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Natural Resources Institute

MILLET CROP-LOSS ASSESSMENT METHODS

Bulletin 62

Overseas
Development
Administration

MILLET CROP-LOSS ASSESSMENT METHODS

edited by
N. D. Jago

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SUMMARY

The crop loss to millet, incurred by Sahelian subsistence farmers, is not currently routinely or adequately monitored. However, estimation of direct grain loss on the millet candle, whether by insect pests or pathogens, is of prime importance as a means of both evaluating and justifying the use of inputs such as chemical pesticides, insect growth regulators or living biological control agents (e.g. insect parasitoids and fungal or viral disease pathogens).

All are agreed that the main pests and diseases producing easily measurable damage to millet candles are grasshoppers (eight main spp.), flower chafers (principally *Pachnoda interrupta*), grain-eating birds, the millet head miner moth (*Heliocheilus albipunctella*), meloid blister beetles (mainly *Psalydolytta* spp.) and fungal pathogens. The direct and indirect effects of millet stem borer larvae (*Coniesta ignefusalis*) on candle formation and reduction in grain weight are not covered here. Damage by *Coniesta* is such that CLA cannot be based primarily on examination of the candles just prior to or just after harvest. Low rainfall may also lead to sterility and reduced grain formation. The appearance of the damage caused by each of these agents is depicted in the section on damage types.

Millet crop-loss assessment (CLA) can be conducted with different levels of accuracy in mind. In general, the more accurate the CLA methods, the more intensive the survey methods (e.g. the USAID adjusted-length method (ALM) cited here) and as a result they will tend to cover a smaller area and be more labour-intensive. Such high levels of accurancy will be an indispensable part of strategic or adaptive research. In contrast, less accurate methods such as those using agricultural-economic questionnaires (the Kremer NRI survey technique), will often be effective enough for the practical analysis required for local and regional government planning; they will cover large areas rapidly and will be less labour-intensive and will be achieved without specialist technical staff. In the long term, however, crop-loss estimation techniques will have to be adopted as routine by local government officials, extension and crop-protection services,and even by the farmers themselves. Each CLA method is presented with guidance on the time and team size required to collect data from a specified number of villages.

This publication offers a choice of CLA techniques. The Kremer farmer questionnaire approach should be accompanied, where possible, by parallel technical CLA based on crop sampling among a smaller sub-sample of the same villages, this being used as a check on the accuracy of the first method. The remaining methods currently offered by GTZ, NRI and USAID, use examination of millet head samples to afford estimates of the grain loss. The methods vary in the way samples are taken, the number of millet candles in the samples and the precision with which the main pest and disease damage components are separately assessed. The quickest methods (as in the simplest NRI system) ignore the contribution made by each pest and simply look at the total grain loss in the candles. This will not be adequate if, for example, we wish to estimate the crop-loss decrease, and hence the benefit/cost ratio of treatment targetted at a particular pest. In the GTZ and USAID methods observations are made using pre-harvest samples. In the NRI section, the candle samples may also be taken from the heaps of candles accumulated post-harvest. This will, however, tend to give an under-estimate of crop-loss because the farmer tends to be selective when making these heaps and badly shattered candles may be rejected or lost.

Pre-harvest sampling in all the main methods attempts to be non-selective. The candle samples are examined for damage. In the GTZ and NRI methods a candle is taken as the unit without mathematical adjustment, but in the adjusted length method (ALM) used by USAID the individual candles are measured, the largest being used as a reference to adjust the amount of grain lost in smaller candles to the reference candle. In the ALM the number of candles sampled is smaller than in the other methods. In the ALM extra precision is attempted by inclusion of estimates of grain lost in *shibra* candles, and loss due to factors such as low rainfall, weed growth, damage to foliage earlier in the growing season and other factors.

CLA can be presented simply in terms of percentage loss or in terms of absolute loss in kg/ha. In the latter case, the estimate of crop loss may be based on actual threshed grain from a known number of candles, the crop density having been estimated previously. Alternatively, since even without any pest or disease damage the weight of grain/ha would vary from year to year due to factors such as rainfall and availability of animal manure, the observed percentage losses may be transformed into weight of grain/ha by calculating the potential yield from samples of undamaged candles.

Each method of CLA is presented as a sequence of steps which will be followed once the choice of technique has been chosen. The choice will be made in the light of government or farmer requirements, time factors and the skills available to those doing the sampling. Farmers do not currently measure field size or plant pocket density themselves. It will usually be necessary for indirect methods (itemized in the Kremer section) to be used to estimate cultivated area in a village and for planting density to be related to figures reached after some years of experience of the area.

Whatever CLA methods are used it should be remembered that on many occasions great precision is not essential. In a low-value crop like millet a treatment must produce a very major improvement in order to justify it being recommended to farmers. Furthermore, local government and farmer co-operatives usually want to use CLA to calculate the degree to which a region is or is not self-sufficient in grain. Lastly, farmers will not adopt unsubsidized inputs unless they can calculate that the outlay in time and money has had a major positive effect on harvested yield. Hence, CLA does not need to be a highly sophisticated and should not be aimed at unnecessarily accurate results.

RESUME

A l'heure actuelle, les pertes des récoltes du millet, subies par les agriculteurs du Sahel produisant le minimum vital, ne font pas l'objet d'une surveillance adéquate ou systématique. L'estimation des pertes directes des graines de la 'chandelle' du mil, que ce soit par suite de l'action des insectes parasites ou des pathogènes, présente toutefois une importance prépondérante en tant que moyen, aussi bien d'évaluation que de justification de l'emploi d'apports tels que les pesticides chimiques, les régulateurs de croissance des insectes ou encore des agents vivants de lutte biologique (par exemple, parasitoïdes des insectes et pathogènes de maladies virales ou fongiques).

Tout le monde s'accorde pour penser que les principaux parasites et maladies produisant des dégâts pouvant être facilement mesurés infligés aux chandelles du mil sont les sauterelles (huit espèces principales), les hannetons des fleurs (principalement *Pachnoda interrupta*), les oiseaux consommateurs des graines, la mineuse des épis de mil (*Heliocheilus albipunctella*), les méloïdes (principalement les espèces (*Psalydolytta*) et les pathogènes fongiques. Les effets directs et indirects des larves des insectes térébrants des tiges (*Conesta ignefusalis*) sur la formation des chandelles et la réduction du poids des graines ne sont pas traités ici. Les dégâts provoqués par *Coniesta* sont tels que l'évaluation des pertes des récoltes ne peut pas se baser principalement sur l'examen des chandelles juste peuvent aussi conduire à la stérilité et à la formation réduite des graines. Les dégâts provoqués par chacun de ces agents sont représentés dans le chapitre traitant des types de dégâts.

L'évaluation des pertes des récoltes peut être réalisée en gardant divers niveaux de précision à l'esprit. D'une manière générale, plus les méthodes d'évaluation des pertes sont précises, plus les méthodes d'évaluation des pertes sont précises, plus les méthodes d'étude sont intensives (par exemple la méthode de longeur ajustée (ALM) d'USAID citée ici) et par conséquent elles auront tendance à couvrir une superficie moins étendue et seront plus exigeantes en main-d'oeuvre. De tels niveaux élevés de précision constitueront un élément indispensable des recherches stratégiques ou d'adaptation. Par contraste, les méthodes moins précises, telles que celles faisant appel aux questionnaires économiques et agricoles (la technique d'étude Kremer du NRI), seront fréquemment suffisamment performantes pour permettre l'analyse pratique requise pour la planification gouvernementale locale et régionale; elles couvrent d'importantes superficies rapidement et exigent une main-d'oeuvre moindre et sont exécutées sans personnel technique spécialisé. A longue échéance toutefois, les techniques d'estimation des pertes des récoltes devront être adoptées à titre systématique par les fonctionnaires des autorités locales, les services d'extension et de protection des cultures et même par les agriculteurs eux-mêmes. Chaque méthode d'evaluation des pertes des cultures est présentée accompagnée de conseils quant à la durée et l'envergure de l'équipe exigées pour la collecte des données en provenance d'un nombre spécifié de villages.

Cette publication propose un choix de techniques d'évaluation des pertes des récoltes. L'optique de questionnaire Kremer aux agriculteurs doit être accompagnée, chaque fois que possible, d'une évaluation technique parallèle des pertes des récoltes se basant sur l'échantillonnage des récoltes parmi un sous-échantillon plus petit des mêmes villages, ceci étant utilisé à titre de contrôle de la précision de la première méthode. Les autres méthodes actuellement proposées par GTZ, NRI et USAID font appel à l'examen d'échantillons de têtes de mil pour permettre les estimations des pertes des graines. Les méthodes varient au plan du prélèvement des échantillons, du nombre de chandelles de mil dans les échantillons ainsi que de la précision avec laquelle les principaux éléments d'endommagement (parasites et maladies) sont évalués à titre distinct. Les méthodes les plus rapides (comme dans le système le moins complexe du NRI) ne tiennent aucun compte de la contribution apportée par chaque parasite et ne font état que des pertes totales des graines dans les chandelles. Cette méthode ne convient pas si, par exemple, l'on souhaite estimer la baisse de pertes des récoltes et par conséquent le rapport avantages/coûts, d'un traitement ciblé pour un parasite particulier. Dans les méthodes GTZ et USAID, les observations sont effectuées au moyen d'échantillons pré-récolte. Dans le chapitre traitant du NRI, des échantillons de chandelles peuvent aussi être prélevés de tas de chandelles accumulées après la récolte. Cette méthode a néanmoins tendance à produire une sous-estimation des pertes des récoltes car l'agriculteur a tendance à être sélectif lorsqu'il fait ses tas et les chandelles très endommagées seront mises au rebut ou perdues.

L'échantillonnage pré-récolte, dans toutes les méthodes principales, tente d'être non sélectif. On examine les échantillons des chandelles au plan des dégâts. Dans les méthodes GTZ et NRI, on prélève une chandelle en tant qu'unité sans ajustement mathématique, mais dans la méthode ALM, utilisée par USAID, on mesure les chandelles à titre individuel, la plus grande étant employée en tant que référence pour ajuster le volume de graines perdues dans les chandelles plus petites par rapport à la chandelle de référence. Dans la méthode ALM, le nombre de chandelles échantillonnées est plus faible que dans les autres méthodes. Dans la méthode ALM, on tente d'obtenir une précision complémentaire grâce à l'inclusion d'estimation de graines perdues dans les chandelles 'shibra' et des pertes par suite de facteurs tels que les faibles précipitations, la croissance des mauvaises herbes, les dégâts provoqués au feuillage pendant la phase précoce de la saison de croissance et autres facteurs.

On peut présenter l'évaluation des pertes des récoltes simplement en fonction de pourcentage des pertes ou en fonction des pertes absolues en kg/ha. Dans ce dernier cas, les pertes des récoltes peuvent se baser sur les graines effectivement battues provenant d'un nombre connu de chandelles, la densité des cultures ayant été auparavant estimée. En variante, du fait que même

sans dégâts causés par les parasites ou maladies, le poids des graines/ha serait variable d'une année à l'autre en raison de facteurs tels que les précipitations et la disponibilité de fumier animal, les pourcentages de pertes observées peuvent être transformés en poids de graines/ha en calculant le rendement potentiel d'échantillons de chandelles non endommagées.

Chaque méthode d'évaluation des pertes des récoltes est présentée en tant qu'une séquence d'étapes qui seront observées après exécution du choix de la technique. Le choix sera opéré en tenant compte des exigences gouvernementales ou des agriculteurs, des facteurs de temps ainsi que des compétences disponibles aux personnes effectuant l'échantillonnage. A l'heure actuelle, les agriculteurs ne mesurent pas eux-mêmes la superficie des champs ou la densité des poches de plantes. Il sera normalement nécessaire de faire appel à des méthodes indirectes (détaillées dans le chapitre traitant de Kremer), pour estimer la surface cultivée dans un village et pour que la densité de plantation soit mise en rapport avec les chiffres obtenus après plusieurs années d'expérience de la région.

Il convient de garder à l'esprit, quelle que soit la méthode d'évaluation des pertes des récoltes utilisée, qu'une grande précision n'est pas indispensable dans nombre de cas. Dans une culture de faible valeur telle que le millet, un traitement doit produire une amélioration extrêmement élevée pour justifier sa recommandation aux agriculteurs. De plus, les autorités locales et les coopératives agricoles souhaitent normalement utiliser la méthode d'évaluation des pertes des récoltes pour calculer le degré auquel une région est ou non autonome en graines. En dernier lieu, les agriculteurs n'adopteront pas d'apports non subventionnés sauf s'ils peuvent calculer que les débours au plan du temps et de l'argent ont eu un effet positif majeur sur le rendement obtenu. Par conséquent, il n'est pas nécessaire que la méthode d'évaluation des pertes soit hyper sophistiquée et ne doit pas avoir pour but l'obtention de résultats inutilement précis.

Section 1

Introduction

N. D. Jago*

Despite its' supreme importance in any practical system of crop protection, crop loss assessment is not routinely included in farmer training programmes or the current schedules of crop protection in Sahelian Africa. Crop-loss assessment fulfills two major roles:

(1) It gives us information correlating crop damage with harvest lost and so enables us to improve the timing of crop protection intervention and the accuracy of economic thresholds. This is essential because damage does not always correlate linearly with crop loss, nor will a particular level of damage mean the same level of crop loss every year. For example, levels of damage by *Heliocheilus albipunctella* (millet head-miner caterpillar) which produce economically important crop loss in years when rains fail, will produce economically unimportant crop loss in years of good to average rainfall.

(2) It enables crop protection departments and farmers' organizations to justify economically the time and expense of IPM interventions. For government departments, this is essential to any system of resource utilization and accountability. For farmers, this focusses on the value of the reduced crop loss in relation to the cost of the equipment and materials they have purchased.

Crop loss assessment is the key to the long-term improvement of IPM and ICM procedures. It is the final measure of our success in any crop protection, be it biologically or chemically based. In a highly variable eco-climatic environment like the Sahel, it is essential that data are gathered starting now, so that patterns of appropriate interventions can be developed.

Yet, crop-loss assessment is studiously ignored. Even consistent operational monitoring of pest density is uncommon and confined to a very small number of species. The concommitent collection of data on crop damage is even less usual. The final step, the collection of data on resulting harvest and crop loss, is extremely rare. Government statistics on subsistence food grain production and cultivated area are based on haphazard collection procedures, which could be greatly improved by farmer, plant protection service and extension agent involvement. In all this crop-loss assessment should play a part.

Nwanze (1988) reviewed four methods which have been used to examine the effect of pests such as *Coniesta ignefusalis* and *Heliocheilus albipunctella* on millet. The majority of the published methods are based on calculation of the incidence of pest attack, but only in some cases is there a quantification of the yield loss attributable to a particular level of infestation.

Pearl millet, *Pennisetum americanum* (L) Leeke, is the major food crop in the Sahelian zone of West Africa. The crop suffers major losses, both direct and indirect, from a range of insects, weeds and diseases (Table 1).

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Table 1 Direct and indirect crop losses

Indirect losses	Direct losses
Causes Competition for light, nutrients and water Pests feeding on . . . germinating seedlings inside stems foliage of older plants	**Causes** Pests feeding on millet heads destroying flower structures, milky and ripe grain Post-harvest grain loss while millet heads drying or after threshing in stores (not covered here)
Results Reduced plant stands and tillers Reduced plant vigour, etc.	
Examples Weeds: annual grasses, dicotyledons and parasitic *Striga* spp. Insect pests: shoot flies (*Atherigona* spp.), chrysomelids (*Lema* spp.), leaf-feeding caterpillars (*Spodoptera* spp. and *Amsacta moloneyi* Druce), grasshoppers, stem borers (*Coniesta ignefusalis* Hampson and *Sesamia* spp.) Fungi: downy mildew (*Sclerospora graminicola* Schroet)	**Examples** Birds: e.g. *Quelea quelea* and *Passer luteus* Insect pests: Meloid beetles (*Psalydolytta* and *Mylabris* spp.), the millet head-miner (*Heliocheilus albipunctella* de Joannis), scarab beetles (*Pachnoda* and *Rhinyptia* spp.), several grasshopper spp. (8) Fungi: smuts

The majority of millet pests produce a characteristic, recognizable form of **direct** pre-harvest crop loss which can be easily assessed from the surface area of heads damaged by particular pests or pest categories. The most difficult crop loss to assess, however, is that which is **indirect** and caused by progressive damage throughout the season. Competition with weeds, major leaf damage, seedling destruction leading to reduction of planted area and loss of young stems or tillers due to stem borers fall into this category (see *Millet Pests of the Sahel: Biology, Monitoring and Control* for commentary on the importance of these losses to the farmer). A good example is crop loss due to death of stems, usually referred to as 'dead heart'. Unfortunately, as they are produced, the dead stems disappear during the growing season because they are eaten by millipedes and other organisms. Consequently, a count of 'dead hearts' at harvest under-estimates the number which have been produced. Even, however, if we had had the time to count all the 'dead hearts', and if they had been healthy, only a small proportion of these would have produced candles. This makes estimate of harvest loss due to dead hearts so complicated that only research scientists have the time and labour force to estimate its effect on harvested yield. Also, where *C. ignefusalis* has only two main generations per year, results in Mali show that crop loss, caused by 'dead hearts' or stem borers in stems with heads, should be ignored for both economic and technical reasons. This manual, therefore, deals mainly with crop loss caused by direct damage to the millet candle. This loss is usually assessed against a theoretical potential yield.

Potential yield will change from year to year due to the physical effects of rainfall. In a field with a given manuring regime, it is definable by farmers and field officers in several ways, but two extremes might be cited:

(1) The yield produced from the millet in a given year in the total absence of weeds, pests and diseases, with or without chemical interventions (seed dressings, herbicides, fungicides, insecticides).

(2) The yield produced from the millet in a given year with good traditional field management and a moderate or slight attack by the usual pests and diseases, but without chemical intervention.

The first can usually only be estimated by research stations, and is an impractical yard-stick for crop loss at the farmer level. The second might best be called '**acceptable yield**', since it is this yield per hectare that is in the mind of a farmer catering for family needs when he makes a statement like 'I have lost half my crop to grasshoppers this year'. In north-west Mali the acceptable yield/ha in areas which receive a mean annual rainfall of 500 mm averages 500 kg, while 90 km further north, where mean annual rainfall is 300 mm the average yield is 300 kg. If we add to these figures those direct pre-harvest crop-losses which are incurred by the millet head, the potential yield rises to 1050 kg/ha in the 500 mm rainfall belt and 500 kg/ha in the 300 mm rainfall belt. It is this definition of potential yield which is being referred to in this manual.

Millet fields in the Sahel are usually sown with the millet plants in groups or pockets. Both pocket density/ha and plant density within a pocket are variable between fields while, at a mean annual rainfall of 300 mm, mean pocket density/ha is lower and head density/pocket higher than in higher rainfall zones. The number of harvestable heads/ha may vary from 25 000 to 60 000 and the number of pockets/ha from 1900 to 23 000. Potential yield and direct crop loss are usually derived from a sample of pockets. The number of heads in this sample must be large enough to be representative of the chosen field.

In an actual case (north-west Mali, 1990) 60 pocket samples taken from a hectare field contained between 162 and 239 heads. Consequently, it is from this relatively small fraction that we would hope to calculate crop loss for the whole field. The potential yield from a millet field can be calculated in many ways. Some of these are presented in this manual by the research group who have been using them in West Africa (Section 5). Methods, however, are based on two main approaches.

Agro-economic approach. Many farmers in many villages are questioned carefully about their estimate of how much direct crop loss they have suffered. Answers may be obtained in terms of percentage loss or more specifically in terms of months of family grain supply by comparison with a good year. Neutral information known to relate to the cultivated area is requested (e.g. number of ploughs; numbers of available hands for field labour). Preferably this type of extensive survey is accompanied by a simultaneous intensive technical estimate. Even without this, however, a brief visit to the farmer's fields can allow a visual estimate of grain loss on millet heads to confirm farmer estimates.

Field sampling approach. Such methods can be carried out by farmers or technicians. Methods of taking the samples differ, but the sample millet heads in all cases are examined and estimates made of the percentage grain lost on each head. In this way the percentage of grain lost from the heads sampled is calculated.

Observation is made of the overall candle density/ha (N) by counting pocket density/ha. The grain lost (kg/ha) is now calculated. This can be approached in two ways:

(1) The weight of grain in the sample (say 60 pockets) gives the weight from n candles. Knowing the estimated number of candles (N) in one hectare, the weight of harvest/ha can be calculated. The percentage of grains lost in n candles can be applied to this estimated harvest weight/ha to calculate the potential yield (kg/ha). Experimental or research teams are recommended to measure the real harvest/ha by mechanical threshing. This will provide an accurate check against the estimated harvest using the grain weight from the sample pockets. It is not, however, practical, economic or safe for untrained personnel to use mechanical threshers.

(2) The weight of grain from 100 randomly chosen undamaged millet heads is taken. The density of heads/ha having been calculated (as in (1) above), the potential harvest grain weight lost in a hectare can be calculated.

In each of methods 1 and 2 damage and crop loss can be broken down by pest group. Again the chosen approach will depend on the accuracy required and the number and calibre of the personnel available. There may also be occasions when losses due to a specific pest are targetted for survey.

The manual does not present a comprehensive summary of all available loss assessment methods, but rather describes the approaches adopted by three research organizations working in the Sahelian zone of West Africa. It is anticipated that the methods described here will be of interest primarily to individuals or groups working in plant protection. No single method is recommended over any other because the suitability of each technique will depend upon the circumstances. Factors influencing the choice of method include the precision required, the speed of assessment required and the total area to be assessed.

Throughout the text the various advantages and drawbacks of each method will be summarized and rough estimates given of the amount of time required to carry out each procedure.

Section 2

Damage recognition

L. B. Coop*, G. P. Dively†, A. J. Dreves* and N. D. Jago

Quantitative assessments of direct losses due to pests depend on the ability of researchers and field workers to distinguish between the various forms of pest damage and identify successfully the major pests from the observed damage. Different assessment methods vary in the number of pest categories they recognize: some methods, for practical reasons, do not attempt to distinguish between pests causing similar types of damage, while others require a species by species breakdown. The following section describes the characteristics of pest damage for some commonly occurring millet pests and provides information which should help field workers distinguish between the various types if necessary. In addition, Krall and Dorrow (1992) have produced a booklet with descriptions of the various forms of damage and plates depicting the pests and diseases. However, even with the information provided by these sources the precise identification of the pest from the appearance of its damage may often prove very difficult. In this situation, accessory information on the presence, numbers and behaviour of pests collected systematically over the growing season, or from interviews with farmers, can help identify and confirm the most probable cause of the observed damage.

During damage assessment, regular cross-checking of all observers is advised to improve precision and to ensure standardization in diagnosing the factors responsible for damage to millet heads.

ACRIDIDAE

These are the grasshoppers: e.g. *Oedaleus senegalensis* (OSE), *Kraussaria angulifera* (KAN), *Cataloipus cymbiferus* (CCY), *Diabolocatantops axillaris* (DAX), *Hieroglyphus daganensis* (HDA) (see Plate 1), *Cryptocatantops haemorrhoidalis* (CHA), *Kraussella amabile* (KAM)

Millet growth stage affected

Spike formation to flowering stage

(a) *Effect on the head*: the florets are destroyed.

(b) *Appearance of damage*: an uneven shaving away of florets, often exhibiting a vertical or helical pattern on the surface of the head (Plate 2). The depth of shaving varies considerably depending upon the pest species, head maturity when injury is initiated and duration of feeding.

Milky stage

This stage suffers the greatest injury from grasshopper attack.

(a) *Effect on the head*: the kernels are completely destroyed.

(b) *Appearance of damage*: sheared areas of shrivelled seed and flower parts. The white endosperm may be exposed if injury was inflicted during the late milky stage (Plate 3). Usually more than 50% of the immature, shrivelled kernels are

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consumed; the remaining portions are too light to be removed from the chaff by traditional threshing methods and are effectively lost. The remaining endosperm is often discoloured by secondary mold infections.

(c) *Distinguishing grasshopper damage from that of* Pachnoda *spp*: adults of *Pachnoda* spp. and grasshoppers both have chewing mouthparts. *Pachnoda* damage often occurs secondarily on the grains already attacked by grasshoppers. Grasshoppers cause both defoliation and damage to the head, whereas *Pachnoda* spp. feed only on developing grain.

Grasshoppers feed less discriminately, generally eating kernels evenly across their surface. *Pachnoda* spp. feed more selectively, resulting in a 'ringing' or 'honeycombing' effect, their small heads and mouthparts allowing them to hollow-out kernels by penetrating more deeply into the interior of the endosperm (Plate 4). Milky stage damage by grasshoppers is usually present with damage inflicted at other growth stages.

Dough stage

(a) *Effect on the head*: the kernels are consumed partially or sometimes completely. At this stage it is too late for compensation by surrounding kernels.

(b) *Appearance of damage*: this injury appears as smooth scrapings of the hardened endosperm, leaving white, flat damaged surfaces (Plates 3 and 5). Usually 50% to 65% of the damaged kernels remain intact and thus contribute to the weight and yield of the head. However, many farmers indicate that these damaged kernels are predisposed to mould during storage and are thus removed during the threshing process (Plate 4).

Without some practice, grains primarily attacked by grasshoppers are often difficult to distinguish from those attacked by *Pachnoda*. For practical reasons, therefore, rapid survey may require the two damage types to be combined, but earlier reports of large numbers of *Pachnoda* should alert farmers and field officers to differentiate, if possible, the damage caused by these beetles from that caused by grasshoppers.

MELOIDAE

These comprise blister beetles, mainly *Psalydolytta* spp. (Plate 6).

The smaller *Mylabris* spp. are selective pollen feeders and empty the anthers on the stamens with their delicate mouthparts. Unlike *Psalydolytta* spp., they rarely cause the wholesale damage to the female stigma.

Millet growth stage affected

Between head emergence and milky stage

(a) *Effect on the head*: pollen and female flowers (ovaries, styles and stigmas) are consumed, resulting in sterilization and failure to produce grain ('blanking') (Plates 7 and 8).

(b) *Appearance of damage*: the tips of developing milky-stage grains are teased open resulting in the escape of fluids, which are consumed, with the subsequent shrivelling of the endosperm. Damage may cover the entire head or occur in contiguous patches. Beetles often feed first from top and work towards the bottom of the head. Kernels may recover from light damage; those that do are often oversized because of compensation.

(c) *Distinguishing blister beetle damage from aborted heads*: a few grains usually escape beetle damage (Plate 7) and there is rarely 100% death of florets. Aborted heads (caused by inadequate soil moisture and floral dessication) normally exhibit complete and uniform symptoms (Plate 11). Surviving kernels are generally larger if bordering destroyed kernels (compensation). The partial feeding pattern and irregular, shredded appearance of the glumes following blister beetle feeding is used to distinguish between beetle-damaged and drought-induced aborted heads. (Plates 9 and 10 respectively). Heads that failed to pollinate or aborted before the milky stage are virtually devoid of wholly formed grain (Plate 11). Late abortion occurs when heads are pollinated but fail to develop grain worth harvesting. In these situations, the grain is either uniformly formed to varying degrees or is completely lacking at the tip of the head.

Without some practice, heads aborted by the stresses of indirect pest injury, drought and other agronomic constraints are hard to distinguish from those damaged by blister beetles. For practical reasons, therefore, rapid survey may require the two damage types to be combined, but earlier reports of large numbers of meloids in a season with adequate rainfall would be confirmation that the damage had been caused mainly by these beetles.

(d) *Distinguishing blister beetle damage from grasshopper damage*: grasshopper feeding during the late flowering and milky grain stages often overlaps earlier injury by blister beetle damage. In these cases the tendency is to record the most obvious injury at harvest, i.e. that by grasshoppers, even though the primary yield-reducing factor is blister beetle feeding. Whenever possible, damage should be attributed to the primary pest although even with careful examination of the injured spikelets of developing grain this problem can not always be avoided. When using loss assessment methods where estimates of individual pest damage are made independently, caution also must be taken to avoid duplication of injured surface area which may lead to over-estimation of total pest loss.

Work has already been published on damage assessment by blister beetles (Zethner and Laurense, 1988), but recent studies by Grunshaw (NRI, in preparation) have considerably extended knowledge of the pest biology and economic thresholds.

SCARABAEIDAE

This group contains scarab beetles, including *Pachnoda* spp., especially *Pachnoda interrupta* (Plate 12).

Millet growth stage affected

From the late flowering to early dough stages
(maximum injury occurs during the milky stage)

(a) *Effect on the head*: at the flowering stage sterilization of the florets may be caused. At the milky and dough stages kernel damage occurs and there is loss of endosperm. During all growth stages feeding by *Pachnoda* spp. often follows that by grasshoppers or blister beetles.

(b) *Appearance of damage*: adult beetles may chew off the tender tips of florets causing the endosperm to remain undeveloped and producing a tattered or shredded appearance. Later, they seem to feed on the milky liquid or soft endosperm of developing kernels causing direct grain loss. Attacked kernels have a 'honeycomb' appearance with the seed coat and glume remaining and only the endosperm removed (Plate 13).

(c) *Distinguishing* Pachnoda *damage to the flowers from that by blister beetles*: these two types of damage are difficult to distinguish, sometimes the secondary damage of scarab beetles obscures the importance of earlier pests. In contrast to blister beetles, *Pachnoda* spp. usually damage smaller areas of the heads leaving a more shredded and less uniform appearance.

(d) *Distinguishing* Pachnoda *damage from grasshopper damage*: late injury is seen at harvest as scattered patches of feeding which overlap areas where grasshoppers have shaved off dough stage kernels indiscriminately. This secondary feeding is characterized by hollowed-out endosperm with generally only the seed coat and glumes remaining, leaving a honeycomb-like appearance.

Pachnoda beetles do not appear to cause major damage to whole seeds in the dough stage. However, after the endosperm is exposed by grasshopper feeding, beetles are able to penetrate it further, probably because of their smaller heads and mandibles. If this secondary feeding takes place when the endosperm is soft, *Pachnoda* adults have a tendency to chew the soft dough into a paste that then appears to fuse the remaining parts of the grain and spikelets together.

NOCTUIDAE

The Millet Head-miner, *Heliocheilus albipunctella* (Plate 14)

Millet growth stage affected

Flowering stage to harvest
(a) *Effect on the head*: loosening of kernels is caused resulting in partial grain formation and head shattering when affected heads are handled during harvesting and threshing.

(b) *Appearance of damage*: larvae feed on the glumes of the head and form helical tracks around it (Plate 15). When estimating loss to the Millet Head-miner it is assumed that 50% of the chaff is pushed out by Millet Head-miner feeding and that all the grain within the damage tracks is lost.

[The damage occurs late in the larval life history of this moth. Consequently, monitoring damage by the caterpillar is useless as a measurement of the economic threshold to justify chemical or other treatment. A clue to likely damage can only be obtained by monitoring the female moths earlier in the year]

BIRDS

Quelea quelea (Plate 16), *Ploceus* sp., and *Euplectes* spp.

Millet growth stage affected

Dough and mature grain stages
(a) *Effect on the head*: kernels are removed wholesale.

(b) *Appearance of damage*: bird damage is seen as patches of missing whole kernels which often follow a U-shaped pattern around the top 1/3 of the head (Plate 17). Usually, the inner glume connected to the spikelet is removed with the kernel, leaving the exposed lower glume which appears as a tiny 'cup' where the kernel was previously attached (Plate 18).

There can be some confusion between bird damage and the 'blanking' due to blister beetle and early grasshopper damage, especially when large species remove chunks of whole grain from the heads. The absence of grains may have other causes such as, for example the falling of ripe, dry grain during strong gusts of wind.

DISEASES

Smut, *Tolyposporium penicillariae* Bref, Mildew, *Sclerospora graminicola* Schroet and Ergot, *Claviceps fusiformis* Loveless.

Millet growth stage affected

(a) *Effect on the head*: the grain develops abnormally.

(b) *Appearance of damage*:

- Mildew: the whole head is covered with 'leafy' growths where grain would normally form (Plate 19);
- Smut: blackened grains are scattered over the head (Plates 20 and 21);
- Ergot: the developing grains exude liquid secretions (Plate 22).

PLATES

↑
Plate 2

← **Plate 1** **Plate 4** →

Plate 3
↓

Plate 1	Mating pair of *Hieroglyphus daganensis* (HDA) resting at the base of a millet head (Source: L. Coop)
Plate 2	Grasshopper damage: early season damage showing shaving of florets (Source: M. Matthews)
Plate 3	Grasshopper damage: late season damage showing exposure of white endosperm (Source: L. Coop)
Plate 4	*Pachnoda* beetle damage: showing excavated endosperm (Source: G. P. Dively)

↑ Plate 5

← Plate 7 Plate 6 →

Plate 8 ↓

Plate 5 Grasshopper damage: early and late season damage combined. Damage to endosperm at the dough stage (Source: M. Matthews)

Plate 6 *Psalydolytta* beetle damage: adults *in situ* eating apices of florets (Source: L. Coop)

Plate 7 *Psalydolytta* beetle damage: overall view (Source: L. Coop)

Plate 8 *Psalydolytta* beetle damage (× 8): close-up showing surviving grains (Source: M. Matthews)

↑ Plate 10

← Plate 9 Plate 12 →

Plate 11 ↓

Plate 9 *Psalydolytta* beetle damage: close-up showing chewed glumes of sterilized florets (Source: G. P. Dively)

Plate 10 Floret sterility due to drought causing aborted kernels (Source: G. P. Dively)

Plate 11 Floret sterility due to drought causing 100% abortion of florets with no surviving kernels (Source: G. P. Dively)

Plate 12 *Pachnoda* beetles attacking millet head at milky stage, in their typical inverted feeding posture (Source: J. Legg)

↑
Plate 13

← Plate 15 Plate 14 →

Plate 16
↓

Plate 13 *Pachnoda* beetle damage: damage initiated at milky grain stage producing this appearance at the dough stage (Source: L. Coop)

Plate 14 *Heliocheilus albipunctella* larva on late flowering stage showing caterpillar in its external mine (Source: M. Matthews)

Plate 15 *Heliocheilus* damage: mined millet heads showing dead florets lifted clear of the central rhachis (Source: N. Jago)

Plate 16 Grain-eating birds: *Quelea quelea* (Source: Frank Lane Picture Agency)

↑
Plate 18

← Plate 17 Plate 20 →

Plate 19
↓

Plate 17 Bird damage showing removal of whole kernels (Source: N. Jago)

Plate 18 Bird damage: close-up showing removal of whole kernels (Source: L. Coop)

Plate 19 Fungal diseases: downy mildew *Sclerospora graminicola* Schroet (Source: G. P. Dively)

Plate 20 Fungal diseases: smut *Tolysposporium penicillariae* Bref. (Source: N. Jago)

↑
Plate 21

← Plate 23 Plate 22 →

Plate 24
↓

Plate 21	Fungal diseases: smut *Tolysposporium penicillariae* Bref. (Source: L. Coop)
Plate 22	Fungal diseases: ergot *Claviceps fusiformis* Loveless on millet (Source: J. Lacey)
Plate 23	Harvester ants retrieving grains from 'shibra' millet which has a head which easily shatters (Source: L. Coop)
Plate 24	Weeds: parasitic weed *Striga hermonthica* growing on millet roots

OTHER PESTS AND FACTORS AFFECTING CROP YIELD

(a) The Millet Stem-borer (*Coniesta ignefusalis*): dissection of stems will reveal the tunnels and exit holes of these stem-boring insects.

Millet Stem-borer damage may be easily confused with damage due to drought; the millet head may not emerge properly beyond the flag-leaf and fungal rot begin in the covered part of the candle. Often all the grains on the head are poorly developed and much smaller than usual. Otherwise perfect heads on stems containing larvae lose 10–18% of their grain weight.

(b) Ants: ants remove all but the core of heads. They usually affect only *shibra* heads or harvestable heads that have fallen to the ground (Plate 23).

(c) The grain midge (*Geromyia penniseti* (Felt.)): this insect causes flattened glumes and a tiny exit hole on the aborted grain. Such damage is distinguishable from both blister beetle and aborted head symptoms once the midge or its parasites have emerged from the grain.

(d) Shoot flies (*Atherigona* spp.): the larvae of these insects feed on the growing point of the shoot, killing it and causing a 'dead heart'. Attack usually results in tillering; in severe cases these additional tillers may in turn be attacked.

(e) *Striga hermonthica* (Del.) Benth. (Plate 24): is parasitic and grows on the roots of millet. Severe infestation may result in considerable crop loss.

(f) *Abiotic factors*, e.g., drought and abortion: little or no grain is produced, depending upon the timing and intensity of the cause of abortion. Kernels are only partly formed or completely lacking. The entire spike is usually affected (Plate 11). The reasons for head abortion are not always apparent, but look for: drought stress symptoms, large numbers of Millet Stem-borer holes and tunnels in stems, mildew symptoms, severe weed competition (especially from *Striga* spp.), competition from surrounding heads of the same pocket. Occasionally heads appear aborted or undeveloped due to reversion to *shibra* millet.

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CROP-LOSS ASSESSMENT METHODS

The four main approaches to millet crop-loss assessment which follow are presented in an order of increasing precision and manpower time. The longer the time required and the more intensive the sampling procedure, the smaller the farmer community that can be covered. For plant protection services and farmer co-operatives or brigades, the chosen method will have to be as simple as possible (perhaps not broken down into loss species by species) and take only a short period of time for completion per village. Simplifying data collection, and organizing the whole farmer community for example, could overcome the labour bottle-neck created by methods currently carried out by officials. We present these methods for testing, comment and modification, in the knowledge that time is always pressing on the farmer, and realizing that millet crop-loss assessment is in its infancy. Flexible and practical methods will only be perfected after testing under demanding field conditions.

The four methods are:

(1) Farmer interview (a socio-economic or agro-economic approach);
(2) The GTZ method (this has so far been using preharvest sampling);
(3) The NRI method (this is subdivided into CLA on pre-harvest and post-harvest millet heads (NRI1 and NRI2 methods));
(4) The USAID 'adjusted length method' (ALM method).

Section 3

Farmer Interviews

A. Kremer*

INTRODUCTION

Informal farmer interviews have been incorporated into quantitative loss assessment methods because of the information farmers can provide on indirect pest losses and the occurrence of pests. For example, farmers can provide information about planted area loss and reduction in pocket quality caused by grasshopper nymphs, *Spodoptera* spp., rodents and birds, even at the end of the season, when all visible evidence of these events has been obscured by weeds.

Information on the occurrence of pests can often facilitate the identification of the most probable cause of direct damage. It is often difficult to distinguish by observation alone between damage caused by *Pachnoda interrupta* and grasshoppers, or between abortion of the head due to drought and damage caused by meloids, such as *Psalydolytta* spp. A farmer, however, will have observed the damage as it happened and thus be able to attribute it to a particular pest. Figure 1 shows a standard farmer questionnaire used by field workers using the adjusted length method (ALM) to record additional information during informal interviews with participating farmers.

Extensive farmer surveys are also carried out independently of, or in addition to, quantitative loss assessment methods. In this case, they provide a rapid means of finding out about crop loss and farmers' perceptions of pests which allows high coverage at low cost. A given area can be covered at much lower cost than with quantitative methods; an interviewer can cover, say, three villages in just one day, which is equivalent to 500–1000 ha of cultivated fields. However, farmer surveys cannot establish losses precisely, either in absolute or in percentage terms. An example of results obtained using this approach is given in Table 2.

PROCEDURE

The following section describes several procedures and safeguards which should be observed when setting up and conducting meetings with farmers; the actual format of the interview will vary between surveys. The section also includes examples of questions used to ask farmers about crop loss and pests. It is not possible to provide a definitive list of such questions, since the relevance of individual questions will vary from situation to situation and according to the survey aims.

Setting up the meeting

Whenever farmer interviews are used to study crop loss certain safeguards must be taken to make sure that the results are not misleading. The following precautions are particularly important:

- Make sure that the villages visited are representative of the area in question.

All the local ecosystems, cropping systems and ethnic groups should, as far as possible, be represented in the sample. On the other hand, it is best to avoid the largest towns lest the meeting becomes unmanageable.

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Crop Loss Assessment in Millet	FORM 3 - ACCESSORY SURVEY INFORMATION

1. Field Identification Collection Date________ Coll. by______________ Farmer Name______________

Field Code______________ Village__________ Region______________ Country__________

2. Crop Information (circle or fill in blanks)

2.1 Source of seed planted: local field // market // improved variety

2.2 Seed treatment against: early disease attack: yes // no // unknown

early insect attack: yes // no // unknown

2.3 Cultivar grown: short cycle souna // long cycle Sanyo // other_________

2.4 Intercropping: none___ cowpeas____ sorghum____ peanuts____ other___

2.5 Percentage millet in field: <30 // 30-50 // 51-70 // 71-90 // 91-100

2.6 Soil Nutrients Added: manure___ rock phosphate___ commercial___

2.7 Number of weedings performed:(0-3) ___

2.8 Number of good rains since planting of the crop ___

2.9 Severity of current drought: none // light // moderate // severe

2.10 Relative yield amount this year: poor // average // good // very good

2.11 Relative yield amount last year: poor // average // good // very good

3. Pest Information

3.1 What were the two major millet pests this year, last year and historically (the last 10-20 years):

	this	last	histor.		this	last	histor.
grasshoppers	____	____	____	blister beetles	____	____	____
head borers	____	____	____	stem borers	____	____	____
disease	____	____	____	birds	____	____	____
other ________	____	____	____				

3.2 How serious were the damages from pests this year: none // light // moderate // severe

3.3 How serious were the damages from pests last year: none // light // moderate // severe

3.4 At what stage did the greatest damage occur this year: seedling // tillering // flowering // milk // dough

4. Treatments

4.1 How many treatments, at what crop stages, and for what pests have pesticides been applied?

	compound name and no. of applications	crop stages present	pests the treatment(s) were directed against
dust	________ ___	__________	stem borers // grasshoppers // head borer // flower pests // other______
liquid	________ ___	__________	stem borers // grasshoppers // head borer // flower pests // other______

4.2 How effective were the treatments in preventing crop loss: very ___ moderate ___ poor ___

Figure 1 ALM/USAID data sheet (form 3) for recording accessory survey data given by each farmer

Table 2 Millet crop-loss assessment obtained from farmer interviews

Village	Population	Area cultivated (ha)	Crop Loss (%) LE	Crop Loss (%) UE	Value of loss per family (1000 × F.CFA) LE	Value of loss per family (1000 × F.CFA) UE	Value of loss per village (millions F.CFA) LE	Value of loss per village (millions F.CFA) UE
1988 Season								
Alaso	663	110	90	95	120	125	5.2	5.49
Dalli	696	140	70	85	110	135	5.15	6.25
Demba Diawara	228	60	70	80	145	165	2.21	2.53
D. Tchakitira	402	105	75	90	155	185	4.13	4.96
Dina Koura	419	85	70	90	110	145	3.12	4.02
Djongodji	255	45	90	95	125	130	2.13	2.24
Mamaribougou Ferribe	1302	260	80	90	125	140	10.92	12.29
Safintara Bambara	363	120	50	75	130	195	3.15	4.73
Sami	479	80	85	95	105	125	3.36	3.99
Tacoutala	270	60	90	95	155	165	2.84	2.99
(Assumes yields of 750 kg/ha under no serious pest attack and millet price of F.CFA 70/kg. Average family size 15 people.)								
1989 Season								
Alaso	663	220	40	60	52	78	3.96	5.94
Dalli	696	190	20	35	43	77	2.27	3.98
Demba Diawara	228	60	25	45	34	61	0.68	1.22
D. Tchakitira	402	105	50	70	59	83	2.36	3.31
Dina Koura	419	130	45	60	69	91	2.63	3.5
Djongodji	255	45	50	70	41	57	1.01	1.41
Mamaribougou Ferribe	1302	260	30	40	68	90	3.51	4.68
Safintara Bambara	363	120	90	95	168	177	4.86	5.13
Sami	479	140	20	40	30	58	1.26	2.52
Tacoutala	270	140	75	90	120	143	4.71	5.68
(Assumes yields of 600 kg/ha under no serious pest attack and millet price of F.CFA 75/kg. Average family size is 15 people.)								

Note: LE lower estimate; UE upper estimate
After: Lock, 1988, 1989

- Make sure that the farmers interviewed are representative of the village in question.

Often the village chief, or the chief and some high-caste family heads are the people immediately prepared to answer questions. Explain that you would like to meet as many farmers as possible. If possible, tell the villagers at least a day in advance and fix a rough time for the visit, otherwise all the real farmers may be in the fields. Similarly, don't be in a hurry to start the meeting unless the villagers are short of time. The rich people are usually the first to turn up for a meeting, because they are not working in the fields. The ordinary farmers come later and may be unrepresented if the meeting starts too soon.

If women's fields take up an important share of the land it may be worthwhile for a female interviewer to meet separately with them.

Holding the meeting

- When the meeting starts, explain clearly who you are, what questions you want to ask and how the information will be used.

If farmers think that their answers may bring them free pesticides or other aid they can bend the truth. Although you have certain questions to ask, the farmers will probably want to discuss something completely different. Listen to whatever they say. After all, you're trying to find out their priorities, not vice versa. If the conversation is really going nowhere, remind them why you have come and press on. The best meeting is a free conversation interspersed with your questions. Although the questions will be disguised as inobtrusively as possible in the conversation, it is nonetheless useful to record the answers on a standard questionnaire. This ensures that no questions are omitted and makes data analysis simpler.

- Be on the look-out for differences of opinion between farmers, as these often reveal new lines of enquiry.

Remember also that the most forceful speakers are not necessarily the most knowledgeable farmers.

- Leave the last word to the villagers.

This leaves them with the impression that the meeting has been conducted according to their priorities.

Questions to ask

Identification and ranking of pests perceived as important by farmers
First find out what is, and what is not, considered a pest. For example, farmers may not consider weeds and plant diseases worth mentioning, because they are always present - part of the field, as it were. The following questions should prove revealing.

(1) What things damage your millet?

Make sure that you know which organisms the villagers are referring to. Go through the pests one by one, asking about their size, colour, what they do to millet and so on until you are certain. It is common for different villages to use the same name for different pests or to give different names to the same pest. Use specimens or an identification poster if necessary.

(2) What caused most harm to your millet this year?

Note the most harmful species. If there is a difference of opinion, note it.

(3) And after that? And after that?

Note the second and third most harmful species.

The distribution and timing of pest attack

(4) Does (pest name) damage one variety of millet more than others?

(5) Are some fields more likely than others to be damaged by (pest name)?

(6) What stage is the millet at when (pest name) does the most damage?

This question is particularly useful to elicit further information on grasshoppers.

Changes over time
Older farmers can provide information on the changes in the importance of different pests with time.

(7) What has done most harm to your millet since you started farming?

(8) Are the things that harm millet now the same as when you were young?

Estimation of area cultivated by the family; estimate of area lost to seedlings destroyed early in the season
It is unusual for a farmer to know the area of ground he has cultivated to millet. However, we may pose the following types of question:

(1) In a year without many pests, how many months of millet grain supply do you expect to produce for your family?

(2) How many months of grain supply did you produce for your family this year?

(3) How many family labourers did you use this year? How many labourers did you hire?

(4) How many ploughs does your family own? Did you hire from friends or neighbours?

(5) How many times did you have to resow your fields? How many days did it take to replant and how many people were involved?

The example of Mourdiah in north-west Mali will illustrate the value of such questions. At this latitude, rainfall allows roughly 500 kg/ha of harvest. For the sake of rough calculation we may take average family size to be 15 people, and with the average yield, 5 ha of cultivated millet would be required. On these light sandy soils, there are also rough relationships between the number of available male farm hands, the number of ploughs and the area cultivated, e.g. the cultivated area per plough is 8.17 to 8.89 ha. We may immediately assess potential self-sufficiency by the number of farm hands and assess the inevitable short-fall (loss in man-days/ha) if many young men are away earning cash to send back to the family (each 40.5 man-days/ha). Early-season crop loss due to reduced field area following seedling damage and resowing, will be a further measure of reduced productivity and can be measured by the number of days spent in resowing. The number of hectares cultivated by a plough and team in a day, will vary from region to region (depending on the type of animal traction, soil type, etc.), so this local knowledge is essential background to transforming the information from indirect questioning into estimates of area under millet and early-season crop loss.

ANALYSIS

The following outputs are simple to produce without computers:

- Recognition table
  Give a pest one point for every village that named it as harming millet. Tabulate the total scores against the pests' names.
- Rank table
  Give 2 points to every pest that a village called most harmful and 1 point to the 2nd most harmful. Tabulate the total scores against the pests' names.
- Pest map
  Allocate a symbol to each pest and plot it on a sketch map wherever it was named as most harmful.
- Glossary of vernacular names for pest species
- Description of the relationships between pest species, millet varieties and field types

The validity of the outputs may be questionable if farmers exaggerate losses because they believe free pesticides are available. Other drawbacks are that farmers rarely consider plant diseases (and weeds) to be pests, may confuse different pest species especially lepidopteran larvae or may lack the vocabulary to communicate a pest's identity to an untrained interviewer. Nevertheless, these outputs give a useful picture of pest attack that would cost many thousands of dollars to obtain across a wide area by more 'scientific' means.

It is important that pest rankings produced as a result of farmer interviews are not mis-interpreted. For example, rankings cannot provide information on the relative losses attributable to pests with different rankings; losses attributable to the first ranked pest are not necessarily twice those attributable to the second ranked pest. The losses could be similar or very different.

Similarly, rankings cannot take account of the variation in yield loss attributable to pests between farmers or regions. For example, a farmer may rank a pest as the most important when the corresponding yield loss is 10 kg/ha whereas the pest ranked most important by a second farmer may cause losses of 100 kg/ha.

TIME AND LABOUR

In practice, this method is extensive rather than intensive. A team of three people, if possible including a woman colleague, may cover 10 villages in a day with practice. The method is best conducted in parallel with technical survey, but this will only be able to cover two villages per day in depth during the time devoted to farmer survey of 10 villages and will require extra staff (see GTZ and NRI methods).

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Section 4

THE GTZ METHOD

U. Pantenius* and S. Krall*

INTRODUCTION

In 1988 efforts were begun in Niger to develop a simple method for determining the extent of yield losses caused by diseases and pests of pearl millet. This was done within the framework of a joint crop protection project implemented by the Federal Republic of Germany and the Republic of Niger (Pantenius *et al.*, 1991). The method was primarily intended to help the crop protection service of Niger, and later those of other countries in the region, to assess the damage situation at the end of each growing season and to perform economic feasibility assessments of control measures. In addition, since the causes of damage are also recorded, trends in the importance of different pests and diseases could be monitored over the years and regional differences ascertained.

Following trials in 1989, 1990 and 1991 the method has been refined to its present form which allows the collection of reliable data on damage to millet heads and the resulting crop loss in large areas without requiring much labour or extensive use of instruments.

The method is based on the visual estimation of damaged surface area using four pictorial keys. Each key represents the appearance of different forms of damage expressed as a percentage, as one observes them on millet heads in the field (Figure 2). They allow an immediate quantification of the seriousness of damage on a sample of millet heads. With the aid of supplementary information, which field officers obtain with a specific questionnaire, these field observations are transformed into an estimate of % grain loss, adjustment to this % crop loss being made according to pest type with the help of a simple computer programme, e.g. birds are considered to remove 100% of a grain; grasshoppers remove less than a whole grain.

PROCEDURE

Collection of supplementary information

The first part of each individual survey is devoted to general parameters and questioning of the farmer to whom the study plot belongs. These data are gathered prior to the field observations. The farmers are asked about their agro-ecosystem, the pest, disease and weed situation, and the control measures taken. The questionnaire (Figures 3 and 4) is also used to obtain qualitative information on the millet during its early growth stages. In particular, the farmers are asked whether they had to replant millet because of caterpillar, rodent or grasshopper damage.

Selection of observation plots

- Randomly select a field for assessment.
- Within the selected field, if possible 10–20 m from the edge of the field, randomly select an area and pace out a plot measuring 30 m on each side; mark three corners of the plot with plastic bags (Figure 4) at A, B and C.

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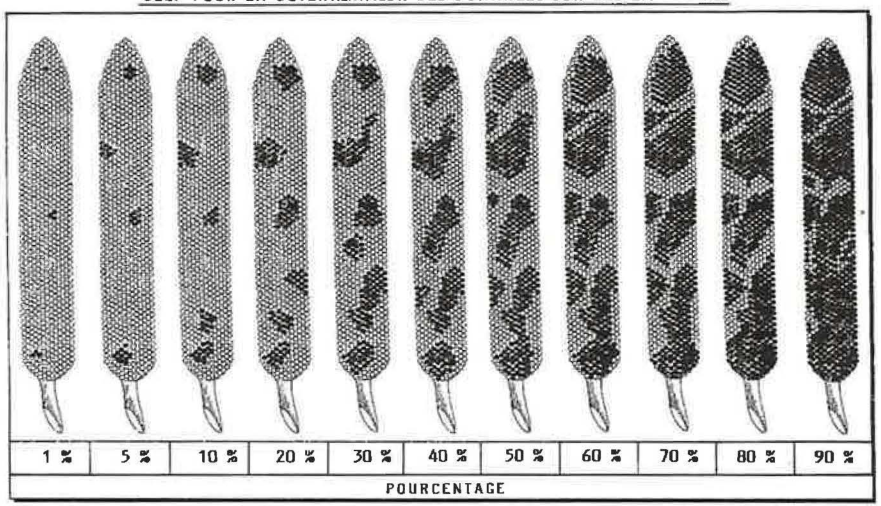
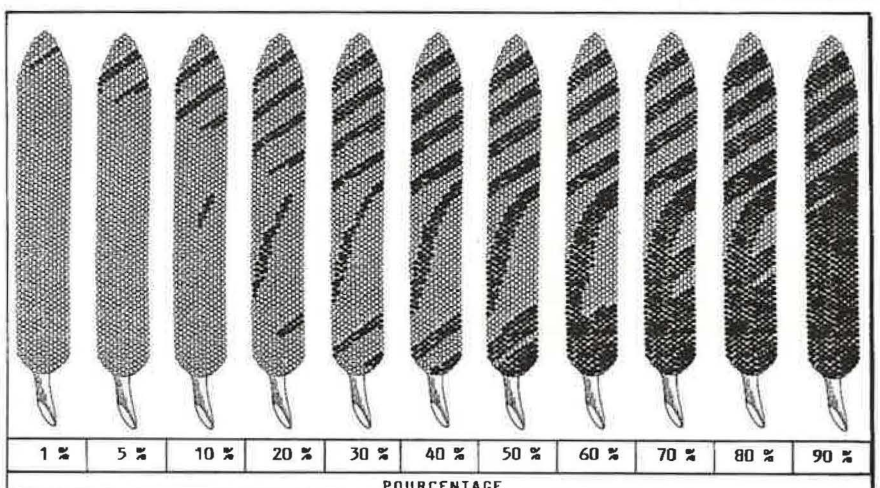
CLEF POUR LA DETERMINATION DES DOMMAGES SUR DES EPIS DE MIL





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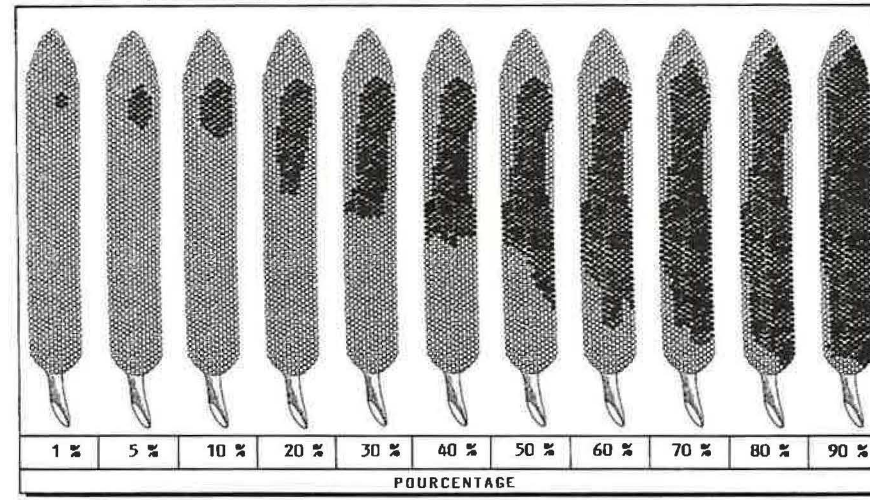
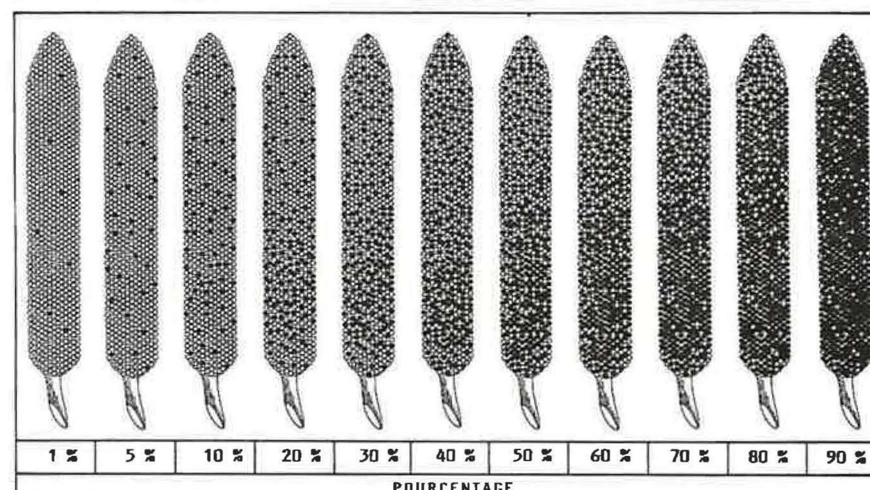




Examen d'une parcelle par un enquêteur chargé d'évaluer les pertes de récolte

Les différentes étapes

I Comment choisir la parcelle d'observation de 30x30 m ?

1. Choisissez un côté du champ et placez-vous au milieu de ce côté.
2. Pénétrez dans le champ en comptant 15 pas et repérez le point A sur une tige de mil.
3. Vérifiez la longueur de vos pas à l'aide du tableau 1 et calculez combien vous devrez faire de pas pour mesurer une longueur de 30 m. Déplacez-vous ensuite le long de la rangée de plante repérée et après 30 m faites une marque qui représentera le point B. Le côté A-B a ainsi été défini.
4. Retournez au point A et mesurez maintenant le côté A-C perpendiculairement aux rangées de plantes. Repérez le point C.

II Détermination de la densité de poquets dans la parcelle

1. Comptez tous les poquets de la première rangée sur le côté A-B.
2. Dénombrez les rangées de plantes entre les points A et C. Les rangées entrecoupées de grands espaces vides ne sont pas comptées.

III Détermination de la densité d'épis productifs sur 20 poquets

1. Dans la première rangée au point A, sélectionnez un poquet et comptez tout d'abord tous les épis présentant un développement normal au stade laiteux, pâteux et au stade mûr, puis tous les épis de Shibra.
2. Faites ensuite quatre pas entre les rangées 1 et 2 et répétez le dénombrement des épis productifs et des épis de Shibra dans le poquet se trouvant devant vous dans la rangée 2. Ensuite, passez à la rangée voisine et répétez cette démarche jusqu'à ce que vous ayez dénombré dix poquets. Les dix poquets suivants sont sélectionnés en progressant en direction opposée.

IV Détermination des dégâts sur 30 épis

1. Placez-vous entre les rangées 1 et 2 au point A. Faites quatre pas en gardant la tête baissée. Placez-vous ensuite à côté du premier poquet productif dans la première rangée. Tendez le bras en détournant la tête pour saisir une tige avec des épis. S'il ne s'agit pas d'un épi portant des grains, il faudra sélectionner une nouvelle tige/un nouvel/ épi ou éventuellement même un nouveau poquet.
2. Identifiez les dégâts que vous observez sur l'épi selon les différentes catégories prévues par le questionnaire et déterminez la surface attaquée en pourcentage de la surface totale de l'épi au moyen des quatre modèles d'évaluation prévus.
3. Mesurez la longueur et la circonférence de l'épi examiné.
4. Passez à la rangée suivante et répétez cette démarche jusqu'à ce que vous ayez examiné 16 épis ou atteint la distance minimum par rapport au bord du champ (10-20m). Passez à la rangée suivante et continuez les examens en progressant dans la direction opposée jusqu'à avoir examiné 30 épis.

PROGRAMME NIGERO-ALLEMAND
D'ESTIMATION DE PERTES SUR LES CULTURES DE MIL

MA/EL DPV

1. Identification

N° de champ	11	Enquêteur	12	Village	13
Arrondissement	14	Département	15	Date / / (jour mois an)	16

2. Description des ravageurs par le paysan

	21 Qu'est-ce qui a causé le plus de dégâts au mil dans la parcelle d'estimation? (cocher une seule réponse)	22 Et en second lieu? (cocher une seule réponse)	23 Et en troisième place? (cocher une seule réponse)
chenilles	1	1	1
rongeurs	2	2	2
borer de tige	3	3	3
sauteriaux	4	4	4
mineuse d'épi	5	5	5
insectes floricoles	6	6	6
oiseaux	7	7	7
maladies	8	8	8
autres ravageurs	9	9	9
pas d'attaque	10		

24 Avez-vous resemé du mil dans la parcelle d'estimation cette année à cause des chenilles?	oui	1	non	2
25 Avez-vous resemé du mil dans la parcelle d'estimation cette année à cause des rongeurs?	oui	1	non	2
26 Avez-vous resemé du mil dans la parcelle d'estimation cette année à cause des sauteriaux?	oui	1	non	2

27 A quel stade de développement le mil de la parcelle d'estimation en était-il quand les sautériaux y ont fait le plus de dégâts cette année? (cocher une seule reponse)	avant montaison	1
	montaison	2
	épiaison/floraison	3
	maturation des grains	4
	pas d'attaque	5

Figure 3 GTZ Identification and pest description sheet

3. La parcelle d'estimation selon l'enquêteur et le paysan

31 Quelle est l'association de cultures pratiquée dans la parcelle d'estimation?	mil pur	1
	mil/niébé	2
	mil/sorgho	3
	mil/niébé/sorgho	4
	autre association	5
32 A-t-on traité les semences de la parcelle d'estimation?	oui	1
	non	2
33 Est-ce que le mil de la parcelle d'estimation est une variété améliorée?	oui	1
	non	2
34 Quel est l'importance du Singa dans la parcelle d'estimation?	nulle	1
	forte	2
	faible	3
35 Quelle est l'importance des autres mauvaises herbes dans la parcelle d'estimation?	forte	1
	faible	2
36 Quelle est le type de sol de la parcelle d'estimation?	sableux	1
	sableux/argileux	2
	argileux	3
37 A-t-on répandu de la fumure organique dans la parcelle d'observation?	oui	1
	non	2
38 A-t-on répandu de l'engrais chimique dans la parcelle d'observation?	oui	1
	non	2

4. Les traitements dans la parcelle d'observation selon l'enquêteur et le paysan

41 A-t-on appliqué de l'insecticide en poudre dans la parcelle d'estimation?	oui	1	si oui ⇒ ⇒	42 Ce mil en état à quel stade de développement lors du traitement?	avant épiaison	1
	non	2			épiaison/floraison	2
					maturation des grains	3
43 A-t-on appliqué de l'insecticide liquide dans la parcelle d'estimation?	oui	1	si oui ⇒ ⇒	44 Ce mil en était à quel stade de développement lors du traitement?	avant épiaison	1
	non	2			épiaison/floraison	2
					maturation des grains	3

45 L'utilisation d'insecticide a visé quel insecte principalement?		1. Traitement	2. Traitement	
	chenilles			1
	borers de tiges			2
	sautériaux			3
	mineuse d'épis			4
	insectes floricides			5
	autres insectes			6
	pas de traitement			7

46 Le traitement a-t-il eu lieu à temps ou trop tard?

	A temps	Trop tard
1. Traitement	1	1
2. Traitement	2	2

Figure 4 GTZ Plot description and treatment record sheet

It is important that the choice of the field, and the plot within the field, is done strictly at random to prevent preference being given to severely attacked or relatively undamaged sampling plots.

Determination of crop density (harvestable heads in 900 m^2)

- Count the number of plants in a planting row from point A to point B.
- Between points A and C count the number of rows. Only count those rows which enter a strip 3 m wide along the edge of the plot (Figure 5) (in the example only 21 rows counted). This approach makes allowance for any large bare areas within a field.
- Enter the data in assessment form (Figure 6).
- Diagonally transverse the assessment plot (following the line of points *a* to *j* and *k* to *t* (as shown in Figure 5). Thus select 20 plant pocket 'sites'.
- At each pocket count the number of productive heads in the milk ripe stage or beyond and the number of plants of the mimetic weed shibra (*Pennisetum stenostachy, P. dalzielii*).

Surface area of 30 millet heads in sample plot

- From the 20 millet pockets selected above choose 30 heads at random. Measure the length and circumference (in cm) of these heads, using a simple measuring tape. The length of the millet head should be taken along the part which bears harvestable grains (the tip and base are often sterile). Calculate the surface area of this 30-head sample.
- Knowing the number of millet heads in the 30 m × 30 m plot calculate the surface area of the productive heads in the whole plot.

Potential yield

Calculation of the potential crop yield is made by collecting 260 undamaged millet heads from the region.

- Measure the length and circumference of each head.
- Calculate the total head area.
- Weigh the grain peeled from the 260 undamaged heads. *Example*: in 1991 average grain weight was 0.95 gm/cm^2.
- The number of harvestable heads in the sample plot gave the surface area of its harvestable heads from which a measure of potential yield can be obtained. *Example*: If this was S cm^2, then in 1991 an estimate of potential yield in the sample plot would be obtained by $(S \times 0.95)/1000$ kg.

Head damage assessment

- Take the 30 millet heads used to assess surface area. These have been selected because they would have been expected to bear yield at harvest time (i.e. at least in the milk-ripe stage).
- Examine the stem of each selected head for the presence of stem borers. Record their presence with a cross under the heading stem borer in the data sheet (Figure 6).
- Inspect each head for damage.
- Compare damage with examples in Section 2. A colour brochure is also available (Krall and Dorow, 1992).

Seven millet head pest/damage categories are recognized by the GTZ team:

- grasshoppers (flower)(early damage);
- grasshoppers (ripe)(late damage);
- head-miner;
- birds;
- empty ears;
- diseases;
- other (unknown) causes.

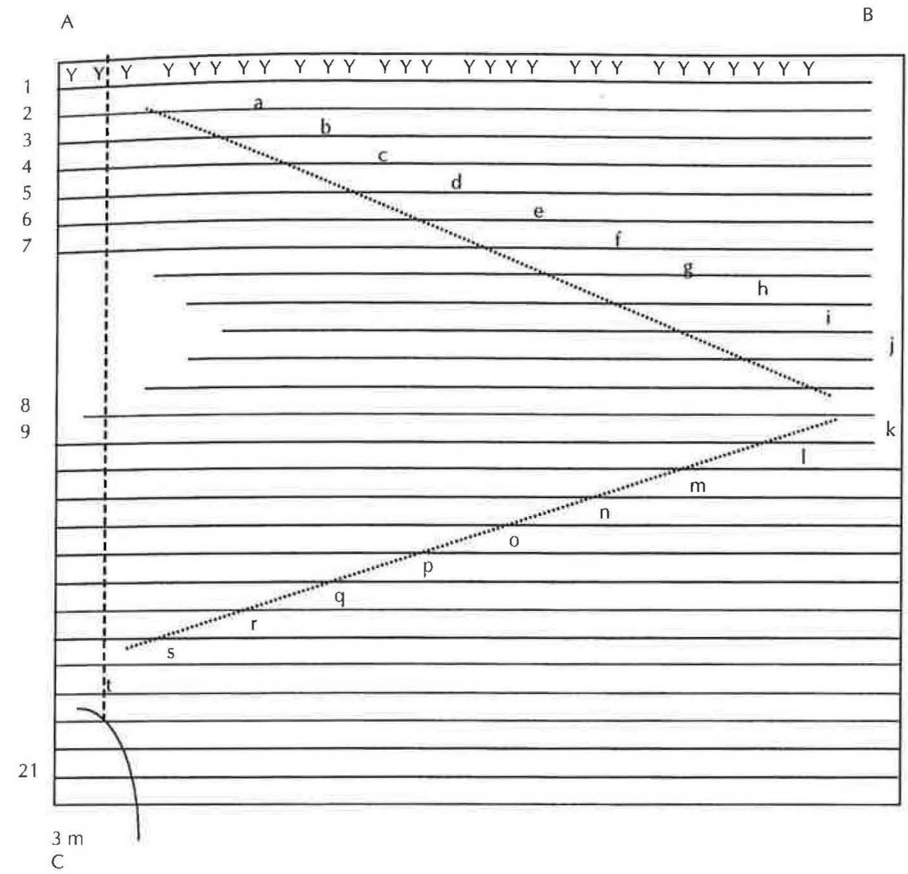
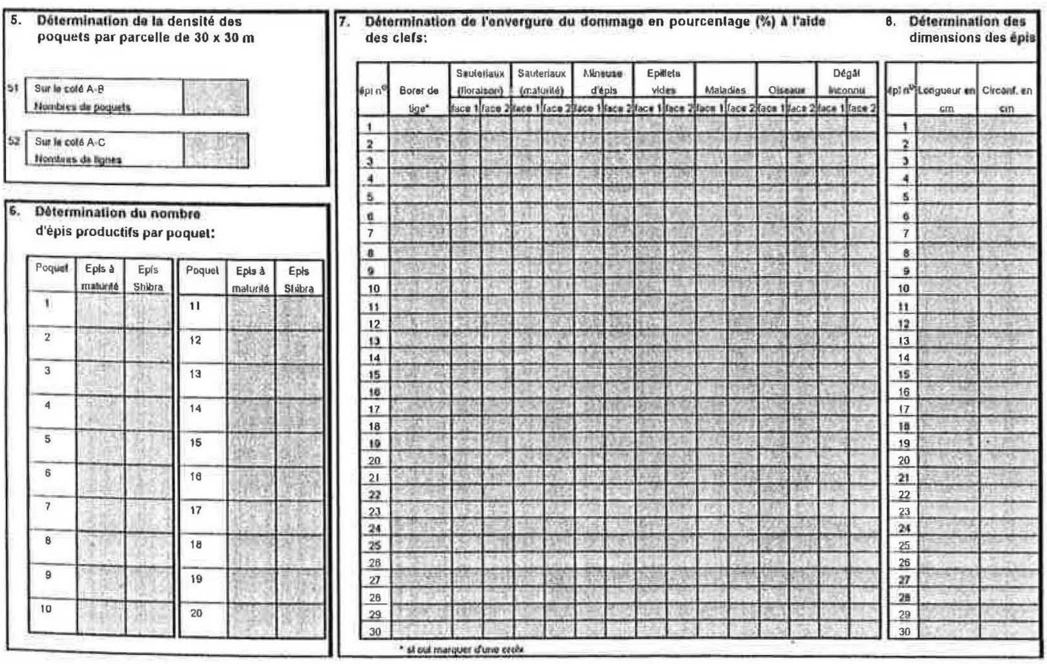


Figure 5 Observation plot; GTZ system. 30 × 30 m plot shows plant rows (1–21) schematically, with the position of sample pockets (a–t) shown along two diagonals



5. Détermination de la densité des poquets par parcelle de 30 x 30 m

51	Sur le coté A-B Nombres de poquets	
52	Sur le coté A-C Nombres de lignes	

6. Détermination du nombre d'épis productifs par poquet:

Poquet	Epis à maturité	Epis Shibra	Poquet	Epis à maturité	Epis Shibra
1			11		
2			12		
3			13		
4			14		
5			15		
6			16		
7			17		
8			18		
9			19		
10			20		

7. Détermination de l'envergure du dommage en pourcentage (%) à l'aide des clefs:

épi n°	Borer de tige*	Sauteriaux (floraison)		Sauteriaux (maturité)		Mineuse d'épis		Epillets vides		Maladies		Oiseaux		Dégât inconnu	
		face 1	face 2	face 1	face 2	face 1	face 2	face 1	face 2	face 1	face 2	face 1	face 2	face 1	face 2
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															
21															
22															
23															
24															
25															
26															
27															
28															
29															
30															

* si oui marquer d'une croix

8. Détermination des dimensions des épis

épi n°	Longueur en cm	Circonf. en cm
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		

Figure 6 GTZ Pocket and head density and damage assessment sheet

(In the case of plant diseases the method does not distinguish between attack by bacteria and fungi.)

All abnormal developments on the head such as excrescences (mildew), deformations of the grain (smut) and liquid secretions (ergot) are pooled under the heading, Diseases.

- Use the keys (Figure 2) to ascertain the percentage of damage attributable to the various pest categories on each head. Each key only represents one side of a millet head. Therefore examine both sides of each head separately and note the % loss noted on the data sheet (Figure 6). *Example*: The USAID used the GTZ methodology on plots in which their system was tested. An example of the data collected is given in Table 3 for 10 millet heads. To obtain the % loss on millet head #1, add 40 + 50 and divide by 2. The GTZ team also gave various loss values to the grains attacked by different pests. Thus, *Psalydolytta* in this example would take the values given in Table 3. However, late grasshopper damage to millet grains might take only half of each grain (in head # 3 the % of late grasshopper grains attacked was (10 + 15)/2=12.5% but since only half of each grain is eaten this is only 6.25%. Such data tables can be refined and modified in the light of later knowledge.

ANALYSIS

A database programme has been developed by GTZ for analysis of the data. The percentages of damage are converted into yield loss values; in the process of doing so different conversion factors depending on the cause of damage are used. For example, bird damage is treated as 100% yield loss, since the birds always remove whole seeds. Grasshoppers by contrast only feed on part of the grain when the millet is in the wax-ripe or fully ripe stage. Consequently, in this case a factor less than 100% is used. Some other factors are still being reviewed, for example, the influence of stalk borer attack on head development.

TIME AND LABOUR

The work is best carried out by pairs of observers, one making the observations and the other recording them on the questionnaire while assisting the colleague (this is important in the cases where the cause of damage is not obvious).

Experience of the method under USAID showed roughly 11 person-h were required to cover three sample plots (excluding farmer questionnaire). Translated into a day of work, two assessors should be able to complete the questionaires and cover three family farms if they limit their 30 × 30 m sample plots to one per farm. Perfect millet heads, collected for estimating the potential yield, will be obtained over a period of days from several villages.

SUMMARY

The advantages of this estimation procedure consist of the large area covered and the large number of data gathered. This allows the survey to be extensive rather than intensive. Observation errors will be counteracted to a large extent because of the large number of farmer plots sampled. Analytical procedures are simple and match the simplicity of the sampling system. The system is probably accurate enough to enable government departments to plan logistically and for farmers and government agents to analyse the effect of inputs, providing the beneficial effects are of the order of 20% or better. The method allows the effect of plant protection measures to be determined in a much more realistic way than with the aid of research-controlled trial plots, conditions of which are rarely met with in farmers' fields.

The method, however, only deals with damage to the millet head; yield loss due to pests or other agents during the development of the plant is not considered in the method, although the farmer questionnaires do provide qualitative information about yield loss in the early millet growth stages.

Table 3 Example of data collected on ten millet heads by USAID Malian project using the GTZ methodology, Mourdiah, 1991

Millet head number	Weight (g)	Millet Growth Stage/Type†	Dimensions (cm) Length	Circum.	Damage Groups (note additional damage groups) Grasshopper* Early	Late	Head miner*	*Psalydolytta*	Bird	Smut	Mildew	Other	Total*
1	37	M	21	8.6		25\30		15\20					40\50
2	27	M	15	7.9		25\20	10\0						35\20
3	37	M	17	8.3	10\5	10\15							20\25
4	15	D	19	7.3		30\20		65\52					95\90
5	18	M	20	6	30\25	40\30	5\5						75\60
6	27	M	19	7.5	20\5	20\15	5\0						45\20
7	17	M	21	7.5	90\90	6\8							96\98
8	33	LM	17	7.8	15\10	25\30	10\5						50\45
9	13	M	15	7.3	30\15	25\20	10\5						55\40
10	14	M	10	7.1	5\10	5\8							10\18

Note: * x\y represent x% grain loss on one side of millet head; y% grain loss on opposite side.
† Growth stage/types: M=mature; D=dough; LM=late milk.

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Section 5

NRI METHOD

N. D. Jago*, M. Matthews† and C. West‡

INTRODUCTION

From 1984 to 1991 (June), the Mali Millet Pest Control Project (MMPP) was involved in developing a practical system of pest management at farmer level, whilst working under the auspices of the Service National de la Protection des Végétaux (SNPV) in the cercle of Nara, north-west Mali.

Two crop-loss assessment (CLA) methods based on visual estimation of the percentage of damaged surface area of millet heads were used by the project to produce quantitative estimates of the absolute and percentage yield loss. Initially, the aggregate crop loss was determined but, in the last two years of the project, crop loss was broken down into its components by pest category. This enabled quantitative estimates to be made of the separate contributions by the major pests of millet within the project region, and to evaluate more fully the various pest control measures applied by the project. In the last two years of the project, paired 0.5 ha plots were studied on the farms of 410 pilot farmers in forty villages around Nara, Mourdiah, Dilli and Fallou. Comparison could thus be made between a treated and untreated plot, treatments consisting variously of IPM and ICM inputs (e.g. chemical fertilizer, resistant varieties, pesticide regimes, etc.).

An example of the kind of crop-loss assessment data obtained using sample plots in farmer fields is given in Table 4. Here the two 0.5 ha untreated plots provide information on crop loss due to five pest types (a–e). Mean grain weight in an undamaged candle was assessed at 37.934 g and the mean weight of grain lost to each *Heliocheilus* mine assessed at 1 g.

It was calculated that, if the sample of plant pockets and millet heads was large enough, a millet head could be used as a unit without adjustment for size. Like the other CLA methods in this handbook, however, only heads which were contributing to harvest were assessed.

In view of the very variable planting densities used by the farmers, and the great intra-plot variability, millet head samples were derived from between 40 and 60 plant pockets in a 0.5 ha subplot. Less than 40 pockets risked an unrepresentative sample; more than 60 pockets made the sampling too unwieldy in terms of time and labour.

Heads were examined as near to harvest as possible. If this is not done some losses, e.g. losses due to birds and late grasshopper attack, may be underestimated.

All harvest CLA was carried out in close liaison with the participating farmers, so that no harvest of the plot(s) took place before the relevant observations had been made.

Farmers and government officers do not require very precise crop-loss assessment methods. Crop-loss estimates are obtained in order to determine whether a village has 2,4,6,8, or 12 months of food self-sufficiency and which

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Table 4 Sample crop-loss data from NRI studies in north-west Mali, 1990

Plot	Candles in 60 pockets	Estimated weight assuming all candles undamaged (g)	GRAINS DAMAGED (a) Acridids and *Pachnoda*				(b) Meloid beetles and drought sterility				(c) Birds				Total loss (a)+(b)+(c) (candles)	(d) *Heliocheilus*		(e) *Coniesta*		TOTAL % LOSS
			Damage category* 2	3	4	5	2	3	4	5	2	3	4	5		Grain loss (g)	% of potential grain weight	% loss due to lower candle wt.	% loss due to dead hearts	
A	162	6145	5.88	2.63	2.5	4.38	6.3	6	11.3	22.8	0.9	0	0	0	62.5	33	0.54	9.79	4.32	53.15
B	239	9066	4.25	3	3.38	4.38	12	6.4	24.4	79.6	4.3	3	3.4	4	152.8	0	0	5.97	3.59	73.49

Note: * Damage category figures are calculated on the number of damaged candles with up to (2) 25%, (3) 26–50, (4) 51–75, and (5) 76–100% damage. To determine the number of damaged candle equivalents, the mid-point %, viz 12.5, 37.5, 62.5, 87.5 was taken. Category (1) is no damage. Example: in Plot A there are 5.88 candle equivalents lost in the category with up to 25% grain loss. *Heliocheilus* damage based on 1.0 g grain loss per mine

† Millet candles taken from samples of 60 pockets from untreated sample plots.

pest has caused or is about to cause major crop loss. Consequently, the NRI team decided that the grain loss on each millet head could be divided into broad loss categories – 0–0.9% loss (perfect heads); heads with 1–25% estimated loss; 25–50% loss; 50–75% loss; and losses higher than 75% up to total loss (5 categories in all (1)–(5)).

PROCEDURE
Pre-harvest millet head damage

This method depends on a visual estimation of the percentage area of damage on individual heads attributable to four types of pest (Table 4). Damage attributable to the fourth pest type, larvae of *Heliocheilus albipunctella* (de Joannis), is recorded according to the number of mines per head (at 1 g grain loss/mine). Damage due to a fifth pest, *Coniesta ignefusalis* (millet stem-borer caterpillar), can only be assessed empirically by laborious monitoring procedures carried out from germination to harvest, because loss due to dead tillers must be taken into account. This will not therefore be considered in detail here, although reference will be made to estimating its direct effect on harvestable heads. It is also proven that *Coniesta* causes crop losses which are usually of minor importance compared with that caused by other pests and that current chemical control techniques are too dangerous, too ineffective and/or to expensive to justify intervention.

Information which provides data for the estimation of some indirect yield losses (Table 5), are collected during harvest.

Table 5 *Coniesta ignefusalis* crop-loss assessment comparing perfect millet heads on stems with and without larval infestation

Head Weight S.D.(n–1)	N=	Mean Weight (g)	Grain Weight N=	Mean Weight (g)	Grain Weight/ Hd Weight (%)
Perfect heads with *Coniesta*					
15.47403	83	54.716	57	31.246	57.11
Perfect heads without *Coniesta*					
15.77301	234	52.1063	183	37.934	72.8

The method itself was assessed during the course of the NRI(ODA) Project by measuring the actual yield obtained from each trial plot using mechanical threshers. In practice, this is neither practical, safe nor essential. The potential yield is calculated from 80+ perfect millet heads while at the same time knowing the density of millet heads/0.5 ha and the number of heads in 60 sample pockets. A sample set of results is shown in Table 4.

Collection of supplementary information

A designated person with training in agricultural economics provided invaluable information on crop loss-related matters, family by family. The questions included:
What area was lost to early-season crop loss (estimated by various mutually cross-checkable answers)?

- The number of ploughs used by the family;
- The number of available hands for cultivation;
- The number of man-days spent in replanting;
- Farmer opinion on main reasons for crop loss (will include lack of labour for weeding, crop loss due to pests, loss due to rains failure). Note that farmer perception of the causes of crop loss may not always match those of the technicians.

In this way a crucial estimate can be made of the area of cultivation belonging to the village and the proportion of this which consists of permanent heavily manured fields and that which consists of 'bush' fields. The latter are usually lower yielding, non-manured and subject to crop rotation involving lengthy periods of fallow.

Selection of the observation plots

A minimum of five farms per village is probably required to give data for CLA. Under the NRI Project, each farmer provided one 0.5 ha plot which received pesticide and/or fertilizer applications etc., while a second, adjacent plot (separated by a clear strip) acted as a control with no treatment. In the following sections all references to the appropriate number of samples, and the descriptions of the procedure for the selection of sample pockets and heads, are based on the assumption that each plot is 0.5 ha (as near to 71 m × 71 m as practicable), but the procedures can be readily adapted to allow the method to be applied on a different scale. If treatment is not being assessed, only a single 0.5 ha sub-plot will be required.

The sub-plots were marked out as rectangular areas within the farm (e.g. 50 × 100 or 71 × 71 or 55 × 91) depending on the space available. A length of knotted string could be used to measure the sides; alternatively sides could be paced out (in this a hand tally counter is a useful tool).

The sample plots should be chosen to be representative of village fields and bush fields (for definition see Jago, 1993).

Determination of crop density

Assume a field of the dimensions indicated in Figure 7 and as nearly square as possible.

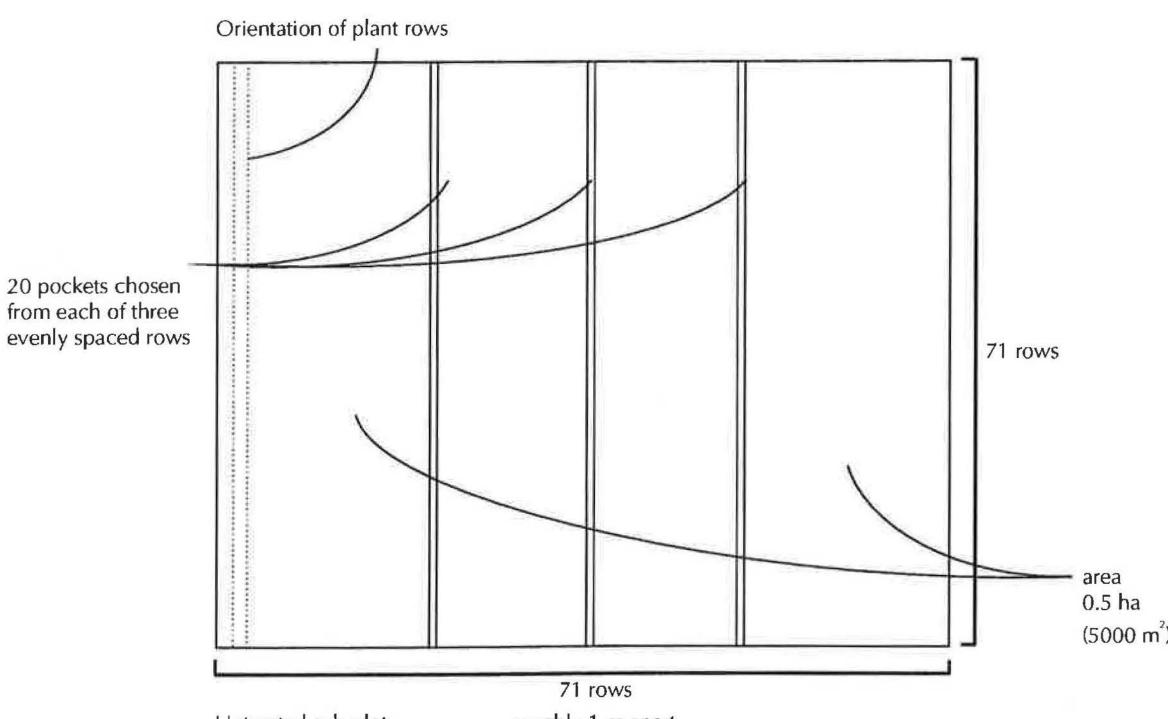

Figure 7 NRI sub-plot layout for crop-loss assessment

(1) Count the number of rows in the sub-plot. Choose three evenly spaced rows, which will provide head samples.
(2) Walk along the first of these rows and count the number of plant pockets. Pockets are usually less then 1 m apart; so in a 71 × 71 m sub-plot the number of pockets in a row might be 80. Divide this pocket number by 21 to get the interval between pockets to be used for head samples (in this example 80/21=3.81). In most cases the samples will be taken from every third or fourth pocket, starting with the pocket three or four pockets in from the field edge.
(3) With string, tie together the stems bearing harvestable heads. Count the heads in each pocket and make a note of the number. Make sure 20 pockets have been tied in this way.
(4) Repeat the procedure for the other two rows. Sixty pockets should now have been tied.
(5) Walk diagonally through the field and take 80 perfect millet heads. Alternatively, if the field has suffered light damage, these may be taken from the 60 sample pockets. Take the 80 perfect candles randomly regardless of size.
(6) Count the number of heads in the 60 pocket samples.
(7) Examine the damage on the heads from the 60 pockets.
(8) Estimate the grain weight on the perfect heads.

At this stage, if the farmer and his family are very short of grain, the sub-plot can be harvested, it being strictly understood that the tied pockets are to be left untouched. Grain from these is returned to the farmer later.

The recording of crop density can be completed within 30 minutes if two people are available; one paces out the distance along and across the rows while counting the rows. The second follows behind counting the number of heads and tying together the stems of the plants in the 60 pockets to be used later for head damage assessment. Adjust the distance walked both along and between rows according to the shape and size of the plot. As a further check pace out the length of all four sides of the plot and record the length of each side individually.

Calculation 1. Crop density/0.5 ha

estimated pocket density (N_1)	=	Mean no. pockets/row from the 3 rows counted	×	no. rows/plot

Calculation 2. Head density/0.5 ha

estimated head density (N_2)	=	estimated pocket density (N_1)	×	Mean no. heads/pocket (from the 60 pockets demarcated for CLA)

If the plot is an irregular shape, or there are areas with large numbers of missing pockets and/or the rows do not run parallel to the edge of the plot, it is more appropriate to divide off several sections of the plot and count all the pockets within that area. The total number of pockets per plot will be the product of the number of pockets in the section and the ratio of section to the total plot area.

Potential yield

The perfect candles may be allowed to dry further or be processed immediately. If they have been cut shortly after heavy rain, sun drying may be essential. As shown in Table 5, grain weight is 60–70% of candle weight. *Depending on the time available and accuracy required, choose one of the following methods of determining grain weight (W_1–W_{4b} using whole candles; W_5–W_{8b} using peeled grains), using a spring balance (accurate to 5 g) suspended from the branch of a tree.* The flow chart (Figure 8) shows the methods listed below schematically.

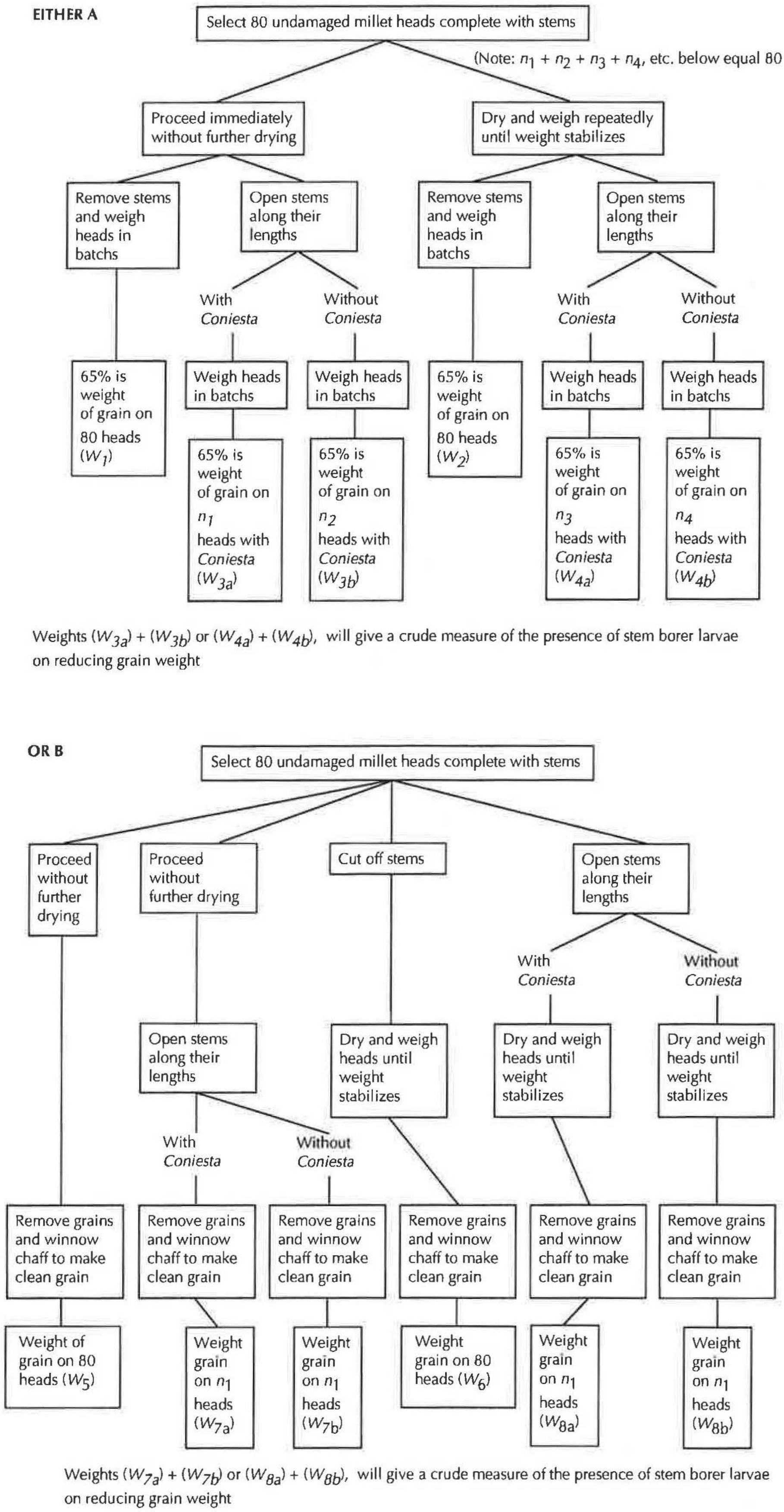

Figure 8 Flow chart showing the steps in estimation of potential millet yield

Millet heads should be cut with 0.5 cm of stem attached. To weigh heads tie in bunches and weigh in batches.

W_1 No further drying; weigh whole heads and take 65% as grain weight.

W_2 Allow heads to dry and weigh repeatedly over several days till no further weight loss detected. Take 65% as weight of grain.

W_3 As in W_1, but as each head harvested divide heads into two groups:
(a) on stem with stem borer (W_{3a})
(b) on stem without stem borer (W_{3b}).
This will give a crude estimate of grain loss in the millet head due to presence of stem borers from among 80 heads.

W_4 As W_2 but with and without stem-borer groupings giving W_{4a} and W_{4b}.

W_5 Examine immediately. Peel grain from each candle and winnow chaff. Weigh grain (using small weighed light cotton bag).

W_6 Examine after period of drying (as in W_2). Peel grain and winnow chaff. Weigh grain as in W_5.

W_7 Separate heads as they are harvested as in W_3 (with (a) and without (b) stem borer). Proceed without further drying immediately with W_{7a} and W_{7b} as in W_5.

W_8 Separate heads as in W_7 but dry thoroughly. Produce two sets of head weights W_{8a} and W_{8b}, with and without stem borers.

Accuracy increases from W_1 to W_{8a}. In general W_1 may be expected to overestimate potential yield, while W_7 and W_8 give a CLA element due to stem borer. *The method of calculating potential harvest should be cited to avoid criticism.*

Calculation 3. Potential harvest/0.5 ha

Potential yield/0.5 ha = (Estimated grain weight in 80 heads)/80 × estimated no. heads/0.5 ha (N_2)

Head damage assessment

This is now carried out on the 60 sample pockets. Use the data recording Data Sheet 5 (Figure 9).

(1) For each pocket record the following information during the harvesting of the pockets:

- The total number of stems per pocket;
- The number of dead hearts;
- The number of stems with immature, aborted and wild type-*shibra* heads;
- The number of normal, harvestable heads.

Of these, record:

- The number of perfect heads with stems (category 1) infested by *Coniesta ignefusalis* (Hampson);
- The number of perfect heads with stems without *Coniesta ignefusalis* (Hampson) infestation;
- The number of damaged heads with stems (categories 2–5) infested by *Coniesta ignefusalis* (Hampson);
- The number of damaged heads with stems without *Coniesta ignefusalis* (Hampson) infestation (see data entry sheet in Figure 9). This pocket information is used to calculate the mean number of stems per pocket and the mean number of harvestable heads per pocket; it can also be used to estimate the effect of stem-borer larvae on head weight and to give a measure of the percentage of stems infested by these insects. The larvae are discovered by slitting the sample stems longitudinally with a sharp knife.

(2) Now sort the severed millet heads for grain loss, pest type by pest type. The candles can be pooled. The assessment is not pocket by pocket (see Figure 10). The following four damage categories are used to categorize grain loss:

						DATA SHEET 5		
Zone			Village					
Farmer No.		Farmer Name:						Date:
Plot No.	Total	Dead	*Shibra*	Harvestable	Coniesta (presence or absence) among			
Plant Pocket	stems	hearts	millet heads	millet heads	harvestable heads			
					Undamaged Head group		Damaged Head group	
					Present	Absent	Present	Absent
1 31								
2 32								
3 33								
4 34								
5 35								
etc.,etc.,								
to								
28 58								
29 59								
30 60								
Total	*173*	*8*	*3*	*162*	*4*	*20*	*78*	*45*
Data in Total section based on actual counts from untreated plot at Mourdiah, North-West Mali 4 October 1990								

Figure 9 NRI plant pocket data sheet showing sample of actual totals

															DATA SHEET 6				
	HEAD DAMAGE DATA SHEET															Date :			
	Zone			Village															
	Farmer No.			Farmer Name:															
	Grasshopper + Pachnoda				Meloids + drought				Bird				Fungal pathogens				Millet head-miner		
Damage category	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5	**1**	**2–3**	**4+**
[insert ticks in																			
appropriate																			
columns]																			
TOTAL																			
[for categories of damage see text: for calculation of missing millet head equivalents use mid-point in each category]																			

Figure 10 NRI head damage data sheet

Category 2 1–25% grain loss;
Category 3 26–50% grain loss;
Category 4 51–75% grain loss;
Category 5 76–100% grain loss.

- Put aside all the undamaged candles (check Data Sheet 5 in Figure 9);
- Take all the damaged candles and start grain loss estimates by pest group. The NRI system divides heads with pest damage into four main categories (2–5) (see Data Sheet 6 in Figure 10). These are:
  (a) grasshopper and *Pachnoda*;
  (b) meloid beetles and drought-related sterility;
  (c) bird;
  (d) fungal pathogens;
  (e) millet head-miner (*Heliocheilus*).

These categories are easy to separate from each other, whereas (see Section 2, pp. 9–13), separating grasshopper damage from that caused by *Pachnoda*, for example, can only be achieved after considerable training. Moreover, in practice, whether damage has been caused principally by *Pachnoda* or by grasshoppers can usually be inferred from observation of the pests in the fields during the growing season (in the simplest case, if *Pachnoda* was absent, the damage can be attributed to grasshoppers). Similarly, damage caused by meloid beetles can be easily inferred when the plot has received good rainfall and/or has been heavily infested with meloids throughout the flowering period. It is economically less important to know whether sterile flowers were caused by meloids or by drought, than to know when meloids are reaching a density threshold in the crop which justifies intervention and subsequently to recognize meloid damage when we analyse whether intervention has reduced the crop loss sufficiently to have justified the expense.

- Sort the damaged heads according to the percentage grain loss attributable to attack by grasshoppers and the scarab beetles *Pachnoda interrupta* (Olivier). Return the heads to a heap for assessing damage caused by the next pest type.
- Sort the damaged heads according to the percentage grain loss attributable to meloid beetles and/or drought causing sterility. Return the heads to a heap for assessing damage caused by the next pest type.
- Sort the damaged heads according to the percentage grain loss attributable to birds. Return the heads to a heap for assessing damage caused by the next pest type.
- Sort the damaged heads according to the percentage grain loss attributable to fungi (smuts, mildew, etc). Return the heads to a heap for assessing damage caused by the next pest type.
- Sort the damaged heads according to the mines produced by *Heliocheilus albipunctella*. Record damage due to the presence of *H. albipunctella* larvae according to the number of mines per head as follows:

Category 1 1 mine;
Category 2 2–3 mines;
Category 3 4+ mines.

You will have now finished the data collection.

Record the number of heads in each damage category for each pest type by inserting a tick into the correct column. At the end of the assessment add up all the ticks in each column, e.g. say 30 in damage category 4 for grasshoppers and *Pachnoda* beetles. (Note: For research CLA rather than operational CLA, it will be necessary to retain the data in stratified form (e.g., to give data head by head and pocket by pocket). This allows an analysis of the variation in the estimated percentage loss at several levels (e.g. among and between plots within a zone and between different zones) and facilitates the identification of the level at which the greatest variation occurs. If necessary, the sample size may subsequently be increased at this level.)

If a rapid assessment of loss is required and no account is to be taken of the variation among and between levels, simply record the total number of candles in each pest/damage category for each plot.

Analysis

Yield losses attributable to each direct pest type

The proportion of heads recorded in each damage category and the mid-point for each damage category are used to calculate a value for the 'mean' percentage damage attributable to each pest category (see Table 4) in terms of lost candle equivalents. The amount of grain destroyed per plot by grasshoppers and *P. interrupta*, meloids and drought, birds, and fungi is calculated using the 'mean' percentage damage for each category and the harvested yield.

Calculation 4. Total number of heads 'lost' per plot to each pest category

Example: The counts showed that the following damage had been caused by grasshoppers and *Pachnoda* beetles.

The number of harvestable candles has been counted in the 60 pockets and found to be 800. Then

Category*	2	3	4	5
No. of millet heads in the damage category	225	160	115	70

*(2) 1–25% = 12.5%; (3) 26–50% = 37.5%; (4) 51–75% = 62.5%; (5) 76–100% = 87.5%.

Assuming a 'normal' distribution of percentage damage within each class, the midpoint can be used to calculate the number of candle equivalents lost in each category, (e.g. in category 2 this is 225 × 0.125 = 28.125).

	2	3	4	5
No. of lost candle equivalents	28.125	60.000	71.875	61.250

Adding the category totals together gives the total number of 'heads' lost due to grasshopper/*Pachnoda*

221.25 millet heads

Calculation 5. The percentage loss for each pest type

Example: Using the example in calculation 4, the percentage loss of harvestable candles is given by

$$\frac{\text{Total number of 'lost' heads}}{\text{Estimated number of heads per plot}} \times 100$$

that is: (221.25)/800 × 100 = 27.66%

Calculation 6: Grain yield loss attributable to each pest type in 0.5 ha

Potential harvest in 0.5 ha = Yield for the plot had it not been attacked by the pest ('Unattacked' Yield) × Estimated % loss in 60-pocket sample.

Example: 85 undamaged heads had a grain weight of 3450 grams or 3.450 kg. The 0.5 ha sub-plot has been estimated to contain 80 550 heads. Therefore potential harvest for the subplot is

(80 550) × (3.450/85) = 3267.35 kg.

In this example, grain loss in 0.5 ha due to grasshoppers and *Pachnoda* beetles is given by

3267.35 × 0.2766 = 903.75 kg.

Estimates of losses due to *H. albipunctella* larvae

Previous estimates of the amount of grain destroyed by *H. albipunctella* larvae have shown that the loss in grain weight increased with grain size and varied from 0.4–1.0 g for a mean yield of 34 g per panicle (Guevremont, 1983; in Nwanze, 1988). Assuming that each mine accounts for the loss of 1 g grain per head, estimates of yield loss due to *H. albipunctella* are calculated from the density of mines (larvae) per plot as in Calculation 7.

Calculation 7. Total density of H. albipunctella *mines (larvae) in 60-pocket sample: estimate of weight lost in 60 pocket plot:*

Example:	Damage Category	1	2	3
		1 mine	2–3 mines	4+mines
No. of millet heads in each damage category		210	140	96

These counts were derived from 60 pockets with 800 heads. It is assumed that heads with one visible mine supported one larva, those with 2–3 visible mines supported on average 2.5 larvae, and those with four or more mines supported four larvae.

Grain weight loss (g) in each damage class	1	2.5	4
Grain weight loss in 60-pocket sample (g)	210	350	384
Total grain loss in 60 pockets (kg)			0.952
Therefore, grain loss in 0.5 ha (80 550 pockets)(kg)			1278.06
Estimated potential yield in 0.5 ha (kg) (80 550 pockets)			3267.35
% grain loss in this example attributable to *Heliocheilus albipunctella*			39.12%

Yield losses attributable to indirect causes

Only the losses due to *Coniesta ignefusalis* will be considered here. Other indirect crop losses, such as that due to weed competition are equally difficult to assess. The direct effect of larvae in the stem have already been considered using the weights of undamaged millet heads (see Tables 4 and 5, and Figure 8). The lost grain (in kg) can be calculated from the percentage loss and the potential yield (based on whole millet heads). Unfortunately, this assessment underestimates the losses due to *Coniesta* because it ignores the effect of early season attack. This destroys the growing points of tillers which would have been able to give millet candles ('dead-hearts').

Two methods of assessing the effect of dead-hearts will be considered:

(1) Knowing the grain harvest yield from the sample plot.

The yield loss attributable to dead-hearts is calculated as the product of the mean density of dead-hearts in the plot (using data from Data Sheet 5 (Figure 9) and stem density/ha) and the mean yield per harvestable head. The mean yield of a harvestable head is calculated from the plot yield and the mean number of harvestable heads per plot.

Calculation 8. Loss attributable to dead-hearts per plot

Mean density of dead-hearts/plot × (Plot yield/mean number of dead hearts harvestable heads for the plot)

The losses due to non-harvestable heads (immature, aborted and wild-type *shibra* heads) is calculated as above using the mean density of non-harvestable heads per plot and the mean yield per harvestable head.

(2) Without knowing the actual grain harvest yield plot.

Calculation 9. The sample in Data Sheet 5 (Figure 9) shows that eight dead-hearts occur in a sample of 173 stems from 60 pockets, i.e. 4.62% Assuming all the dead-hearts would have produced harvestable heads, in our example the potential yield being (see Calculation 6) 3267.35 kg/0.5 ha, the loss due to 'dead-hearts' (at harvest) will be 150.95 kg/0.5 ha.

Time and labour

Experience has shown that a small team of two or three people working together can complete three assessments per day (one village maximum). This assumes that the material is dry enough for grain weight assessment to be valid. The process of harvesting and assessment might have to be done as separate exercises in order to give sufficient time for millet heads to be hung and drying completed. This means that a village assessment requires between 4 and 6 man-days for completion.

Summary

Assumptions underlying the calculation of the yield loss estimate and the implications for the accuracy of the loss estimate

There are several assumptions underlying the calculation of yield loss, using the methods as they are here described, which will affect the accuracy of the yield loss estimates.

Direct losses

(1) The use of range mid-points as the imputed values for each damage category.

In each damage category the mid-point between the lowest and highest class value is used as an estimate of the mean % damage in the class. For example, in category 1–25%, the imputed mean value is 12.5%. However, if the distribution of actual % loss within in each category is skewed the use of the range mid-point is inappropriate; an imputed value closer to one end of the class range would be a better estimate of the actual class mean.

(2) The use of a larger number of damage classes throughout the method (for example, see the GTZ method) would limit the degree of error introduced by the use of mid-point values and/or facilitate the calculation of adjusted class means.

(3) Alternatively, examination of a sample of heads in each damage class (e.g., 0–25%) and classification of the actual percentage damage on a more 'precise' scale would provide information about the underlying distribution of percentage loss in each class. If the distribution of loss in a category is shown to be skewed it may be more appropriate to use the modal value than the range mid-point.

(4) In situations where an accurate measurement of yield loss is required it is possible to calibrate the percentage damaged surface area/percentage grain loss relationship for each damage/pest category (see Appendix 5.1).

If these modifications to the calculation steps are adopted the direct yield loss estimates produced will still be inaccurate because of a second assumption underlying the method, that of additivity. The method as described assumes that direct losses attributable to each pest category are additive. On the basis of this assumption it is possible to produce estimates for the total percentage yield loss in excess of 100% which obviously represents an overestimate of actual yield loss. It is not possible to quantify, nor to adjust for, the error which is introduced by making this assumption.

Indirect losses

The indirect yield loss estimates are based on various assumptions.

(1) Non-harvestable heads and heads lost to dead-hearts are assumed to yield the same as an average harvestable head. This may overestimate yield loss if the

heads were lost from pockets with a relatively large number of harvestable heads.
(2) Every dead-heart is assumed to represent a lost harvestable millet head. Work in progress (Jago, in prep.) indicates that of the total stems (tillers other than dead-hearts) produced during a season only 30–40% reach harvest. Furthermore, of these only 80–95% produce harvestable candles. In aggregate this may mean that, although total dead-hearts produced during the season may represent 15–35% of the stems at harvest, in terms of lost millet heads they represent only 4–8.5%. On this basis, a count of dead-hearts at harvest, and a loss of millet heads on a 1:1 basis, will give an over-estimate of crop loss due to *Coniesta*.
(3) No dead-heart tillers are assumed lost during the season. Analysis of data (Jago, in prep.) shows that this is clearly not the case. The biggest dead-heart production occurs early in the season. By the end of season 60–70% of all dead-hearts have disappeared and are thus missed at harvest. They are probably lost to scavengers (e.g. millipedes). Harvest counts in this case lead to an under-estimate of crop loss due to *Coniesta*.

Post-harvest millet head damage

Data collection

This method has been used to produce an estimate of global percentage loss in which no attempt is made to identify the pest type(s) causing the observed damage. There is no pre-harvest sampling of heads or collection of additional pocket information: the sample of heads is taken from harvest piles. The calculation steps are, in principal, similar to those of the pre-harvest method, however, there is no attempt to quantify indirect yield loss. The method is rapid both in terms of the collection of sample heads and damage evaluation.

Comparison of the yield loss estimates produced by the pre- and post-harvest estimates respectively shows there is a significant relationship between the two which allows conversion of post-harvest estimates to a pre-harvest equivalent.

Randomly select 50 heads from the piles of harvested millet. Sort the heads according to the degree of pest attack and record the numbers of heads in each of the following damage categories:
Category 2 1–25% grain loss;
Category 3 26–50% grain loss;
Category 4 51–75% grain loss;
Category 5 76–100% grain loss.

Table 6 Post-harvest crop-loss assessment. Actual data based on harvested millet heads, Mourdiah, north-west Mali, 1990

	Candle Counts (sample of 50)					
	SITE 1			SITE 2		
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Damage Category (1–5)						
1 Undamaged	10	7	2	3	0	0
2 1–25% (12.5%)	33	34	28	19	21	30
3 26–50% (37.5%)	7	6	8	6	10	12
4 51–75% (62.5%)	0	2	7	12	10	7
5 76–100% (87.5%)	0	1	5	11	9	1
Total loss of grain in candle equivalents	6.75	8.63	15.25	21.63	20.5	13.5
% LOSS	13.5	17.25	33.29	43.96	42.3	23.7
Loss due to *Coniesta* %	2.43	3.01	9.79	2.73	4.47	5.97
TOTAL % CROP LOSS	15.95	20.27	43.07	47.54	46.77	34.67

Analysis

The global percentage grain loss for each plot is calculated as follows.

Proportion of sample heads in each damage category × Mean(*) % = Loss for each damage class.

* (the range mid-point for each damage category: 1–25% = 12.5; 26–50% = 37.5; 51–75% = 62.5; 76–100% = 87.5.) An example is given in Table 6.

Time and labour

Experience has shown that a small team of two or three people can complete 6 to 8 harvest samples per day, hence a maximum of two villages per day.

Summary

The yield loss estimates produced using this method are lower than those produced by the pre-harvest method at the same levels of actual damage because farmers leave severely damaged heads in the field at harvest. Consequently, the heads in harvested piles do not represent the actual range of damage occurring within the plot. At very high levels of pest attack and damage, the two damage estimates tend to converge because heads which may otherwise have been rejected are included in harvested piles.

APPENDIX 5.1 CALIBRATION OF THE DAMAGE SCALE: PERCENTAGE DAMAGE/GRAIN LOSS RELATIONSHIP

Examination of the relationship requires a sample of (a) undamaged heads (category 1) and (b) pure damage heads, i.e. heads in each damage class with damage attributable to a single pest category only. Undamaged heads are treated as a control against which the mean weight of heads in each damage class is compared.

It is important that the heads used in the analysis are representative of those found in the survey area; the collection of heads should not be restricted to a small proportion of the survey area.

If several distinct zones with differing yield potential due to factors such as the amount and distribution of rainfall are included in the study, samples of heads should be taken from each zone and analysed separately. ANOVA should be used to examine whether or not the calculated percentage grain loss in a particular damage class is significantly different between the zones. If not, the samples can be pooled.

The number of undamaged heads required will depend on the variation in head weights within the survey area. Similarly, the number of heads in each damage class required for calibration will depend upon the variance of the calculated % weight loss estimate and the level of error which is acceptable according to the research priorities. A minimum sample of twenty groups of heads in each damage category, with ten heads per group is suggested.

Head damage assessment

(1) Select heads with damage attributable to a single pest type (e.g. pure bird damage).

(2) Sort the heads in each pure-pest type into the following grain loss categories:

Category 2 1–25%;
Category 3 26–50%;
Category 4 51–75%;
Category 5 76–100%.

(3) If insufficient heads are available in a single pure damage category (e.g., 1–25% pure bird damage), pool the heads with (pure) damage attributable to other pest categories (e.g., 1–25% meloid/drought and 1–25% early milk-stage grasshopper damage) to provide a larger sample of heads in the damage class.
(4) For each pure-pest type (or pooled sample) weigh and record the weight of the groups of heads in each damage category. After weighing, thresh and record the weight of the grain in each damage category. Thresh heads belonging to different damage categories separately; as damage increases, the proportion of chaff/core to grain in the total head weight will increase slightly.
(5) Record the weight of individual, undamaged heads; thresh the heads and record the weight of the grain.

Analysis

A. The mean weight of grain 'lost' in each damage category is the difference between the mean weight of grain for undamaged heads and the mean weight of grain in each damage category.

$$\text{\% grain loss in each damage category of a given pest type} = \frac{\text{Mean weight of grain (Undamaged heads)} - \text{Mean weight of grain in a damage category}}{\text{Mean Weight Grain (Undamaged heads)}}$$

The calculated percentage grain loss for each damage category can be inserted in place of the mid-point for each damage class. Continue the calculation as in section 2.

B. Calibration of the damage scale: number of *H. albipunctella* mines/grain loss relationship.

Repeat the procedure as for the calibration of the damaged surface area % grain loss, using the weight of threshed grain from heads with 1, 2–3 and 4+ mines respectively.

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Section 6

THE ADJUSTED LENGTH METHOD

L. B. Coop, G. P. Dively, A. J. Dreves and B. Sidibe*

INTRODUCTION

The adjusted length method (ALM) was developed to help solve some of the common problems associated with other millet crop-loss assessment procedures. It involves the sampling of millet heads and assessment of the damage to plant pockets. It allows rapid and relatively precise estimation of direct pest damage without the need to record data for individual heads and provides a method for calculating the actual yield and pest loss without having to thresh the grain. Further, the sampling of pockets rather than individual heads reduces the bias that can occur when selecting a 'random' sample of single heads from an observation plot or post-harvest pile.

Visual estimates of pest damage are expressed as an accumulation of the lengths of damaged heads (cm) adjusted relative to a standard head diameter for each pocket sampled. The procedure provides a weighted average of data from millet heads of variable size. Significant bias and/or estimation error that occurs when pests selectively damage heads that are larger or smaller than average is avoided by this method, because damage length estimates are corrected (adjusted) for head size. Although some training is required to use the method, damage assessment using the ALM is at least as fast and efficient as other methods, which normally estimate percentage area damaged.

The field sampling of missing, aborted and harvestable pockets allows estimates of potential yield as the sum of actual yield, pest losses, stand reduction and aborted heads. The difference between estimates of actual and potential yield give an indication of combined losses from direct pests, indirect pests and abiotic factors such as drought. The underlying assumptions outlined in this method have been validated and the measurement of adjusted length has been shown to be an excellent predictor of head weight.

The ALM has been used to estimate millet yield and pest losses on a regional basis in five USAID-sponsored surveys conducted in Senegal (1983) the Gambia (1984) Chad (1987) and Mali (1990 and 1991). During this period the method has been refined to produce the version described below.

PROCEDURE

Selection of observation plots

Select fields close to the village and fields further into the 'bush' from the village. Divide each field into four equal sectors to ensure that the entire field is included in the sample (Figure 11). Draw a map of the field with the sector layout within the space provided on data form I (Figure 12).

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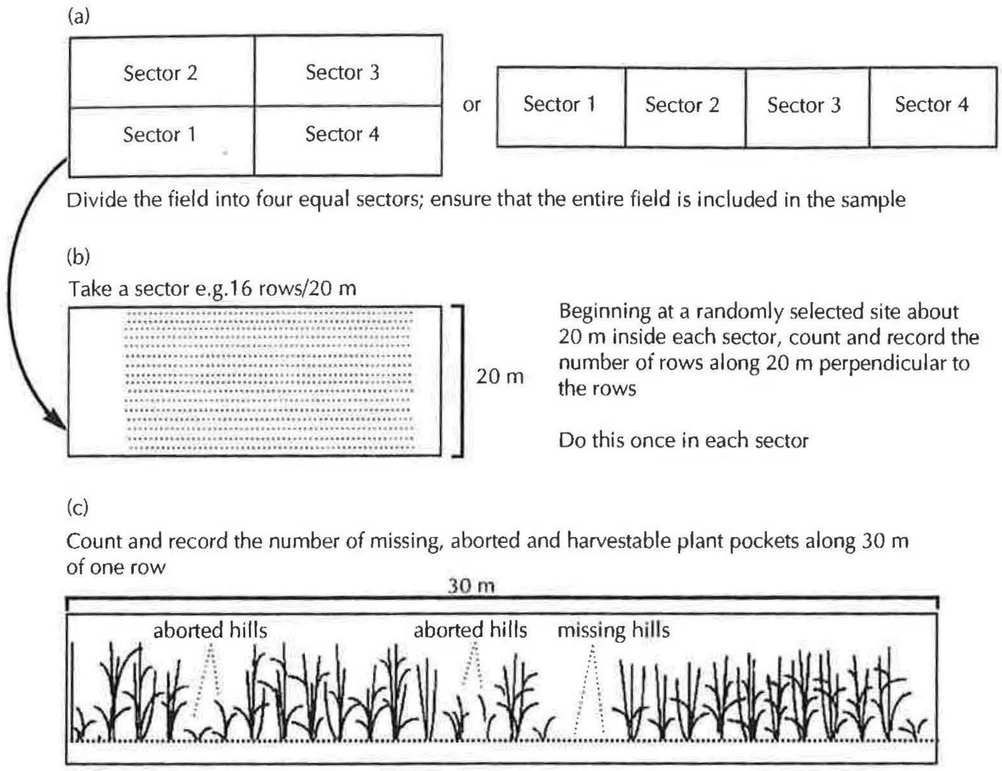


Figure 11 **(a)** Sample field layout showing sectors **(b)** Sample sector showing estimation of row numbers prior to estimation of pocket density **(c)** Estimation of pocket numbers per row

Determination of crop density

(1) Crop density data are recorded on data form 1.
Beginning at a randomly selected site about 20 m inside each sector, count and record the number of rows along 20 m perpendicular to the rows (Figure 11).

(2) At the same locations, count and record the number of harvestable, missing and aborted plant pockets along 30 m of one row (Figure 11).

- Harvestable plant pockets. These have at least one grain-forming head in the pocket.
- Missing plant pockets. These can be counted by observing gaps between regularly spaced pockets. They are caused by germination failure, seeds carried off by ants, seeds blown away by wind or early die-back due to seedling pests.
- Aborted plant pockets. These are caused by early infection by mildew, the Millet-Stem borer (*Coniesta ignefusalis*), shoot flies (*Atherigona* spp.), drought or unknown causes. If aborted hills are common and a causal factor can be recognized, it should be noted in the commentary section of the data form.

Sampling scheme

(1) Movement in the field. Starting at the edge of the field move about 20 m into the field. Select the nearest harvestable plant pocket for the first collection. Subsequent plant pockets are selected in alternating directions at 20 m intervals (Figure 13a). If the nearest plant pocket at each site contains no harvestable heads, a randomly selected nearby pocket should be chosen provided that it has harvestable heads.

The reasons for sampling plant pockets are:

- To collect heads needed for the damage assessment, and
- To make additional counts of various factors contributing to indirect loss.

L'Estimation des Pertes sur les Cultures de Mil	FICHE 1 - POQUET DATA

La Méthode de Longueur Ajustée (ALM)

N Parcelle ____ Village ____________________ Nom d'Agriculteur ____________________

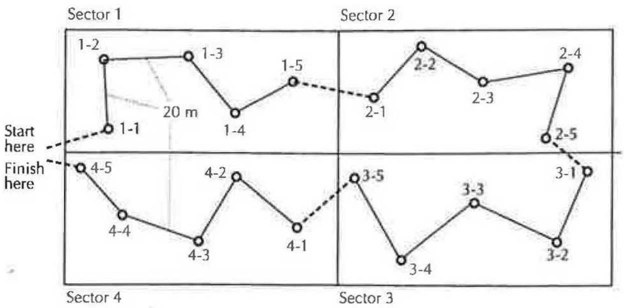
Date ___/___/___ Coll. par ____________________

		Densité des poquets				Poquet Data								
Sec teur	Poq- uet	(30 m échan./sector) bon	absent	avort	rayon /20 m	mauv herb (cote 0-2)	défoliation (cote 0-2)	Striga (cote 0-2)	Coniesta (cote 0-2)	N l'epi mature	N l'epi avort	explication (code)	N l'epi bon	autre commentair
1	1													
	2													
	3													
	4													
	5													
2	6													
	7													
	8													
	9													
	10													
3	11													
	12													
	13													
	14													
	15													
4	16													
	17													
	18													
	19													
	20													

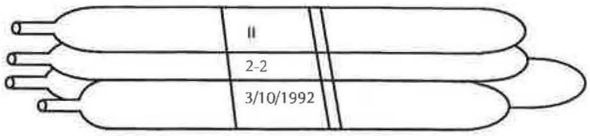
Carte de parcelle/Commentaires	Striga tige et Coniesta sortie enreg	dégré d'enherb. et relatif de défol.	la cause probable de l'avortement
	cote	*cote - pourcentage*	*code - cause*
	0 - absent	0 léger 0 - 20	CO - Coniesta (Acigona)
	1 - 1 to 5 présent	1 moy. 21 - 50	ST - Striga
	2 - > 5 présent	2 fort 51 - 100	MH - mauvaise herbe
			MD - le mildiou
			GC - facteurs génetiqués
			AT - les autres causes

Figure 12 ALM, USAID data sheet (form 1) for recording crop density data

(2) Collection of heads. Usually, plant pocket samples are best collected by a team of three; one to cut heads and make counts, one to bundle and bag heads, and one to record data and label heads.



Starting at the edge of the field move about 20 m into it. Select the nearest harvestable plant pocket for the first collection. Subsequent plant pockets are selected in alternating directions at 20 m intervals.



Label each bundle of heads with sector and pocket number.

Figure 13 **(a)** Random selection of plant pockets in four sectors for millet head samples **(b)** Head samples collected into a bundle labelled with sector number (2) plant hill (2) on 3 October 1992

At each plant pocket selected for sampling, locate and cut all harvestable heads at their base. Bundle the heads together with masking tape or string and label the bundle according to the sector and pocket sample number (Figure 13b). In addition, the collection date and the field number should be recorded on the label for easy identification later during damage assessment.

- Count and record the numbers of harvestable, aborted and immature heads in the pocket.
- For each aborted head, carefully examine the plant to determine the cause of abortion. Refer to the manual section concerning damage recognition and use the codes noted in the legend of the data form to record the suspected causes. These include the Millet Stem-borer, *Striga hermonthica*, competition by other weeds, mildew, genetic factors (i.e. *shibra* heads), and other causes (including drought, lack of nutrients and within plant competition) and unknown causes.

Collection of supplementary information

At each plant pocket, additional counts are made to help determine causes of crop loss as follows.

- Record the relative weed abundance (grass and broad-leaved weeds combined) using a rating from 0 to 2 according to percentage coverage of the soil in a diameter of 1m surrounding the plant pocket.

Percentage (%)	Description	Rating
0–20	light	0
21–50	medium	1
51–100	heavy	2

- Record *S. hermonthica* abundance as follows: '0' if no stems are present in the 1m surrounding the plant pocket, '1' if 1–5 stems are present and '2' if 6 or more stems are present.
- Record Millet Stem-borer abundance as follows: '0' if no exit holes are found, '1' if 1–5 exit holes are found, and '2' if 6 or more exit holes are found.

- Record the relative percentage of defoliation caused by grasshoppers and/or other leaf-feeding pests. The same scale as given for percentage weed coverage should be used.
- Collect additional survey information for each field surveyed regarding source of seed, planting and cultivation of the crop, pest damage history, pesticide and other field treatments. The accessory survey form (form 3; Figure 1) should be filled out during an interview with each farmer participating in the survey. These data need not be analysed statistically, but they will help in the interpretation of the crop-loss assessment results.

Yield measurement

(1) Collection of undamaged heads
At the same time as the sampling of plant pockets a collection of undamaged but representative heads may be made. These heads are used to determine the relative weights of grain, chaff (glumes, spikelets, awns, etc.), and core (rachis). In each sector, select six heads at random which have no pest damage evident on the surface of the grain. Bundle and label these as undamaged heads. Include the date and field number on the label.

(2) Weighting factors
Certain pests, such as flower-feeding insects, birds, and grasshoppers feeding at the flower and early milk stages destroy all of the grain when feeding. This grain is consequently 'lost' and does not contribute to the weight of the head. However, grasshoppers feeding during the late milk and dough stages damage only a portion of the kernel; some of the grain weight remains and adds to the total head weight. Weighting factors are used in the calculation steps to correct for this 'partial loss'. (For dough stage grasshopper damage, about 53% of the grain weight remains, so a weighting factor of 0.53 (WF-LATEGH) is used.)

Kernels affected by smut have about 40% of the grain weight of undamaged kernels, so a weighting factor of 0.4 (WF-SMUT) is used in the calculations.

The Millet Head-miner loosens about half the chaff of the damaged grain. A factor of 0.5 for the chaff portion of the head weight is then used for the Millet Head-miner (WF-MINER).

In the case of pests removing all the grain no correction factor is required. No correction factor is required for compensation by surviving grains which may fill out parts of damaged areas.

Another type of weighting factor is used to account for the relative weight of the grain, chaff, and core portions of the head. These are either determined for each field assessed or are assumed to be very close to standard values published for a given variety, region, yield potential, or other variable which is related to head component weights. Note that the proportion grain weight of heads is reduced by factors such as early harvest or drought. The proportions of grain, chaff, and core relative to the head weight are independent of the head length. To determine relative weights of head components proceed as follows.

- Allow the sample of undamaged heads to dry for several days
- Weigh all the heads together
- Remove all grain and chaff from cores by hand
- Thresh the grain by the traditional mortar and pestle method and winnow to remove chaff from grain
- Weigh both the grain and the cores
- Subtract grain and core weights from whole head weights to obtain chaff weights
- Divide individual component weights by the whole head weights to obtain component proportion weights. The proportion grain weight will be used later for calculations
- Divide the proportion grain and chaff weight by the proportion core weight to obtain the relative weighting factors. The core weighting factor is assigned a value of 1.0.

Table 7 Examples of head component weight proportions and relative weight factors for short cycle (*souna*) millet, for grain (RWGN), chaff (RWCF) and core (RWCR) (survey averages)

Region	Year	No. of fields	Average yield kg/ha	Weight Proportion Grain	Chaff	Core	Relative Weighting Factor Grain RWGN	Chaff RWCF	Core RWCR
Senegal	1983	42	800	0.74	0.21	0.05	13.1	3.7	1
Chad	1987	10	172	0.75	0.2	0.05	15.4	4	1
Mali	1990	32	556	0.7	0.25	0.05	14	5	1
Senegal 1983 and Mali 1990 results pooled by yield categories:									
			<300	0.62	0.33	0.05	11.4	6.1	1
			300 to 600	0.68	0.29	0.04	18.4	7.7	1
			>600	0.72	0.25	0.03	21.1	7.3	1

See Table 7 for some example head component weight proportions and relative weighting factors from several ALM surveys conducted for short cycle millet (*souna*) in West Africa.

(3) Yield per plant pocket
The estimated actual yield per plant pocket is the product of the average weight of the undamaged portion of candles and the proportion of the head weight which is attributable to the grain (see Equation 4).

The weight of the undamaged portion of candles is calculated by adjusting the total weight of candles using the equations below. The equations use the total adjusted head length, the adjusted damage length for each pest and the correction terms described above which include the weighting factors for smut, *H. albipunctella* and late grasshopper damage. There can also be other pests which either remove chaff or leave a portion of the grain.

Equation 1.

Weight of undamaged portion of heads = Weight of all heads × Undamaged relative weight/Total relative weight

The total relative weight is the sum of all head component adjusted lengths (core, chaff, and grain) multiplied by their respective weighting factors:

Equation 2.

Total Relative weight = (total length of all heads × RWCR)
+ (total length of all heads × RWCF)
– (length of head borer damage × WF-MINER × RWCF)
+ (length of undamaged portion of heads × RWGN)
+ (length of smut damage × WF-SMUT × RWGN)
+ (length of late grasshopper damage × WF-LATEGH × RWGN.

The undamaged relative weight is simply the undamaged length of heads (obtained from the total head length minus the total damage length from all pests) times each weighting factor:

Equation 3.

Undamaged Relative weight = (undamaged length of all heads × RWCR)
+ (undamaged length of all heads × RWCF)
+ (undamaged length of all heads × RWGN)

The undamaged length is the total candle length minus the total damage length, where the total damage length is the sum of the adjusted damage lengths for all pests.

The estimated average yield per plant pocket (g) is the average weight of undamaged portion of heads (Equation 1) times the proportion of heads attributed to grain (See Table 7 and Equation 4).

Equation 4.

$$\text{Average Yield per Plant Pocket} = \text{Average Weight Undamaged Portion of Heads} \times \text{Proportion Grain Wt.}$$

(4) Yield per hectare
The number of harvestable plant pockets per square metre is equal to the average number of harvestable pockets per 30 m times the average number of rows per 20 m divided by 600. The result is multiplied by 10 000 to obtain average plant pockets/ha. This value is multiplied by the average yield/plant pocket and divided by 1000 to obtain the average yield/ha (kg). The factors 10 000/(600 × 1000) reduce to a divisor of 60:

Equation 5.

$$\text{Yield/ha} = \text{Average Yield/Plant Pocket} \times \text{Average No. Harvestable Pockets/30 m} \times \frac{\text{Average No. Rows/20 m}}{60}$$

(5) Stand reduction and yield loss due to head abortion
The samples of missing and aborted plant pockets and aborted heads counted at harvest are used to estimate corresponding yield losses. Calculations for stand reduction yield loss from missing and aborted plant pockets are similar to Equation 5.

Equation 6.

$$\text{Stand Reduction Yield Loss} = \text{Average Yield/Pocket} \times \text{Average No. Missing Pockets/30 m} \times \frac{\text{Average No. Rows/20 m}}{60}$$

Equation 7.

$$\text{Aborted Pocket Yield Loss/ha} = \text{Average Yield/Pocket} \times \text{Average No. Aborted Pockets/30 m} \times \frac{\text{Average No. Rows/20 m}}{60}$$

The total loss from aborted plants is the total of Equation 7 added to the loss from individual aborted heads which were recorded during the time of head collection. The aborted heads are assumed to yield potentially the same as an average, 'harvestable' head:

Equation 8.

$$\text{Aborted Head Yield Loss/ha} = \text{Average No. Aborted Heads/Plant Pocket} \times \frac{\text{Average Yield/ha}}{\text{Average No. Harvestable Heads/Plant Pocket}}$$

Equation 9.

$$\text{Total Aborted Yield Loss/ha} = \text{Aborted Pocket Yield Loss/ha} + \text{Aborted Head Yield Loss/ha}$$

Estimation des Pertes sur les Cultures de Mil FICHE 2 - MESURES D'EPI

La Méthode de Longueur Ajustée (ALM)

No. Parcelle _______ Village _________________________ Nom d'Agriculteur _______________

Date recolte __/__/__ Date ___/___/___ Coll. par _________________

Secteur/ Poquet #	Poquet poids (gm)	# epi	Total adj. longueur (cm)	Longueur de dégâts ajustée (cm) - Méthod de longueur ajustée									
				oiseaux	insectes floncoles	flor/lait acridiens	pateux acridiens	Helio-chelius	charbon	mildiou			

Figure 14 ALM, USAID data sheet (form 2) for recording adjusted length damage categories

Head damage assessment

The purpose of the head assessment is to know the damage caused by each pest for each sampled plant pocket. The average of the estimated yield and losses for the plant pockets will be used with the crop density estimates to determine yield and loss per hectare.

An evaluation team of 3 to 6 persons is recommended for sufficient cross-checking of damage diagnosis and estimation, and for efficient recording of data. Use Data Sheet 7 (shown in Figure 14) for recording head damage. It is helpful if symptoms of damage by all pest categories are known before assessments begins.

- Leave the head bundles to dry in a dry, well-ventilated area for several days.
- Weigh the bundle of heads from the first plant pocket using a balance. Record the weight on the data form.
- Separate and order individual heads from the bundle from the largest to the smallest diameter. The largest diameter head will be used to standardize or adjust the measured total and damage lengths in centimetres of all smaller heads.
- Measure the length of grain covering the reference head using a tape measure. Marking this length with a finger, cumulatively add the adjusted lengths of the smaller heads to get the total adjusted length for the plant pocket (Figure 15). Lengths of the small heads are adjusted according to the size of the diameter relative to the reference head. For example, if the head has a diameter that is about 70% of the diameter of the reference head then the adjusted length is only 70% of the measured length. Record the total adjusted length accumulated for all heads from the plant pocket.
- Use a tape measure or callipers to test estimates of relative head diameters. Practise this adjusted length technique many times before beginning an actual assessment. If one or more heads have the same diameter as the reference, then their lengths will not require adjustment.

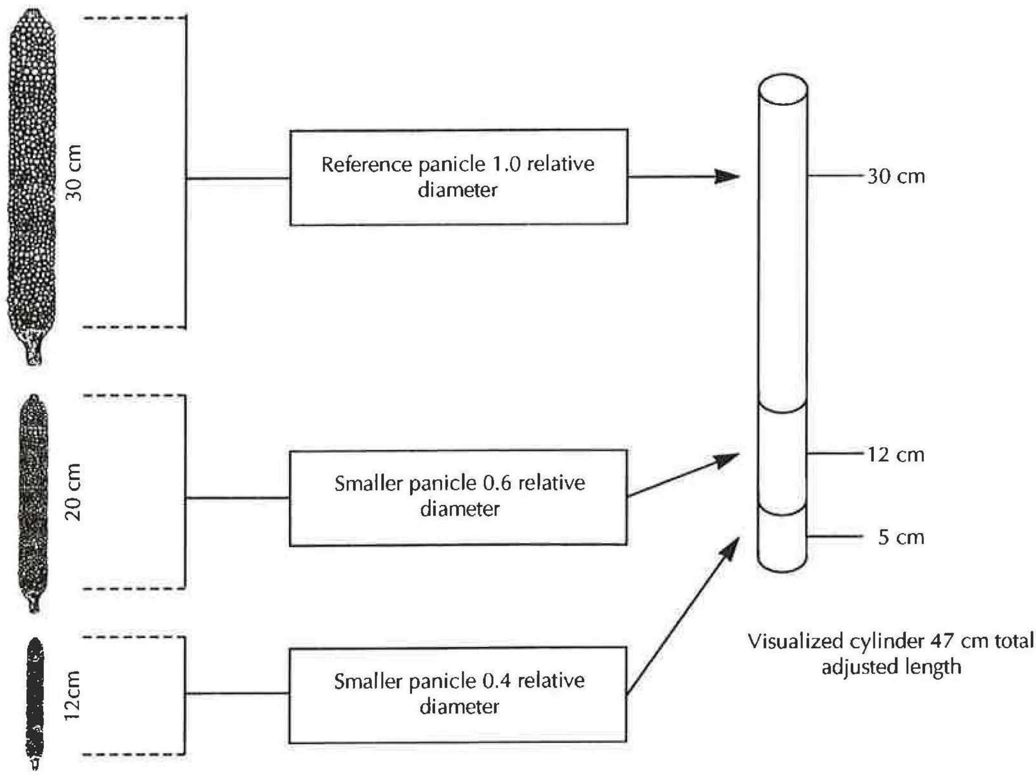


Figure 15 Example showing how the total length of the panicles at a pocket is adjusted in proportion to the relative diameter of the reference panicle

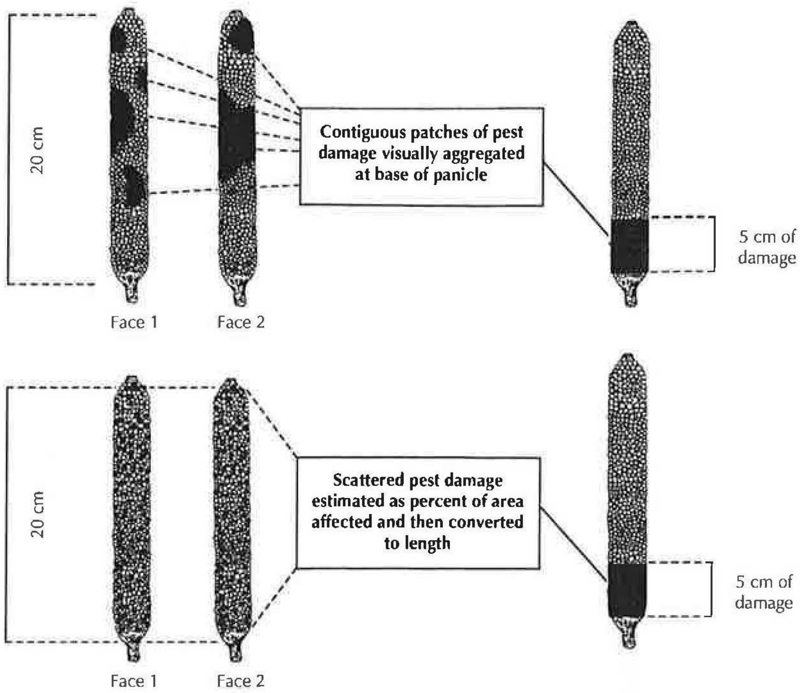


Figure 16 Examples of pest damage estimation by damage type using units of adjusted panicle length

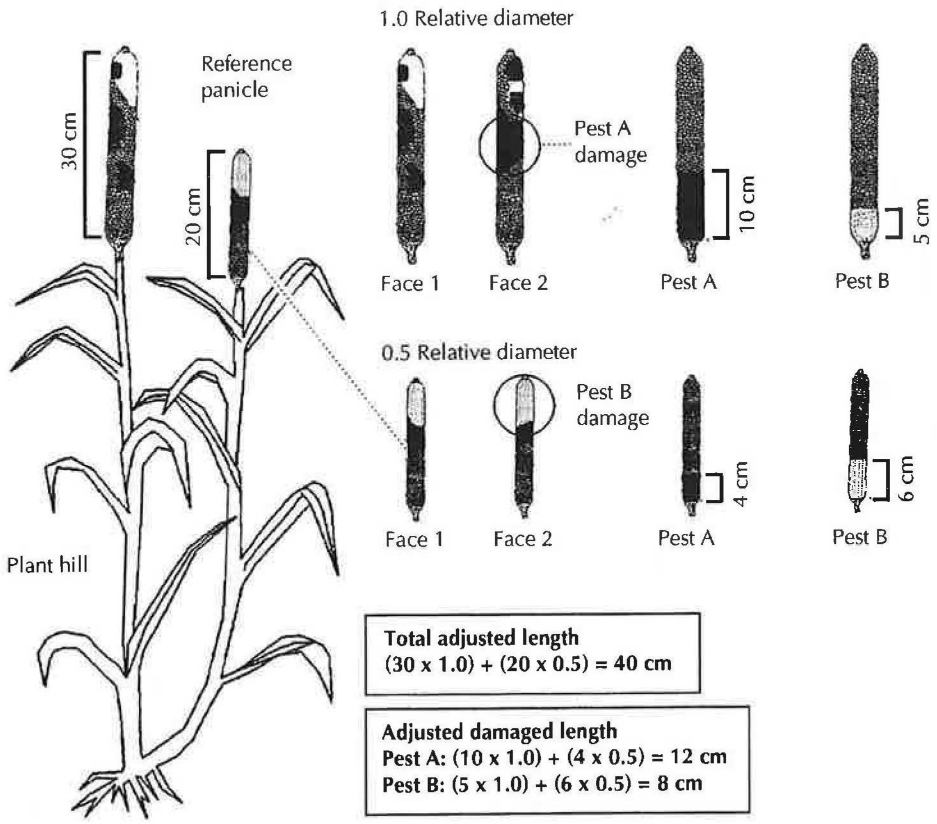


Figure 17 Example of use of adjusted length measurement records for total and damaged panicle length at a plant pocket with two types of pest damage. The damaged length caused by each pest is visually estimated by aggregating all damaged areas to form an imaginary cylindrical section at the base of the panicle. The total and undamaged lengths are adjusted in proportion to the relative diameter of the reference panicle and summed over all panicles.

- This procedure is used in a similar manner to accumulate the adjusted damage lengths for each type of direct pest. For each category, the damage is visually gathered and spread evenly around the middle of the head for estimation of the length damaged. A tape measure or calibrated string is used to help visualize and measure the damage lengths. When the damage is all located together in one or a few places on the head, the damage length may be easily measured and then adjusted with the tape (Figure 16, top). If the damage pattern is widely spread or scattered over the head, it may be difficult to visualize all of it in the same place in the middle of the head. In this case, as for example with smut damage, it may be easiest to first estimate the percentage damage and then convert this to the length of damage (Figure 16, bottom). Standard charts used to estimate percentage damage for the different damage patterns (See GTZ visual percentage charts) can be used here as helpful reference aids.
- For example, the adjusted total length and adjusted damaged length for a plant pocket with 2 heads is shown in Figure 17. Head 2 has a diameter half the size of the larger, reference head. The total adjusted length for the plant pocket is then the full length of the reference head added to 0.5 times the length of head 2. Similarly, the adjusted damaged length for the plant pocket is the full measured length of damage for the reference head added to 0.5 times the measured length of damage of head 2.
- This procedure of accumulating the total adjusted damage length over a plant pocket is repeated for each category of pest.
- In some cases, two or more pests can cause damage with the same or very similar symptoms. A particular damage category will then represent both of the pests and additional survey data will be needed to determine the relative importance of each pest.
- In other cases a pest will damage the millet after another pest has already destroyed part of it. The damage should then be assigned only to the primary pest, assuming its symptoms remain visible.
- It can be helpful to record the investigator's name or initials for each plant pocket assessed, both on the data sheet and on the tape used to bundle heads, so that way if mistakes occur or if biased estimates are suspected, then the problem can be more easily tracked down and corrected.

ANALYSIS

This section provides the detailed definitions and equations needed to convert the recorded data to estimates of yield and yield loss for each damage factor. The adjusted length method calculations depend on a number of assumptions expressed as proportionality equations. (A computer diskette is available through D. L. Coop, University of Oregon, which has a program to simplify data entry and the analysis of ALM results.)

Assumptions

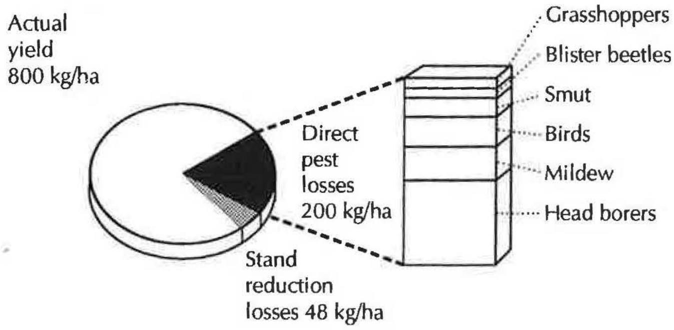
(1) Yield loss attributed to each pest is proportional to damaged length of heads adjusted to a standard diameter. The ratio of damaged to undamaged head is the same as the ratio of weight loss resulting from that damage to the weight of the undamaged portion of the head.

$$\frac{\text{damaged length}}{\text{undamaged length}} = \frac{\text{weight loss of head}}{\text{weight retained}}$$

For example, the weight of grain damage by birds per plant pocket is assumed to be equal to the weight of undamaged portion of the heads for the pocket times the ratio of the length of bird damage to the length of undamaged portion of the head.

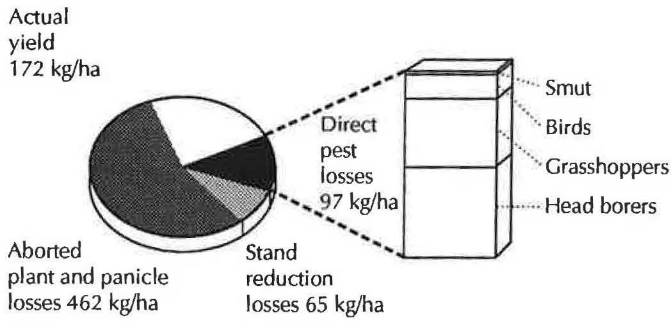
(2) The millet plant does not compensate for any direct damage to the heads which occurs during the flowering and grain development stages thus, the amount of grain removed or the extent of sterilization resulting from flower feeding was assumed to be directly proportional to yield loss.

Senegal 1983



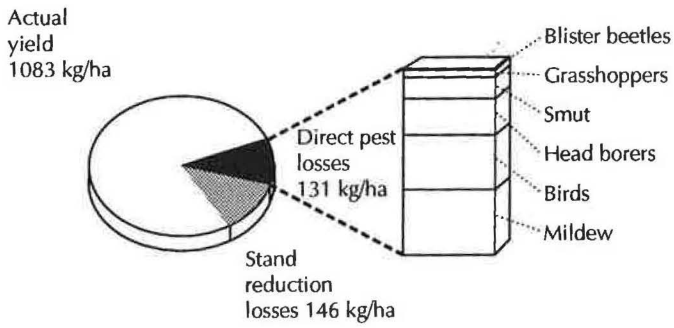
Survey of 42 fields in 8 villages in Sine-Saloum region

Chad 1987



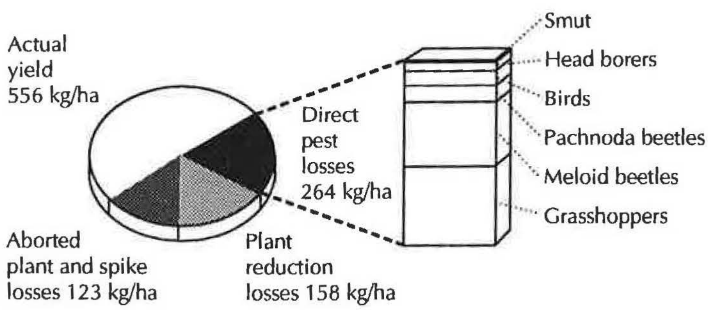
Survey of 10 fields in 10 villages in the Ati region

The Gambia 1984



Survey of 88 fields in 15 villages in the MacCarthy and North Bank regions

Mali 1990



Survey of 39 fields in 14 villages in the Koulikoro region

Figure 18 Yield loss profiles from millet loss assessment surveys in Senegal (1983), Gambia (1984), Chad (1987) and Mali (1990)

(3) All pest damage assessed is considered lost grain before use. For example, the area damaged by *H. albipunctella* and by dough stage grasshopper feeding will be lost during transport, storage, and processing of the grain. This assumption is conservative and may result in a slight over-estimate of losses.

Yield losses from each pest category

Pest-induced yield loss calculation assumes that the weight-to-length ratio for damaged heads is the same as the weight-to-length ratio for undamaged heads; resulting in the following proportionality equation:

Equation 10.

$$\text{Weight of Damage by Pest } n\text{/Pocket} = \text{Length of Damage by Pest } n \times \text{Weight of Undamaged Portion of Heads} \;/\; \text{Length of Undamaged Portion of Heads}$$

These values are calculated for each pest and each plant pocket. The average weight of damage per plant pocket is then converted to yield loss/ha for each pest category:

Equation 11.

$$\text{Pest } n \text{ Yield Loss/ha} = \text{Average Weight of Damage by Pest } n \times \text{Average No. Harvestable Hills/ha} \times \text{Proportion Grain Weight}$$

The total yield loss from pests is the sum of losses from each pest category. These calculations assume that damaged head areas result in zero yield for each pest. In some cases, such as for late grasshopper damage, some of the damaged grain can be separated from the chaff with undamaged grain during traditional threshing and winnowing.

Potential yield estimation

Total potential yield can be estimated as the total of actual yield, stand reduction yield loss, total aborted yield loss, and yield losses from all pest categories. Profiles of potential yield and components can be readily displayed by use of pie and bar charts (e.g. Figure 18). Although potential yield estimates are theoretical because they assume that plant pockets and heads which are missing aborted could yield the same as harvestable heads, they give a relative comparison among fields, regions, or years. Since the grain weight of harvestable heads can also be reduced from drought, estimates of potential yield will underestimate the maximum attainable yield, defined as the yield of crops grown under optimal conditions using fully the available technology (Zadoks, 1981).

Indirect damage interpretation

For recorded *S. hermonthica* and *C. ignefusalis* abundance ratings, obtain the average value for each field. These values fall between 0 (no infestation) and 2 (highest infestation).

- For *S. hermonthica*, average yield losses per stem of 1–3% were reported in millet from the Gambia (Carson, 1988). Similarly, 1.3% yield loss per stem was recorded in Mali (1991 unpublished data, USAID). From these results, each additional 0.1 of the 0–2 scale represents an average of about 0.3–0.9% yield loss. This relationship is influenced by many variables, such as crop variety, soil nutrients, and weed control practices. It would be best to develop a density/loss scale in each region surveyed. *S. hermonthica* is often a major cause of crop loss; a relative scale can help to show its impact between different years and regions.
- For *C. ignefusalis* damage has not readily been correlated with infestation rates (Nwanze, 1989; Harris, 1962). Significant yield losses (5–10%) sometimes occur for average damage ratings greater than 1.0.

Other weeds, and leaf defoliation ratings, are based on percentage estimates, and average ratings fall between 0 (little or no impact) and 2 (greatest impact).

- For weeds, yield loss is potentially significant only when infestations are greater than 60% or have an average rating greater than 1.2. If weed abundance exceeds this level, and the farmer weeded once or not at all, then early weed competition probably decreased yield potential. More precise estimates will be difficult even under experimental conditions; the relationship between weed density and millet crop loss has not been defined, and and will in any case vary with local conditions.
- For defoliation (usually by grasshoppers) the estimated effect on yield depends upon the timing of defoliation (based upon defoliation research with sorghum).

Table 8 Percentage yield loss estimated by average percent defoliation and defoliation rating

Crop Growth Stage	% Defoliation: / Defoliation rating:	50 / 1.1	75 / 1.5	100 / 2
Boot		15	27	45
Early Milk		13	25	38
Early Dough		6	12	17

Additional information which can be used to qualitatively rank the impact of indirect losses include the causes of head abortion recorded during head collection and the responses obtained from the farmer by surveys of pest damage and drought. The use of a drought index, such as the water requirements satisfaction index (WRSI), can show the relative influence of drought from year to year or from comparable regions (see FAO, 1979; 1986 for application of these techniques).

TIME AND LABOUR

The ALM is intensive rather than extensive. In 1990, a team of 3–6 USAID staff surveyed 14 villages in 3 weeks. In each, sampling used fields owned by four farmers/village, and one field per farmer. This should have meant pro rata a sample of 56 fields. In practice, 39 fields were sampled. Thus, less than two fields were sampled and data analysed per day, though this rate might be improved upon with practice.

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At present, losses to the millet crop of Sahelian subsistence farmers are seldom adequately monitored, yet an assessment of such losses is essential in evaluating the effects of and need for different farming inputs and methods.

Millet Crop-Loss Assessment Methods offers a range of assessment techniques, each presented as a sequence of steps, including sampling, calculation, interpretation and comparative accuracy. Choice of the most appropriate method will depend on government or farmer needs, time constraints and available skills.

This publication will be of interest to all those involved in practical agricultural research and extension work in semi-arid areas, either at the level of the individual farmer or village or at the regional and national level of policy evaluation.