pest n.

Using the relationships above, it was assumed that the millet plant does not compensate for direct damage that occurs during the flowering and grain development stages. Thus, the amount of grain removed or the extent of seedlessness as a result of pest feeding was assumed to be directly proportional to yield loss.

Loss Profile - Although other yield loss factors attributable to certain indirect pests (i.e. insect defoliators, *Acigona* (first generation), shoot flies, weeds, etc.) were not assessed in this study, it was assumed that the ten factors listed above account for most of the difference between actual and attainable millet yield. Thus, estimates of these factors were used to establish a partial crop loss profile described in concept by Pinstrup-Andersen et. al (1976) and defined as:

$$ATTAINABLE_YIELD = ACTUAL_YIELD - YLF_1 - YLF_2 \ldots YLFn$$

where YLFn = the loss in yield caused by the different loss factors

To show the relative importance of each factor, yield losses were expressed as a percentage of the attainable yield.

Variance Components - To characterize the variability of yield and pest losses at each level of sampling (village, farmer, field, plant), a nested ANOVA was performed on three variables of adjusted spike length per plant. These variables included UNDAMLTH = the total undamaged length as an indicator of actual yield; DAMLTH = the total damaged length as an indicator of yield losses due to pests; and TOTLTH = total length of harvestable spikes as a measure of attainable yield without pests. The cost of assessing yield and pest losses at each level of sampling was determined by measuring the average time required to sample one unit at each level. Using these time lapse factors as a function of the variance component at each sampling level, the most efficient design was determined for a one day period of sampling effort (Sokal and Rohlf 1969).

RESULTS AND DISCUSSION

Actual Yield - The histogram in Figure 1 depicts the frequency of grain yield per hectare of the 42 millet fields sampled. Yield ranged from 150 to 2060 kg/hectare and averaged 800 ± S.E. = 71. About 60% of the fields yielded higher than the reported average millet yield in Senegal of 520 kg per hectare (Dancette 1978).

Yields varied significantly among villages and among farmers within villages. Figure 2 presents the average yield per farmer in the eight villages surveyed. The variation in yield among villages was largely due to differences in rainfall patterns during the growing season. Although records of rainfall were not taken, it was obvious from grower interviews that both the timing of the first rains and the accumulated totals were quite different from one village to the next. Since the participating farmers planted their millet shortly after the first rains, the range in planting dates from 21 June to 7 July reflected the magnitude of variation in the onset of the rainy season. Furthermore, timing of the first rains as a yield limiting factor was more critical in 1983 because the rains came 2-3 weeks later than normal in the Sine-Saloum Region.

Yield differences within villages were primarily due to agronomic and sociological differences among farmers. These differences were related to such factors as weeding schedules, seed selection, location of field from village, planting and cultivation methods, use of manure, and the value that each farmer places on millet. Twenty-nine percent of the fields were fertilized with manure - this frequency probably represents a higher than normal use of manure on millet fields in Senegal. It is interesting to note that the five farmers with the highest yields used manure on their fields. Another factor that is highly correlated with the use of manure is the distance from the field to the village. Fields nearest to villages (within 0.5 km) normally receive the greatest amounts of manure. The six fields of the two farmers with the highest yields were all located within 0.5 km of the village. The effect of distance from village on millet yields is further substantiated by the results summarized in Figure 3. Yield decreased significantly as the distance from the field to the village increased.

Yield Loss Factors - Figure 4 shows the estimated yield losses caused by each of the ten factors (YLFn). The relative importance of each of these factors for limiting attainable yield is illustrated in Figure 5. Total losses averaged 2[illegible]%

and ranged 8-50% among fields. In both figures, yield losses due to ergot, grain feeding insects, stem borers, and wild boar were combined into the category termed "others" because they accounted for a small percentage of the total losses.

Yield losses varied greatly among the factors. The head borer, Raghuva albipunctella, was the major loss factor which accounted for 33% of the total losses. Head borer damage was present in all fields and caused an estimated 93 kg/h or 8.9% loss in attainable yield. This pest also accounted for the highest single loss of 12.4% in 1982. R. albipunctella emerged as a severe problem in the early 1970's during the drought and has probably shifted over from a wild grass species to cultivated millet. Previous studies by Vercambre (1979) reported up to 25% of the millet crop lost through direct consumption of grain by the older larvae. Younger larvae attack the spike during flowering and the early stages of grain development but their feeding damage does not appear to result in yield loss. Since the older larvae feed directly on the kernels, assessment of the prospective losses was relatively simple and accurate.

Stand reduction below optimum plant populations was the second highest loss factor. Yield losses averaged 48 kg/ha with a range from 0 to 356 kg/ha and amounted to 4.6% of the attainable yield. Although reductions in the initial plant density occurred in all fields, it was assumed that yield losses did not occur in 27 fields because the final plant density exceeded the optimum of 10,000 per hectare. In 27 out of 42 fields, rows were either planted too close together (less than 0.9 meters) or not thinned to the optimum plant spacing of 1 meter apart. The highest initial plant density was 19,792. It is believed that farmers tend to thin less to establish more plants as a buffer against the higher risks of not producing a crop when the rains are late which was the case in 1983.

It was not possible to partition the stand reduction losses into specific causes. Reductions can be due to a combination of biotic and abiotic factors. Germination failures are caused by soil insects, soil-borne fungi, rodents, birds, millipedes and a lack of adequate moisture. Seedling mortality results from mechanical destruction during cultivation, severe soil moisture stress, early season downy mildew infection, grasshoppers, heavy stem borer damage, and dead-heart injury caused by chloropid shoot flies. Based on the distribution of the final plant population, lack of moisture was probably the major cause for reductions in plant density. Large areas without plants were present in most of the fields that suffered significant stand reductions and were usually associated with drier soil conditions. Stand reduction losses were probably underestimated due to this nonrandom pattern of missing plants. Several fields with final plant densities exceeding the optimum level also had areas completely void of plants yet losses were assumed to be zero. Studies have shown that high between plant variance reduces yields markedly even though the actual plant population per hectare is optimum (ICRISAT 1982).

Downy mildew infections accounted for the next highest loss in yield. An estimated average of 3.5% of the attainable yield was calculated from the adjusted length of mildew damaged spikes. Subramanya (1981) stated that maximum infections of downy mildew occur with plants 9 days old and these plants normally die. Plants infected after this period survive but show symptoms of infection as completely or partially malformed spikes. Subramanya also determined that the main stalk and primary tillers of pearl millet are only susceptible to the disease for 26 and 42 days, respectively. Losses from mildew as a result of seedling mortality were not measured but accounted for in stand reduction. Thus,

the estimated loss assessed at harvest was probably less than the actual loss due to mildew infections during the entire growing season.

Birds caused an average of 3% loss in all fields but ranged as high as 15.8%. Estimates of bird damage were fairly accurate because the depredation occurred primarily on the mature grain and was readily identifiable at harvest. Although birds were not observed during the sampling process, the presence of many nests near the fields and the farmers' comments about birds suggested that village weavers were the most persistent pests.

Smutted spikes accounted for 1.8% loss in attainable yield and were present in all fields. Ergot was found in only 7 fields and losses due to this disease were negligible. Unlike mildew, smut and ergot primarily cause yield losses by direct infection of the florets and developing grain. Thus, assessments of infected spikes were made without difficulty and the assumption that the adjusted length of smutted or ergot infected area is directly proportional to yield loss was probably true.

Losses to flower feeding insects amounted to only 1.0% and were primarily due to blister beetles based on the farmers' interviews. It was sometimes difficult to differentiate seedless areas due to flower feeders, particularly in low yielding fields where many secondary and tertiary spikes were immature as a result of drought conditions. Seedless areas caused by flower feeding insects generally exhibited some sort of nonrandom pattern on the spike whereas drought-related seedlessness was usually associated with the entire or upper portion of the spike.

Other minor factors that attributed to yield losses included stem borers (0.5% - noticeably found in 9 fields), grain feeding insects (0.1% - found in 13 fields) and wild boar damage (0.2% - found in only one field where it caused a significant loss of 9.3%).

The geographic area affected by each yield loss factor varied considerably as shown in Figure 6. Yield losses due to head borers ranged from 2.3 to 23% among villages. Since the moths appear about one month after the first rains, this variation could be due in part to differences in the onset of flowering when the eggs are laid. Higher incidences of Reghuva were also associated with low yielding fields and damage was significantly more prevalent on the less mature spikes. Stand reduction losses also varied widely. The southernmost villages of Niore, Dinguiraye, Ngapak, and Sanghil Serere suffered the least primarily because rainfall was more adequate and initial plant populations were well above the optimum. Farmers in the other villages conformed more to the optimum of 10,000 initial plants per hectare and experienced drier dinditions. Disease losses varied significantly but there did not appear to be any obvious reason why one village experienced more disease than another since none of the farmers use seed treatments. Differences in humid conditions during the early infection period and in seed quality are probably responsible for the observed variation.

Yield losses were associated with the location of the field from the villages (Figure 7). Both bird and stem borer damage decreased significantly as the distance from the field to the village increased. Bird damage was higher in fields near to villages because their nesting sites were located on the shade trees around the village compound. Stem borers were also more abundant because this insect diapauses during the dry season as pupae in the old millet stalks that are used for building material in the villages. The reverse pattern was true for

head borers which were associated with the lower yielding fields that were usually located farther away from the villages.

Other Pests - Weeds, particularily during the early season, can cause considerable yield loss in millet by competing for nutrients, moisture and solar energy. A study by Umrani et. al (1979) revealed that weeds caused 35 to 90% reductions in millet yield depending upon weed density. This same study showed that the 20-30 day period immediately following sowing of pearl millet was the most critical for weed competition and that weed removal after the initial 30 day period did not significantly increase yields.

Most farmers indicated that what they perceived as adequate weed control could be achieved during the first 30 days of millet growth. All fields were weeded twice at an average of 15 and 36 days after sowing. Only 13 out of 42 fields were weeded twice within the first 30 days. These later weeding schedules do not necessarily mean that serious yield reductions resulted from weed competition. There was no association between low yielding fields and late weeding dates to indicate that severe weed competition occurred during the early season. Some studies have suggested that weeds can be allowed to compete for up to 6 weeks under certain conditions without significant yield losses. In 1983, dry conditions prevailed after crop emergence in many fields which tended to reduce flushes of new weed growth after the first weeding and thus eliminate the need for a second weeding within the 30 day period.

Weeds were present in all fields and covered an average of 20.4% of the surface area around the millet plants. Only 2 of the 42 fields had significant weed growth covering greater than 40% of the surface. The composition of weeds consisted of 20% grasses and 80% broadleaves of mostly annual types.

Although there were occasional plants of Striga spp. in several fields, only one field had significant populations. The effect of this parasitic weed on crops has been shown to be much greater than its appearance would indicate. Unpublished data from the Weed Research Organization indicated that when the dry weight of Striga was less than 1% of the dry weight of the host (in this case sorghum), the host dry weight was reduced by up to 25%. Much of the damage done to the host crop by Striga occurs before the parasitic plant emerges from the soil, thus surveys often underestimate the impact of this weed. Estimates by Obilana (1983) place yield losses due to Striga on indigenous millet strains in West Africa at 15-30% while improved resistant millet strains show little or no significant loss.

Since early season observations of weed competition were not taken, it was not possible to estimate the loss in yield from weeds. However, based on the farmer interviews, low weed populations at harvest, and the fact that each field was weeded twice, weeds were probably not a major yield limiting factor.

Days of Food - Yield losses estimated for each factor are expressed in Figure 8 as the number of days of food lost per family unit. Food days were calculated by summing the total losses due to each factor in all fields of each farmer and then dividing total yield loss by his family's daily consumption of millet. The major yield loss factor, head borers, caused an average loss of 78 days of food and varied widely from 8-212 days. Stand reduction and mildew losses resulted in 31 and 21 days of food lost, respectively. These figures can be interpreted as the number of additional days of food expected to occur if the particular factor was removed on all farms.

Figure 9 presents the total number of actual days of food available to each farmer and the attainable days of food if all yield loss factors were eliminated. It was surprising to find that 70% of the farmers produced more than one year's supply of millet for their family. The 17 cooperating farmers produced an average of 556 days of food ranging from 188 to 1522. Even after the total production is adjusted for storage losses (approximately 5%), donations for religious beliefs, (10%) and small amounts that the women sell to buy cooking items, more than half the farmers still would have plenty of food to feed their family for one year. The additional production obtained without stand reduction and direct pest losses would add an average of 184 extra days and increase the potential supply of food to 740 days.

Several reasons suggest that participating farmers were not representative of the average Senegalese farmer. First, the total crop of millet cultivated per farmer averaged 4.7 hectares compared to 2-3 hectares per family unit typical of the Sine Saloun region. Secondly, the fields sampled were more fertile and thus more productive than the average millet field. As previously noted, the average yield of 800 kg/h was well above the normal expected in Senegal. Thirdly, the participating farmers were asked what they considered to be a "good" total production of millet based on all their fields. It was felt that a farmer would have a better perception of how much millet he had to grow to meet his family's needs than he would in terms of production per hectare. Figure 10 presents a graphic comparison of the total production which each farmer considered "good" enough to meet his needs with his actual production achieved. Roughly half of farmers achieved a total millet production greater than what they perceived to be "good". Three out of the four farmers who produced less than one year's supply of food also had actual production less than "good". Thus, the estimations of millet production expressed as actual food days correspond fairly well with production levels that were considered adequate for each farmer's needs. Based on the reasons above and interviews with the farmer, it was obvious that the selection of participants at the village level was biased toward the wealthier farmers who owned better land and tilled more millet than the average farmer in the Sine-Saloum region.

Value of Yield Losses - Although the estimations of millet production and days of food were biased, the losses per hectare can still be used to determine the justifiable expenditure to remove each loss factor if appropriate technology is available. The value of these losses can be viewed as the value of the additional production obtained or, more realistically, the monetary cost required to replace the food in the marketplace. Figure 11 expresses the yield loss (kg/ha) for each factor, presented in Figure 4, as a cost in CFA per hectare required to replace each loss. Three prices of millet were used to calculate the market value. The average prices immediately after harvest, 6 months later, and just prior to the next harvest were computed from information obtained by farmer interviews. These latter two price levels are probably more realistic for estimating the value of losses because farmers, who deplete their millet supply before the next harvest, normally buy millet during the last six months.

Looking first at the major loss factor, the millet lost to head borers would cost an average of 8,212 CFA if purchased 6 months after harvest or 11,794 CFA if purchased just prior to the next harvest when the market price of millet is highest. This represents the range in the average value of losses due to Raghuva. However, any effort to control head borers entails a cost. Hence, the value of the losses less the costs associated with bringing about control can

provide an estimate of potential net benefits from research and extension efforts aimed at removing Raghuva as a yield loss factor. Currently, there are no local methods for control of head borers. Cultural methods have been investigated but none are satisfactory; in fact, adjustments of the planting date to avoid Raghuva have exposed millet to heavier attack by other pests. On the other hand, chemical control trials have demonstrated that adequate control of head borers can be achieved with insecticides if applied twice at an interval of 5-7 days during the flowering period and directed only at the spikes (Vercambre 1979). Chemical control costs to the Senegalese farmer would include the price of the chemical, investment in the sprayer, and labor, and any costs associated with the risks of using pesticides.

It is generally agreed that the value:cost ratio should be greater than 2 to provide an economic incentive to the subsistence farmer to implement pest management practices (IFDC 1977). In the case of Raghuva losses in 1983, most farmers would have realized a ratio greater than 2 if perfect control could have been attained. However, estimations of actual net benefits must take into account the probability of satisfactory control (which is less than 1) and the likeliness that farmers will adopt the pest management practice. These two factors should be weighed against not only the basic costs of applying the chemical control but also the farmer's need to produce more food, his knowledge of pesticides, his literacy status, his skills in applying control, and the fact that he may have insufficient crop area to employ such investments as sprayers. Hence, it is probably not feasible for the farmer or the government to control Raghuva with pesticides unless average losses increase significantly over the levels experienced in 1983 or an inexpensive control tactic is developed that has an expected higher rate of adoption among farmers.

On the other hand, chemical control of mildew may have a higher value:cost ratio because partial suppression of certain pathogens of this disease can be obtained with fungicide seed treatments which are relatively cheap and have a higher rate of adoption among farmers (Nyvall 1979). The value of mildew losses averaged 3,133 to 4,498 CFA per hectare depending upon the market price of millet at the end of the season. The cost of seed treatment amounts to less than 600 CFA per hectare.

The value of losses due to the other factors may also be high enough to justify an increased use of traditional means of control, particularly to prevent stand reduction, smut, and bird damage. Stand reduction losses are due to a complex of agronomic and pest-related causes and hence it was not possible to construct a realistic value:cost ratio without information on the specific causes and the costs of removing each cause. Losses to smut infection can be avoided in part by crop rotation (GDA, 1981). Bird damage also was high enough in most fields to encourage traditional means of bird scaring.

Optimization of Sampling Design - Relative variance components and time lapse estimates at the four levels of sampling are presented in Table 2. It is not surprising that the plant to plant variation accounted for the largest portion of the variance (60-86%). Plant differences in damaged length were considerably more variable than undamaged or total length of spikes. Variation among fields contributed 6-17% of the total variance and was probably underestimated since the selection of farmers was biased toward the better fields that were no doubt more uniform. Seven to 14% of the total variation in adjusted spike length per plant was attributed to the village level, whereas only 2-10% was due to variation

among farmers. Farmer variation also was probably underestimated due to the bias toward better farmers.

The sampling design used each day in 1983 involved one village and an average of 2.1 farmers, 2.5 fields per farmer, and 25 plants per field. Using the variance components and time factors in Table 2, the 1983 design would require 7.9 hours of sampling time each day and would provide estimations of TOTLTH per plant with a variance of 937. Given the restriction that only one village can be sampled each day, the most efficient design with minimal cost and minimal variance is one village, nine farmers, one field per farmer, and only 6 plants per field. This design would require 7 hours of sampling time and provides estimates with a variance of 813 (21.4% more efficient than the 1983 design). Since it may be difficult to obtain the cooperation of nine farmers per village and select 6 plants without bias, the following design is suggested. Each day, one village should be sampled involving six farmers, one field per farmer, and 15 plants per field. This design would be more operationally feasible and still 15.2% more efficient than the sampling scheme used in 1983.

CONCLUSIONS

1. This study demonstrated a relatively simple and precise procedure for assessing millet losses at harvest due to stand reduction and direct pests.

2. The method was particularly sensitive to pests that directly attack the spike such as smut, mildew, ergot, bird, rodents, head borers, flower feeders, and grain feeders.

3. The average yield was 800 kg/ha - higher than the average of 550 kg/ha reported for Senegalese farmers as a whole.

4. Yield varied significantly among villages primarily due to differences in rainfall.

5. Yield decreased as the distance from the field to the village increased. Fields nearest to the village were more fertile (more manure used) and probably received more attention.

6. Ten yield loss factors were assessed and caused a total loss of 203 kg/ha or 23.7% of the attainable yield.

7. The head borer, Raghuva albipunctella, was the major loss factor and caused a loss of 93 kg/ha or 8.9% of the attainable yield.

8. Losses due to stand reduction, mildew, birds, smut and flower feeders amounted to 4.6, 3.5, 3.0, 1.8, and 1.0%, respectively.

9. Three other minor factors, stem borers, grain feeding insects, and wild boar damage, attributed only 0.9% yield loss.

10. The geographic area affected by each yield loss factor varied significantly, particularly head borers, stand reduction, and disease. Differences in the onset of flowering, amount of rainfall, and cultural practices were probably

major reasons for this variation.

11. Yield loss was associated with the location of the field to the village. Both bird and stem borer damage decreased significantly as the distance from the village increased. The reverse pattern was true for head borers.

12. Weeds were present in all fields but only 2 out of 42 fields had significant weed growth covering greater than 40% of the ground surface. Noticeable Striga populations were found in only one field.

13. Because of low weed densities at harvest, the farmers' opinion that weeds were not important, and the fact that each field was weeded twice, weeds were not considered a major yield limiting factor.

14. The seventeen farmers produced an average of 556 days of food with a range from 188 to 1522. Seventy percent of the farmers produced more than one year's supply of millet for their family.

15. The additional production obtained without the ten yield loss factors would add an average of 184 days and increase the potential supply of food for 740 days.

16. The selection of cooperating farmers at the village level was biased toward the wealthier farmers who owned the more fertile land and tilled more millet.

17. Losses per hectare were expressed as a value in increased production from removing each loss factor (or as the monetary cost required to purchase the food lost to each factor). These values provided reasonable estimations of the potential payoffs from the development and implementation of pest management programs directed at each loss factor.

18. Although Raghuva head borers caused the greatest loss in yield, the actual net benefits from removing this pest may not be high enough to outweigh the costs and risks of using pesticides and the uncertainty that farmers will adopt these tactics. However, higher levels of losses and/or more practical and effective methods of control together with farmer education could provide the justification for the development and implementation of a pest management program for Raghuva.

19. Even though losses to mildew and smut were half those of head borers, control of these diseases may have higher value:cost ratios because fungicide seed treatments and rotation are relatively inexpensive practices and easy to apply.

20. A more efficient and operationally feasible sampling plan for assessing millet losses using the above procedures is to sample one village per day, six farmers per village, one field per farmer, and only 15 plants per field rather than 25.

RECOMMENDATIONS

What is needed at this point in the millet loss assessment project is an extensive survey, using the improved methodology developed in 1983, in a major production region in which the villages and farmers are selected at random. The following work plan is proposed for 1984.

Target Area - Because of logistical constraints and the diversity in millet production, climate, and sociological conditions, it is impractical to assess millet losses on a nationwide basis unless the country is small. It is proposed, therefore, that loss assessments be conducted in the Gambia or in the middle Casamance region of Senegal where the millet production is more uniform but characteristic of the Sahel region as a whole.

Another reason for selecting the above areas is the higher annual rainfall which ensures more consistent yields, reduces within-field variability, and promotes more weed growth (a loss category that was not adequately assessed in previous attempts).

Overall Design - The basic approach used in 1983 should be followed with some modifications. The target area can be divided into grids in which the number of villages selected should be proportional to the population and millet production in each grid. Villages should be selected first at random and then the actual number surveyed can later be restricted due to logistical constraints. Six fields in each of 15 villages will be surveyed. Fields can be randomly selected at varying distances from each village. Any fields, cultivated by farmers who refuse to cooperate, can then be eliminated after the random selection is made.

Unlike the 1983 project, no attempts should be made to sample the entire millet crop of each participating farmer. A sample of farmers from each village can be interviewed to obtain socioeconomic information, particularly the average daily consumption of millet per individual and the costs involved in obtaining food when the millet is depleted. Yield losses in each pest category can again be expressed as days of food per individual and related to the socioeconomics of the village as a whole.

Pre-harvest visits to each village can be conducted in late June-early July after the thinning and weeding operations are completed. This step would take at least 20 days to locate and measure fields, estimate initial stand density, assess weed populations, and explain the purpose and future harvest activities to the participating farmers. During these visits, much of the socioeconomic data and field history information can be obtained by interviews.

At harvest, a loss assessment team can estimate the actual yield and pest losses in each field as one sampling process. This step will take at least 21 days during late August-early September. The assessment procedures should be the same as those outlined in this report.

Personnel and Equipment Requirements - The personnel needed to carry out the 1984 survey activities would consist of two teams employed at different times of the season. Both teams can be based at a convenient location within the target area.

During the pre-harvest visits, one Crop Loss Assessment Specialist working with two CPO's would be required to set up the survey fields, collect the preliminary data, and interview the farmers. One CPO should have previous experience with millet loss assessment, preferably recruited from the Dakar Training Center. The other CPO should be recruited from the target area and thus familiar with the villages and local practices. This three man team should spend two weeks on these pre-harvest activities, followed by another 1-2 weeks during which the two CPO's can complete the farmer interviews and field measurements. A vehicle and gasoline would be needed to carry the pre-harvest team.

At harvest, a team of four Crop Loss Assessment Specialists and two CPO's would be required to survey pest losses to millet in the target area. The CPO's should be the same individuals involved in the pre-harvest work. Unskilled laborers would also be required to cut millet in each village. Two vehicles and gasoline would be needed to transport the harvest team.

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Table 1 - The proportion and relative weights of the grain, chaff and core components of millet spikes and the relative weight of smutted grain.

Spike Components	Proportion of spike	Standard error	Coef. of variability (%)	Weighing factor
Grain	0.74	0.0080	1.1	13.14
Chaff	0.21	0.0070	3.4	3.72
Core	0.05	0.0027	4.8	1.00
Smutted grain 1/	--	--	--	5.32

1/ The weight of smutted grain was 40.5% of the weight of good grain.

Table 2 - Relative variance components and time lapse estimates at the four levels of sampling for adjusted UNDAMLTH, DAMLTH and TOTLTH of harvestable spikes per plant. 1/

Sampling level	% Total Variation			Avg. time lapse for each level
	UNDAMLTH	DAMLTH	TOTLTH	
Village	14.1	6.7	13.5	60 min.
Farmer	8.8	1.7	9.7	10 min.
Field	16.8	5.8	17.1	15 min.
Plant	60.3	85.8	59.7	2.5 min.

1/ UNDAMLTH = adjusted undamaged length of harvestable spikes per plant (indicator of actual yield);
DAMLTH = adjusted damaged length of harvestable spikes per plant (indicator of yield losses;
TOTLTH = adjusted total length of harvestable spikes per plant (indicator of attainable yield).

Figure 1. Histogram of grain yield per hectare of the 42 millet fields sampled. Sine Saloum Region, Senegal, 1983.

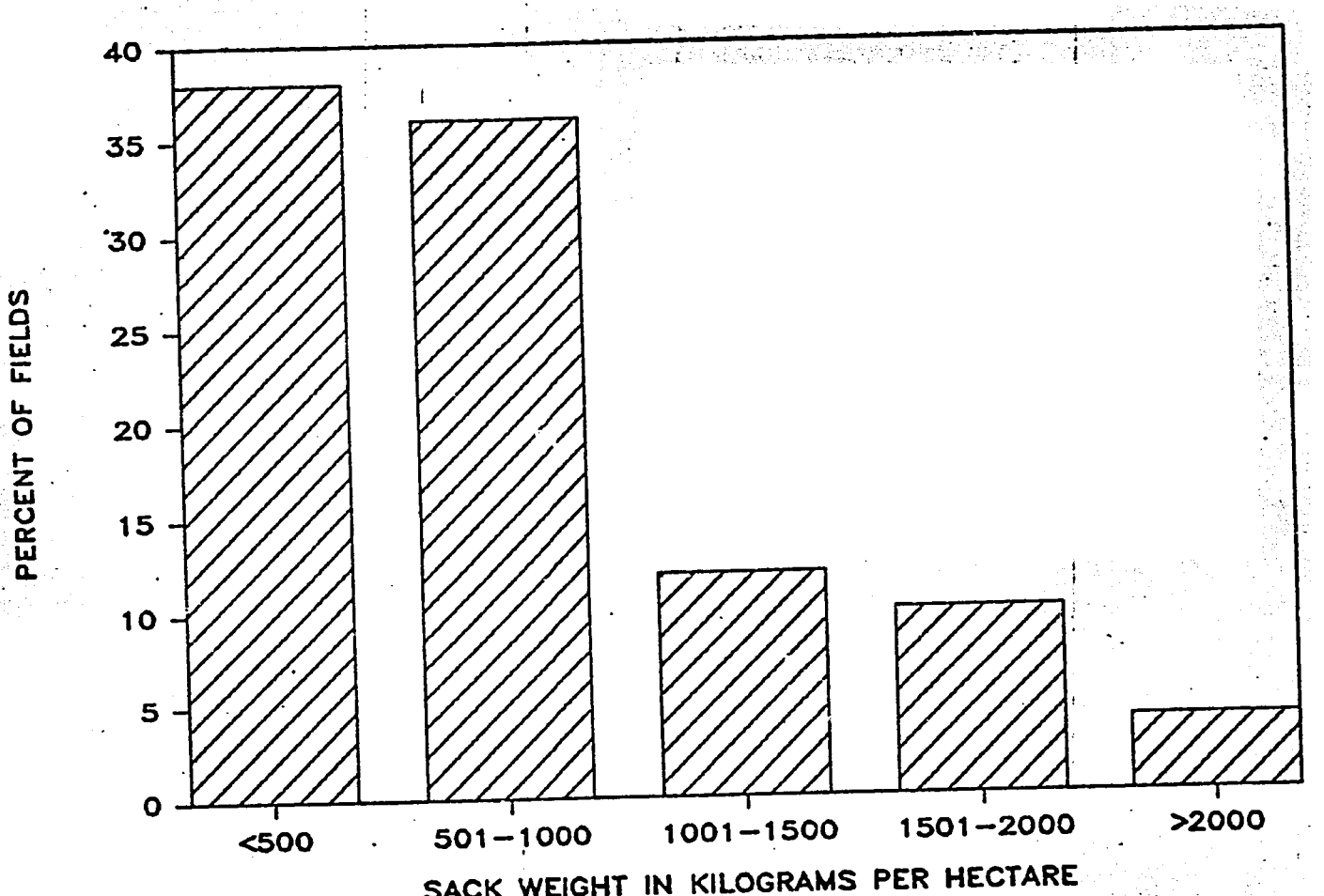

Figure 2. Average grain yield per cooperating farmer in the eight villages surveyed. Sine Saloum Region, Senegal, 1983.

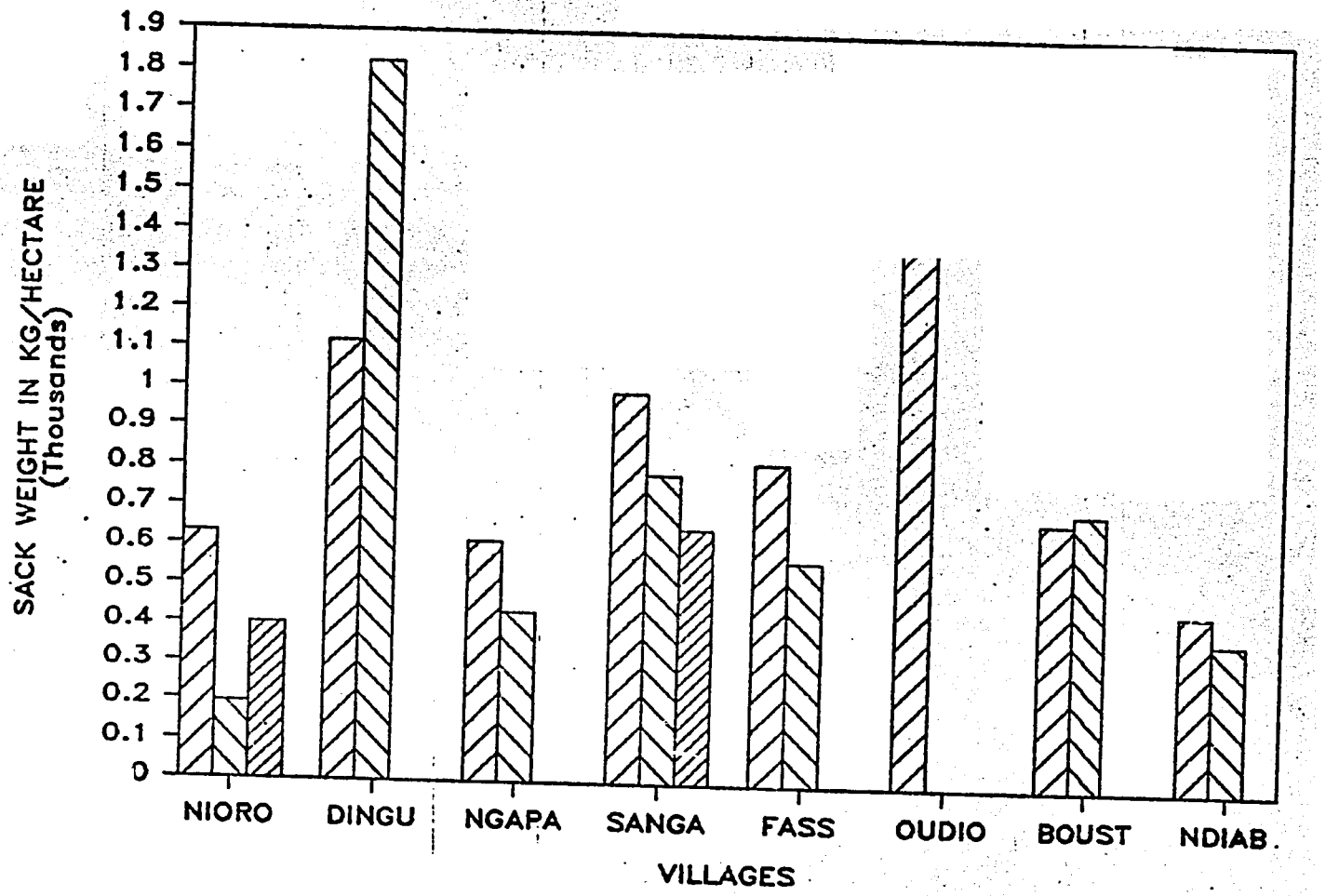

Figure 3. Average grain yield per hectare in relation to distance from the field to the village. Sine Saloum Region, Senegal, 1983.

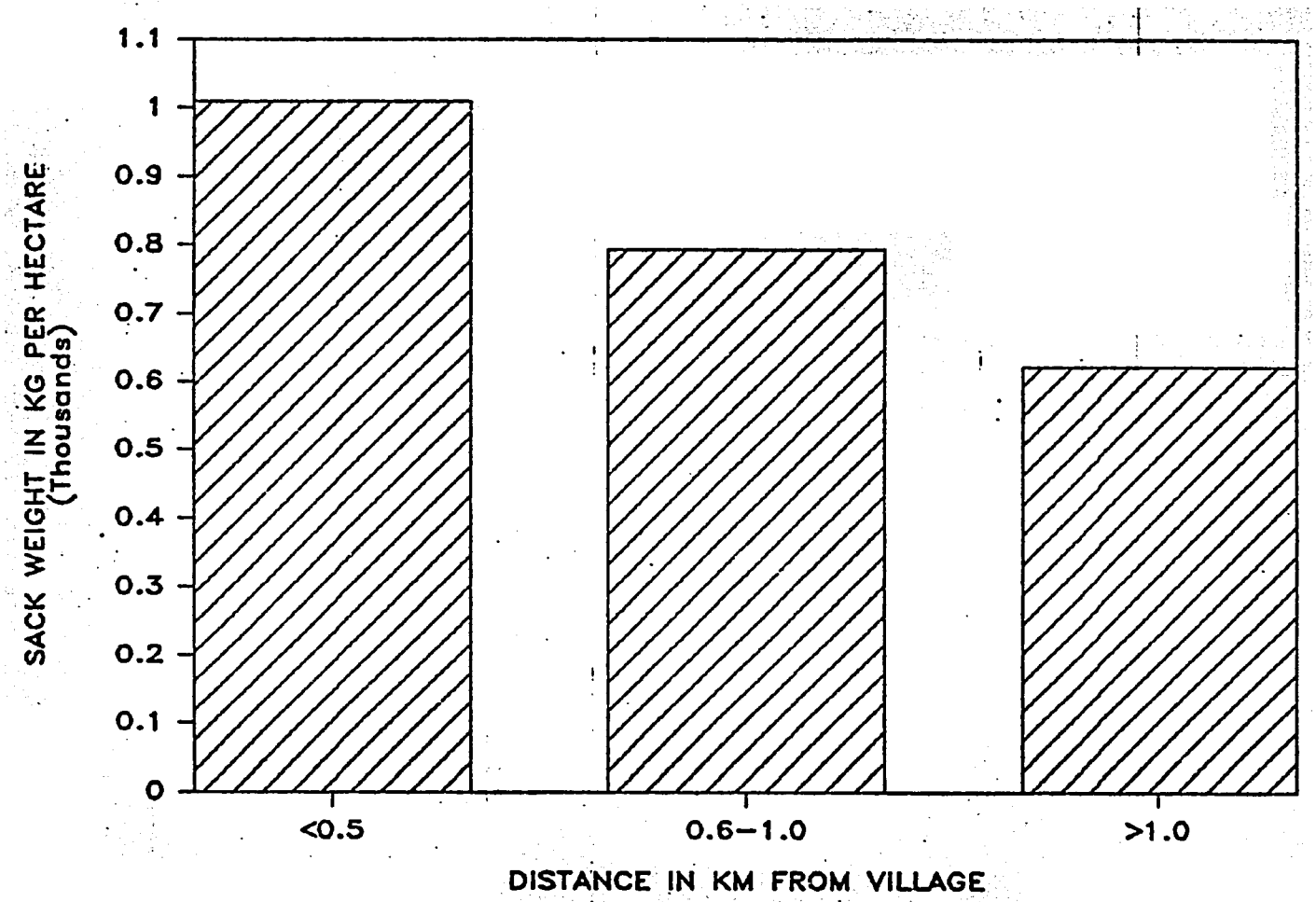

Figure 4. Estimated losses in grain weight per hectare caused by various yield loss factors. Numbers at top of bar indicate the range. Sine Saloum Region, Senegal, 1983.

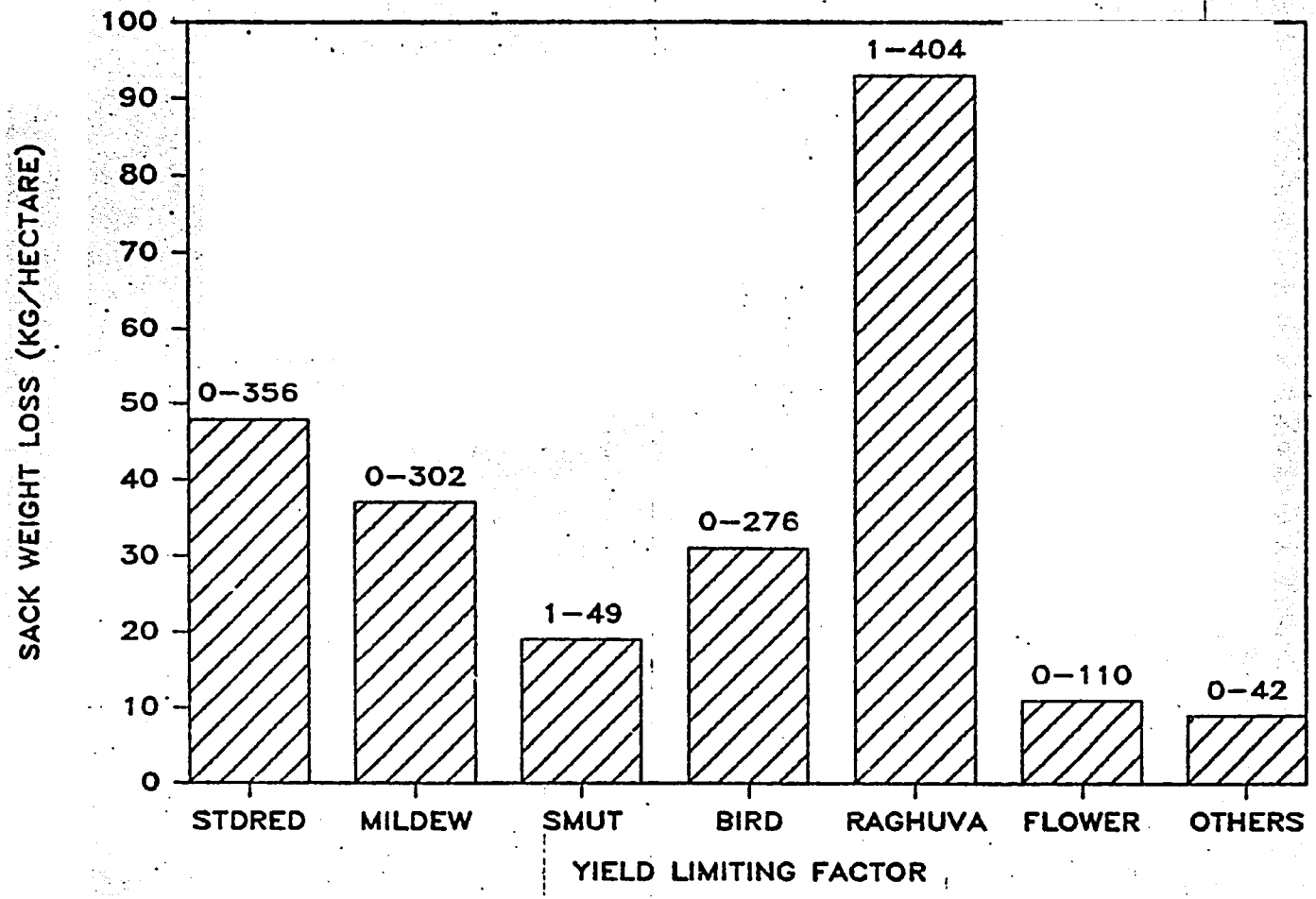

Figure 5. Relative importance of yield loss factors in limiting attainable yield. 'Others' include stem borers, ergot, other grain feeding insects, and wild borer.

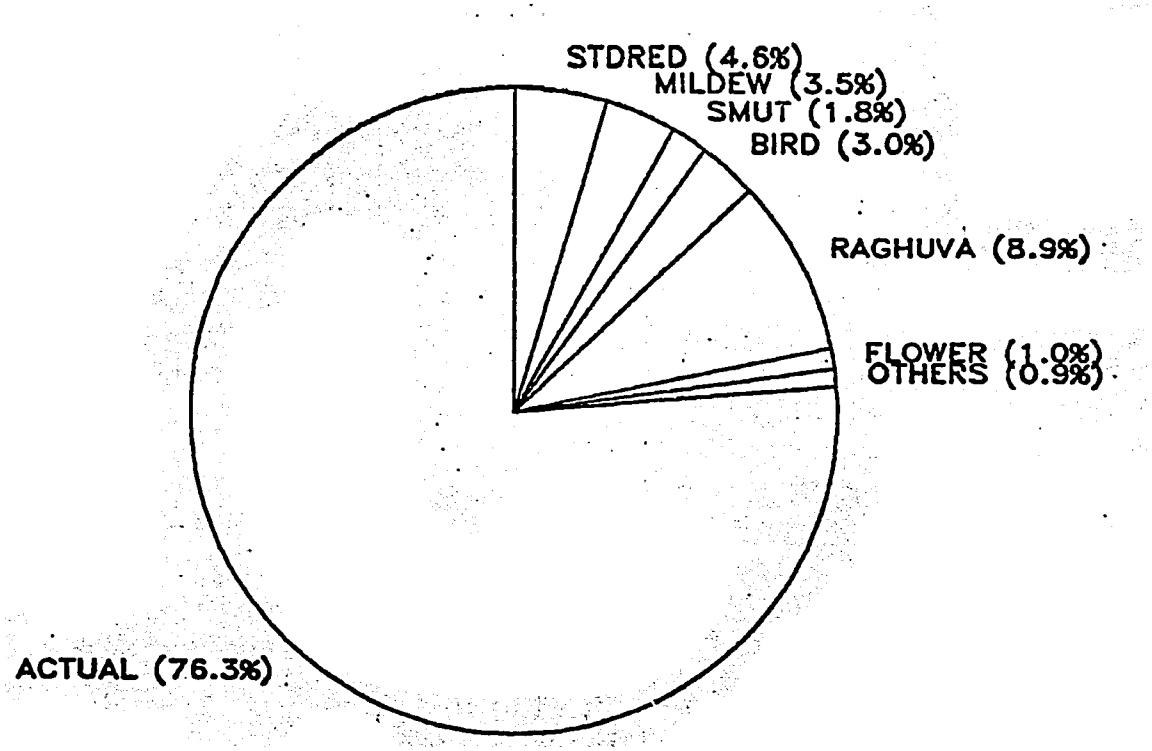

Figure 6. Profiles of the percentage of millet losses for each yield loss factor at each village. Sine Saloum Region, Senegal, 1983.

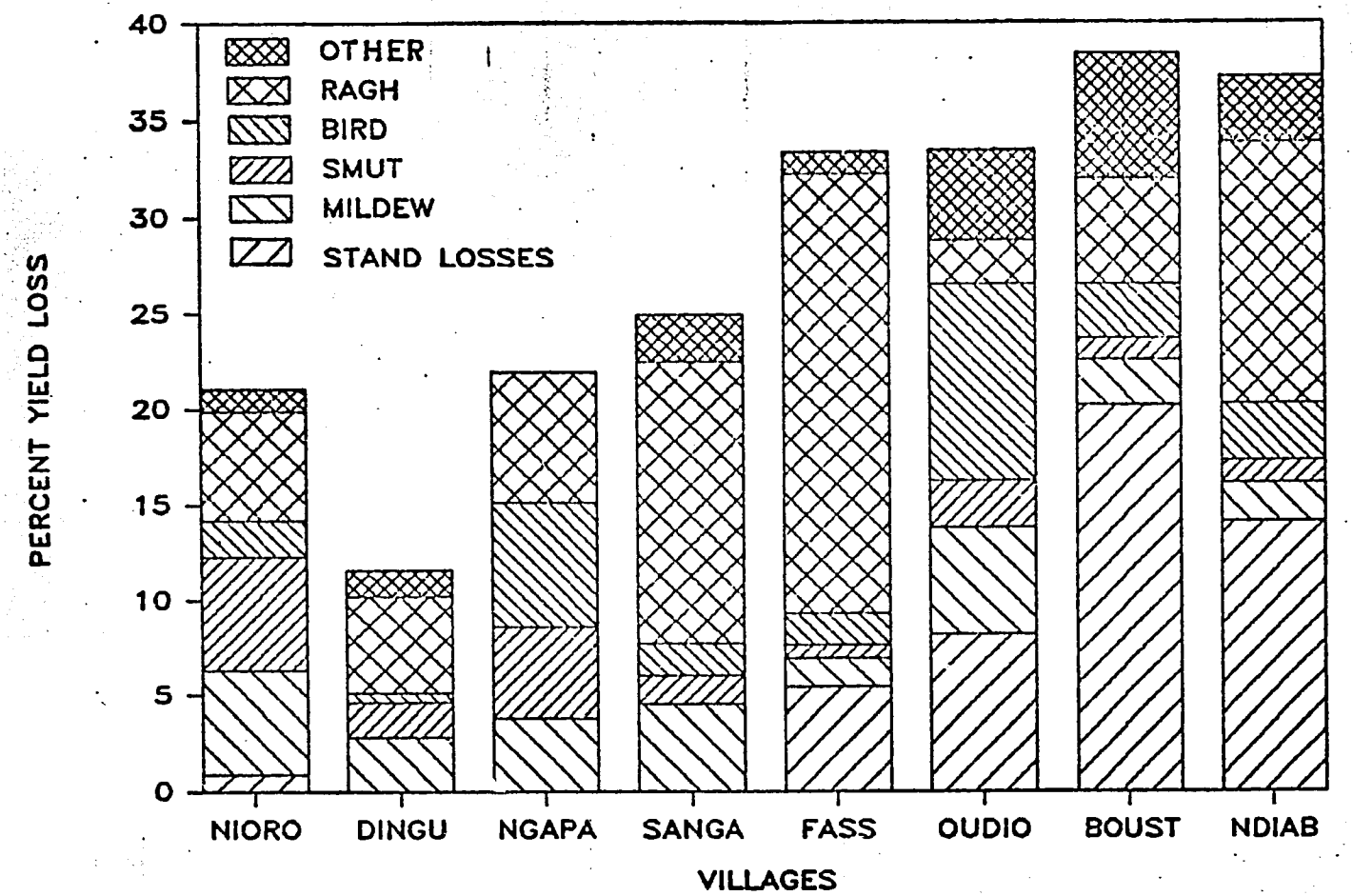

Figure 7. Millet yield loss for each factor grouped according to the location of the field from the village. Sine Saloum Region, Senegal, 1983.

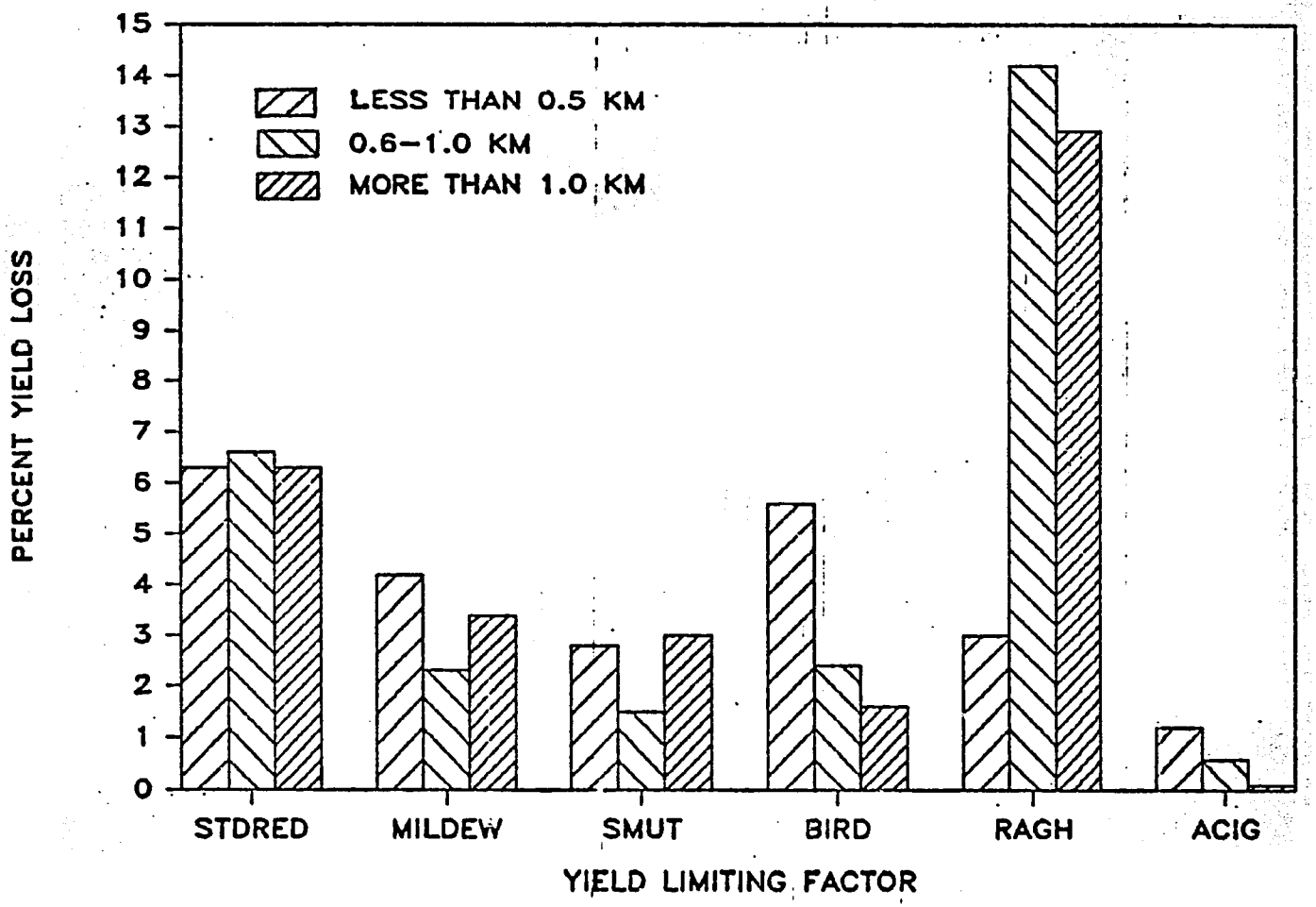

Figure 8. Number of days of food lost to various yield loss factors. Numbers at top of bar indicate range.

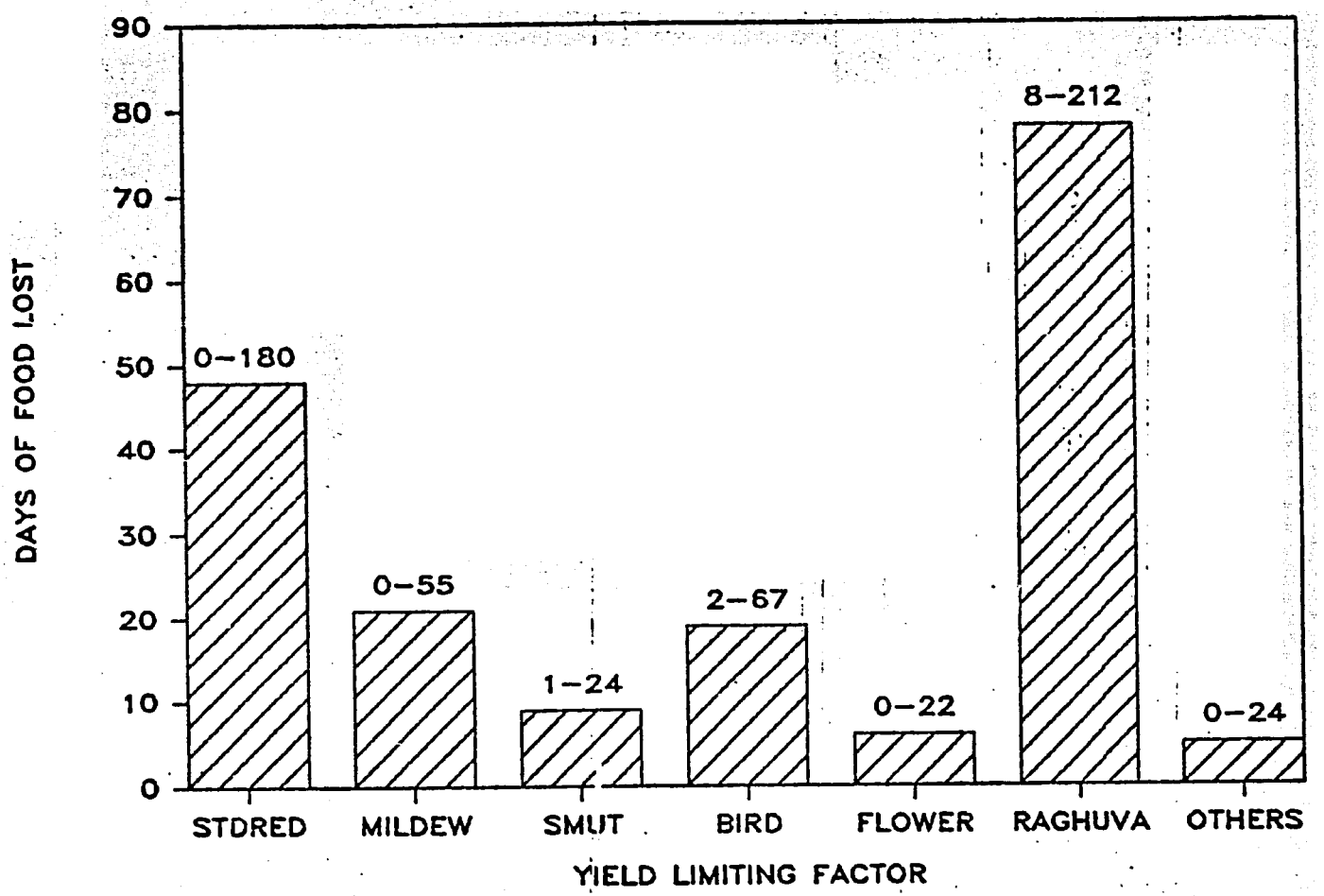

Figure 9. Total number of actual days of food available to each farmer and the attainable days of food without the yield loss factors. Cine Saloum Region, Senegal, 1983.

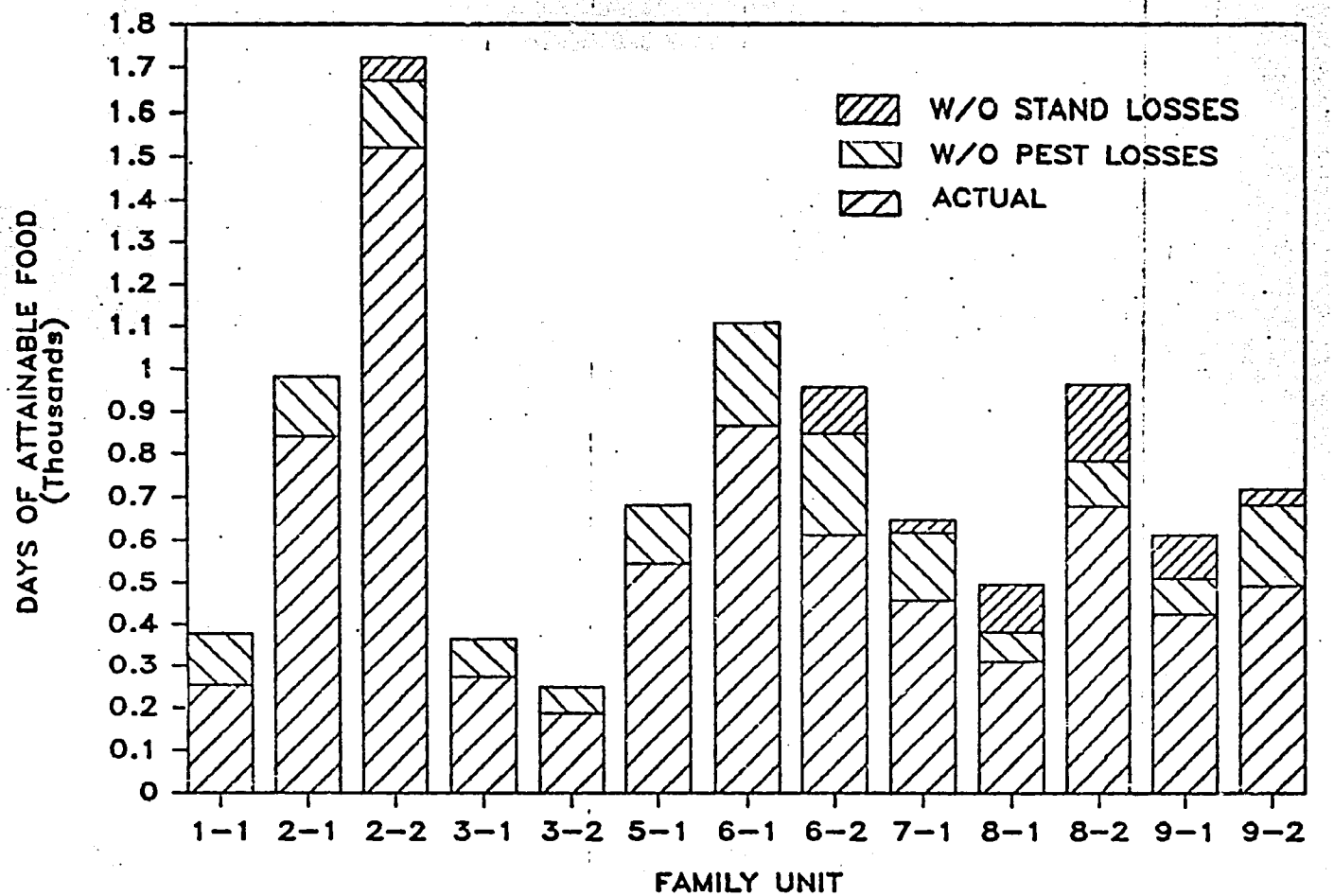

Figure 10. Graphic summary of the actual millet production obtained by each farmer compared to what each farmer considered 'good' enough to meet his family's needs. Actual yields of farmers plotted below the diagonal line exceed what they perceived to be 'good'.

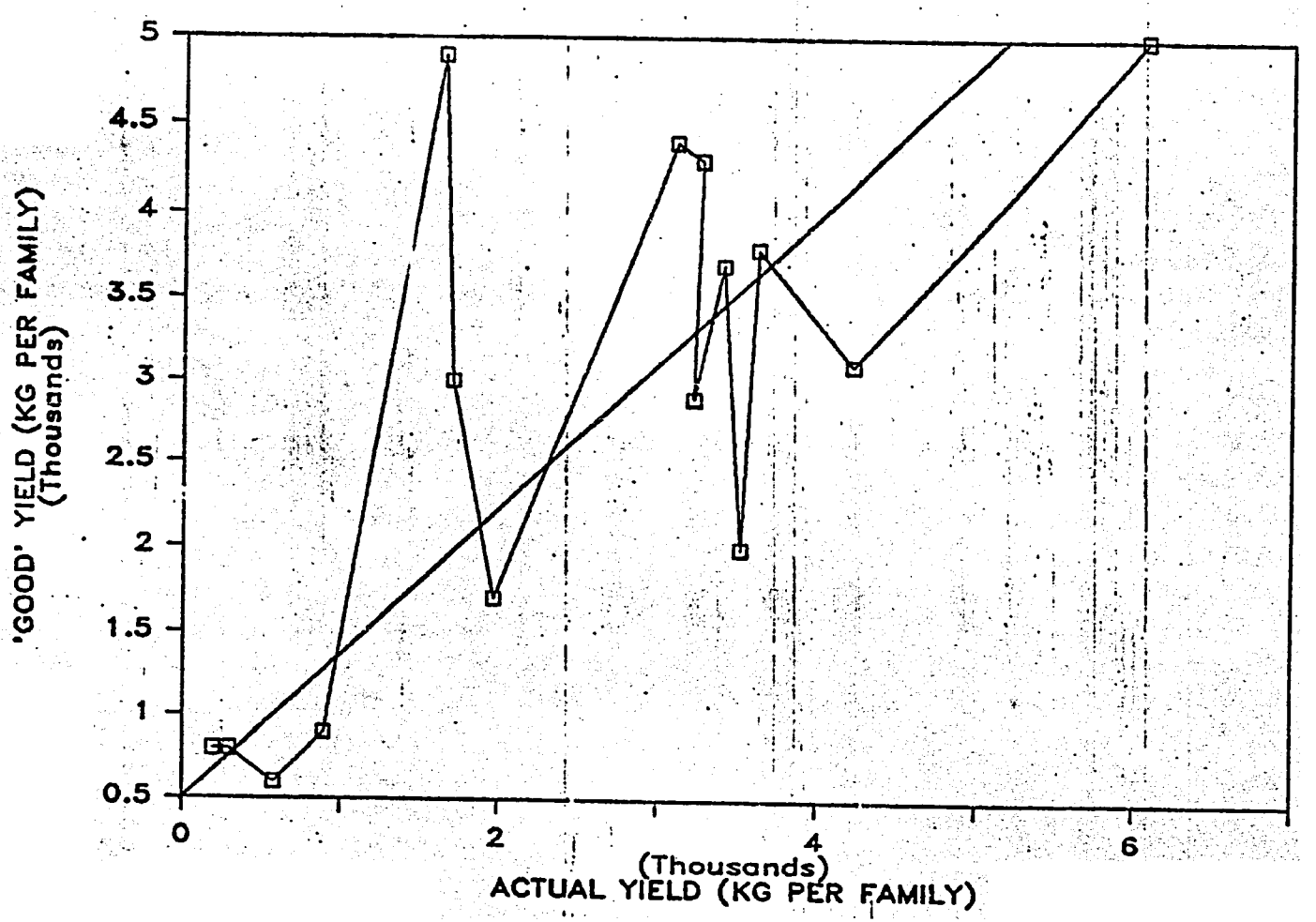
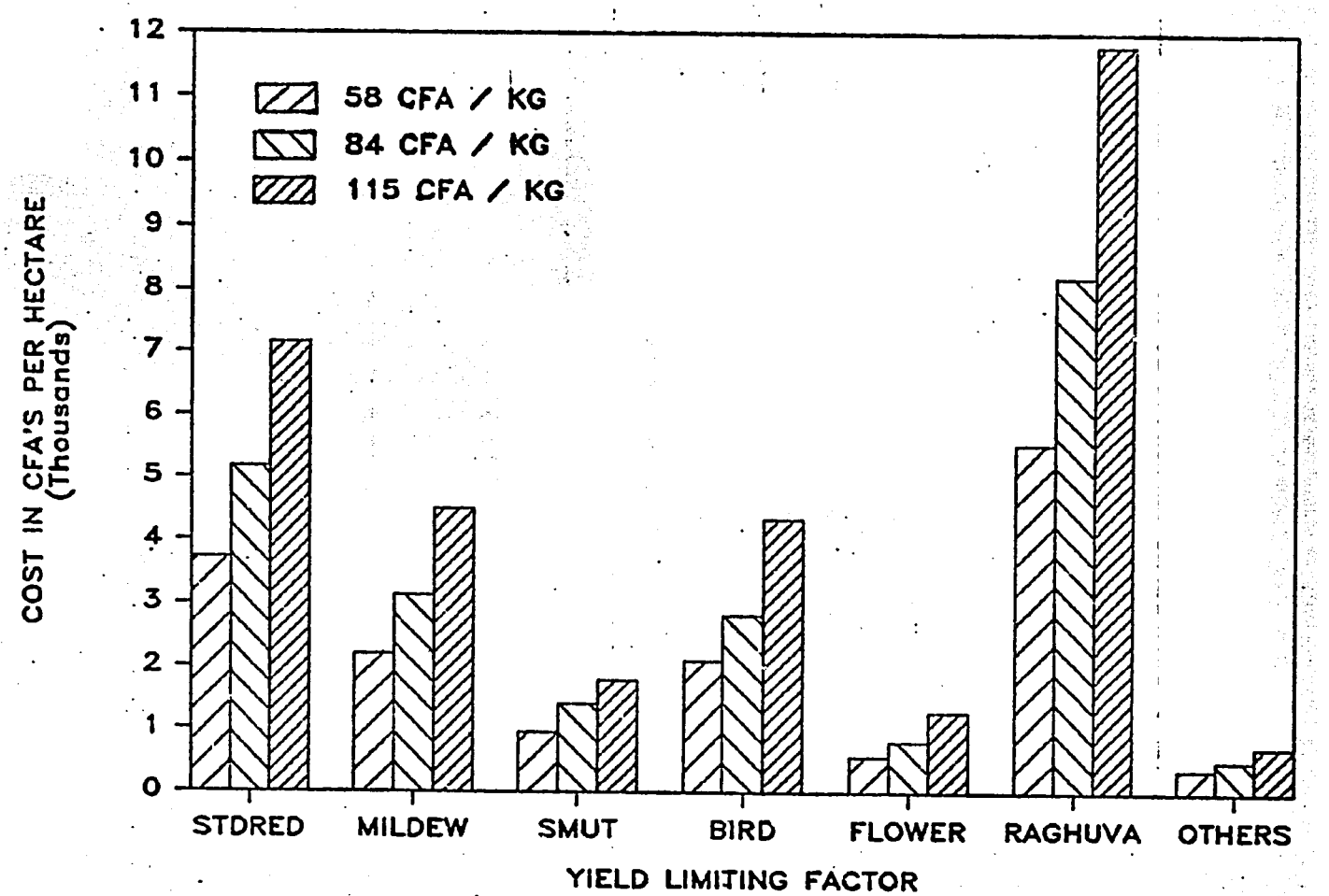
Figure 11. Yield for each loss factor expressed as the value of the additional production obtained without losses or as the cost required to replace the food in the marketplace. Cost of food was based on the prices immediately after harvest, 6 months later, and prior to the next harvest.