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Section I. Pearl millet damage by five grasshopper species (Orthoptera: Acrididae) in Mali

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Section II. Grasshopper pests of millet: Intervention decision worksheet

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Section I. Pearl millet damage by five grasshopper species (Orthoptera: Acrididae) in Mali

Abstract

Pearl millet, Pennisetum glaucum (L.) R. Br., spike damage rates were compared for five grasshopper species that occur in millet in Mali, West Africa. Species tested were Kraussaria angulifera (Krauss), Oedaleus senegalensis (Krauss), Hieroglyphus daganensis Krauss, Cataloipus cymbiferus (Krauss), and Kraussella amabile (Krauss). One female adult was confined in a sleeve cage for four days over spikes at early flower, late flower, early milk, late milk, and dough stages of the non-bristled, unimproved Souna variety. Cages built around millet hills were used to test the influence of millet foliage and the weed, Digitaria ciliaris, (Retz.) Koel., to spike and foliar damage by K. angulifera. Six female adults were held for five days over millet thinned to three mainstems and spikes.

Feeding damage in sleeve cages (cm^2 millet surface area per day per grasshopper), averaged over all spike stages, was higher for the larger C. cymbiferus (9.5 cm^2/day) and K. angulifera (8.0 cm^2/day), than for the smaller H. daganensis (3.4 cm^2/day), K. amabile (2.5 cm^2/day) and O. senegalensis (2.3 cm^2/day). Mean damage from all species was higher for early milk, early flower, and late flower stages (7.9, 6.5, and 6.4 cm^2/day) than for late milk and dough stages, (3.3 and 1.9 cm^2/day). There was significant interaction between grasshopper species and spike stage attacked; larger species were more destructive than smaller ones to flower stages. The grain weight to grain surface area ratio, used to estimate actual yield losses, was 0.26 g/cm^2 ($SE = 0.01$). Damage potential ratios relative to 1.0 for O. senegalensis, calculated using damage rates per day and spike stage durations from early flower to mid-dough were 3.1, 3.7, 1.5, and 1.2 for K. angulifera, C. cymbiferus, H. daganensis, and K. amabile. Relative damage potentials for these species adjusted for their dry weights were

1.0, 0.93, 0.92, 0.74, and 1.26, indicating that body size accounts for much of the variation observed. The smaller species, K. amabile and O. senegalensis, may have greater affinity for spikes, while H. daganensis causes less than expected damage for its size.

The rate of milk-stage spike damage by K. angulifera held in whole-plant cages with foliage and ground vegetation removed did not differ from that seen in sleeve cages. These data support continued use of cost-effective sleeve cages for testing spike damage rates. Spike damage was decreased by 55% when millet foliage was present ($F = 4.5$, $P < 0.01$), which indicated some preference for foliage during grain filling. Defoliation in large cages averaged 56% ($SE = 4.8$). Spike damage was not affected by D. ciliaris, with or without millet foliage. This weed was not readily eaten by K. angulifera; but it reduced foliage loss by 38% ($F = 10.0$, $P < 0.005$), which indicated that feeding behavior was affected by this plant, possibly due to altered movement. Artificial (100%) and partial ($\bar{x}$ = 47%) grasshopper-induced defoliation caused grain weight losses of 30 and 57%, respectively compared to controls. Millet defoliation by grasshoppers can be high and related indirect yield losses should not be overlooked in millet crop loss assessments or in estimating economic thresholds. Implication for grasshopper management from these studies are also discussed.

Introduction

Pearl millet, Pennisetum glaucum (L.) R. Br., a subsistence food crop grown in West Africa and in other semi-arid tropical regions, is especially vulnerable to pest attack during the period of spike development. In the Sahelian (northernmost sub-Saharan) zone of Africa, several species of the grasshopper complex that normally feed on grasses and broadleaves of the savanna can invade millet fields before or during spike development. These grasshoppers cause the greatest damage during the milk stage of spike development (Popov 1988). Kraussaria angulifera (Krauss) is among the most important of these species throughout the Sahel (Popov 1988). Also, the migratory, gregarizing grasshopper Oedaleus senegalensis (Krauss) can damage early or late-season millet from local or immigrant populations (Launois 1979, Popov 1980, Launois & Launois-Luong 1989). The life cycle and general behaviors of economically important Sahelian grasshoppers are reviewed in Centre for Overseas Pest Research (COPR)(1982), Popov (1988), and Steedman (1990). Determination of economic thresholds is difficult, because damage rates on all spike stages have not been quantified for the different species.

Damage rates of five grasshopper species for the milk stage of millet development were examined in 1990 using sleeve cages (Coop & Croft 1992). Damage rates were also studied for three spike development stages with one species, Hieroglyphus daganensis Krauss. Although relative damage rates were determined, some negative effect of the cage design resulted in high mortality for some grasshopper species, which may have caused an underestimation of damage rates.

In 1991, studies were conducted using a modified cage design and a greater range of spike stages for five grasshopper species: K. angulifera, H. daganensis,

O. senegalensis, Cataloipus cymbiferus (Krauss), and Kraussella amabile (Krauss). Also, larger cages encompassing entire millet hills (pockets or clusters of 3 or more millet plants) were used to determine how a greater range of movement, possibly different resting habitats, and the added availability of foliage may affect spike damage rates by K. angulifera. Both millet foliage and a common annual grass weed, Digitaria ciliaris (Retz.) Koel. (Graminae) were used as treatments to test the effect of alternate food sources on foliage and spike damage rates. These results will be used for crop loss assessment and improved planning, decision making, and analysis of treatment programs. Specifically, our results will be used to improve the damage component of models created to evaluate the effects of late-season grasshopper treatment campaigns and determine economic thresholds (Coop et al. 1991).

Materials and Methods

All experiments were conducted 2 km west of Mourdiah, Mali (14°28'N, 7°28'W), in a field of farmer-grown, non-improved or 'land-race' pearl millet, Souna variety, that had been planted in millet yearly for more than ten years. Local limited-input management practices were used; no irrigation, chemical fertilizers or pesticides were applied to the field. Millet was planted in rows of hills, with 4-6 plants in a hill, and 1.0 m between adjacent hills and rows. Crop emergence was on 7 July, about 2-3 weeks later than most fields in the area. Use of a later planting was necessary to obtain locally sufficient adult grasshopper populations during millet reproduction (spike emergence to maturity). For most other fields in the local area, the millet matured early relative to grasshopper build-up. Rainfall totaled 445 mm from 1 June to 29 September, when trials were harvested. The rainfall pattern was evenly distributed and drought was not significant during the growing season. Yields in the area averaged 800-900 kg/ha, and were near maximum for the local region that year (Coop, unpubl. data).

Sleeve Cage Experiment

To compare potential millet spike damage rates, grasshoppers were enclosed around millet spikes using sleeve cages. Cages were sewn into 42 x 14 cm sleeves from 1 mm mesh nylon fabric. Each cage was shaped into a cylinder using two 9 cm diameter wire rings, which were sewn or stapled inside the cages. Beginning with first spike emergence, sleeve cages were used to protect spikes from other pests, such as the locally abundant Psalydolytta spp. (Coleoptera: Meloidae)(Coop & Croft 1992). Grasshopper species used in treatments were K. angulifera, C. cymbiferus, H. daganensis, K. amabile, and O. senegalensis, the latter of which were in the solitary phase. Eight to ten replicates were used for each treatment. Sleeve cages were left on the plants after treatments ended for continued protection of the spikes until harvest. Each replicate consisted of one adult female caged on a plant for four days. Treatments also included the early flower, late flower, early milk, late milk, and dough stages of spike development. A 100-point cereal growth scale was used to estimate and track the exact stage of spike development during treatments (Zadoks et al. 1974, IBSNAT 1988, Coop and Croft 1992). The scale was modified as follows: 49 - 90% spike emergence from the leaf sheath; 50 - 95% spike emergence; 51 - 10% stigma emergence; 55 - 50% stigma emergence; 59 - 90% stigma emergence; 61 - 10% anther emergence; 65 - 50% anther emergence; 69 - 90% anther emergence; 73 - early milk; 77 - late milk; 83 - soft dough; 87 - hard dough; 92 - mature. The growth stage was estimated daily with a precision of about +/- 1.5 points. From these records, the average growth stage of each treatment and mean duration of each growth stage were estimated.

Grasshoppers were checked daily and replaced if dead or moribund. Grasshoppers were dried and weighed to determine damage rates per g grasshopper weight. Damage was evaluated by visual estimation of surface area destroyed. The visual estimation depended on agreement between two damage assessment techniques. The first technique was to measure whole-spike grain surface area (length *x* circumference) to estimate damaged area from the percentage area destroyed. Reference charts developed for millet crop loss assessment by the German office for technical cooperation (GTZ) (Natural Resources Institute 1992) were used as aids to determine damage area percentages. The second technique was to directly estimate area destroyed in cm^2 using 1, 2, and 6 cm^2 paper squares as references. Analysis of variance was used to determine effects of millet growth stage and species on damage rates. Fisher's Least Significant Difference (LSD) test ($P = 0.05$) was used to compare means (SAS Institute 1987).

To convert damage area estimates to grain weight loss, a sample of 15 spikes from the trials was selected at random to obtain a conversion factor. Undamaged grain areas 4.0 cm^2 were marked, and kernels were removed, counted, and weighed. The grain weight (g) was obtained by multiplying the area (cm^2) times the conversion factor (g/cm^2).

Large Cage Experiment

In the same field used for the sleeve cage experiment, large cages were constructed around millet hills to permit greater grasshopper movement and some choice of foods for one species, *K. angulifera*. Objectives were to determine 1) Whether spike damage rates in sleeve cages were similar to those in a much larger cage design, 2) The effect of millet foliage on spike damage rates, 3) The effect of the weed D. ciliaris on spike and foliar damage rates. Millet hills were prepared for caging by thinning to three mainstem plants. The cages, 1.0 m^2 area x 2.2 m high, were built around the hills using 0.27 cm opening (8-mesh) wire cloth, 0.6 m high, bamboo corner stakes, and nylon mosquito netting. A center bamboo pole was used to support the mosquito netting, which was sewn around the top edge of the wire cloth. Hills were weeded and thinned to provide the following treatments: 1) Millet spikes with mainstem leaves intact; 2) Spikes, leaves, plus D. ciliaris; 3) Spikes and D. ciliaris only, leaves removed by hand; and 4) Spikes only. D. ciliaris, which was entering the reproductive stage, was planted at a density to provide a significant (70-80%) ground cover, 15 to 30 cm high. Cages with D. ciliaris were watered and maintained for several days prior to inoculation with grasshoppers. Treatments were replicated 3-4 times. Six immature female adults, captured in the fields and surrounding bush within 2 km of the site, were placed in the cages for five days during the time the spikes passed through early-to-late milk stages. The grasshoppers were checked and counted each day and were replaced if any were found dead or moribund.

Following treatments, cages were kept in place until spikes were mature. At that time, spikes were harvested and spike damage was estimated as described earlier. Percentage defoliation of plants in treatments with leaves present was estimated visually and gravimetrically. Visual defoliation was based on the mean of two observers' estimates to the nearest 5% on a per plant basis. The gravimetric procedure was: 1) Before treatments were initiated, the length of each leaf and its position were recorded for each plant. 2) After treatments, the remaining leaves were removed, bundled, dried, and weighed. 3) Leaves from six undamaged control plants were measured for leaf position and leaf length, then dried and weighed. 4) The length vs dry weight relationship of the control leaves was used to estimate undamaged leaf dry weights for the treatment plants. 5) The percentage leaf weight defoliation was estimated from the difference of damaged versus undamaged plant dry weights. D. ciliaris biomass and the relative amount of feeding were not determined. From observations made during the trials, there was no evidence of any feeding on the weed. D. ciliaris is not a preferred host of K. angulifera (Coop, unpublished observations). Analysis of nontransformed results was by ANOVA, and Fisher's Least Significant Difference (LSD) test (SAS Institute 1987). Defoliation estimation methods were compared by a one-tailed t-test (SAS Institute 1987).

Effect of Defoliation on Grain Weight

In addition to direct spike damage, millet is especially susceptible to grasshopper-induced stand reduction (destruction of seedlings) early in the season, and to defoliation before and during grain fill, which causes a decrease in grain weight. To address the latter form of damage, grain samples from the sleeve cages and large cages were collected to determine the effect of defoliation in the milk stage on grain weight. Twenty-five undamaged kernels per spike were used to estimate average grain weights. The weights were expressed as percent weight reduction versus the average grain weight from non-defoliated plants used in sleeve cages. Assumptions for the analysis were that plants with spikes had near-zero defoliation rates, which averaged less than 5% from field counts, and that defoliation had no effect on other yield components such as number of grains per spike or spikes per plant. Plants with broken stems caused by handling or storms ($N = 6$) were not analyzed, since stem breakage stops all phloem transport which would obscure damage. T-tests and linear regression (SAS Institute 1987) were used for data analysis.

Results and Discussion

Sleeve Cage Experiments

Mean damage rates (cm^2/grasshopper/day) varied with species and with spike stage (Table 1). Mean damage rates for all species combined were 7.6, 6.3, and 6.2 cm^2 during the milk, late flower, and early flower stages; which were significantly higher (P = 0.01, Fisher's LSD) than values for the late milk and dough stages, 3.3 and 1.9 cm^2. Damage rates for all spike stages were higher for the larger grasshoppers C. cymbiferus and K. angulifera, (9.5 and 8.0 cm^2/day), than for H. daganensis, K. amabile, and O. senegalensis, (3.4, 2.5, and 2.3 cm^2/day). A mean weight of grain per surface area of 0.26 g/cm^2 (SE = 0.01) was estimated for spikes used in this study. This value can be used to convert area damage to yield loss in grams, if it is assumed that partially damaged grain is not a part of final yield (see below).

C. cymbiferus and K. angulifera generally caused the greatest damage for all millet spike stages, except the dough stage, when rates were low for all species, and the late flower period, when damage by H. daganensis did not differ from that by C. cymbiferus and K. angulifera (Table 1). Damage by C. cymbiferus was greater than K. angulifera during the early milk stage, 17.6 cm^2 and 7.9 cm^2. At other spike development stages, C. cymbiferus and K. angulifera did not differ. Early and late flower damage by K. angulifera was higher (but not significantly higher) than damage in the milk stage. This early flower-stage susceptibility was not observed for the other species and was not reported in an earlier choice experiment for O. senegalensis (Boys 1978). Millet may thus be susceptible to damage by K. angulifera for a longer period than can be expected for the other species. The rate of damage by H. daganensis did not differ from K. amabile and O. senegalensis except at the late flower stage.

The cumulative damage potential throughout the millet reproductive period was computed using estimates of the duration of each developmental stage. The mean stage durations of spikes were 1.75, 2.75, 2.80, 2.90, and 5.60 days for early (female) flower (Zadoks scale 51-59), late (male) flower (60-69), early milk (70-74), late milk (75-79), and early-mid dough (80-86). The following conditions of testing prevent the direct use of these damage potentials to estimate economic injury levels and economic thresholds: 1) Freedom of movement was greatly restricted within cages, with largely unknown effects on feeding behavior (but see below), 2) No alternative food sources existed, 3) Grasshoppers were pre-reproductive female adults only, and 4) Spike area was not limited, preventing the testing of non-linear damage relations. Despite these limitations, the cumulative differences in damage potentials among the larger and smaller species were readily apparent (Fig. 1). Total cumulative damage potentials were 33, 102, 124, 49, and 40 cm^2/grasshopper for O. senegalensis, K. angulifera, C. cymbiferus, H. daganensis, and K. amabile, from first flower to mid-dough (51-86). Expressed as ratios and setting O. senegalensis to 1.0, damage potentials were 3.1, 3.7, 1.5, and 1.2 for K. angulifera, C. cymbiferus, H. daganensis, and K. amabile. These values reflect the relative capacity to damage millet during the entire susceptible spike development period. Damage potential ratios adjusted for grasshopper dry weights were (relative to 1.0 for O. senegalensis) 0.93, 0.92, 0.74, and 1.26 (same species order), indicating that although body size accounts for much of the differences observed, the smaller species K. amabile and O. senegalensis may have a greater affinity, relative to their size, for millet spikes, while H. daganensis caused less damage per gram body weight than average.

Milk stage damage per grasshopper was 1.5-3.4 times greater ($\bar{x}$ = 2.2) for the five species during this trial than that found in 1990 (Coop & Croft 1992). Factors that may have contributed to the higher damage rates are: 1) Addition of cage support rings, which maintained a more cylindrical shape than in the previous study; 2) Use of one grasshopper per sleeve cage eliminated possible mutual interference; 3) The experimental dates were 7-10 days earlier relative to average time of grasshopper maturation than in the previous year. Pre-reproductive grasshoppers will feed at higher rates than reproductive adults (Sanchez & De Wysiecki 1990); and 4) The number of grasshoppers requiring replacement was 86% less than in 1990, when replacement was associated with decreased damage potentials for two of the species (Coop & Croft 1991). In the current study, the average numbers replaced per cage per four grasshopper-days were 0.10, 0.0, 0.04, 0.04, and 0.16 for K. angulifera, K. amabile, C. cymbiferus, H. daganensis, and O. senegalensis. Although previous results were similar in giving relative rates for the five grasshopper species, this study may better represent maximum damage potentials.

Large Cage Experiment

The rate of milk-stage spike damage by female K. angulifera adults averaged 7.3 cm^2/insect/day in large cages supplied with stems and spikes only, and 7.1 cm^2/insect/day in large cages containing D. ciliaris (Table 2). These rates did not differ significantly from each other or from the mean of early and late milk-stage rates obtained for K. angulifera in the sleeve cage experiment (early and late milk stages combined), which was 6.3 cm^2/insect/day ($F = 0.16$, df = 33, $P = 0.85$). These findings suggest that the confinement and artificial surroundings of the sleeve cage design do not appear to interfere with rate of millet feeding by K. angulifera. Whether this finding could be extended to other grasshopper species is uncertain, as each species differs in feeding and resting habits (COPR 1982, see discussion below).

Grasshoppers fed extensively on foliage in cages, and significantly reduced spike damage (Table 2; $F = 9.2$, df = 38, $P = 0.0001$), with a 56.5% reduction in damage in cages without D. ciliaris, and a 61.1% reduction in damage with D. ciliaris. This indicates a relatively high preference of K. angulifera for green, non-senescent millet foliage over the spike during the milk stage. As with the millet in cages without millet foliage, the presence of D. ciliaris did not affect spike damage rates. Since K. angulifera was not observed feeding on D. ciliaris, and is known to climb, the presence of the weed canopy ca. 1.5 m lower than millet spikes probably had little impact on K. angulifera spike feeding behavior. From these results, K. angulifera appears to prefer millet foliage over milk-stage spikes, and ground cover such as D. ciliaris does not modify spike damage rates. Similar tests with other weeds, such as the tall growing forbe Phyllanthus amarus Schum et Thonn. and Cenchrus biflorus, a major savanna grass, would add insights to our preliminary conclusions.

Foliage consumption was considerable, reflecting the reduced spike damage in cages with foliage (Table 2). The mean whole plant defoliation levels, estimated using the visual and gravimetric methods were 56% and 48%, in the cages without D. ciliaris. These values, expressed as percent/day defoliation per grasshopper per plant, were 5.6 and 4.8 %/day, for visual and gravimetric methods of estimation. The addition of D. ciliaris significantly reduced defoliation by 37.9% (visual method, $F = 10.0$, df = 20, $P = 0.005$) and 33.5% (gravimetric method, $F = 5.0$, df = 20, $P = 0.038$). Defoliation estimates using the gravimetric procedure averaged 5.5% less than estimates using the visual method ($t = -1.92$, df = 20, $P = 0.03$). The visual estimation method may have been biased to overestimate damage, whereas the gravimetric procedure is probably biased to underestimate damage due to the lack of a factor to account for midrib dry weights. It is not clear why D. ciliaris caused a decrease in defoliation but not in spike damage. One possible explanation is that while the upper-canopy grasshopper activity was not strongly affected by the grass, the mid-and lower canopy activity was. Although counts were not made of the resting positions of the grasshoppers as they were checked daily, notes indicated that K. angulifera was utilizing the D. ciliaris for resting more frequently than bare soil, thus providing an alternative to the insects' climbing habit. A more thorough study of the daily movement and resting patterns of grasshoppers and modifications caused by different foliar habitats would be needed to fully account for these results.

Our results do indicate, however, that if defoliation is used as an indicator of potential spike damage, then weed presence should be taken into account. Weed presence in millet will support higher grasshopper populations with relatively lower defoliation levels than when weeds are absent. However, late season drought, which is common in the Sahel zone, due to southward movement of the intertropical convergence zone, will force foliage and weed feeding grasshoppers increasingly to the millet spike for moisture and food. The relatively high defoliation observed in the large cages was during a period with plentiful rain, whereas lower defoliation levels and greater spike injury would be expected under drought conditions. Although the interactions between grasshopper species, weed species, millet stage and condition, and drought creates a difficult array of variables to deal with, a number of carefully designed cage studies could help to quantify these relationships. Perhaps a series of simple choice experiments involving millet spikes and leaves, and several major weed species, would also help to better relate grasshopper feeding preferences and reveal how weeds affect grasshopper damage to millet.

Effect of Defoliation on Grain Weight

The effect of defoliation on grain weight yield was considerable. In the cages with foliage available for grasshopper feeding, grasshoppers produced a mean defoliation of 46.8% (SD = 18.2, n = 21), and grain weight reduction of

30.4% (SD = 16.8, n = 14) relative to the mean grain weight of non-defoliated plants used in sleeve cage studies, which was 0.2904 g/25 grains (SD = 0.064, n = 40). This reduction was significant ($t = 4.7$, df = 53, $P < 0.0001$). In cages with 100% artificial defoliation, average grain weight reduction was 57.3% (SD = 13.0, n = 16), and grain weights were significantly less than for spikes subjected to partial defoliation ($t = 4.9$, df = 29, $P < 0.0001$). These results can be expressed in a regression equation as: % grain weight reduction = -1.07 + 0.599 x % Defoliation ($r^2 = 0.59$, df = 68, $P < 0.0001$). A variable describing the crop stage index at the midpoint of defoliation was not significant when added to the regression equation ($P = 0.44$). The overall stage at defoliation was the milk stage (growth stage $\bar{x} = 74.5$, SD = 3.1, range = 69 - 79). This study supports the need to consider defoliation as a major factor causing yield loss. The indirect effect of defoliation on yields should be considered in addition to the more obvious direct losses by grasshoppers in crop loss assessment and definition of economic thresholds.

Management Implications

Although determination of millet damage rates gives an indication of the potential losses to grasshoppers when feeding solely on millet spikes, there are several other factors which should be considered before management guidelines are formulated. For example, some characteristics of grasshopper behavior are known that relate to millet damage (reviewed in Steedman 1990, COPR 1982, Popov 1988, G. B. Popov, pers. comm.): The preferred habitat for O. senegalensis is relatively dry and barren compared to the other grasshoppers, a condition in which millet often occurs in contrast to the surrounding savanna zone. Commonly, this grassland habitat is dominated by the annuals Cenchrus biflorus and Eragrostis sp. and the perennial Aristida sp. on very sandy soils. O.

senegalensis readily feeds on all three grasses, in approximate proportion to their abundance (Boys 1978). In feeding preference tests conducted in India, O. senegalensis readily accepted eight graminae spp. and rejected 8 non-graminae; all plants were from its natural habitat. Of the eight grass species, Cenchrus sp. was preferred over the others, including pearl millet (Chandra 1982). Conversion of this land to millet production also provides a readily acceptable habitat to O. senegalensis. Both millet foliage and milk stage grain are favored food hosts, and mature female adults showed a preference for the latter in a laboratory choice study (Boys 1978). At higher densities O. senegalensis tends to gregarize, usually in small groups in the nymphal stages, thus causing a potentially non-uniform pattern of damage as compared to other grasshopper species. The affinity for millet and the aggregative nature result in much higher maximum field densities than the more solitary species. K. angulifera is partly arboreal, and tends to climb and feed on foliage and stalks of grasses and broadleaves. This tendency puts millet spikes at higher risk of attack. The relatively high spike damage measured in the large cages, even when supplied with millet foliage, reflects the climbing tendency of K. angulifera to some degree. C. cymbiferus, which produced the greatest milk stage damage in sleeve cages, is less likely to be found high on a millet stem, due to a preference for moderate-to-high moisture conditions, thick vegetation and undergrowth. H. daganensis is primarily graminivorous and has a wide tolerance of ecological conditions, but prefers shade, and hides behind stems and in leaf whorls of millet. K. amabile feeds mainly on grasses and occurs near the ground in grasslands, and is relatively less inclined to leave this habitat for clean cultivated millet fields than the other species. K. amabile was sometimes observed feeding on newly emerged millet spikes during this study, although flower stage damage by this species was no greater than was observed for O. senegalensis, which is not inclined to feed on flower stage millet spikes (Boys 1978).

Except for O. senegalensis, all species studied have a single generation per year in the Sahel, and all overwinter within diapausing eggpods. Nymphal eclosion generally occurs when millet emerges just after commencement of the rainy season. In general, these species reach the final instar and become adults at about the same time that Souna, the local 70-80 day millet, also reaches the reproductive stage. In 1991, however, Souna developed earlier than grasshoppers and largely escaped damage, at least near the study site. Conditions likely to attract grasshoppers into the field include poor weeding within fields and between field margins and adjacent grasslands. Fields free of both grasses and herbaceous weeds are less likely to attract and support the grasshoppers we studied. O. senegalensis differs because it prefers open areas, like clean-cultivated millet. Therefore, unless O. senegalensis is the only species expected to threaten the crop, management practices should attempt to discourage and repel grasshopper entry. In addition to thorough weeding and border cultivation, such practices could include the use of sorghum, a less-preferred host plant, in border rows next to grasslands. This action might repel grasshoppers.

Calculations of simple economic injury levels, as outlined previously (Coop & Croft 1992), can be developed for each species, using results from this study. However, additional information is needed on grasshopper feeding preferences, timing of attack, treatment effectiveness, rate of pest reinvasion for each species and developmental stage, plus market price of the millet. Because of the complexity of this system, our results will be used with modeling approaches (Coop et al. 1991), and empirical field data (Coop & Croft, in preparation) to obtain improved threshold estimates. Improved economic thresholds will be used to improve decision making for control interventions, and to develop IPM of millet for the semi-arid tropical regions.

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Table 1. Damage caused by five grasshoppers species caged over five spike development stages of pearl millet[1]

Species	n	Surface area of spike damaged (cm^2) per insect/24 h $\bar{x}$		SD	Stage of spike at midpoint of exposure[2] $\bar{x}$	SD	Dry weight per insect (g) $\bar{x}$	SD
Early Flower Stage								
Kraussaria angulifera	9	14.37a	a	12.42	62.6a	2.42	0.87a	0.23
Kraussella amabile	8	1.14b	b	1.03	63.7a	2.83	0.26c	0.08
Cataloipus cymbiferus	9	11.67a	b	7.21	61.5a	3.95	1.07a	0.20
Hieroglyphus daganensis	8	1.56b	b	1.78	64.8a	2.24	0.47b	0.22
Oedaleus senegalensis	8	2.19b	ab	1.28	64.0a	2.48	0.25c	0.04
Late Flower Stage								
K. angulifera	9	9.27a	ab	4.77	69.2a	1.15	1.21a	0.51
K. amabile	8	2.55bc	ab	1.92	68.6a	1.24	0.25c	0.11
C. cymbiferus	9	10.89a	b	5.13	69.2a	1.31	1.06a	0.20
H. daganensis	9	7.79ab	a	11.85	69.3a	1.14	0.64b	0.22
O. senegalensis	9	1.22c	b	1.15	69.6a	1.69	0.27c	0.04
Early Milk Stage								
K. angulifera	8	7.89b	ab	6.08	74.7a	1.92	0.83b	0.35
K. amabile	8	4.24b	a	2.93	75.2a	1.54	0.29c	0.12
C. cymbiferus	10	17.57a	a	6.46	74.0a	1.57	1.19a	0.33
H. daganensis	9	4.36b	ab	4.35	74.6a	1.06	0.57b	0.30
O. senegalensis	9	4.20b	a	4.12	73.6a	1.39	0.29c	0.06

Late Milk Stage								
K. angulifera	8	4.75a	b	5.01	78.6a	0.64	0.94b	0.47
K. amabile	8	2.13a	b	1.45	78.6a	0.74	0.27c	0.09
C. cymbiferus	9	4.83a	c	4.87	78.1a	1.05	1.33a	0.33
H. daganensis	9	2.19a	ab	1.06	78.2a	0.71	0.48c	0.20
O. senegalensis	8	2.39a	ab	1.19	78.0a	0.74	0.30c	0.04
Dough Stage								
K. angulifera	8	2.81a	b	1.70	82.8a	0.83	0.79b	0.11
K. amabile	8	2.38ab	ab	1.30	83.4a	0.72	0.26d	0.06
C. cymbiferus	9	1.83abc	c	0.65	82.8a	0.52	0.98a	0.22
H. daganensis	9	1.07c	b	0.86	82.4a	0.96	0.41c	0.08
O. senegalensis	9	1.36bc	b	0.50	81.9a	0.86	0.27d	0.04

[1]Means within a column under same spike stage heading followed by the same letter in the first column, did not differ significantly ($P > 0.05$; Fisher's LSD). Means within a column under same grasshopper species heading followed by the same letter in the second column, did not differ significantly ($P > 0.05$; Fisher's LSD).

[2]Zadoks cereal growth scale (Zadoks et al. 1974).

Table 2. Spike and foliar damage caused by *Kraussaria angulifera* female adults caged over pearl millet plants[1]

Treatment	No. Cages	No. Plants	Surface area of spike damaged (cm^2) per insect/24 h		% foliar area destroyed per insect/24 h			
					visual method		gravimetric method	
			$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Spikes only	3	9	7.07a	0.71	-	-	-	-
Spikes, *Digitaria ciliaris*	3	9	7.29a	0.83	-	-	-	-
Spikes, foliage	4	12	3.17b	0.72	5.58a	0.44	4.82a	0.47
Spikes, foliage, *D. ciliaris*	3	9	2.75b	0.83	3.47b	0.50	3.21b	0.55

[1]Means within a column followed by the same letter did not differ significantly ($P > 0.05$; Fisher's LSD).

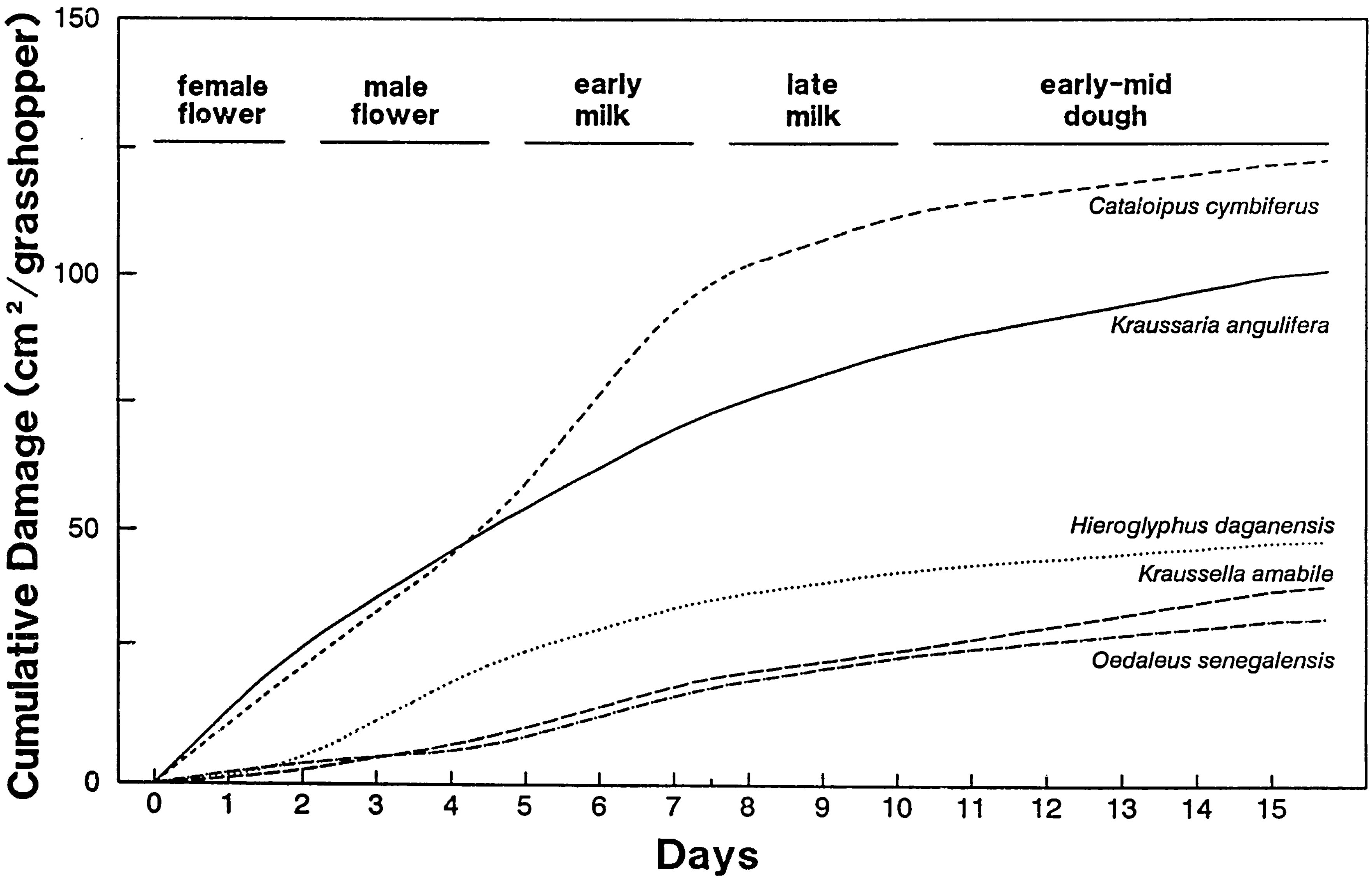

Figure 1. Cumulative pearl millet spike damage by five grasshopper species, Mourdiah Mali 1991.

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II. Grasshopper pests of millet: Intervention Decision Worksheet

Version 1.0 - Leonard Coop, Oregon State University 17 July 1992

Symbol	Variable	Units	Source	Value(s)		
	Compound	-	Input	Ripcord ULV		
(E)	Efficacy	proportion killed	Input	0.8		
(C)	Treatment Cost	FCFA/ha	Input	6250		
(Y)	Yield [1]	kg/ha	Input	700		
(M)	Millet market price	FCFA/kg	Input	50	100	150
(V)	Crop value	FCFA/ha	(MY)	35000	70000	105000
(B)	Break even level	% of Crop value	(C/Vx100)	17.86	8.93	5.95
(G)	Grain wt. conversion	g/cm2 surface area	Constant	0.18		
(Q)	Grain surface yield	cm2 spike/m2 area	(Y/Gx10)	388.89		
(T)	Tolerance	cm2 surface area	(BQ/100)	69.44	34.72	23.15
(DS)	Cumulative damage	cm2/grasshopper	Coop 1993	see table		
(A)	Affinity for millet [2]	calibration factor	Coop 1993	see table		
(F)	Field Conditions [3]	proportion	Field obs.	0.2	0.4	0.6
			Description	weeds	normal	drought

Species	(DS) Cumulativ damage	(A) Affinity for millet
Kraussaria angulifera (KAN)	102	0.6
Cataloipus cymbiferus (CCY)	124	0.4
Hieroglyphus daganensis (HDA)	49	0.5
Kraussella amabile (KAM)	40	0.5
Oedaleus senegalensis (OSE)	33	0.5

Derivation of formula used to generate EIL values in table 1:

The starting formula, EIL = T/DSP is from Coop and Croft (1992) and is based on a breakeven analysis (Mumford & Norton 1984) The formula was modified by expanding P, the proportion of feeding directed to the spike, into (FA), which allows separate factors for the condition of the crop (F), and grasshopper species affinity for millet (A). Also efficacy, (E), was added to the denominator to account for incomplete control.

Notes:

[1] - The yield is factored out of the EIL equation, therefore it is not important to estimate accurately.

[2] - Field observations and reports, as reviewed in Coop (1993) (section I of this report), lead to empirical values of 0.5 for 3 species, and slightly higher and lower affinity for KAN and CCY. More choice-type experiments are needed to improve these estimates.

[3] - Crop conditions affecting the degree of feeding on millet spikes

weeds - field was poorly weeded, offering greater supply of alternate host plants for grasshoppers.

normal - neither high weed abundance nor drought conditions present in field.

drought - late season drought has caused browning of weeds and millet foliage, making the millet spikes more vulnerable to attack.

Table 1. Economic Injury Levels for grasshopper pests of millet:
The pest density expected to cause losses equal to the cost of intervention (# per square meter)

	Market price of millet (also see assumptions and special considerations)								
	50 FCFA/kg Field Conditions			100 FCFA/kg Field Conditions			150 FCFA/kg Field Conditions		
Species	weeds	normal	drought	weeds	normal	drought	weeds	normal	drought
Kraussaria angulifera (KAN)	7.1	3.5	2.4	3.5	1.8	1.2	2.4	1.2	0.8
Cataloipus cymbiferus (CCY)	8.8	4.4	2.9	4.4	2.2	1.5	2.9	1.5	1.0
Hieroglyphus daganensis (HDA)	17.7	8.9	5.9	8.9	4.4	3.0	5.9	3.0	2.0
Kraussella amabile (KAM)	21.7	10.9	7.2	10.9	5.4	3.6	7.2	3.6	2.4
Oedaleus senegalensis (OSE)	26.3	13.2	8.8	13.2	6.6	4.4	8.8	4.4	2.9

Assumptions:

- Treatment cost (FCFA/ha): 6250 In $US $20.83
- Treatment efficacy (%): 80
- As the tabled values are economic injury levels, not economic (action) thresholds, consideration must be made for for best timing of interventions, grasshopper population dynamics, etc.
- There is little or no developmental variation of millet plants within field.
- These values were derived from studies of immature female adults; populations with males and nymphs would cause slightly less damage

Special Considerations:

A. Factors contributing to crop damage (increasing the need for intervention, which would decrease threshold values in table)

- Significant defoliation at flowering and early milk stage decreases grain fill and subsequent grain weight (Coop and Croft 1993).
- Late season drought increases damage by grasshoppers.

B. Factors decreasing crop damage (and need for intervention, which would increase threshold values)

- Grasshopper late nymphs and early adults do not coincide with the early milk stage of millet.
- Plentiful rains increase health and vigor of alternate hosts in and around millet (accounted for in part by the factor for field conditions).