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FINAL DRAFT

ECONOMIC ANALYSIS OF AFRICAN LOCUST/GRASSHOPPER CONTROL

PART I. GHLSIM TECHNICAL REFERENCE

Submitted to:
Office of Natural Resource Development
Bureau for Africa
U.S. Agency for International Development

By the:
International Plant Protection Center and
Dept. of Entomology at
Oregon State University

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Through the
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I. Introduction

Grasshoppers and locusts cause significant losses to food and forage crops in most arid regions of the world. Serious crop losses during the grasshopper and locust outbreaks from 1986 to 1988 prompted major intervention programs in Africa costing enormous sums of money. Intervention, whether in response to emergency or routine pest build-up, has been based primarily on the use of chemical insecticides, applied from the ground or air. Both the AID AELGA Project's Programmatic Environmental

Assessment (PEA); (TAMS/CICP 1988) and a recent evaluation of the AELGA project point out the need for additional work on the economics of grasshopper/locust control. Unfortunately, knowledge of the relationship between pest numbers and crop losses under varying cropping environments is a major constraint to a more rational control strategy. Without this knowledge, there is no framework for developing intervention thresholds and comparing the benefits resulting from various control practices.

The Sahelian Grasshopper Crop Loss Simulation, or GHLSIM, was implemented as computer software for analyzing the efficiency and utility of grasshopper control efforts, and to provide a systems framework to improve decision-making. GHLSIM was designed to simulate grasshopper feeding injury and the cost-effectiveness of grasshopper control campaigns in millet and sorghum. Simulation is an approach to dealing with the dynamics and variability of the system that static methods do not address. Crop losses and treatment benefits vary with grasshopper population dynamics, feeding behaviors, crop varieties, yields, treatment tactics and their properties, and the timing of events. GHLSIM accounts for these variables to the extent current knowledge of the system allows. The GHLSIM simulation system is also intended for tasks related to training, decision-making, and economic threshold analyses associated with grasshopper treatment campaigns. In this documentation, an overview of the technical aspects of GHLSIM will be discussed. Part II - GHLSIM User Manual contains more detail on how to use the software system. An example use of GHLSIM with supporting data is documented in Part III - Analysis of the 1987 Grasshopper Campaign in Chad.

II. Program Overview

The approach used within GHLSIM is to use a crop growth/defoliation simulation for both insecticide-treated and non-treated grasshopper populations in the major cultivars of millet and sorghum. This method incorporates much of the system's biological complexity, including grasshopper densities and stage-specific consumption rates, crop stage-susceptibility factors, grasshopper preferences for crop stage and variety, and non-linear damage relations. Currently GHLSIM is limited to working with the major Sahelian grasshopper pest species Oedaleus senegalensis (Krauss) (OSE). OSE population dynamics are based on output from the OSE biomodel, developed by PRIFAS (Launois 1979, Gigault 1984, FAO 1986b), which is now in use in the Sahel. GHLSIM is constructed so that other pest submodels may later be incorporated to allow the simulation of impacts by multiple pests.

GHLSIM was written in Turbo Pascal and runs on IBM PC's and compatibles. The user interface consists of familiar pull-down menus and data entry screens for ease of learning and use. The principle database for simulation inputs is derived directly from grasshopper survey sample reports. GHLSIM allows a query of the database for processing multiple sites in batch mode. Other data accessible to the user include crop yields and prices, treatment tactic costs, treatment effectiveness, treatment tactic risk ranking for five environmental categories, and options to control model output displays. Behavioral analysis options allow the user to perform "what if" analyses, such as varying the date of intervention or the control tactic used. Outputs from the program include text and graphics displays of population dynamics and injury simulation in progress, a report of the calculated crop yields and losses with and without the influence of the intervention tactic, and the economics and risk rating of the tactic for each of the sites simulated and averaged by region. A plotting routine allows graphing of grasshopper sample densities versus estimated benefits of control.

A simulation run is prepared by inputting information into the DATABASES for grasshopper samples, crop data and treatment agents (Fig. 1). Model RUNTIME OPTIONS are selected for types of output preferred. The program was designed to simulate behaviors for multiple sites, one at a time (a site is characterized primarily by records in the grasshopper sample database). A subset from the available grasshopper samples may be selected for model processing by a query system (LOCATIONS), which enables users to select records based on country and prefecture, a selected range of grasshopper sample densities, or by a set of individual record code numbers. BEHAVIORAL OPTIONS may be selected to override database values for treatment tactic and date. RUN is selected to conduct the simulation. The model will determine the proper parameters for each site simulated in successive order. Results reflect both individual sites and the aggregated analysis from all sites. Upon completion of model processing, results may be EDITed or printed. From the ANALYZE submenu, net treatment benefits may also be plotted versus grasshopper sample densities as a way of estimating economic threshold levels.

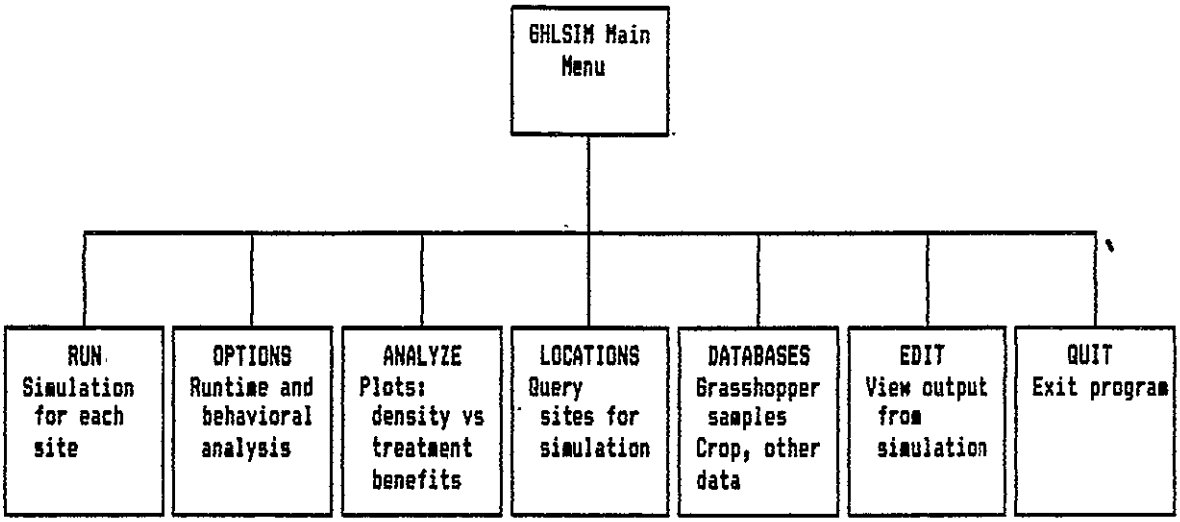

Figure 1. Main Menu of GHLSIM Sahelian grasshopper/crop loss

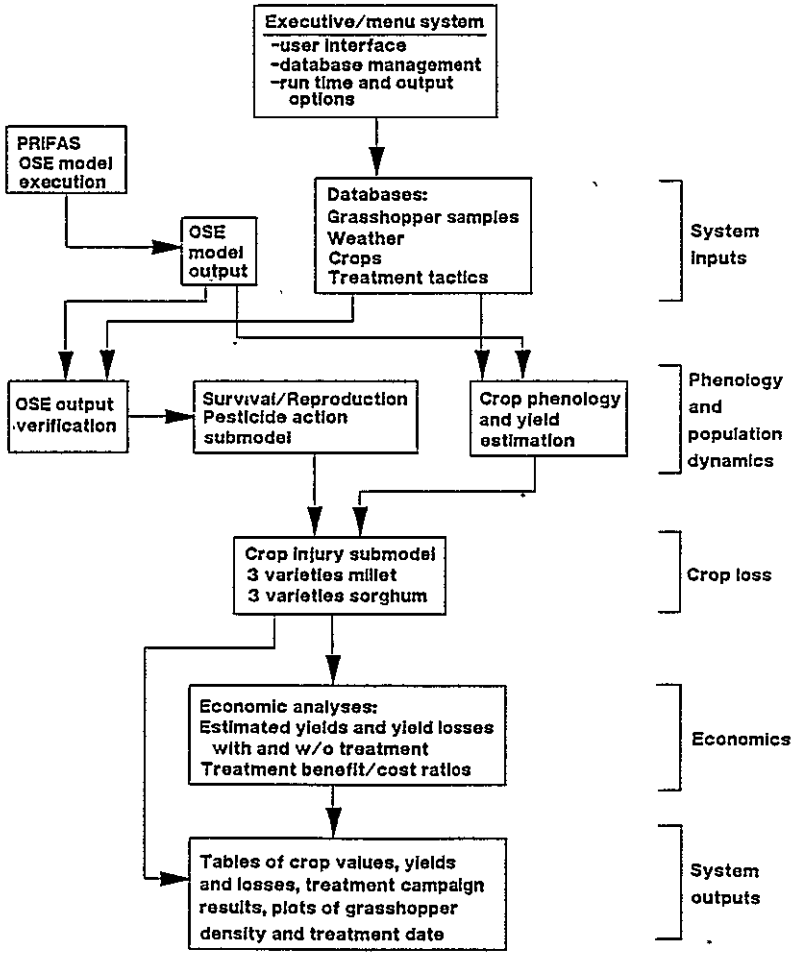

Figure. 2. Components of GHLSIM grasshopper/crop loss simulation model.

System inputs include grasshopper sample data, weather data (precipitation, PET), crop yields and varietal characteristics, treatment parameters (efficacy, residual characteristics), OSE biomodel output files, and behavioral options. System outputs

include a summary table of crop values, yields, and benefit/cost ratios of treatment (Fig. 2). GHLSIM is modularized by into separately compiled units and executable (.EXE) files. The control of model execution (Fig. 3) is handled by separate .EXE files once GHLSIM sets up the appropriate data and determines values for missing data (from defaults set up in the databases) by a procedure known as SUPPLYUN. The submodels used in model execution are listed here:

a. The millet and sorghum yields and planting dates submodel (GHLCROPS).
b. The OSE biomodel output translation/verification, grasshopper population dynamics submodel (GHLOSE).
c. The crop injury calculation submodel (GHLINJ).
d. An economic analysis for each model run (GHLECON).
e. A module for aggregating and presenting final results (GHLAGGR).

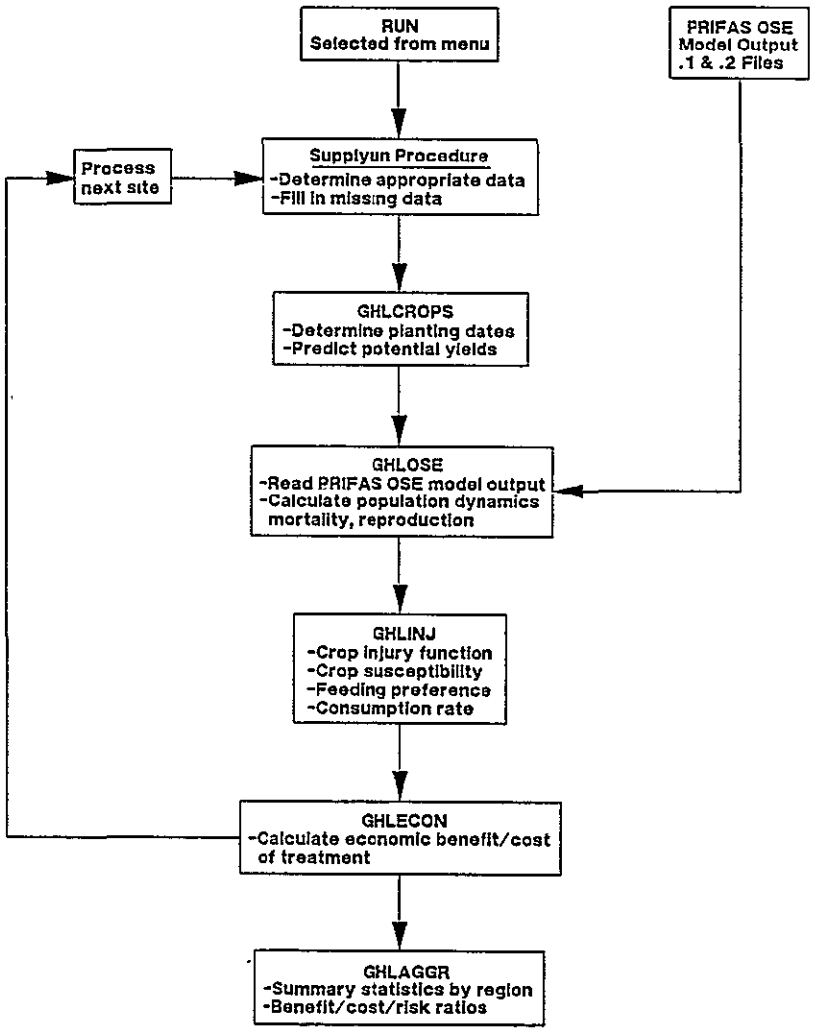

Figure 3. Overview of GHLSIM program execution flow.

Each of these modules produces either detailed or abbreviated screen output as specified in the runtime options screen. Detailed descriptions of these outputs are found in Part II - GHLSIM User Manual. All subsequent details on GHLSIM will be made in reference to these submodels.

III. Summary of Economic Analysis Methods

GHLSIM was initially used to conduct a benefit-cost analysis for the anti-grasshopper campaign in Chad in 1987. Other countries of the Sahel and other years can be evaluated as the data are input for use in the system. Data required to run the system include:

a. Output from the OSE biomodel, implying the need for weather data as required by the OSE biomodel.
b. Additional average precipitation and PET (potential evapotranspiration) data for use in the crop yield and phenology submodel.
c. Grasshopper sample data as collected during the crop season.
d. Treatment tactic cost estimates, maximum effectiveness, residual half-life parameters, and risk ratings for birds, predators, human health, aquatic life, and secondary pest outbreaks.
e. Average yield, cultivated areas of millet and sorghum and cultivar percentages for each region included in the analysis.
f. Default value estimates for missing data in grasshopper sample records, including insecticides used, area treated, crop cultivars attacked, and percentage control obtained.

Costs of treatment operations are estimated by one of three methods, depending on the site. If a site is part of a large-scale control campaign, as with most late-season aerial (Phase II) campaigns, the cost of treatment is normally calculated externally for specified subregions and input in GHLSIM in tabled form. If treatment costs have not been fully estimated externally (and are not present in the campaign lookup table), GHLSIM will produce treatment cost estimates via the treatment tactics default database for prices and a worksheet for costs of surveying, application, transportation, and miscellaneous costs. Indirect costs of treatment are not readily determined. The environmental considerations concerning grasshopper control has been recently reviewed (TAMS/CICP 1988). Accounting for grasshopper treatment side effects costs within GHLSIM is currently the responsibility of the user. The

environmental risk rating system provided by GHLSIM provides a qualitative assessment of negative treatment effects, however.

The approach used for the economic analysis of treatment tactics is to compare the direct costs versus the estimated benefits of treatment. Two ratios are calculated; one utilizing only the first year benefit and the second utilizing an additive carryover benefit of the second year. The first year benefit of treatment is estimated as the crop value times the difference between yields, which are derived from yield losses as simulated in GHLSIM for treatment and no-treatment situations. Crop yields are either reported or estimated by the GHLCROPS submodel and are normally assumed to be the same as 'treated' yields.

Calculation of second year benefits of treatment in GHLSIM is based on a breakeven analysis of eggpod density samples. It relies on eggpod surveys made before and after the phase II control operation of 1987 in sprayed and unsprayed regions. From the analysis, the campaign was initiated in some regions having relatively high eggpod densities while no campaign was conducted in areas with lower eggpod densities. Some moderate density was thus used as a threshold for whether or not to prepare for a campaign in each region. Some density near this threshold would serve as a breakeven density, at which the expected benefit of treatment just equals the cost of treatment. In GHLSIM, simulated final eggpod densities at harvest are compared to the breakeven density to estimate the potential losses for those populations. The difference in potential losses for treated and non- treated areas are then the second year benefits. A more detailed discussion of the first and second year cost-benefit analyses can be found in later sections of this document.

IV. Simulation Model Description

1. Crop Yield and Phenology

GHLSIM uses the submodel GHLCROPS to calculate planting dates and crop yields for 3 varieties of millet and 3 varieties of sorghum. A summary of major control flow steps of GHLCROPS is presented in Fig. 4. The site and weather data are read in, planting dates and yields are calculated, and results output for use in GHLOSE and GHLINJ. A vegetation greenness factor is also calculated from precipitation data within GHLCROPS, as is described in the section on crop loss calculation. Algorithms for yield estimation and planting dates will be described next.

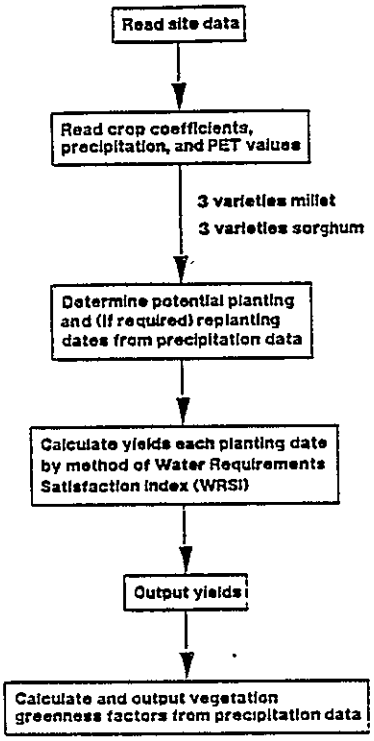

Figure 4. GHLCROPS: Crop planting dates and yield estimation submodel.

a. Crop Yields

Modeling the growth and yield of millet is difficult because of the plant's capacity for producing multiple tillers (Huda et al. 1984). Recent versions of millet and sorghum models (e.g. CERES Sorghum - V2.00, Alagarswamy et al. 1989) require daily climatic data, which are typically unavailable from Sahelian millet growing areas. A relatively simple model using 10-day (dekad) climatic and agronomic data to predict crop yield was developed for the Food and Agriculture Organization of the United Nations (FAO) in Doorenbos et al. (1979) and Frere and Popov (1979) and has since proved useful in 30 countries (FAO 1986a).

The FAO crop model is intended for use only in rainfed agricultural areas, such as the Sahel, where precipitation is the main yield constraint. The model produces a "water requirements satisfaction index" (WRSI) measuring the cumulative water balance of the crop in successive stages. A negative water balance during any stage is assumed to stress the crop irreversibly and produce a corresponding reduction in yield. Details of the model are in Frere and Popov (1979) and FAO (1986a). Because this model forms the basic algorithm for determining millet and sorghum yields in the GHLCROPS submodel of GHLSIM (Fig. 5), some important points are described here.

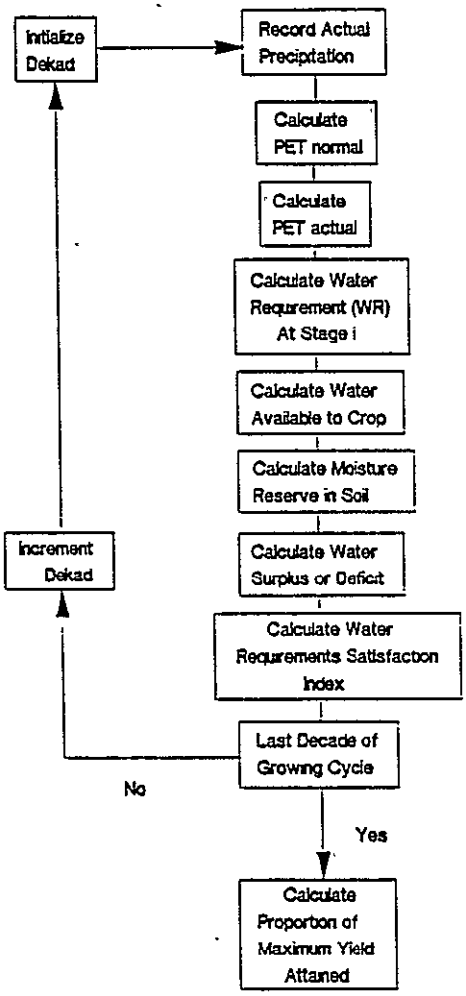

Figure 5. Basic algorithm for estimating millet and sorghum yields in GHLCROPS using the procedure described by Frere and Popov (1979).

Climatic parameters, other than precipitation, affecting the crop are represented in the model by the calculation of potential evapotranspiration (Penman 1948). Optimally, potential evapotranspiration (PET) is calculated using actual data. If these data are unavailable, climatic normals may be used. Site-specific historical data are preferred, but neighboring station data may be used if site-specific data are unavailable. Dekad data are less variable than daily data, and, in the Sahel, PET is much less variable in space than precipitation (FAO 1986a). Neither actual PET data nor data necessary for calculation of PET were available from Chad for 1987. The PET data used in GHLCROPS were derived from the 30-year averages of monthly totals published by FAO (1984). Each month's total divided by three was assumed to equal the total of that month's median dekad. The dekads between the median dekads of successive months were interpolated linearly.

Biological parameters of the crop are summarized through the use of crop coefficients relating the stage-specific water requirements of the crop to those of a reference crop (Penman 1948). Derivation of crop coefficients is detailed in Doorenbos and Pruitt (1977); coefficients used in GHLSIM for millet and sorghum were taken from FAO (1986a). Water available to the crop is a function of precipitation and accessible soil water, with soil water storage a function of soil type. Because site-specific soil data are not available from many Sahelian stations, soil type was assumed to be "sandy loam" (Kramer 1983) with approximately 60mm of useful water reserve (FAO 1986a).

The final WRSI, determined from the cumulative balance of precipitation, available soil water, and crop requirements, is not directly proportional to final yield. FAO (1986a) provides tabular values, determined from field experience, relating final WRSI to percent yield loss. A simplified function was derived from these values for use in GHLCROPS:

if Final WRSI < 50 then
% of maximum yield = 20.0 x (WRSI/100);
if Final WRSI >= 50 then
% of maximum yield = (182.9 x (WRSI/100)) - 85.14.

The potential maximum yield can be extrapolated from a regression of observed yields on final WRSIs, or from an average of the three best yields during the previous ten years (FAO 1986a).

b. GHLCROPS Validation

No site-specific, matched yield and precipitation data were available from Chad for model validation; therefore, derived data were used for validation. Site-specific 1987 precipitation data, reported by the US Agency for International Development's Famine Early Warning System (FEWS) were averaged by prefecture and matched with normal PET and precipitation data from the nearest station having historical data. This approach provided a data set representing each of the eight Sahelian prefectures in Chad.

To test the accuracy of the function predicting percent of maximum yield, predicted percents of maximum yield for each prefecture were compared with those recommended by FAO (1986a) for the same WRSIs (Fig. 6).

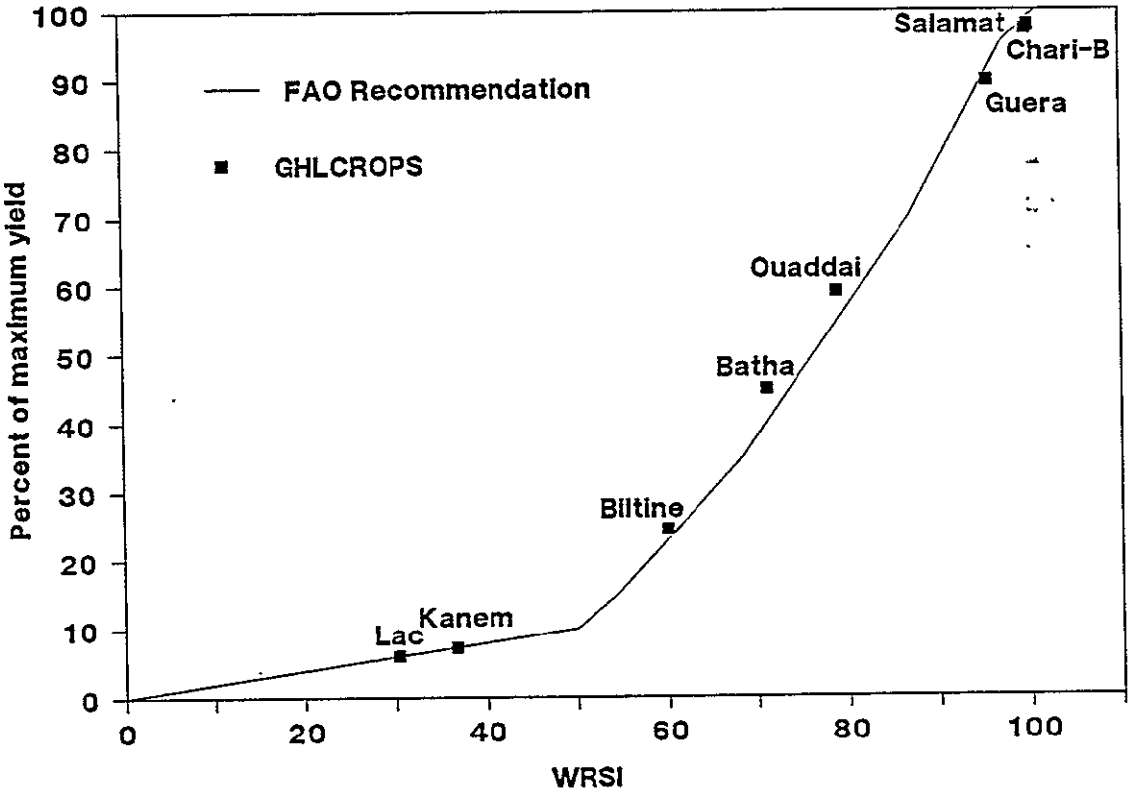

Figure 6. GHLCROPS predicted percents of maximum yield in relation to water requirements satisfaction index.

Because few historical or 1987 yield data were available from Chad, indirect methods were used to estimate the potential maximum yield. Regression of FEWS reported 1987 prefecture average yields (observed) on WRSIs (predicted) indicated a potential maximum yield of 435 kg/ha when WRSI = 105 (yield = 85.3 + 3.33(WRSI); $R^2 = 0.71$). A WRSI of 100 produces less than 100% of maximum yield (FAO 1986a). The observed yields, however, reflect damage from direct and indirect pests as well as drought. Thus, 435 kg/ha indicates the potential yield only when pests are present at levels seen in 1987.

Synoptic data published by FAO (1976) were therefore used to estimate the default potential maximum millet yield of 800 kg/ha, the yield anticipated from low input agriculture in suitable to very suitable land in African warm tropical lowlands. Prefecture average millet yields for 1987 were then regressed on GHLCROPS predicted millet yields (Fig. 7). The model explained a highly significant amount of the variation associated with observed millet yields ($F = 15.71$, $P < .01$). Observed

yields were about one-third of the predicted yields, probably reflecting yield reductions caused by pests. Pest losses of this magnitude were seen in Chad in 1987 during a crop loss assessment survey on millet by Fischer and Murphy (1987). Because GHLCROPS is intended to provide GHLSIM with a potential yield from which to decrement pest damage, predictions of yields higher than observed (which reflect pest damage) are most useful.

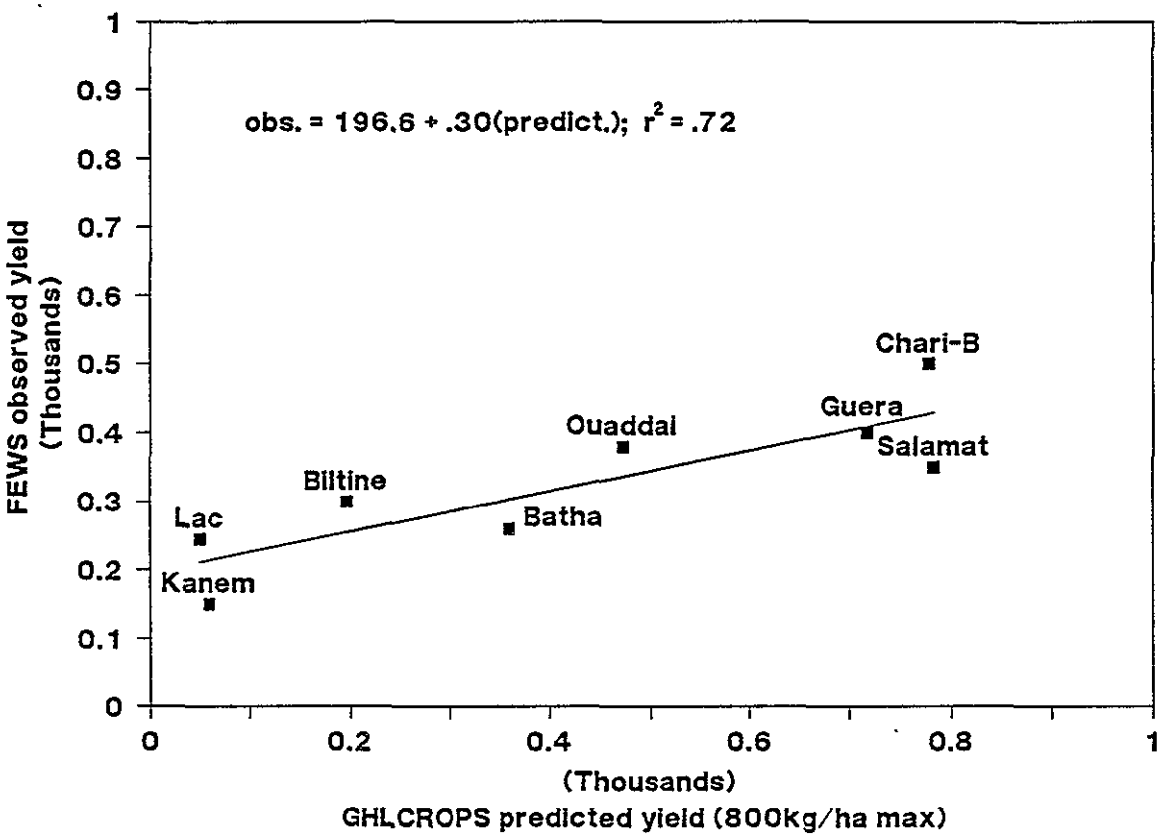

Figure 7. Comparison of millet yields predicted using GHLCROPS versus average prefecture yields reported for Chad, 1987 by FEWS.

The predictive ability of the GHLCROPS submodel is presently restricted to average yields at the level of prefectures. Without further validation/calibration tests using more resolute and accurate data, the precision of yield estimates at the subprefecture or village levels cannot be known. Given accurate data, however, the results of the validation using prefecture average data indicate that the original FAO algorithm and subsequent GHLCROPS modifications will provide useful predictions of potential yields.

c. Crop Phenology

Crop planting dates are determined within GHLCROPS according to an algorithm for minimum rainfall requirements for seeding and establishment. Rainfall of at least 15 mm in a dekad is sufficient for the GHLCROPS to perform a yield estimation for the crops starting with that dekad. If the following dekad has at least 10 mm rainfall, then no reseeding is necessary for the planting. Otherwise, reseeding requires at least 15 mm on any subsequent dekads (ICRISAT 1987). Crop yields are also predicted by GHLCROPS using the following 3 dekads as planting dates for each variety. If any of these four planting times have insufficient rainfall required for seedling establishment on the following dekad, then succeeding dekads are used as potential reseeding dates. Of the four dekads used as planting dates, the one with the highest predicted yield is used as the actual planting date within GHLSIM. When late reseeding occurs due to low rainfall, crop varieties are assumed to follow the same phenology due to a basic photo-insensitivity of the varieties grown in the Sahelian zone (ICRISAT 1987). Crop events follow the schedule in Table 1 (from Vanderlip 1972, Maiti and Bidinger 1981, ICRISAT 1987, FAO 1978, FAO 1980).

Table 1. Millet and sorghum phenology as used in GHLSIM.

	Days After Planting Crop Variety (season length)					
	Millet			Sorghum		
Crop Stage	75	90	120	90	100	130
Seedling begin	8	9	11	9	10	12
Seedling end	18	21	27	21	23	29
Grain fill begin	27	33	62	33	38	71
Grain fill end	61	67	97	65	71	107
Harvest	77	89	119	89	99	129

2. Grasshopper Population Dynamics

Population dynamics of O. senegalensis (OSE) as treated in GHLSIM is summarized in Fig. 8. The primary task performed in the GHLOSE submodel is to output a matrix of untreated and treated daily grasshopper densities. As alternative submodels for OSE and other grasshopper species become available, incorporation into the modular design of GHLSIM should be relatively easy.

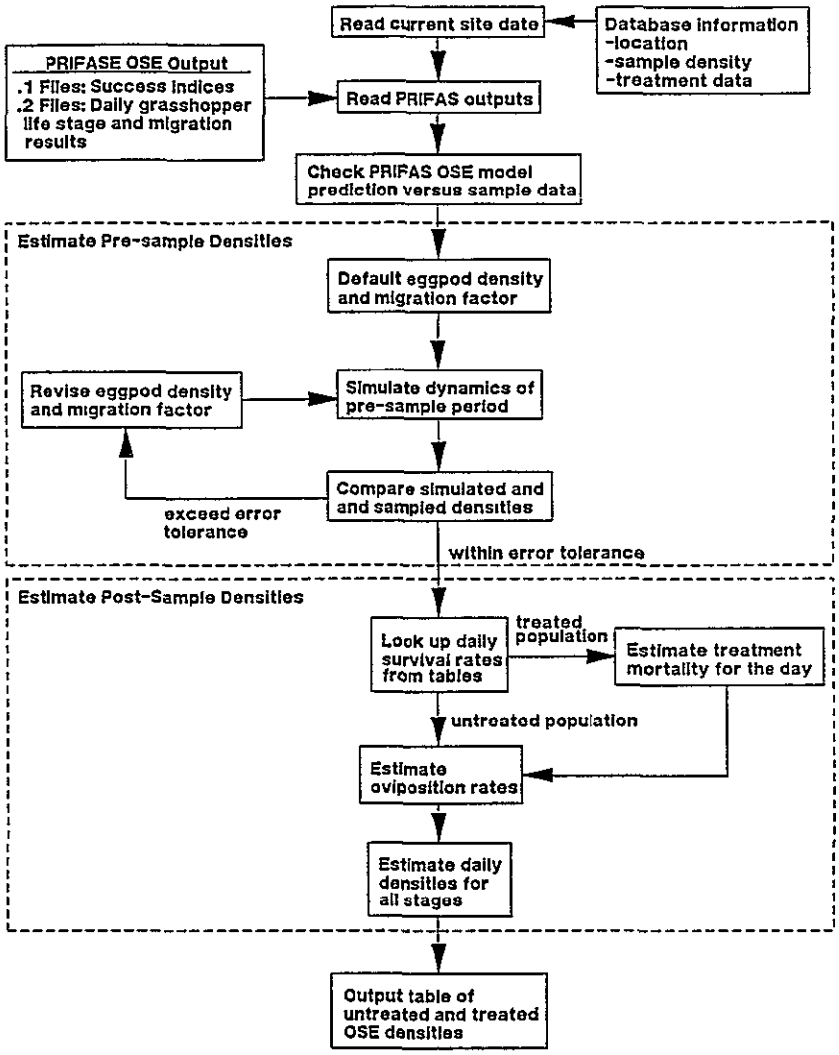

Figure 8. GHLOSE: O. senegalensis population dynamics submodel.

a. OSE Output Translation

OSE population dynamics within GHLSIM now rely upon output from a recent version of the OSE biomodel (FAO 1986b). The form of this output for the currently used version of OSE consists of success factors for grasshopper stages on a per dekad basis and grasshopper presence/absence dynamics on a daily basis. Success factors are determined within the OSE biomodel by a table look-up for eggs, nymphs, adults, immigration, and emigration for the current photoperiod, temperature, and a hydrological factor. Output from the OSE biomodel is found in a set of two files for each site simulated; example names are 001487.1 and 001487.2. The *.1 files contain success index values for each life stage and dekad. Also the *.1 files have estimates of millet and sorghum seedling and grain filling periods and indicate when these crops are likely to be at risk due to corresponding high success indices for grasshoppers. The *.2 files track individual grasshopper populations and display life stage

information on a daily basis. Recent OSE biomodel results based on rainfall weather data only were found to be 80% accurate compared to FAO grasshopper sample reports (Launois and Launois-Luong 1985). The OSE biomodel has been used regularly in the Sahel for several years now.

b. Survival Rates

The success indices output by the OSE biomodel were used as the basis for daily survival rates in GHLOSE. Due to a lack of studies concerning OSE natural mortality rates, other grasshopper species' mortality rates were used here on the assumption that survivorship curves for OSE are similar to other species and that variations of such mortality curves for OSE will follow ranges observed for other species.

Onsager and Hewitt (1982) studied natural mortality rates of six species of grasshoppers in North America for a three year period. The full ranges of stage mortality rates per day observed by Onsager and Hewitt for the six species were used here (Table 2).

Table 2. Survival rates per stage (from 6 rangeland grasshopper species; Onsager and Hewitt 1982).

	Success Index					
Stage	0	1	2	3	4	5
L1	.40	.48	.53	.60	.68	.75
L2	.75	.76	.78	.79	.80	.81
L3	.86	.87	.88	.89	.90	.91
L4	.91	.92	.93	.93	.94	.94
L5	.94	.94	.95	.95	.96	.97

Survival rates per stage were converted to survival rates per day (Table 3) by the formula (Onsager and Hewitt (1982)):

$$S_{ld} = S_l^{(1/D_l)}$$

where

S_{ld} = % survival per day, S_l = % survival per stage, and

D_l = Duration of the stage in days

In the OSE biomodel, higher development success index values reflect faster development rates (OSE biomodel Table T2).

Table 3. Survival rates per day from Table 1 above and Table T2, OSE biomodel.

	Success Index					
Stage	0	1	2	3	4	5
L1	.944	.935	.923	.918	.926	.931
L2	.976	.970	.959	.954	.963	.959
L3	.992	.989	.986	.983	.983	.981
L4	.995	.993	.992	.990	.990	.988
L5	.997	.996	.995	.994	.993	.994
Adult	.900	.910	.920	.930	.950	.960

This preliminary derivation of survival rates will be subject to calibration and validation analyses, once adequate OSE population data are made available. A survival rate sensitivity and calibration factor will be user-modifiable in GHLSIM to allow for calibration and sensitivity studies.

c. Effect of Treatment Tactics

Effects of treatment tactics are estimated through a function relating pesticide half-life to differing susceptibility levels of grasshopper life stages. The half-life function (Fig. 9) is similar to one used in a model of grasshopper injury to wheat (Hardman et al. 1985). Two parameters determine survival rates on a daily basis: the maximum efficacy of the treatment tactic, and the residual half-life of the tactic. Both of these values are stored and modified within the Treatment Tactics Defaults database. The survival rate function used is:

$$S_t = 1 - Max \times \exp^{(-0.6931 \times t / HL)}$$

where

S_t = the daily survival rate

Max = the maximum efficacy of the treatment tactic (proportion killed)

t = time in days since treatment

HL = the half-life interval of the treatment tactic (days)

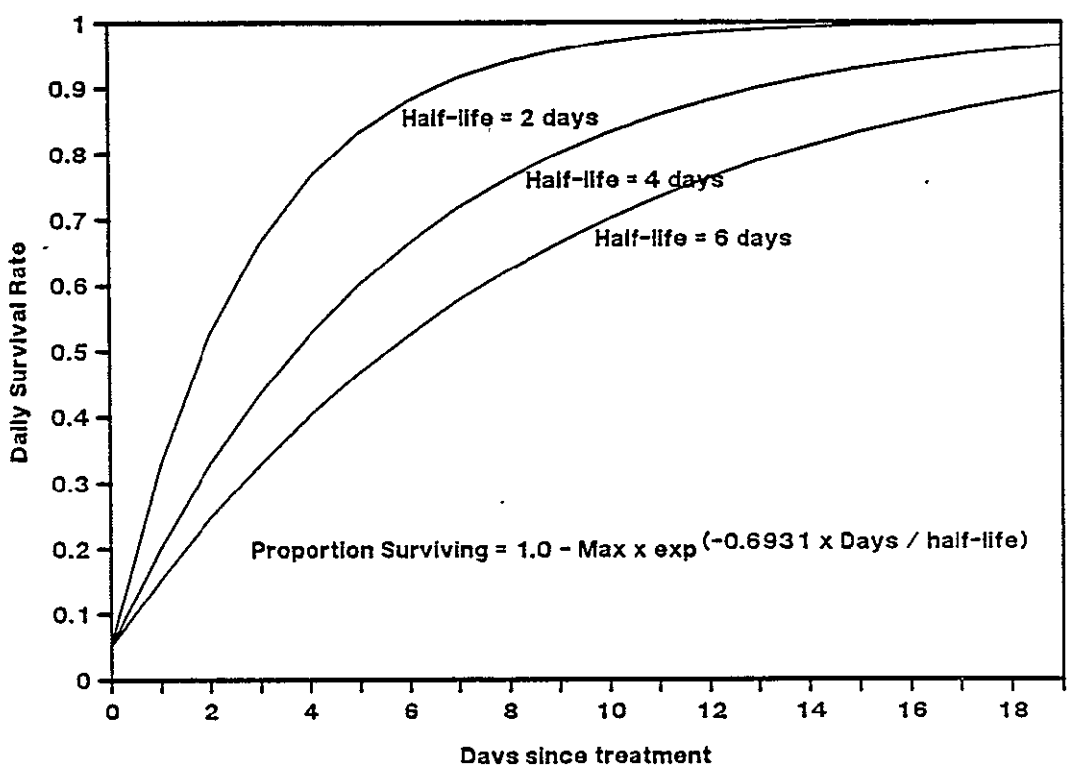

Figure 9. Function used to describe residual activity of treatment agents in GHLSIM.

d. Reproduction

OSE reproduction in GHLSIM is a function of whether the population is local or immigrant, the success index for mature adults, the success index of immigration, the fecundity rate, and the density of the population. The proportion of females laying eggs is density dependent with the number of successful ovipositing females gradually falling off at densities above $20/m^2$ (Fig. 10):

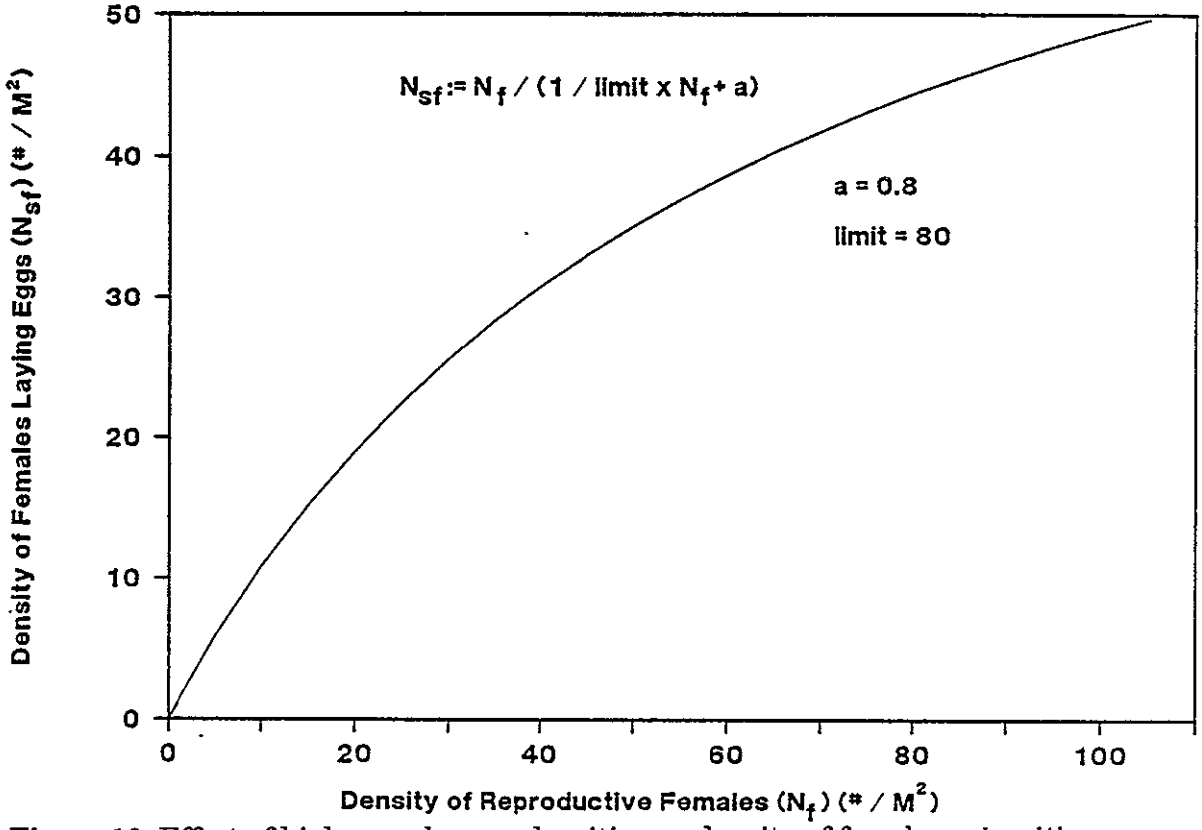

Figure 10. Effect of high grasshopper densities on density of females ovipositing.

$$N_{sf} = N_f / (b \times N_f + a)$$

where

N_f = **the current density of reproductive female OSE**

N_{sf} = **the density of ovipositing females**

a = **0.8**

b = **0.0125 (1/80)**

Reproduction (density of offspring) is a function of the density of ovipositing females times the reproductive rate, the current success factor for eggs (IRO), and the current success factor of immigration (IAA):

$$E_{sf} = N_{sf} \times f \times \max(1,IRO)/25 \times \max(1,IAA)/5 \times C$$

where

E_{sf} = the density of eggs

f = average fecundity (60 eggs/ female) (Popov 1985, USAID 1987)

IRO = the current success index of eggs (range 0-5) (from OSE biomodel)

IAA = the current success index of immigration (range 0-5) (from OSE biomodel)

C = calibration constant

When either IRO or IAA are low, conditions are not ideal for egg laying and number of eggs is reduced. The current status of this function is that it is calibrated to achieve realistic model output but it has not been separately validated.

3. Crop Injury Simulation

Crop injury is simulated in the GHLINJ submodel, which uses output from GHLCROPS and GHLOSE (Fig. 11). Injury equivalent values are calculated daily and are determined by grasshopper stages, grasshopper densities, the consumption rate for each stage, a consumption calibration factor which takes into account the grasshopper development rate, the proportion of feeding made on the crop, an index of crop preference as influenced by natural vegetation greenness, and the susceptibility of the current crop stage. There is also a factor where crop injury is gradually diminished as the crop is removed from the field during harvest.

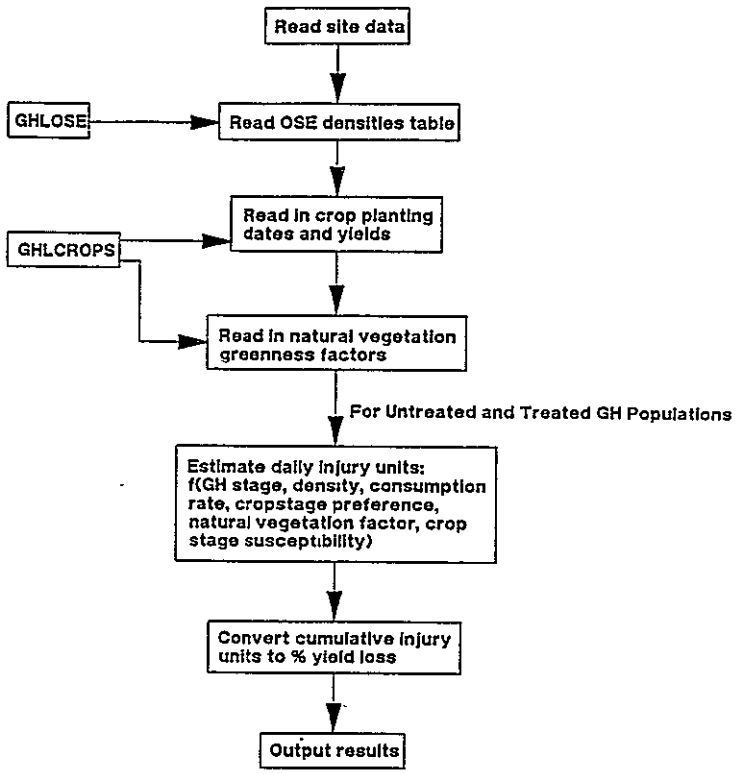

Figure 11. GHLINJ: Crop injury submodel.

The equation used in GHLINJ for crop injury units accumulation for each crop variety is:

$$IUs_{day} = \sum_{s=3}^{8} (Dens_s \times CRate_s \times CCal_{s,IV} \times PCrop_{cs} \times VPref \times CSusc_{cs} \times Pharv_c)$$

where

IUs_{day} = the accumulated crop injury units for the crop for the day

s = the grasshopper stage 3=3rd instar nymph, 8=ovipositing adult

c = the crop (millet or sorghum)

cs = the crop stage

$Dens_s$ = the current density of the grasshopper stage

$CRate_s$ = the consumption rate of the grasshopper stage

$CCal_{s,IV}$ = the consumption calibration factor due to the grasshopper stage and the current index for development

$PCrop_{c,cs}$ = the crop preference for the current crop and stage of crop

VPref = the current factor due to greenness of natural vegetation

$CSusc_{cs}$ = the current susceptibility the crop stage to defoliation

$PHarv_c$ = the proportion of the crop remaining to be harvested

Components of crop injury unit calculation are treated individually in subsequent sections.

a. Consumption Rates

OSE consumption rates are derived from stage-specific OSE wet weights (Launois 1978), and grasshopper stage dry weights which are estimated from wet weights using the method of Van Hook (1971):

$$\mathbf{Dwt = P1 \times Wwt^{P2}}$$

where

P1 = 0.059

P2 = 1.272

Consumption per nymphal instar and adult substage are then estimated using the method of Gander (1982), which uses a conversion factor between dry weight of grasshopper and dry weight of foliage consumed:

Cfac = 0.35

The wet weight and foliage consumption values estimated using the procedure above are listed in Table 4.

Table 4. OSE wet weight and foliage consumption values.

Stage	#	Wet Wt. (mg)	Foliage Consumption (mg foliage/stage)
Nymph 3	3	53	3.2
Nymph 4	4	100	7.2
Nymph 5	5	240	22.0
Adult Soft	6	180	15.3
Adult Pre-OV	7	119	9.01
Adult Post-OV	8	100	7.2

Consumption rates per stage must be converted to daily estimates to be used in GHLSIM. The OSE biomodel uses stage-specific grasshopper success indices, presented in a table (Launois 1978), to determine development rates. Generally, the

higher the index value, the faster the rate of development. Daily consumption rate similarly increases with the success index. As the development rate decreases from optimum, the consumption rate is reduced proportionally (Table 5).

Table 5. Factors used to correct OSE consumption rates for suboptimal development rates.

	Grasshopper Stage					
Success Index	3	4	5	6	7	8
20..25	1	1	1	1	1	1
15..19	5/6	5/6	5/6	3/4	10/12	1
10..14	5/7	5/7	5/8	3/5	10/15	1
5..9	5/9	5/9	5/10	3/6	10/19	1
1..3	5/13	5/13	5/14	3/9	10/27	1
0	5/20	5/20	5/20	3/12	10/40	1

Plant material destroyed but not consumed should be considered as an additional impact of grasshopper feeding on crop loss (Mitchell and Pfadt, 1974). This aspect of crop loss is currently treated as a constant within GHLSIM.

b. Feeding Preferences

OSE feeding preference refers to the tendency of the insect to feed on the crop rather than on weeds and surrounding natural vegetation. OSE tends to prefer native vegetation over millet and sorghum and prefers millet to sorghum (Table 6).

As crops are planted at the beginning of the rainy period, seedlings may emerge earlier than native vegetation. Seedlings are particularly susceptible to defoliators which clip the foliage. Early crop failure due to grasshoppers normally is remedied by reseeding, however, minimizing their impact on crop production. There normally is also a rapid greening of native vegetation by the late seedling stage. In GHLSIM, grasshoppers have a low feeding preference for early crop stages. As the season progresses, if the native vegetation remains green, then feeding on the crop is reduced. Late in the season, as the intertropical convergence zone (ITCZ) recedes,

grasses and crop foliage dry up, leaving only the developing panicle as potential food for grasshoppers and locusts. Late in the cropping season, then, relative preference for the crop increases and the damage becomes more direct relative to the harvested commodity. In GHLSIM, the crop preference is divided into two factors, the degree of preference due to crop variety and stage (Table 6), and the preference as affected by the greenness of native vegetation, which is a function of cumulative precipitation (Fig. 12).

Table 6. The factor for crop preference as influenced by crop (millet and sorghum) and crop stage (planting through harvest).

	Crop Preference Factor	
Crop Stage	Millet	Sorghum
0 (pre-emergent)	0.0	0.0
1 (emergent)	0.2	0.05
2 (seedling)	0.4	0.1
3 (tillering)	0.3	0.075
4 (grain fill)	0.75	0.375
5 (mature)	0.7	0.35
6 (harvesting)	0.7	0.35

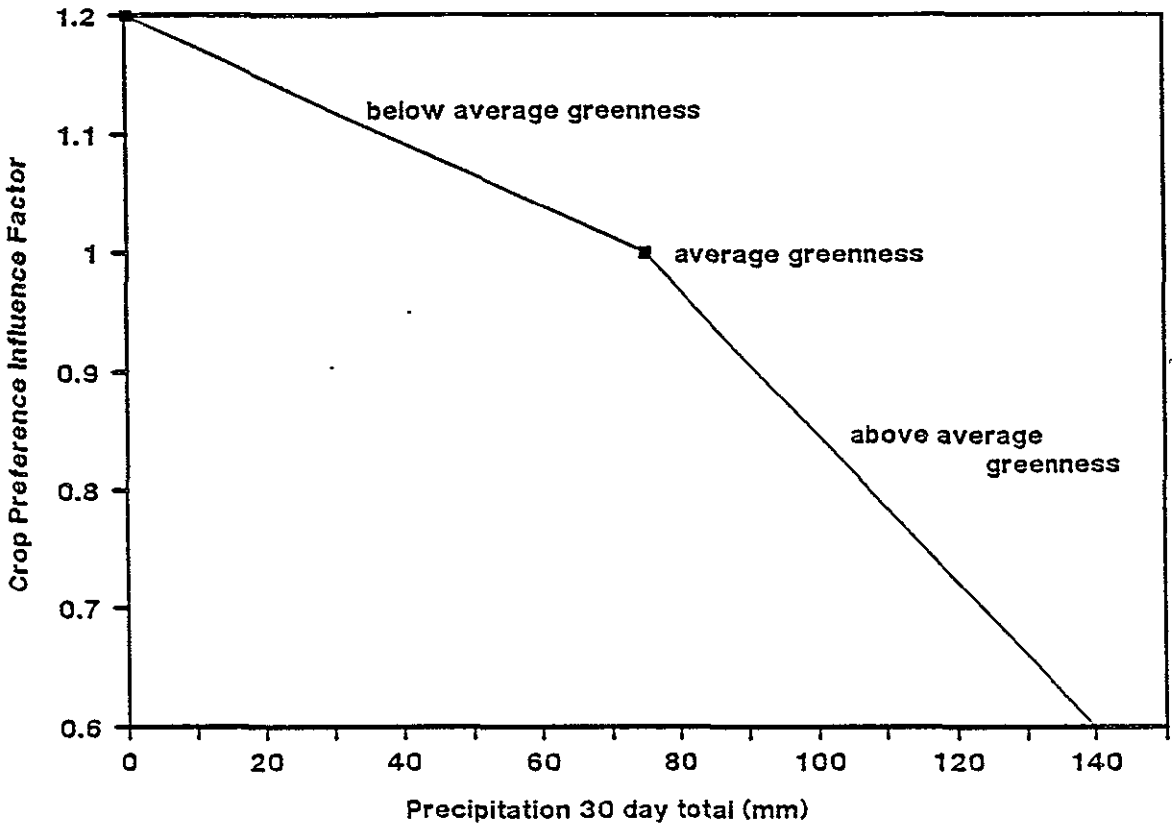

Figure 12. Influence of cumulative rainfall on vegetative greenness factor used for O. senegalensis crop preference.

c. Crop Injury Susceptibility Factors

Another factor affecting the accumulation of crop injury units is the susceptibility of the crop to feeding injury. The crop susceptibility factor reflects the crops ability to compensate injury, which is determined by the plant part consumed and the intrinsic effect of defoliation at each crop stage on yield loss. Defoliation studies on cereal grains have shown widely differing compensatory abilities of different crop stages. Sorghum was most susceptible to defoliation by lepidopteran larvae during head formation 30-40 days after planting, while early injury to leaves caused negligible yield loss (Starks and Burton 1979). Complete regeneration occurred after defoliation in the early growth stages of sorghum and maize (Brown and Mohamed 1972). Complete defoliation to the main stem of sorghum in the early stages was compensated due to tillering activity later. In simulated hail injury to maize at 5-6 leaves (Eldredge 1935), very little yield reduction resulted from cutting the plant off at the surface, due to the growing point being below ground level. Greatest sensitivity to defoliation was at 50-55 days post-emergence, decreasing to nearly complete insensitivity at 70 days. Accumulation of carbohydrates in stems,

sheaths and panicle accounted for compensation of the loss of photosynthetic area. Crop losses to maturing millet and sorghum increase as grasshoppers and locusts feed directly on the developing panicle rather than on drying foliage.

The values currently used for crop stage susceptibility reflect our understanding of stages of millet and sorghum considered at greatest risk (seedling and grain filling), and the reported regrowth abilities of other grain crops studied (Table 7).

Table 7. Crop susceptibility factors used for millet and sorghum.

Susceptibility Crop Stage	Factor
1 (emergent)	0.5
2 (seedling)	0.25
3 (tillering)	0.10
4 (grain fill)	0.25
5 (mature)	0.20
6 (harvesting)	0.15

d. Final Yield Loss Function

At harvest, the accumulated injury units are converted to percentages of yield loss for each of the six crop varieties. Because the crop stage susceptibility factors are intended to convert plant tissue consumed to units that may be applied to crop loss, GHLINJ currently assumes a linear relationship between crop injury units and damage until a maximum threshold is approached. Generalized damage functions usually show a leveling of crop loss at higher levels of injury, due to the effect of competition or increased dispersion among pests (Bardner and Fletcher, 1974). This function is displayed in Figure 13. At 40% yield reduction, crop injury units begin to have a decreasing effect on yield up to a maximum yield reduction of 85%.. The resulting values estimated by GHLINJ are the percentage crop losses for both treated and non-treated situations. These values are then used (in GHLECON) to estimate the benefits of treatment.

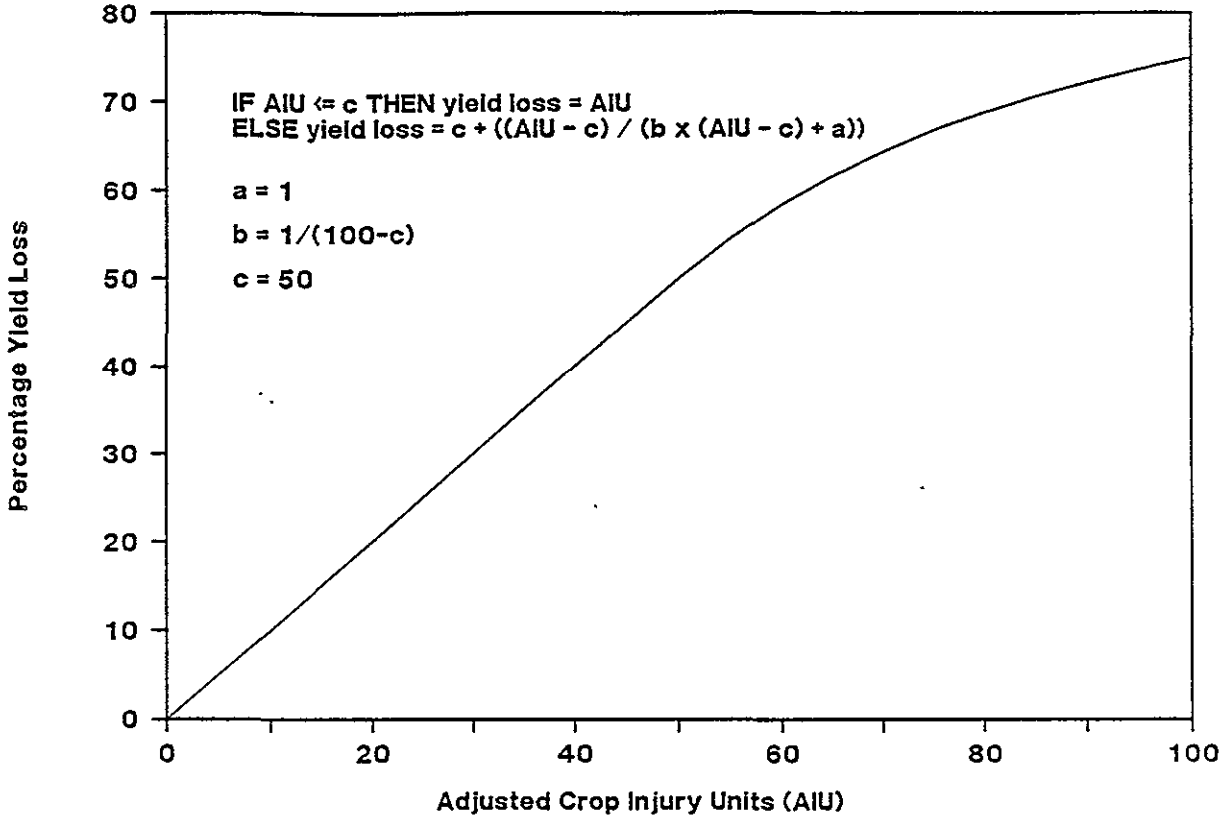

Figure 13. Injury unit - percent yield loss function used in GHLINJ.

4. Estimation of Costs and Benefits of Treatment

Costs and benefits of treatment for the current year and second year are calculated in the GHLECON submodel (Fig. 14).

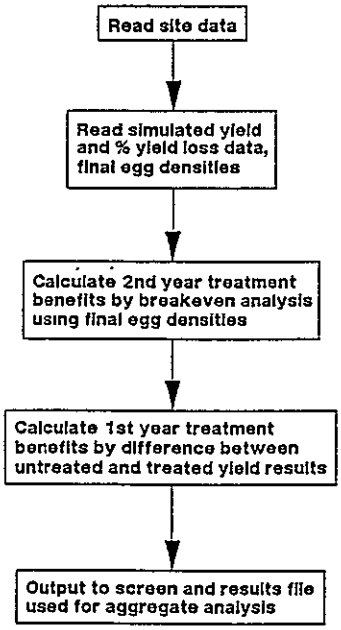

Figure 14. GHLECON: Treatment benefit/cost submodel.

a. First Year Benefits

The potential yield is hypothetical but necessary to account for losses from grasshoppers that survive treatment:

$$Y_p = Y_t / (1 - L_t)$$

where

Y_p = the potential yield (hypothetical; no grasshopper impact),

Y_t = the reported yield, equal to the treated yield, (estimated by GHLCROPS if unavailable)

L_t = the proportion crop loss after the treatment date (treated) (from GHLINJ)

The crop yields used are either reported (if available) or estimated by the GHLCROPS submodel and are assumed to be the same as 'treated' yields. This assumption is based on the GHLSIM objective to evaluate the economics of a treatment campaign. Therefore, the reported yields should reflect the losses incurred by grasshoppers surviving treatment.

Yields in the non-treated situation are estimated as one minus the proportion yield loss (non-treated) times the potential yield:

$$Y_{nt} = (1 - L_{nt}) \times Y_p$$

where

Y_{nt} = the non-treated yield, and

L_{nt} = the proportion crop loss after the treatment date (non-treated)

The benefit of treatment is estimated in dollars as the crop price times the difference between the treated (t) and non-treated (nt) yields:

$$B_t = P \times (Y_t - Y_{nt})$$

b. Second Year Benefits

Some of the benefits of treatment are not realized until the season(s) following the treatment effort, due to the carryover effect of disrupting pest population dynamics. Estimating the carryover benefits of treatment by simulation require following each population through the next season and measuring the yield losses for treated and non-treated situations. The degree of difficulty in forecasting conditions for the next year is the reason this approach was not taken. A simpler way of

estimating the second year treatment benefits is to use a breakeven analysis, where overwintering egg densities generated by GHLSIM are used to estimate the potential for crop losses the following season (Fig. 15). The breakeven density, defined as the density of grasshopper eggs producing a population causing losses equal to the treatment cost, is used to estimate crop losses for the second year. The difference between treated and non-treated egg densities is used with expected crop values and treatment costs for the following year to determine the second year benefit of treatment. The second year benefits are discounted before adding them to the first year benefit of treatment.

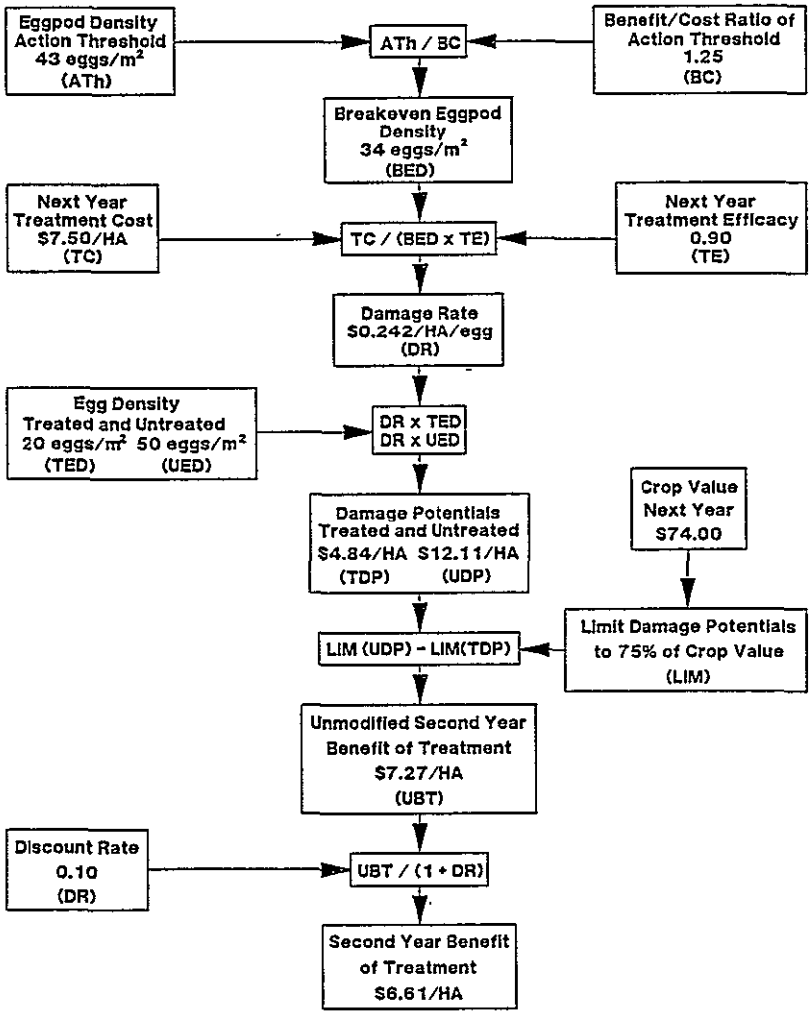

Figure 15. Breakeven analysis method used in calculation of second year treatment benefit.

Egg density data were collected for use in the planning phase of treatment campaigns and were used in determining the relative need for treatment activities in differing regions (FAO/Donor review of the 1987 grasshopper campaign). During

1987, in the early planning stages of the campaign, regions were selected for intervention based on egg densities above an approximate threshold. Model predicted densities are used to estimate the potential value of crop losses the following season. A relationship between egg density and expected loss was derived primarily from the breakeven threshold value.

The campaign threshold egg density was estimated from an average of the two highest non-treated densities and the two lowest treated densities reported for the campaign (USAID 1987; Annex 2); average = 43/m^2. This campaign threshold was probably higher than a breakeven density, since for any area treated, benefits should be significantly greater than costs. The default millet value ($74/HA) and cost of treatment ($7.50/HA) were from the 1987 USAID campaign, and treatment efficacy set to a default of 0.90. The breakeven density (34.4/m^2) was calculated by dividing the campaign threshold density by the expected benefit/cost ratio for that density, temporarily set to a default of 1.25. The density/loss function was assumed linear until higher grasshopper egg densities no longer cause equally higher losses. The slope of the density/loss function up to the break point is the treatment cost divided by the breakeven density, 7.50/(34.4/0.90) = 0.242. The upper limit of the function was set to 75% of the crop value, and the break point was set at 40% of the crop value. All of the above mentioned defaults are user-modifiable within GHLSIM.

V. Discussion of GHLSIM use for Other Purposes

1. Estimation of Economic Thresholds

The economic injury level has been defined as the density of pests causing crop losses equal to the cost of preventing such losses. The generally accepted method for estimating economic injury levels is based on a breakeven formula for costs and benefits of treatment (Norton 1976, Reichelderfer et al. 1984):

$$PdDPR = C$$

where

Pd = the pest density

D = the crop loss per pest

P = the crop price

R = the reduction in the pest population due to the treatment tactic

C = the cost of treatment

This formula is then manipulated to solve for the economic injury level (Pd*) to result in:

Pd* = C/DPR

In reality, though, the above variables are not static but change in space and time. The pest density changes on a daily basis. The crop loss per pest can vary with the pest stage and density, preference for the crop, and stage and vigor of the crop. The reduction of the pest population due to the treatment tactic also varies with the pest stage, treatment efficacy, and other variables. When these dynamics are considered, then actual treatment threshold guidelines can be derived. A treatment or economic threshold is the time when the pest density is first predicted to exceed the economic injury level (Stern et al. 1959). Nominally, treatment thresholds are determined non-analytically, based on an informal assessment of the above variables and of risks involved. Simulation models such as GHLSIM that incorporate these dynamics offer a comprehensive protocol for deriving treatment guidelines. GHLSIM can be used to study how threshold levels vary as a result of changing any of these variables.

Because GHLSIM simulates crop losses and calculates the benefit-cost ratio of the treatment tactic, and because time of treatment may be experimented with using behavior options, it is possible to not only determine breakeven grasshopper densities (B/C ratio = 1.0), but to also determine the treatment timing that maximizes B/C ratios. The timing may be specified relative to crop stage, date, or grasshopper population development. One method recommended for deriving average treatment threshold levels using GHLSIM is to run a simulation using a group of grasshopper samples which all share the same treatment tactic. The grasshopper sample densities are then plotted versus the net benefit for each sample using the analysis menu item of GHLSIM. If some of the sites treated had a negative net benefit, and others positive, then the analysis will fit a regression line that will cross the x-axis at the density that on average would result in a net benefit of 0.0. This density would be near the treatment threshold level and provide a starting point for deciding on practical treatment threshold guidelines for use in the field.

2. Real-time Decision Support

Use of GHLSIM for real time decision support will require using one or more future weather scenarios with the OSE biomodel to predict grasshopper phenology.

Because all components of GHLSIM interact with weather variables, output reliability is linked with the uncertainty involved in weather prediction. Historical average, maximum, and minimum weather data should be used to obtain a range of possible scenarios. As the OSE biomodel provides the basis for grasshopper population dynamics, and has provisions to operate in a predictive mode (FAO 1986b), then GHLSIM may similarly be used in this manner. The OSE biomodel has an option for using minimum, average, or maximum historical precipitation data for filling in missing values. Rainfall and other weather variable forecasting models have not yet been incorporated into the OSE or GHLSIM models. Such forecasting models could be run separately and weather variable predictions converted into the necessary formats. A rainfall information system (RIS) has been developed for the Sahelian countries and has certain historical-data based forecasting methods (Linhardt 1989). It is also be possible to enter short-term meteorological forecasts into the weather files and predictively model grasshopper impact. Additional crop prices and yield predictions would also be entered in the databases to use GHLSIM for real time decision support.

3. Education and Training

While in some instances there may be insufficient data to use GHLSIM for management and planning, it can serve a role in teaching the basic components of an economic crop loss analysis from a biological perspective. It reflects the state of our knowledge about Sahelian grasshopper and locust management and accordingly can reveal knowledge gaps and identify future needs of research in this area.

Example scenarios where GHLSIM could serve a role in education and training of crop protection personnel include:

a. Indicate the variables needed to conduct a simulation and show how grasshopper survey forms should be completed with regard to densities, stages present, crop stages, and treatment methods.

b. Display, using the graphics output of the injury submodel, how grasshopper populations develop and cause variable crop injury depending on crop stage, pest stage and density, and treatment tactics used.

c. Show how new technology can provide tools to organize and analyze information for resource management.

d. Through sensitivity analyses, aid in defining the areas of knowledge and data most needing refinement.

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i. Summary

Two approaches to conducting an analysis of the AID anti-locust campaign in Chad during 1987 are presented. The first was based on a data-gathering mission to Chad the following season. The second approach utilized the GHLSIM model (Version 1.0), which is under development to provide an analysis protocol for grasshopper treatment campaigns in the Sahel. Although neither approach can be considered comprehensive due to inadequate data, results from both methods tended to support one another and indicated that the campaign was effective in preventing crop losses to

an equal or greater value than the cost of control. Both analyses resulted in estimated benefit/cost ratios of around 3.0, while second year benefits made using GHLSIM increased this estimate to 4.2. The GHLSIM model may currently be calibrated to over-estimate benefits by some amount, however. A behavioral sensitivity analysis conducted using GHLSIM indicated that the timing of the campaign was within 5-10 days of providing optimal benefits of treatment. Data collected from the field including reported yields, crop loss estimates, and grasshopper densities point to an overall economic justification of the campaign. The large scale of the campaign (134 thousand Ha) and very high grasshopper densities treated before end-of season reproduction also reduced the likelihood of outbreaks over large areas the following season.

ii. Introduction and Review of the Project

Grasshoppers and locusts periodically cause significant crop losses in the Sahelian countries of Africa. Large scale control efforts, in the attempt to prevent decimation of food crops and the subsequent need for massive food donations, were conducted during 1987. Little data exist, however, to assess the cost-effectiveness of these control efforts. There is considerable need for the development of data collection procedures and analysis protocols to perform treatment campaign cost-benefit analyses. Two approaches to analyzing the benefits and costs of the USAID campaign in Chad in 1987 are presented here as part of the project contracted between AID and IPPC. The first approach was by sub-contract to Habib Khoury to retrieve specific crop treatment and yield data for the areas treated. This was intended to provide an independent assessment of the campaign as well as to potentially provide information to validate the GHLSIM benefit-cost model. The second approach was to use the GHLSIM model itself to perform an evaluation of campaign benefits and costs. Although the model has not yet undergone extended testing and validation, it was calibrated to reflect treatment threshold guidelines in current use and is more responsive to interactions between weather, crops, and grasshopper populations than are simple threshold guidelines.

MISSION REPORT

ON

COST/BENEFIT ANALYSIS

FOR THE

1987 AERIAL TREATMENT OPERATION

IN CHAD

BY

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I. INTRODUCTION

Grasshoppers in the Sahelian countries in Africa causes regularly substantial damages to food crops and contribute largely to yield losses.

Following the severe grasshopper outbreak of 1986, Chad was faced, during the 1987 growing season, with another heavy grasshopper infestation. The problem in 1987 began with the first rainfall in early June that favored hatching of diapaused eggs laid late in the 1986 season.

The grasshopper population, due to regular rains in July, August and September 1987, continued to grow, develop,and increase in numbers producing the second and third generations in the sahelian zone of the country. Infestation, in general, however was less severe than expected, nevertheless was heavy in many areas that required aerial spraying as well as ground treatment.

The USAID assistance to the government of Chad in its effort to control the grasshopper infestation in 1987 was directed to the aerial spraying operation in the eastern part of the country. In this operation, that started early September and ended late October, USAID achieved 90% of its objective by spraying about 134,000 hectars of millet fields (including a buffer zone of range-land surrounding the treated fields) using about 65,000 liters of Malathion ULV 96% and 180 hours of spraying time.

Following the end of the program, USAID in Washington was interested furthermore in the economic evaluation of the 1987 aerial operation in Chad. Thus the mandate was assigned to the International Plant Protection Center (IPPC) of Oregon State University, USA, to conduct that evaluation, as a part of their studies in Crop Loss Assessment in Chad.

Consequently, IPPC organised this mission to Chad that took place from June 26 to July 14, 1988 and included a field trip to three prefectures : Batha, Ouaddai and Guera, from July 4 to July 9, 1988.

The following report contains mainly the cost-benefit analysis of the 1987 USAID aerial spraying operation. It descibes first the approach of the analysis, the bases of the calculations, then it discusses the results and it ends with the conclusions and recommendations. The list of persons contacted during the mission and the documents reviewed are presented in annexes 4 and 5.

II. OBJECTIVES

In order to fulfil the required mandate for IPPC, the following three primary objectives were set for the mission :

1) Collection of data on aerial treatment costs contributed by USAID in 1987, and then determining the treatment cost per hectar;

2) Collection of other data regarding the aerial operation and serving for the economic evaluation and cost-benefit analysis of the USAID program. Among these data are yield and price of millet, grasshopper infestations, and aerial treatment efficacy.

3) Establish a loss function relationship for the grasshopper damages, in order to contribute to the Crop Loss Assessment studies.

III. APPROACH OF THE ANALYSIS

The cost-benefit analysis of the USAID's 1987 grasshopper control program in Chad required the collection of the following main five basic information :

1) The total costs of the aerial treatment program based on the total financial assistance allocated by USAID for the treatment operation during the 1987 growing season.

2) The total area sprayed by air for each operating site. This information was gathered from the last year record-books maintained by the Field Manager of the USAID control program and from the Crop Protection Service (CPS) reports.

3) The millet price. Millet was chosen as the only crop under this study since it was the crop that has been damaged the most by grasshopper attacks and it was the only crop sprayed under the USAID aerial treatment operation. Also, millet is the major food crop cultivated and produced in Chad. Available prices of many commodities in Chad are the market prices given in the monthly reports of ONDR (the National Extension Service). Millet price in this analysis was the price taken from these reports and averaged over the latest 12 months (June 1987 -May 1988).

4) The millet yield. Precise information on millet yield was difficult to obtain, particularly those specific yield data per village which were practically non existant. The only few villages that had yield data in the Sahelian zone were the villages surveyed by the two projects : SAR (Systeme d'Alerte Rapide) and SAP (Systeme d'Alerte Precoce) associated with FEWS project (Famine Early Warning System) and the Statistics Bureau of the Ministry of Agriculture. In general, yield data available in the ONDR reports were limited to that of the prefecture and sub-prefecture and rarely to the 'Canton' level.

The original plan for the analysis was to compare between yields obtained in treated and untreated villages in order to evaluate the benefit of the aerial treatment. The almost unavailability of these data limited the comparison and greatly decreased its precision.

A very important point is to be realized, that yield reduction in the sahelian zone was not due merely to grasshopper damages. Many other factors affected millet yield, mainly drought during the growing cycle that has retarted maturity and reduced yield; and secondly damages caused by other pests such as stem and head borers, which were responsible for additional serious losses in some areas. These factors were often reported in the ONDR reports reviewed.

5) Grasshopper population densities. Data concerning these densities were collected from the "Fiches de Signalisation" completed along the season by the field prospection teams. These data indicated the location of infestation, the grasshopper species and densities as well as the importance of damage and information regarding ground treatment.

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The cost-benefit analysis presented in this report used two approaches. The first was a straight forward approach in which comparisons were made in two ways : a) between yields obtained in few treated and untreated villages, and b) between yields of the treated villages and the yield average of the corresponding sub-prefecture.

The second approach was developed in response to the lack of precision in estimating yield benefit and the nearly non-existance of yield estimate per village. This approach used the "Breakeven" analysis inwhich the calculated treatment cost per hectar was converted to its equivalence in millet weight, using the yearly average of millet market-selling price. This weight equivalence represented the minimum yield gain required to consider aerial treatment economically beneficial. This breakeven value in fact adjusts for variability in prices among sites. To adjust furthermore for variability in yield among locations, the breakeven value was divided by the corresponding yield estimated for the site to produce the breakeven ratio.

Breakeven values obtained from this second approach were used for comparison among operating sites. The breakeven ratio (BER) seemed to be the most liable for comparisons, since it adjusts treatment cost for variabilities, among operating sites, in both of millet price and yield.

In addition to the use of this second approach for the present analysis, the developed model can also be utilized for future projection in evaluating ahead the cost effectiveness of a similar future aerial treatment program. In most cases, the four parameters - required for the calculation of this model - are normaly known before the start of the operation : the finacial assistance pledged for the control program, the targeted area to be sprayed, the average millet price for the latest 12 months, and the expected usual yield per hectar for the targeted area.

Concerning the establishment of a loss function, the poor yield data available did not permit the development of the desired relationship between grasshopper densities and yield. Data collected from about 400 villages, prospected along the season, provided the required populations densities in the completed forms "Fiches de Signalisations"; but no corresponding yield data were available for those villages. This, unfortunately, attributed to the failure in achieving the third objective of the mission.

IV. BASES OF THE CALCULATIONS

1) The treatment cost

The USAID aerial treatment operation during the 1987 Grasshopper Control Program costed about $ 1,180,000 (Source: ADO/USAID/CHAD). This cost consisted of seven elements:

i. Purchase of 90,000 liters of Malathion 96% ULV and their transport to Chad by air. Their cost was estimated at $ 5.40 per liter arriving N'Djamena.

ii. In country transport of 438 Malathion drums to the 9 operating sites by trucks. The unit cost of this operation was calculated at $ 32.00 per drum.

iii. Purchase of 364 drums of fuel and their transport to the operating sites by trucks. The unit cost for this operation was calculated at $ 275.00 per drum.

iv. Tertiary transport of Malathion and fuel drums among operating sites, during and at the end of the treatment operation. As it was difficult to determine the exact number of drums to account for per site, it was judged pertinent to calculate this cost on the basis of half of the total number of transported Malathion and fuel drums per site. The $ 9,000 allocated for this operation was then divided by 400 drums to produce the unit cost of $ 22.50 per drum.

v. Aerial spraying operation. The aerial spraying services contract amounted to $ 400,000 where 180 hours of total spraying time were used during the opertion. The unit cost then was estimated at $ 2222.00 per spraying hour, including all other operational costs involved such as ferry time among operating sites and costs of the ground support team.

vi. Technical assistance. Account for this assistance was prorated per day over the 50 days duration of the aerial spraying operation in the field. The cost of technical assistance was estimated at $ 2,500.00 per spraying day, considering that this amount includes all other costs needed for the assistants to do their preparatory work before and after the field operation. Prorating per spraying day was particularly chosen in order to give every operating site its proper share for the unequal number of days spent per site for aerial spraying.

vii. Field prospection. Six prospection teams costed $ 46,000 for regular evaluation of grasshopper densities along the season and for preparing maps of infested areas per operating site. Due to the difficulty in allocating the share of each team to a particular site, the whole amount was divided equally to each of the 10 operating sites (including Bokoro). Thus every site was allocated $ 4,600.00 for the prospection.

.../...

For the purpose of producing the proportion of costs per operating site, calculation was based on unit costs for the quantities used in each site for each of these elements. Dividing the total cost of these seven elements for each site, by the corresponding area treated in hectar, resulted on obtaining the marginal aerial treatment cost per hectar per site.

The unused quantities of Malathion and fuel drums remained and stored at the end of the operation were not included in the calculation of treatment cost. However, they were only considered in the initial calculation to obtain the unit cost of the purchase and transport of Malathion and fuel drums.

Results obtained per operating site from the previous calculation are presented in annex (2). All costs pesented in this annex are valued in US $ based on the rate of 1 US $ = 300 FCFA.

It should be noted that costs calculated in the three operating sites : Mongo, Biltine, and Iriba included also costs involved in spraying adjacent areas of Bitkine, Am-Zoer, and Guereda respectively. In addition, treatment in Bokoro was not included in this analysis (except for calculating prospection costs) since Fenitrothion (not Malathion) was the insecticide used for spraying and the operation was conducted from Mongo operating site within one day.

2) Breakeven value and ratio

a) Yiel value. The yield value is a very essential element in the calculation of the breakeven ratio. The millet yield value was simply the product of multiplying yield obtained (in Kg per hectar) in a given area by the millet price per Kg for the same area.

Yields per hectar as well as millet market price by sub-prefecture were collected from the monthly reports of the Chefs sub-Secteur of ONDR, during the field trip of the present mission to Ati (Batha), Abeche (Ouaddai), and Mongo (Guera). Yields for the sub-prefectures presented in annex (1) are the official figuers given by ONDR for the 1987 growing season. The millet price, on the other hand, is the average selling price per Kg in the market place during the last 12 months (June 1987 - May 1988) which was considered as the period where the last year millet production was affected or sold. Certainly this price included the seller's profit which was not possible to measure and exclude.

b) Breakeven value. This value is calculated from dividing the estimated treatment cost by the average millet market price for each of the operating sites. The value calculated represented the minimum quantity of millet required for the farmer to gain above his normal yield to judge the worthiness of the aerial treatment.

.../...

c) Breakeven ratio. This ratio is calculated from dividing the estimated treatment cost per hectar by the yield value. The ratio is presented in percentage and measures the cost effectiveness threshold of the aerial treatment. The breakeven ratio could be considered as the minimum percentage required in yield increase to be resulted from aerial spraying. In fact, this ratio adjusts for the large variability in both yield obtained and millet selling price among sites.

The following three equations summarize the calculations used in the second approach and describe also the developed model that can be utilized for future projection:

TRC = FNC / ASP .....(1)

BEV = FNC / (ASP * PRC) <u>or</u> = TRC / PRC .....(2)

BER = FNC * 100 / (YLD (ASP * PRC)) <u>or</u>

= BEV * 100 / YLD <u>or</u> = TRC * 100 / YDV .....(3)

where TRC is the treatment cost in $ per hectar.
BEV is the breakeven value of millet in Kg.
BER is the breakeven ratio in percentage.
FNC is the financial contribution to aerial treatment in $.
ASP is the area aerially sprayed in hectar.
PRC is the yearly average of millet price in $ per Kg.
YLD is the average yield in Kg per hectar.
YDV is the yield value in $. (YLD * PRC).

IV. DISCUSSION AND ANALYSIS OF RESULTS

1) Treated vs untreated areas

As mentioned previously, collecting yield data in specific villages was difficult to obtain. However, very few information were available and gathered from different sources, particularly the SAR and SAP projects (where their data were computerized by FEWS project), and the ONDR reports.

Analysing results between treated and untreated areas relied completely on available yield data which are presented in annex (1). It should be noted that yield per village given in this annex is the average calculated from millet yields of 2 to 8 fields ("exploitant") per village according to SAR and SAP survey. Data shown indicated that in three of the four prefectures (Batha, Guera and Biltine) no comparable pairs of treated and untreated villages, situated in the same canton, were possible to be matched. Every canton had one or two villages only, where either both were treated or both were untreated. Only in the prefecture of Ouaddai two pairs of treated and untreated villages, belonging to the same canton, were comparable. For the first pair, yield was twice as much in the treated village, Goz-Beida, than that of the untreated village, Korai II. Whereas for the other pair, yield was rather tripled in the treated village, Attachane, versus the untreated village, Hille Tama. Although findings of this comparison propose the high yield benefit of aerial treament, yet two pairs are insufficient to advance a general conclusion.

Given this poor number of comparable pairs of villages, another procedure was used. This procedure was based on comparing yield estimated in each village with the overall average yield estimated by ONDR for each of the sub-prefectures or that of the prefecture, in the case of Biltine prefecture.

By this second procedure, we notice that yield estimated in the treated villages was always higher than that of the sub-prefecture average. The percentage increase in the Batha and Guera prefectures varied from 49% to 85% with an average of 70%, excluding the high yield increase observed in the two villages of Bola I and Keketchou, since their yield given was the expected before harvest. In the other two prefectures, yield increase was doubled and even tripled in the treated villages. On the contrary, yield estimated in the untreated villages was always either equal or lower than the yield average of the sub-prefecture.

These results strongly suggest that aerial spraying seem to have resulted in reducing losses caused by grasshoppers, and then reflected in a yield increase in the treated areas. According to prospections conducted before treatment, population densities in the millet fields were estimated between 25 to 40 individuals per square meter over large area. This high density level, observed on millet heads, caused very serious direct damages to developing grains and thus justified the necessity of spraying.

In fact, the high mortality rate, resulted from Malathion spraying, that reached over 95%, 24 hours after treatment, have effectively reduced the existing grasshopper population and almost instantly stopped the damages in the treated fields and consequently reduced losses significantly.

If we consider only just the half of this average percentage yield increase (i.e. 35%) in the sprayed area (given the poor precision and low liability of data) has resulted from treatment effect, we can still recognize a higher yield benefit. Assuming basically that all other factors, other than aerial spraying, causing either a reduction or a gain in yield for the same region (canton) have a common effect on the treated and untreated areas.

This result, in fact, was supported by the observation reported to the mission, by the ONDR personnel, during the field trip. The ONDR Chefs Secteur and Sub-Secteur stated, from their field observations and from their contact with farmers, that yield in the aerially treated zones were absolutely higher than that of the untreated. They estimated that increase by about 50 to 70% .

2) Breakeven approach

a) Treatment cost

Treatment cost values for each of the 9 operating sites are calculated and presented in table (2) in annex (2). Results indicated that treatment costs varied from about $ 6.00 to $ 9.00 per hectar, except in Iriba where costs reached $ 11.29 per hectar. In fact, Iriba was the first operating site where aerial spraying started and where administrative delays retarted the begining of treatments. It can be noticed then that this site had the second lowest area sprayed accompanied with the highest technical assistance allocation, which indicated high number of field days due to delays. This additional assistance costs may have increased treatment cost by about $ 2.00 per hactar, in comparison with about the same area treated in Adre or Oum-Hadjer.

The overall average of the aerial treatment cost was calculated at about $ 7.50 per hectar, based on the used portion only of the total contribution of the USAID control program.

The two principal elements that composed 77% of the treatment costs were: a) the aerial spraying services with 40% of the cost (i.e. $ 3.00 per hectar); and b) the Malathion purchase and its in-country transport to operating sites with about 37% of the cost (i.e. $ 2.78 per hectar).

.../...

b) Breakeven value

Based on calculations, the overall breakeven value average was equal to 31 Kg of millet per hectar. The values calculated, however, varied among operating sites between 30 Kg to 40 Kg with an average equal to 33 kg, where the majority of values were skewed around the 30 Kg's level. This value represented the quantity of yield increase that farmer should gain, above his normal or usual yield, as a result of aerial treatment. This gain represents to the farmer about 12 Koro of millet per hectar (note: a Koro is a local measurement that weights about 2.5 Kg).

c) Breakeven ratio

Considering the breakeven ratio, results in table (2) showed an overall calculated average of about 10% of the yield value. Unlike the breakeven value, the breakeven ratio greatly varied from 6% to 26% among operating sites. Combination of low yield and high price increased the ratio to the maximum (26.4%) in Abeche.

This ratio of 10% could be considered as the cost effective threshold that farmer should at least gain in yield due to aerial spraying. This threshold gets higher in areas of low production.

From meetings during the field trip and according to chefs Secteur and sub-Secteur in the visited prefectures, farmers that had their millet fields treated confirmed that aerial spraying saved their crop. They admitted also that their neighbouring untreated fields had virtualy no yield, which could means very low yield or much less than their normal yield. However, those farmers and Chefs Secteur estimated that yield in the treated fields was about 50% to 70% greater than that of the untreated fields. Considering again a high range of error and low precision, the minimum of half of this percentage (i.e. about 30%) would still suggest that aerial treatment was beneficial and cost effective, since it exceeds the threshold level of 10% . Trying to examine this estimated benefit in monetary terms, a 20% yield surplus (i.e. 30% -10%) would be equivalent to about 60 Kg (or 24 Koro) of millet or about $ 14.00 per hectar.

3) <u>Other benefits</u>

By late August and early September of 1987, grasshopper infestation was generalized across the country and was heavy in the Sahelian zone. In September, and till end of season the grasshopper population followed his customary pattern of moving from drying grasses to millet fields. At this period, millet had reached the heading stage and grasshoppers were causing direct damages to developed grains. In addition, adults of this population (usualy the latest generation) normaly lay eggs massively that would survive the dry season in diapause, and hatch in the following rainy season.

.../...

Aerial spraying conducted in September and October 1987 succeeded in accomplishing two simulteneous benefits.

The first benefit was immediate. Effectiveness of aerial spraying over large, highly productive, and highly infested areas using 0.5 liter per hectar of Malathion ULV with an average mortality rate of 95% (24 hours after spraying) greatly reduced the population size and stopped the damage caused to the millet heads in the treated areas. This, in fact, resulted in obtaining higher yields in those areas.

The second benefit had a long term effect. Prospections conducted just before treatment in the targeted sites, in September and early October 1987, indicated that the grasshopper population was composed in majority of late nymphal instars and of small proportion of young adults that had not laid eggs yet. However, investigations in targeted sites, treated in late October, revealed that adults had reached their maturity and they had already began to lay eggs before the spraying team reached the site. Eventually, it was practically not possible to conduct the aerial spraying in all sites in a shorter period or even spraying two sites at the same time. Nevertheless, aerial spraying has significantly eliminated that population and effectively reduced the number of adults having the potential of laying eggs in the treated areas. Consequently, this contributed to an important reduction in the grasshopper population expected to hatch in the 1988 rainy season.

This second benefit was actually verified and confirmed by the "grasshopper egg-pod survey" conducted by the CPS agents in February and March of 1988. Findings of this survey was obtained from USAID/CHAD, copied, and presented, as is, in annex (3).

The table in annex (3) compared results obtained from two years of egg-pod survey carried out in sites aerially treated in the second year and in sites never treated in both years. Among treated sites, the first comparison indicated a significant decrease in egg density oviposited per square meter in all investigated villages in the second year with an overall average of 43% . The Ouaddai prefecture had an average decrease of 71% ; whereas the average in the Guera prefecture was estimated at 33% . On the other hand, the second comparison in the untreated sites showed a remarkable increase in egg density in all surveyed villages (with two exemptions). This increase highly varied among villages and reached for instance 418% in NDjamena-Bilala (Ati, Batha). The overall average increase was calculated at 175% .

Another observation that confirms this long term benefit is the actual grasshopper situation in Chad this 1988 season. According to the CPS agents and the ONDR personnel in the three prefectures visited during the field trip of this mission, the grasshopper situation was described as so far calm, their population level is relatively low, and no major infestation has been reported until mid-july 1988.

.../...

VI. CONCLUSIONS AND RECOMMENDATIONS

Results obtained in this report concluded that USAID aerial treatment in 1987 costed about $ 7.50 per hectar, ofwhich $ 3.00 (40%) was the cost of aerial spraying services and $ 2.78 (37%) was the cost of pesticides (their purchase and their in-country transport).

Comparisons between treated and untreated villages, in the first approach, indicated a high yield benefit of at least double in the treated fields. The poor number of comparable pairs, however, could not allow a definite conclusion.

According to the "breakeven" approach used in this analysis, the report provided a cost effectiveness threshold level for millet yield. Results of this second appraoch suggested that for aerial treatment to be worth and cost effective, yield benfit in treated fields should exceed either the calculated threshold of 10% of the yield value, or 30 Kg (12 Koro) of millet per hectar above the normal yield.

However, results obtained from the two approaches of the analysis presented in this report, in addition to other benfits achieved, concluded that the 1987 USAID aerial spraying in Chad was beneficial. Unfortunately, the exact quantity gained was not possible to be obtained due to the lack of appropriate data. But, in general terms, based on calculations from the first appraoch and according to observations from farmers and ONDR personel in the field, the treated fields had a minimum yield gain of 30% .

The report discussed also the achieved immediate and long term benefits resulted from aerial spraying in 1987. First, that the grasshopper eggs oviposited late in 1987 were significantly lower than that of the previous year in the treated zones; and second that the initial grasshopper population observed this season was consequently low and no major infestation was reported till mid-July 1988.

In addition, the analysis in this report developed a model that can be utilized for future projection to evaluate the cost effectiveness of a similar aerial treatment operation before its execution.

Since, the analysis could not produce an exact value for the benefit-cost ratio due to the difficulty in quantifying benefit, it is strongly recommended that a specific mission should be organised at harvest time to collect the needed specific yield information in the treated areas, as well as in the neighbouring untreated fields, if a precise economic evaluation is required in the future.

The report, unfortunately, could not also present the required loss fuction concerning grasshopper damages due again to the lack of yield data specific to villages. For that, the previous recommendation applies even strongly to establish this important relationship.

Annex (1)

TABLE (1). MILLET YIELD DATA PER VILLAGE
FOR THE 1987 SEASON IN FOUR PREFECTURES IN CHAD

A R E A	ESTIMATED YIELD (Kg/Ha)	AERIAL TREATMENT STATUS	YIELD INCREASE (%) VILLAGE TO VILLAGE	YIELD INCREASE (%) VILLAGE TO S/P.
Pref. : BATHA	260			
S/P. Ati	300			
C. Kouka				
V. Loubane	556	Treated	N/A	85.3%
S/P. Oum-Hadjer	250			
C. Massalat				
V. Kiezi	234	Untreated	N/A	-6.4%
V. Am-Koumy	74	Untreated	N/A	-70.4%
C. Ratanine				
V. Toutoubaye	229	Untreated	N/A	-8.8%
C. Kouka				
V. Ad.-Doungous	150	Untreated	N/A	-40.0%
V. Ad.-Awal	443	Untreated	N/A	77.2%
Pref. : GUERA	400			
S/P. Monço	300			
C. Dadjo I				
V. Banda	532	Treated	N/A	77.3%
C. Yalnas				
V. Bola I *	940	Treated	N/A	213.3%
V. Keketchou *	1,450	Treated	N/A	383.3%
S/P. Bitkine	700			
C. Dangueleat				
V. Korbo Bet	155	Untreated	N/A	-77.9%
V. Mele	260	Untreated	N/A	-62.9%
S/P. Mangalme	500			
C. Moubi Zarga				
V. Rague Hilele	745	Treated	N/A	49.0%
Pref. : OUADDAI	385			
S/P. Abeche	115			
C. Kachm Al-Wadi				
V. Atoulo	118	Untreated	N/A	2.6%
V. Djarwa	0	Untreated	N/A	N/A
S/P. Adre	200			
C. Guergne				
V. Attachane	578	Treated	204.2%	189.0%
V. Hille Tama	190	Untreated		-5.0%
S/P. Goz-Beida	250			
C. Goz-Beida				
V. Goz-Beida	2,020	Treated	105.1%	708.0%
V. Korai II	985	Untreated		294.0%
S/P. Am Dam	650			
C. Dadjo				
V. Zeriba	640	Untreated	N/A	-1.5%
Pref. : BILTINE	300			
S/P. Biltine				
C. Kodoi I				
V. Djamar	229	Untreated	N/A	-23.7%
V. Douguine II	229	Untreated	N/A	-23.7%
C. Ouled Djama				
V. Gamara	1,133	Treated	N/A	277.7%
S/P. Am Zoer				
C. Aboucharib I				
V. Toumadi	391	Untreated	N/A	30.3%
V. Ille Dama	258	Untreated	N/A	-14.0%
S/P. Guereda				
V. Marien	149	Untreated	N/A	-50.3%

* Yields given are the expected yield due to lack of estimated.

Notes: All yields given are the averge of 2 to 8 fields per village. (Source: FEWS and ONDR reports).
Pref. = Prefecture ; S/P. = Sub-Prefecture ; C. = Canton ; V. = Village.

Annex (2)

TABLE (2). DETAILS OF TREATMENT COSTS PER OPERATING SITE
USAID AERIAL TREATMENT CONTROL IN CHAD
1987 GROWING SEASON (US $)

COST ELEMENTS	GLOBAL ($)	PREF. BATHA		PREF. GUERA		PREF. OUADDAI			PREF. BILTINE	
		ATI	OUM-HADJER	MONGO	MANGALME	ABECHE	ADRE	GOZ-BEIDA	BILTINE	IRIBA
* Malathion purchase	345,465	44,820	20,142	88,506	44,820	31,374	26,892	32,481	32,454	23,976
* In country transport of Malathion	9,888	1,230	576	2,528	1,230	896	768	928	928	704
* Fuel purchase and in country transport	47.300	3,575	2,475	11,550	4,125	7,425	5,500	4,400	3,300	4,950
* Tertiary transport of fuel and Malathion	5,402	585	315	1,350	608	608	495	518	473	450
* Aerial spraying	383,073	57,328	23,998	78,214	33.997	43,551	39,329	22,442	43,551	40.663
* Technical assistance	125,000	17,500	5,000	17,500	10,000	17,500	12.500	10,000	10.000	25.000
* Field prospection	41,400	4,600	4,600	4,600	4,600	4,600	4,600	4,600	4,600	4,600
TOTAL COST (US $)	957,528	129.688	57,106	204,248	99,430	105,954	90,084	75,369	95.306	100.343
Area treated (Ha)	127,955	16.600	7,460	32.785	16.600	11,620	9.955	12,030	12,020	8,885
Treat. cost ($/Ha)	7.48	7.81	7.65	6.23	5.99	9.12	9.05	6.27	7.93	11.29
Millet price ($/Kg)	0.24	0.25	0.25	0.20	0.16	0.30	0.23	0.18	0.27	0.31
Millet yield (Kg)	307	350	250	500	500	115	200	250	300	300
Yield value ($)	73.73	87.50	62.50	100.00	80.00	34.50	46.00	45.00	81.00	93.00
Breakeven value (Kg)	31	31	31	31	37	30	39	35	29	36
Breakeven ratio (%)	10.1%	8.9%	12.2%	6.2%	7.5%	26.4%	19.7%	13.9%	9.3%	12.1%

Annex (3)

MARCH 16, 1988

EFFECT OF U S A I D AERIAL SPRAYING ON END-OF-SEASON OVIPOSITION.

1- A comparison of specific sites sprayed in 1987 and 1988.

VILLAGE	SUB-PREFECTURE	PREFECTURE	APRIL 1987 AVERAGE NUMBER OF EGGS/M2	FEBRUARY 1988 AVERAGE NUMBER OF EGGS/M2	% INCREASE OR (DECREASE)
ABOUNDOUROUA	ABECHE	OUADDAI	226.14	14.42	(94%)
ATECHANE	ADRE	OUADDAI	74.50	29.89	(60%)
DJEDIDI(TCHARO)	GOZ-BEIDA	OUADDAI	101.79	41.42	(59%)
BANDA	MONGO	GUERA	70.04	25.31	(64%)
BOLA I	MONGO	GUERA	58.21	32.92	(43%)
BOLA II	MONGO	GUERA	43.43	32.92	(24%)
NIERGUE	MONGO	GUERA	38.57	32.17	(17%)
SARA-ARAB(KINGA)	BITKINE	GUERA	43.50	34.69	(20%)
IREYGE	MANGALME	GUERA	57.21	46.58	(19%)
MAINE(AIRPORT)	MANGALME	GUERA	47.54	21.58	(55%)
IGENE(MANG.SUD)	MANGAL-SUD	GUERA	43.50	34.69	(20%)

2- A comparison of sites not sprayed in 1987 and 1988.

VILLAGE	SUB-PREFECTURE	PREFECTURE	APRIL 1987 AVERAGE NUMBER OF EGGS/M2	FEBRUARY 1988 AVERAGE NUMBER OF EGGS/M2	% INCREASE OR (DECREASE)
KEKEDINAN	MAO	KANEM	11.00	43.56	296%
TCHAKORI	MONGO	GUERA	22.14	43.39	96%
AMERON	DOUM DOUM	LAC	00.00	36.56	N/A
DOUM-DOUM	DOUM DOUM	LAC	00.07	80.89	115,557% *
MASSAGUET	MASSAGUET	CHARI.BAG.	676.00	16.00	(98%)**
ASSARTINI	OUM-HADJER	BATHA	34.79	43.94	26%
YAO	OUM-HADJER	BATHA	12.11	37.72	211%
NDJAMENA-BILALA	ATI	BATHA	18.78	97.33	418%
ALKELANI	DJEDAA	BATHA	21.14	68.72	225%
ALADARA	DJEDAA	BATHA	44.82	76.86	71%
ALLUKA	DJEDAA	BATHA	46.71	70.72	51%

* The large increase may be due to poor data collected in 1987.

** The reduction in oviposition in Massaguet may be the result of aerial spraying by French/FAC aircraft.

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DOCUMENTS REVIEWED

Annex (5)

- Evaluation de la campagne agricole cerealiere, 1987-88. Division de la statistique agricole, en collaboration avec la DPA/ONDR - October 1987

- Enquete sur l'estimation des recoltes dans la zone sahelienne (Campagne Agricole 1987-88). Bureau de la Statistique Agricole - Mai 1988

- Bilan de la campagne de lutte antiacridienne 1987. Direction de la Protection des Vegetaux

- Site reports of USAID aerial spraying operation 1987. MAF reports for operating sites.

- Final report - USAID locust/grasshopper control program in Chad - 1987 season. USAID/NDJAMENA, November 30, 1987

- Aerial treatment journal and record-book of the 1987 aerial spraying operation. Field Manager of the USAID operation in Chad.

- Enquete sur la prevision et l'estimation des recoltes au Tchad. Campagne 1987-1988. FEWS diskettes containing data.

- Monthly reports of the Systeme d'Alerte Precoce project.

- ONDR monthly reports of the Sub-Secteur for 1987 and 1988 in the three visited prefectures : Batha, Ouaddai and Guera.

- Fiches de Signalisation - 1987. Forms completed by the prospection teams during the 1987 growing season in all prefectures in Chad.

B. Review of Other Reports Related to the Campaign

With the exception of the campaign evaluation conducted by Habib Khoury in July 1988 as a part of this project, no detailed efforts were made to address the economic costs and benefits of the 1987 anti-grasshopper campaign in Chad. The FAO/Joint Donor review and the USAID campaign report offer only general comments and no presentation of data in support of conclusions reached. The conclusions and comments made within these reports are (is) relevant to this evaluation, however, and will be excerpted herein. The crop loss assessment conducted in Oct-Nov 1987 by IPPC personnel was severely restricted by security problems associated with the war between Chad and a neighboring country. These crop loss data would have provided a means of partially calibrating and validating the benefit-cost model being developed. Each study involved with the campaign will be quoted/paraphrased before any further discussion of their implications:

I. FAO/Joint Donor review.

General. The campaign was thought to be successful in regard to technical assistance, overcoming logistical problems, etc. "All specialists agree that these treatments were efficient...This campaign will certainly have a great effect in reducing grasshopper populations, because it must be added to the more natural factors which did not favour the grasshopper populations in 1987, that is, poor rainfall and parasitism."

Crop Losses. "No systematic attempt was made to measure the damage grasshoppers caused to crops. There were undoubtedly some losses in millet in the Sahelian zone due to the general irregularity of the rains, and, locally, to grasshoppers and stem borers, but they are very difficult to quantify... In Chad, experts estimate that losses due to grasshoppers were relatively limited this year, because of the very energetic control campaign, and because climatic conditions worked against the insects, particularly the second generation." Cost/Benefit Analysis. "The figures available do not allow a cost/benefit analysis to be made."

Recommendations. "There is no national system assessing crop losses. The mission recommends that such studies be regularly undertaken at the end of the agricultural season, and that they be as exhaustive as possible."

II. Final Report USAID campaign

Results. "Areas selected for spraying indicated that grasshopper densities were never less than 15 to 20 individuals per square meter. In most areas treated, larvae composed a high proportion of the grasshopper population which made a good target and the treatment was most efficient in terms of timing for grasshopper control and crop protection. Larvae

were killed before they reached the adult stage and when they were most sensitive to pesticides...Surveys after treatment showed mortality rate averaged higher than 95%. Surviving grasshoppers manifested symptoms of being affected by the pesticide and died later. It should be noted here that many messages received from local farmers indicated their complete satisfaction with the effectiveness of the aerial spraying."

Recommendations. "With timely and effective aerial treatment in Eastern Chad, most of the grasshopper population was killed over the major agriculture areas before the end-of-season's heavy egg laying. We thus conclude that the initial grasshopper population at the beginning of the 1988 season will be low and the infestation will be light in Central-Eastern Chad...In the southern part of Eastern Chad's Sahelian zone where aerial treatment occurred a bit late in October, some of the last generation adult grasshoppers reached maturity and laid eggs just as aerial spraying was taking place, In these areas (Mangalme and Goz-Beida) we may expect moderate infestations at the beginning of the 1988 growing season."

III. USAID-sponsored Crop Loss Assessment conducted by Oregon State University/IPPC, Oct-Nov 1987, Chad.

The mission involved using the a modified Dively procedure for assessment of crop losses to millet, near Ati, Batha, in 1 field per village, 10 villages. Fields were supposedly not treated during the phase II (aerial) campaign:

Yields averaged 172 Kg/Ha (SE = 52). Losses attributed to grasshoppers averaged 35 Kg/Ha, 22% of actual yields. Total losses due to all pests (including grasshoppers/locusts, Raghuva, smut, birds, and rodents) represented 15% to 306% of actual yields.

Crop losses were also analyzed in two villages near Ati, Batha, which were treated during the campaign (Murphy 1987). Crop loss due to grasshoppers averaged 10.7 Kg/Ha, 17% of the actual yields in the two villages. This yield loss is approximately 1/3 of those averaged for the untreated fields near Ati, indicating that the treatment was effective in protecting the crops from grasshoppers.

IV. IPPC Independent Evaluation of the Campaign

The purposes of the independent study, conducted in the field by Habib Khoury, included A) Obtaining any data pertaining to the goal of a thorough post-campaign B/C analysis and 2) Obtaining yield data for treated and untreated sites as a way of validating the benefits of aerial treatment.

Only two village pairs were available for yield comparison. The first, in Goz-Beida Beida, Ouaddai, treated yields were 2X higher than nontreated yields. The second, in Adre, treated yields were 3X higher than nontreated yields.

Another approach, comparing village yields to sub-prefecture averages, brought similar results, where an overall average yield increase of 70% was found.

Additional comments quoted from the report: "According to prospections conducted before treatment, population densities in the millet fields were estimated between 25 to 40 individuals per square meter over large area. This high density level, observed on millet heads, caused very serious direct damages to developing grains and thus justified the necessity of spraying....This result, in fact, was supported by the observation reported to the mission, by the ONDR personnel, during the field trip. The ONDR Chefs Secteur and Sub-Secteur stated, from their field observations and from their contact with farmers, that yields in the aerially treated zones were absolutely higher than that of the untreated. They estimated that increase by about 50% to 70%....based on calculations from the first approach and according to observations from farmers and ONDR personnel in the field, the treated fields had a minimum yield gain of 30%....grasshopper eggs oviposited late in 1987 were significantly lower than that of the previous year in the treated zones; and second that the initial grasshopper population observed this season was consequently low and no major infestation was reported till mid-July 1988.

V. Discussion

All of the efforts to document the 1987 campaign noted above promote the conclusion that the campaign was effective in preventing at least as much value of crop loss as was spent for treatment. From Khoury's analysis, the breakeven ratio was 10% (31 Kg/Ha), while his estimate of prevented crop losses was "minimum yield gain of 30%". This indicates a benefit/cost ratio of at least 3.0 for first year effects. From the IPPC crop loss assessment, the average yield loss due to grasshoppers in untreated fields was 20%, which seems low and just meets the estimated breakeven ratio of 18% for those particular fields. The two treated fields from the crop loss assessment had 1/3 of the level of grasshopper-induced crop loss compared to the 10 untreated fields surveyed.

Second year benefits are very difficult to quantify but, from Khoury's analysis of the CPS eggpod surveys, eggpod densities decreased by an average of 43% in the treated areas sampled and increased by an average of 175% in the untreated areas sampled. Although statistically valid inferences may not be made from these results, they are indicative that aerial treatment was successful in reducing end of season oviposition through most of the regions treated. Unless compensatory mortality from predators and weather greatly

reduced these differences, there should have been a marked decrease in grasshopper induced crop losses in the treated areas for the following year.

Chapter II. Use of GHLSIM version 1.0 for Campaign Analysis

I. Introduction

Prompted by a need for a decision framework for grasshopper and locust control, GHLSIM version 1.0 was created as a means of analyzing the benefits and costs of treatment through simulation of grasshopper populations and crop injury effects to millet and sorghum. Documentation of the model may be found in the GHLSIM user manual and the GHLSIM technical reference manual (submitted concurrently with this document). Data used for default values in version 1.0 apply to the task of analyzing the 1987 AID anti-grasshopper campaign in Chad and are derived from sources given below.

II. Data Relevant to GHLSIM Campaign Analysis

A. Summary of Treatment Areas and Costs

A breakdown of treatment costs and Ha treated for each of the 9 principal regions in the campaign can be found in Chapter 1, Annex 2. Costs for the additional region treated in Bokoro, Chari-Baguirmi (CHB) were assumed to be average for the analysis. Total costs were estimated to be (US $) $942,237; $989,817 including CHB. The actual aerial spraying operation maps (1:200,000) of all regions treated (except Bokoro) were collated and are summarized in Fig. 1. Treated area totaled 127,955 Ha; 133,955 including CHB. These data are within the "Campaign" and the "Grasshopper Sample" databases of GHLSIM.

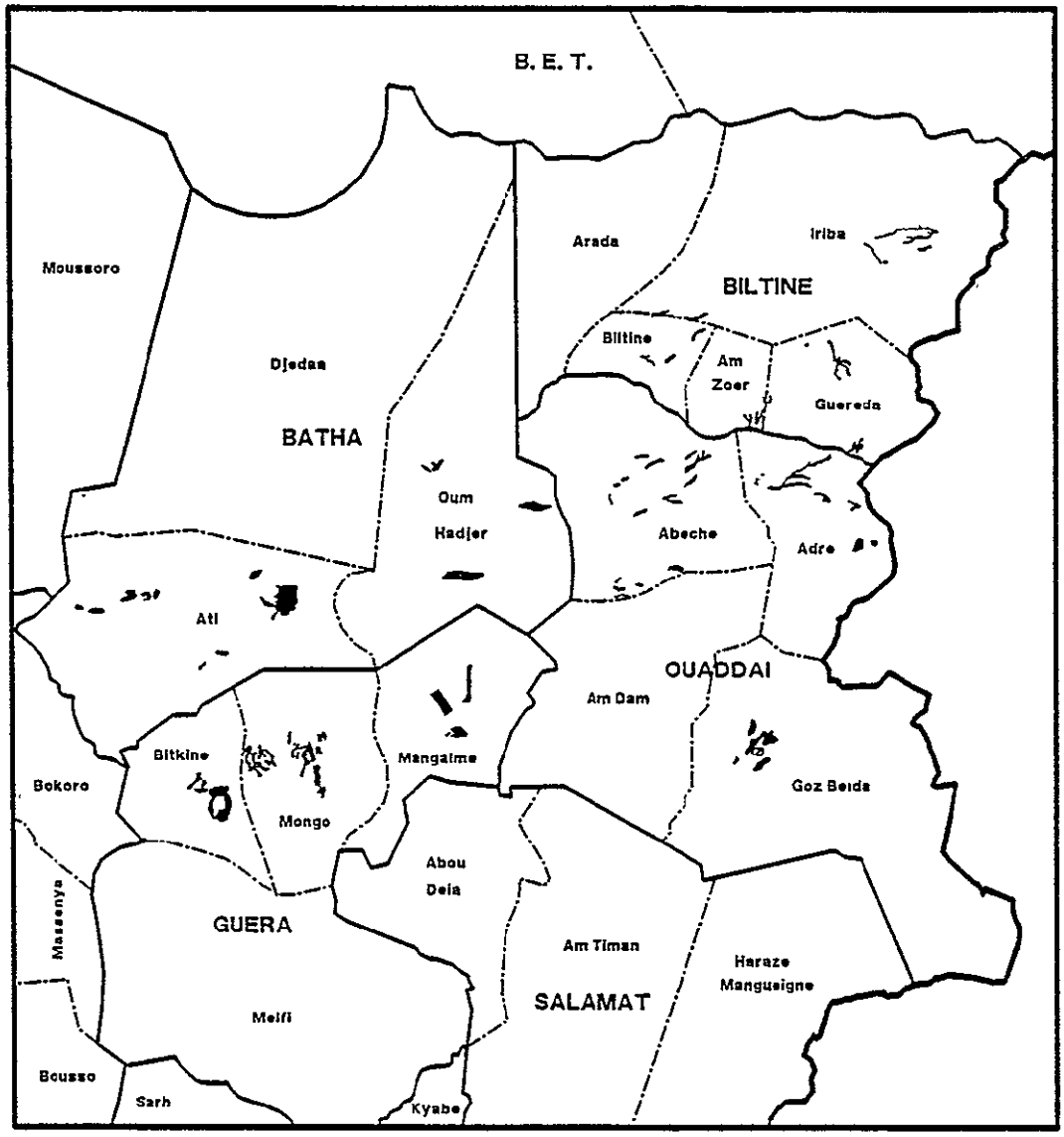

Figure 1. Areas treated in Chad during the USAID aerial anti-grasshopper campaign, 1987.

B. Crop Prices, Yields and Harvest Dates

Several sources of crop price and yield data are available. Values collected in-country for Khoury's analysis (Annex 2, page 19) were considered the most appropriate for use in the model analysis. These figures also largely agree with the Government of Chad/National Office of Rural Development and Division of Agricultural Statistics estimates (FEWS/PWA, December 1987) and an analysis of harvests in the Sahelian zone (Bureau de la Statisique Agricole, Mai 1988). Millet and Sorghum prices ($0.24/KG and $0.31/KG) for Dec, 1987 N'djemena estimates from FEWS reports (USAID/FFP Apr 2, 1988) and, for millet, matched the average price from Khoury's figures. Average harvest dates were estimated as a result of notes taken during the IPPC crop loss assessment in Chad, Oct-Nov 1987. Crop

yield, price and harvest dates were entered into the Treatment Tactic Campaign database within GHLSIM. The option to use the FAO crop model estimates for yields and phenology was not used in the analyses.

C. Weather Data

Precipitation data used in the analysis were from all available locations reporting data per dekad (Fig. 2). In most cases, areas treated were near weather station sites (refer to Figs. 1 and 2). Solar radiation and temperature data were obtained from the primary sites and were applied to the precipitation-only sites on the basis of proximity.

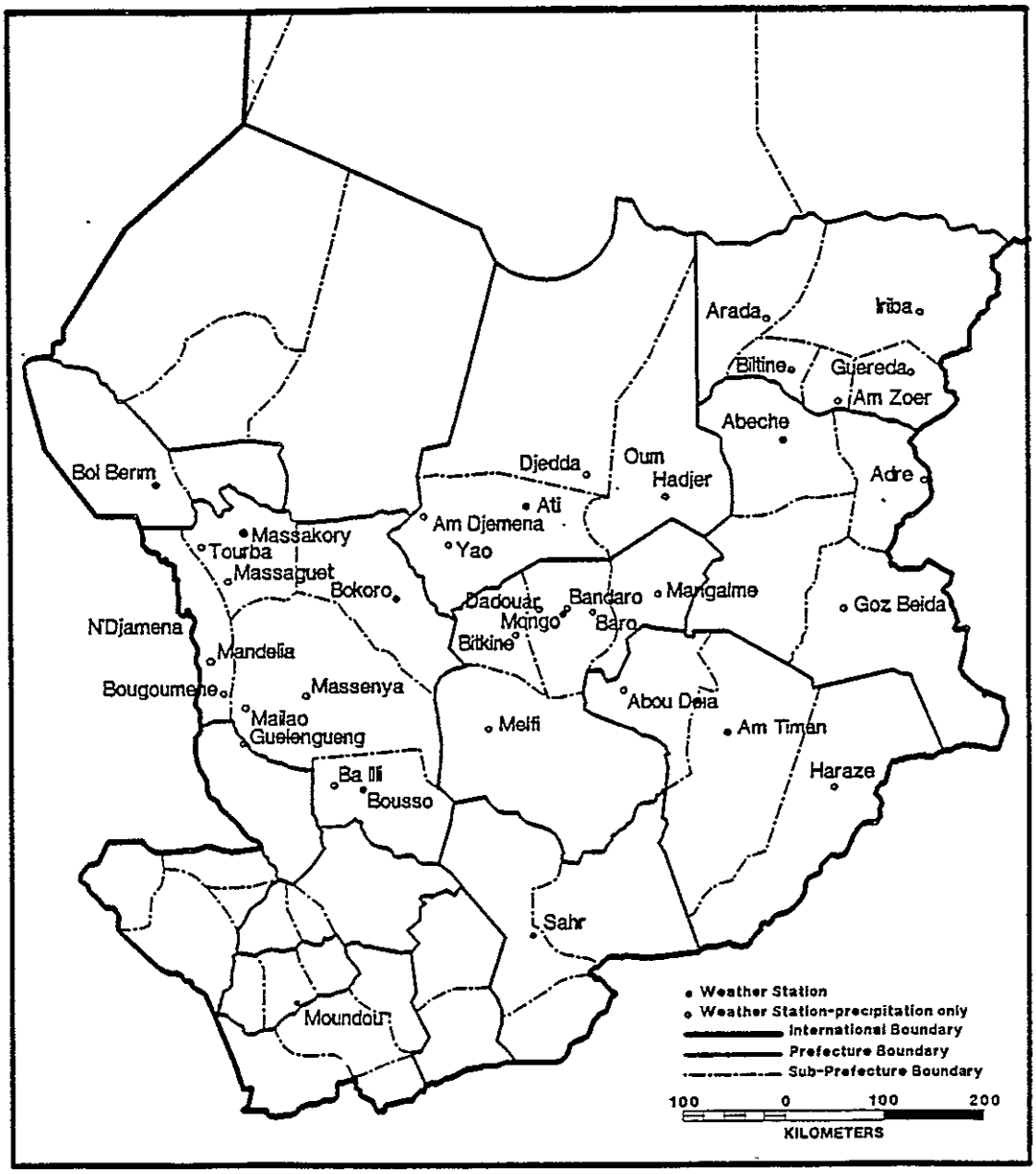

Figure 2. Location of weather stations in Chad.

D. Treatment Tactics - Secondary Impacts

The GHLSIM treatment tactics defaults database allows input of secondary impacts to the environment based on an indexed risk ranking system. The secondary impacts of treatment tactics on human health were rated from a combination of the US Environmental Protection Agency's signal words, the World Health Organization's hazard classifications (ASAP/CIRAD 1987), and LD_{50} values (both oral and dermal) found in Meister (1989), and in Edwards and Huddleston (1986). The LD_{50} values were also used to determine impacts on mammals. Impacts on egg predators and parasites were estimated by analyzing the toxic effects of a tactic on all arthropod natural enemies documented in the SELCTV database (Theiling and Croft 1988). In the database, toxicity is rated from 1 to 5, and the mean toxicity to natural enemies was calculated and rounded to the nearest whole number. Values for secondary impacts on birds were based primarily on classifications used by Edwards and Huddleston (1986). Little information was available to determine the impacts of Nosema locustae, neem, or diflubenzuron; therefore, preliminary estimates of the secondary impacts of these tactics were made after considering plausible biological scenarios. Default values for these impacts, as with values for the other impacts, may be modified by the user if desired, or may be overridden for any particular analysis.

E. Treatment Tactics - Percent Efficacy

In Burkina Faso, Bartholf (1986) reported ca. 85% control using fenitrothion. Malathion provided 92 percent control of S. gregaria adults after 2 days at a rate of 700 g/Ha in Morocco (MacCuaig 1983). Radio messages to USAID/Chad from field crews associated with the 1987 spray campaign in Chad indicated that mean percent efficacy using fenitrothion was 81.8% (n=15, SD=11.2, range: 60-97%). Two radio reports from areas where malathion was used indicated efficacy to be 90 and 92% respectively, and three reports indicated a propoxur/fenitrothion mix provided 80% control. The GHLSIM default values for fenitrothion, the propoxur/fenitrothion mix, and malathion were estimated from these reports. An efficacy value of 90% was used for the campaign analysis for Malathion and Fenitrothion. Efficacy from carbaryl baits was determined from information in Walgenbach, et al. (1987) and PRIFAS (1988). Efficacy values for carbaryl and propoxur dusts, and carbaryl and lindane sprays, were estimated from PRIFAS (1988). Diflubenzuron efficacy was estimated to be similar to that reported by the European analogue teflubenzuron (PRIFAS 1988). As was the case with secondary impacts, control provided by Nosema locustae and neem was estimated and included for potential future use and modification.

F. Treatment Tactics - Residual Activity

In the treatment tactics defaults database, two values represent the residual activity of a tactic. The value in column "a" refers to the approximate number of days till maximum effectiveness is reached. This parameter is not used in version 1.0 of GHLSIM. The value in column "b" refers to the approximate half-life of the tactic. Values for malathion and carbaryl were taken from Phillips (1986) and Anon. (1987a). Values for several of the compounds are from MacCuaig (1983).

G. Grasshopper Sample Densities

The grasshopper densities used for analysis of the campaign in GHLSIM derive directly from the "Fiches de Signalisation - 1987" (AID 1987); the forms completed by the prospection teams during the 1987 growing season in all prefectures in Chad. Estimates were derived by first assembling the subset of relevant records and second by averaging density estimates when multiple records existing for a site were found. These average densities were input into the grasshopper sample database for the 13 areas to undergo analysis. Treatment dates, Ha treated, crops attacked, etc. were also input to prepare for the analysis.

III. Model Calibration and Tests

Calibration exercises were conducted in preparation for use of GHLSIM for analysis of the 1987 Chad grasshopper control campaign. Ideally, a calibration could be conducted from data including 15 or more sites paired for treatment/no treatment and having grasshopper stage and density information, crop stage and yield information, treatment efficacy data, and grasshopper yield loss estimates. For now, published treatment threshold guidelines were used as a basis for an objective calibration.

A. Calibration Methods

Initial calibration of the model was by adjusting the factor for conversion of damage units to % crop loss and crop susceptibility factors so that breakeven densities from a sample of 16 sites best match modified threshold densities for the various crop stages as recommended for grasshoppers in the Sahel. The procedures used for calibration included:

1) Four grasshopper sample databases representing four treatment dates and crop stages were created for sixteen sites in Central and Western Chad using a set of nominal calibration conditions. These included locations with weather stations from Biltine, Ouaddai, Batha, Guera, Northern Salamat and Chari-Baguirmi.

2) For each of the 16 sites, the four treatment dates were determined according to the beginning of the second quarter of the seedling, tiller/spike, milky grain, and dry grain crop stages.

3) Grasshopper densities were set equal to the guideline threshold densities for grasshoppers in the Sahel as established by AID and SAS (USAID 1987, SAS 1988). These thresholds are tabulated according to crop stage and to grasshopper stage and were modified slightly to serve calibration needs (Table 1):

Table 1. Threshold guidelines derived from AID (1987) and SAS (1988) used for calibration of GHLSIM for Chad 1987 grasshopper campaign analysis.

	Grasshopper Density (#/m^2)		
Crop Stage	Small Nymph	Large Nymph	Adult
Seedling	16	12	10
Tiller/Spike	36	25	20
Milky Grain	28	16	14
Dry Grain	40	30	20

4) OSE biomodel output for the sixteen sites was examined for grasshopper stages present on the four treatment dates. Threshold densities for the appropriate stages were then entered into the grasshopper sample databases. An example of one of the four databases used for the calibration is summarized in Table 2.

Table 2. Example settings used for grasshopper sample database in GHLSIM calibration (milky grain stage).

#	Pre-fect.	GH Stg	Dens #/m2		Date Obs. /treated	Trt Code	HA	% Eff.	Comments, GH stages present
1	IRI	A	14	M	07-Oct-87	FV	25	90	CAL. 1 - m grain, E A
2	GUE	L	16	M	17-Sep-87	FV	25	90	CAL. 1 - m grain, SL LL
3	BIL	L	16	M	17-Sep-87	FV	25	90	CAL. 1 - m grain, E LL
4	ABE	L	16	M	17-Sep-87	FV	25	90	CAL. 1 - m grain, E LL
5	ADR	LA	14	M	27-Sep-87	FV	25	90	CAL. 1 - m grain, E LL A
6	GOZ	LA	14	M	27-Sep-87	FV	25	90	CAL. 1 - m grain, E SL A
7	OUM	LA	14	M	17-Aug-87	FV	25	90	CAL. 1 - m grain, E SL A
8	ATI	L	16	M	27-Sep-87	FV	25	90	CAL. 1 - m grain, E SL LL
9	YAO	LA	14	M	17-Aug-87	FV	25	90	CAL. 1 - m grain, SL A
10	MON	L	16	M	07-Aug-87	FV	25	90	CAL. 1 - m grain, SL LL
11	BIT	L	16	M	07-Aug-87	FV	25	90	CAL. 1 - m grain, SL LL
12	MAN	L	16	M	07-Aug-87	FV	25	90	CAL. 1 - m grain, SL LL
13	ABO	L	28	M	17-Aug-87	FV	25	90	CAL. 1 - m grain, SL
14	BOK	LA	14	M	17-Aug-87	FV	25	90	CAL. 1 - m grain,ESL LL A
15	NDJ	LA	14	M	07-Aug-87	FV	25	90	CAL. 1 - m grain, E SL A
16	MAS	LA	14	M	07-Aug-87	FV	25	90	CAL. 1 - m grain, SL A

5). Other assumptions and procedures used in the calibration included:

- The cost of treatment was nominally set to $7.48 for all sites. This was the average treatment cost for the 1987 campaign in Chad.

- Only millet was used for the initial calibration. Sorghum was later calibrated by reducing crop preference factors to 25% that of millet for the first three crop stages, and to 50% that of millet for the last three crop stages. Only millet was used in the nominal campaign analysis.

- Several considerations for specifying agreement between model output and threshold values were made. Although the threshold densities published do not specify crop value or treatment costs, they probably assume moderate to good yields and crop prices and low treatment costs. Yields used in the calibration are actual reported averages, which were low to moderate due to sporadic rainfall in 1987. Crops with lower vigor are more susceptible to pest injury but are also of lower overall value, making it difficult to adjust the published threshold values one way or the other. However, net treatment benefits should generally exceed zero when such thresholds are used, so that breakeven densities would be lower than action thresholds in this case. Also, net benefit of treatment calculated by GHLSIM varies over the 16 sites. Calibration factors were adjusted so that for the majority of sites, the benefit of treatment exceeds zero. In the first year benefits calibration at the

milky grain stage, it was assumed that the 25th percentile of the normal curve fitted to the simulation results would have a zero net benefit of treatment. Treatment net benefits therefore would fall below zero for any sites under the 25th percentile. This calibration criterion was also used for the dry milk, tillering/spike and seedling calibration steps. Treatment at later crop stages relies more on benefits from reducing oviposition as is reflected in second year benefits in GHLSIM.

- At the milky grain crop stage, post-treatment fecundity rates were calibrated to bring average second year treatment benefits to 50% of the control costs for the 16 sites. This criterion was established due to a lack of more objective measures. Some regions, however, could be matched for testing purposes between the campaign analysis results (Appendix I) and the eggpod density samples collected by the CPS (Chapter I, Annex 4, page 20). Differences between mean egg densities were not great enough to justify further calibration of post-treatment fecundity rates at this time (untreated regions, $N = 3$, $P > 0.5$), treated regions, $N = 6$, $P > 0.5$).

B. Calibration Results

Values obtained for the factors calibrated and the corresponding model results are given in Table 3. Mean first year benefits varied from a low of $13.3/Ha for the milky grain crop stage to a high of $19.6/Ha for the tiller/spike crop stage. The high first year benefit from the tiller/spike stage apparently resulted from the higher grasshopper density threshold values associated with this crop stage, and is due to treatment benefits accumulating during the later milky and dry grain stages. This effect may indicate that early treatment can have a significant impact on reducing later crop losses and that threshold values for this crop stage may be too high relative to other stages. Treatments made at the tiller/spike stage also resulted in the highest estimated second year benefits. Again, this is due to the greatest reduction in egg-laying adults during later crop stages, when overwintering eggs are deposited. Simulation results from the milky grain stage calibration are shown as an example in Table 4.

Table 3. Results of calibration of GHLSIM using published threshold values and a criterion of breakeven levels set to the 25% percentile of first year treatment benefits; 16 sites.

Calib. step	Crop Stage	Factor calibrated	Calib. value	% Yield increase	Benefit ($/HA) avg	SE	2nd yr benefit
1.	Milky Grain	Post treatment fecundity factor	1.14	--	--	--	3.77
2.	Milky Grain	Feeding Impact	0.0148	19.6	13.3	2.3	3.77
3.	Dry Grain	Yield Compensation	0.958	25.2	15.8	3.3	4.45
4.	Tiller/Spike	Yield Compensation	0.590	53.4	19.6	4.5	8.03
5.	Seedling	Yield Compensation	1.600	33.2	18.6	4.1	1.68

Table 4. Example aggregate economic analysis from GHLSIM calibration in preparation of 1987 Chad campaign analysis - milky grain stage.

				Result of Treatment ($/HA)							Benefit		
Region	#Sites	Avg Dens	Trt Code	%Yld inc	Benefit Yr 1	Yr 2	Cost	Net Benefit	Area HA	Avg Risk	/Cost Yr 1	/Cost Both	/Risk Index
IRI	1	14	FV	4.5	3.12	4.51	7.48	0.15	25	2.8	0.4	1.0	0.4
GUE	1	16	FV	26.6	15.08	7.76	7.48	15.36	25	2.8	2.0	3.1	1.1
BIL	1	16	FV	21.5	12.60	3.01	7.48	8.13	25	2.8	1.7	2.1	0.7
ABE	1	16	FV	20.3	15.27	3.01	7.48	10.80	25	2.8	2.0	2.4	0.9
ADR	1	14	FV	14.5	11.59	3.05	7.48	7.16	25	2.8	1.5	2.0	0.7
GOZ	1	14	FV	3.0	2.70	3.53	7.48	-1.25	25	2.8	0.4	0.8	0.3
OUM	1	14	FV	25.6	12.70	5.71	7.48	10.93	25	2.8	1.7	2.5	0.9
ATI	1	16	FV	50.3	20.80	6.08	7.48	19.40	25	2.8	2.8	3.6	1.3
ATY	1	14	FV	13.5	7.34	2.81	7.48	2.67	25	2.8	1.0	1.4	0.5
MON	1	16	FV	15.3	12.67	0.89	7.48	6.08	25	2.8	1.7	1.8	0.6
BIT	1	16	FV	14.6	12.30	0.89	7.48	5.71	25	2.8	1.6	1.8	0.6
MAN	1	16	FV	12.4	10.66	0.89	7.48	4.07	25	2.8	1.4	1.5	0.6
BOK	1	14	FV	50.2	40.15	8.72	7.48	41.39	25	2.8	5.4	6.5	2.3
NDJ	1	14	FV	12.4	13.12	4.27	7.48	9.91	25	2.8	1.8	2.3	0.8
MAS	1	14	FV	8.9	9.83	1.42	7.48	3.77	25	2.8	1.3	1.5	0.5
Avg	15	15	N/A	19.6	13.33	3.77	7.48	9.62	375	2.8	1.8	2.3	0.8
Stdev					8.70								

First Year Benefit: $ 4,998 Second Year Benefit: $ 1,414
Cost of Treatment : $ 2,805 Net Benefit : $ 3,607

IV. Assumptions and Sources of Error in the Analysis

1. Analysis of treated areas was by using data averaged for Sub-Prefectures. Due to a lack of data at the village or canton level, analyses were conducted at the Sub-Prefecture level. The effect of averaging at this level includes the possibility that benefits are over-estimated. Since data collection and reporting as conducted in developing countries would tend to emphasize the higher values for grasshopper densities and for crop yields, then crop losses would tend to be over-estimated. Also, in the averaging of grasshopper densities and crop yields even within a single field, if the damage function (density-crop yield curve) assumes a convex shape as often occurs for foliar injury, then a damage estimate based on average densities and crop yields will overestimate actual damages. This possibility for error due to averaging also applies to the assumption that densities are uniformly distributed within crops (Auld and Tisdell 1988).

2. Assumption that OSE is representative of all grasshoppers for each site. OSE was the species most often reported at a given location as recorded in the grasshopper sample reports (AID 1987). The biology and damage potential differ for each species, however. A sensitivity analysis might be used to test the effect of this assumption.

3. In the computation of second year benefits, the crop value and treatment costs anticipated for the second year are assumed at their average value for the entire region analyzed. Emigrant grasshoppers are not included in calculations of estimated second year benefits, only eggs laid locally for each region. Since this problem should eventually be approached from a more inter-regional capability, there should also be a factor accounting for the total area treated in the campaign. The greater the area treated, the greater the reduction in eggs on a region-wide basis.

4. The area treated was assumed to consist entirely of fields producing millet in the nominal analysis. Some small but unknown portions of each area treated were actually surrounding, non-productive lands while significant portions were cultivated in sorghum and in other crops. Regional economic benefits are over-estimated when significant areas were in non-production or cultivated to the less-preferred sorghum crop. Additional analyses addressed this assumption by conducting the simulation for a mixture of millet and sorghum and for sorghum alone.

5. Use of primary weather stations for filling in missing data to nearby secondary (precipitation only) weather stations. Refer to Fig. 2 for a map of weather stations. The FAO crop model and the OSE biomodel both depend less on the temperature and solar radiation data than on precipitation data. It was assumed that the secondary stations, having precipitation data much closer to the treated areas than primary stations, would result in much better estimates than when limiting the analysis to only primary sites. The

degree of improvement associated with this assumption has not been tested. The proximity required between sites simulated and weather stations is also unknown, but should be much greater for precipitation data than other weather data.

V. Campaign Analysis Methods

The GHLSIM grasshopper crop loss simulation model automatically performs the analysis once the data are input and the "Run" option selected. Grasshopper population dynamics and estimated yield loss in untreated and treated situations are simulated for each site. The region of Goz-Beida, Ouaddai was treated during two separate periods during the campaign: 9/22 and 10/21-22. The simulation was therefore performed twice for the region. A portion of Bokoro, Chari-Baguirmi (6,000 Ha) was treated in response to requests although it was not initially included in the areas of responsibility to USAID. This area was included in the analysis for the purpose of completeness. The GHLSIM technical reference should be consulted for a review of how the model simulation functions. A nominal analysis assumed that all treated areas were planted in millet. This allowed direct comparison with the results of Khoury (Chapter I, this report). Although sorghum was planted in significant proportions in most of the regions treated in the campaign, those proportions are not readily determined. The proportion of sorghum cultivated relative to millet at the prefecture level (Government of Chad, 1987) was used in a comparative analysis. An analysis run was conducted based on the assumption of only sorghum present also for comparative purposes. A behavioral analysis was conducted to determine if treatment dates were near an optimal time relative to maximizing first and second year benefits of treatment. This analysis involved varying the treatment date from 5 to 30 days later and from 5 to 40 days earlier at 5 day increments than actual treatment dates using the "Behavior Analysis" option of GHLSIM. Additionally, a sensitivity analysis was performed where the treatment efficacy was altered from a nominal 95% to 85% and 75%, to determine how sensitive the model is to varying treatment efficacy rates.

VI. Campaign Analysis Results

A summary of results from using GHLSIM to simulate the AID anti-grasshopper campaign in Chad for 1987 is presented at the end of Appendix I. Results specific for each of the 13 areas simulated are also presented in Appendix I. In general, results showed both a good correspondence to the calibration data set (and thus to the modified threshold values used therein) and to the conclusions made from Khoury's analysis (Chapter I of this report). The estimated increase in yields due to the campaign averaged 47% (all averages weighted by Ha treated). Yield increases ranged from 0% in Goz-Beida, Ouaddai (treatment Oct 21-

22) to 322% in Guereda, Biltine. First year treatment benefits in crop value were low relative to percent yield increases, at $20.86 per Ha (SD = $18.36), reflecting relatively low crop prices ($0.16-0.31/Kg) and low reported yields (115-500 Kg/Ha). This represents a benefit/cost ratio of 2.8, very close to the approximate value of 3 determined from Khoury's analysis. Highest first year benefits were in Guera, which had the highest reported grasshopper densities (75/m^2) with first benefits nearing the maximum at $55/HA. In Batha, first year benefits were $33-$34/HA, where densities were reported at 25-35/m^2 and treatment was made during the milky grain stage, which is more sensitive to grasshopper defoliation than later stages. In Ati, Batha, model results showed that millet yield losses in untreated fields were 38%, as compared to an average of 22% grain loss to Acridids reported by Fischer and Murphy (1987) for 10 untreated villages near Ati. There was some question whether all the villages sampled had actually not been treated during the Phase II campaign as intended for areas of the crop loss assessment (Murphy, personal communication). This discrepancy (38% vs 22%) is also not unreasonable due to possible sample error and lack of indirect damage inclusion in crop losses as estimated by the Dively procedure (Fischer and Murphy 1987).

First year benefits were less than the treatment cost for only two sites. In Abeche, the final grasshopper population ended a short period after the date of treatment (Oct 8 versus Sept 29). The final area treated, Goz-Beida, Ouaddai, on Oct 21-22, occurred after grasshopper populations had completed development in the model resulting in zero treatment benefits for both first and second year outputs. Although in reality there must have been grasshoppers present at that time, it was reported that the treatment was too late to prevent egg-laying by the population present, in effect confirming model output. Model output for first year benefits was realistic for most of the sites (Appendix I). Second year benefits averaged $9.89/Ha, about one-half of the first year benefits. A comparison of final egg densities made with the CPS eggpod surveys gave variable results; but overall means did not differ with model predictions for the sites available for pairing. The consistently high second year benefits predicted by the model support assertions made during the campaign that egg-laying late in the season was significantly reduced and added substantially to the benefits of the campaign. In the other region cited in the campaign results (AID 1987) as having been treated after significant egg-laying; Mangalme Guera, second year benefits were $12.62, reflecting a possible lack of agreement between model output and field reports in this case.

The simulation was repeated with sorghum and millet and sorghum alone for comparison with results based on using only millet. First year benefits decreased to $12.87 (-38%) for sorghum alone. This decrease is reasonable considering that although sorghum

is not a preferred host, the grain stages are susceptible late in the season. Only a slight reduction of first year benefits to $19.64/Ha (-6%) resulted when millet and sorghum crops were used at the ratios reported for the prefecture level. This small difference is partially due to the generally higher reported sorghum yields and to the small proportion of sorghum grown in several of the Prefectures, including Biltine, Batha, and Ouaddai. It appears then that the assumption of no sorghum grown used for the nominal analysis was reasonable.

Results from the behavioral analysis, in which the effects of varying treatment date on treatment benefits was examined, are given in Figure 3. Since this analysis was for all sites together rather than by individually finding optima for each site, then results will reflect the average of all sites weighted according to the Ha treated per site. The trend for first year benefits in Fig. 3 indicates that the time of treatment was between 5-10 days too late on average to produce the greatest economic benefit during the later (grain fill) crop stages.

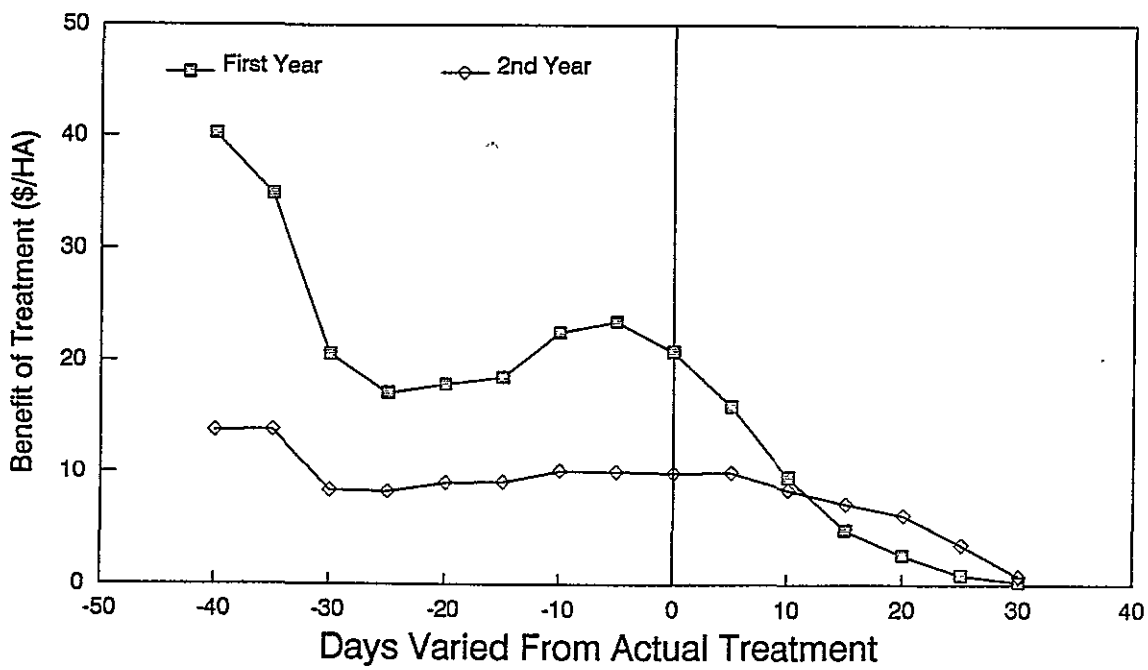

Figure 3. GHLSIM behavioral analysis to examine the effect of varying treatment date of 14 regions in Chad, 1987 anti-grasshopper campaign.

The trend also reflects possibly greater benefits if treatment were made 40 days earlier, in August and early September during the susceptible juvenile crop stages. Some of the areas had in fact been treated at that time, during Phase I of the campaign which

focuses on ground applications (AID 1987). From 20 to 30 days before the campaign, crops were largely at the tillering and spike stages, which are less susceptible, as reflected by the lower treatment benefits for the period. Treatment benefits rapidly decreased for treatments made later, as expected since crop maturity was approaching soon after the actual treatment times at most sites. Second year benefits were relatively insensitive to treatment date, and were near optimal for the actual treatment dates. Reducing the treatment efficacy to 85% resulted in a reduction in treatment benefits for year 1 to $16.51/Ha (-21%) and for year 2 to $7.20/Ha (-27%). A reduction in efficacy to 75% lowered benefits to 10.21 (-49%) for the first year and to 3.83 (-39%) for the second. These effects indicate that GHLSIM is perhaps overly sensitive to treatment efficacy and that more efforts should be made to improve the treatment action component in the model.

VII. Conclusions

No definite conclusions will be made here toward the cost-effectiveness of the 1987 Chad campaign. Grasshopper densities were generally very high, the potential for heavy crop losses was great. An average of 47% yield increases and total first and second year benefit/cost ratio of 4.2 was estimated for the treatment campaign by the GHLSIM simulation model. These estimates very likely err on the side of favoring the campaign, however. The compounds used, Malathion and Fenitrothion, are considered among the safest approved for grasshopper control and were not expected to cause significant environmental effects at the low rates used (0.50 L/Ha).

The campaign was organized and conducted according to sound integrated pest management principles, including the use of grasshopper density surveys and economic threshold guidelines for determining the need for treatment on a site by site basis. This conclusion is supported by the decisions made to forego treatment of Salamat, Southern Guera, and Am Dam, Guera, and individual sites in the regions that were treated due to sub-economic threshold densities.

VIII. Plans for Improvements to GHLSIM

Version 1.0 of GHLSIM (Oct. 1989) reflects a strong effort in software design, a good conceptual understanding of the components needed for the problem at hand, and gives realistic output of grasshopper effects to millet and sorghum when given proper inputs. The model is largely unvalidated and is weak in several areas which will be discussed here. Some of these areas will be addressed in version 2.0 (currently under development).

1. More recent version of OSE biomodel. A major source of inaccuracy of GHLSIM can be derived from the OSE biomodel. Efforts will be made to obtain an updated version of

the biomodel (Launois and Launois-Luong 1985) and to modify GHLSIM to make use of new features. The newer versions of the biomodel may allow geographical dependencies which are lacking in the version now used. Another option that will be included in version 2.0 of GHLSIM is to use an alternative grasshopper biological model for short-term (within generation) density estimation. Such an option may increase accuracy of short term predictions, especially useful for end-of-season treatment evaluation.

2. Physiological crop model to allow dynamic injury/growth capabilities. The current crop model should be replaced with a modified version of the CERES millet model, an IBSNAT standard physiological crop development and yield prediction model (Alagarswamy et al. 1988). The crop injury portion of GHLSIM will be rewritten to allow the crop to dynamically compensate for injury suffered depending on crop vigor as influenced by other factors. Due to a physiological basis for crop growth, a model such as CERES millet will be potentially more accurate, more robust over the Sahelian regions, and better handle multiple pest loads. CERES is a standard for agronomists and crop physiologists and can be modified to work with the fewer data inputs available in the Sahel.

3. A sensitivity analysis to determine what aspects of the model most require further development and validation. Sensitivity analysis can add considerable insight into what variables and parameters require accurate estimation and can help guide the definition of further model improvements.

4. Further collection of calibration/validation data sets. Efforts to obtain grasshopper sample data with corresponding crop yields and crop loss estimates will be increased. Emphasis will be placed on obtaining the data from already established sources such as FEWS, the CPS in various Sahelian countries and existing research projects.

5. A working version of GHLSIM translated to French. Installation of the model in much of the Sahel necessitates a French version. Cooperation with AID personnel in translation from English will be made a priority.

6. Refinements to the user interface and model functionality.
Feedback from demonstrations and workshops and further testing will reveal new bugs, errors needing correction, and desirable new features which will be incorporated into the new version of GHLSIM.

7. Treatment Threshold Tables. Tables which incorporate GHLSIM model results, treatment costs, crop values, and practical considerations will be produced that will reflect many of the dynamic aspects of grasshopper/crop loss/treatment interactions without the need for extensive input data.

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X. Appendices

Appendix 1. GHLSIM output for analysis of AID aerially-treated sites in Chad, 1987. Nominal run conditions; set for comparison to analysis of Khoury (this report Chapter I). Crops cultivated: Millet; Spatial resolution for grasshopper densities, precipitation data, treatment costs, crop yields, crop prices, harvest dates: Sub-Prefecture level;

Information for run no. 1 of 14 runs.
Record code: 1 Sample message number: 116 Campaign code: CDA87
Grasshopper sample date: 10-Sep-87 Treatment date: 10-Sep-87
Location: IRIBA AVG IRIBA BIL

Weather site code	: 7
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 25
Ha sampled	: Unknown
Crops	: millet
Crop stage	: Unknown
Treated Ha	: 4335 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: H. KHOURY/IRIBA

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.90	0.08	0.02	0.90	0.08	0.02
Seeded:	Jul-29	Jul-29	Jul-19	Jul-29	Jul-29	Jul-9
Seedling:	Aug-8	Aug-10	Aug-3	Aug-10	Aug-11	Jul-25
Tiller/Spike:	Aug-18	Aug-22	Aug-24	Aug-22	Aug-25	Aug-18
Milky Grain:	Sep-3	Sep-9	Sep-28	Sep-8	Sep-11	Sep-27
Dry Grain:	Oct-2	Oct-9	Oct-29	Oct-8	Oct-7	Oct-29
Harvest:	Oct-14	Oct-26	Nov-15	Oct-26	Nov-5	Nov-15
Yld Loss NoTrt:	34.0%	37.6%	35.7%	18.3%	16.9%	18.0%
Yield Loss Trt:	1.6%	1.7%	1.6%	0.8%	0.8%	0.8%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	56.90	30.70	26.20
Crop loss ($/HA)	12.41	6.69	5.71

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
CROP	Price $/KG	Loss %	Yield KG/HA	Loss %	Yield KG/HA	Benefit Yr 1	Benefit Yr 2	Cost	Net Bene	Area HA	Yr 1	Both
MILL	0.31	34.3	200	1.6	300	30.95	5.71	11.29	25.38	4335	2.7	3.2
SORG	0.15	18.2	281	0.8	340	8.92	5.71	11.29	3.35	0	0.8	1.3

Information for run no. 2 of 14 runs.
Record code: 2 Sample message number: 160 Campaign code: CDA87
Grasshopper sample date: 20-Sep-87 Treatment date: 20-Sep-87
Location: GUEREDA AVG GUEREDA BIL

Weather site code	: 111
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 75
Ha sampled	: Unknown
Crops	: millet
Crop stage	: LAIT/PATEUX
Treated Ha	: 4550 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: SECT.AGRI./BILTI

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.90	0.08	0.02	0.90	0.08	0.02
Seeded:	Jul-29	Jul-29	Jul-19	Jul-29	Jul-29	Jul-9
Seedling:	Aug-8	Aug-10	Aug-3	Aug-10	Aug-11	Jul-25
Tiller/Spike:	Aug-18	Aug-22	Aug-24	Aug-22	Aug-25	Aug-18
Milky Grain:	Sep-3	Sep-9	Sep-28	Sep-8	Sep-11	Sep-27
Dry Grain:	Oct-2	Oct-9	Oct-29	Oct-8	Oct-7	Oct-29
Harvest:	Oct-14	Oct-26	Nov-15	Oct-26	Nov-5	Nov-15
Yld Loss NoTrt:	77.5%	77.7%	77.8%	48.2%	43.9%	53.3%
Yield Loss Trt:	5.0%	5.4%	5.8%	2.7%	2.5%	2.9%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	201.80	29.70	172.10
Crop loss ($/HA)	38.85	6.48	32.38

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
CROP	Price $/KG	Loss %	Yield KG/HA	Loss %	Yield KG/HA	Benefit Yr 1	Benefit Yr 2	Cost	Net Bene	Area HA	Yr 1	Both
MILL	0.24	77.5	71	5.0	300	54.69	32.38	7.93	79.14	4550	6.9	11.0
SORG	0.15	48.0	182	2.6	340	23.76	32.38	7.93	48.21	0	3.0	7.1

Information for run no. 3 of 14 runs.
Record code: 3 Sample message number: 160 Campaign code: CDA87
Grasshopper sample date: 28-Sep-87 Treatment date: 24-Sep-87
Location: BILTINE AVG BILTINE BIL

Weather site code	: 9
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 15
Ha sampled	: Unknown
Crops	: millet
Crop stage	: EPIAI-MATUR
Treated Ha	: 8700 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: OCLALAV-IRIBA

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.90	0.08	0.02	0.90	0.08	0.02
Seeded:	Jul-29	Jul-29	Jul-19	Jul-29	Jul-29	Jul-9
Seedling:	Aug-8	Aug-10	Aug-3	Aug-10	Aug-11	Jul-25
Tiller/Spike:	Aug-18	Aug-22	Aug-24	Aug-22	Aug-25	Aug-18
Milky Grain:	Sep-3	Sep-9	Sep-28	Sep-8	Sep-11	Sep-27
Dry Grain:	Oct-2	Oct-9	Oct-29	Oct-8	Oct-7	Oct-29
Harvest:	Oct-14	Oct-26	Nov-15	Oct-26	Nov-5	Nov-15
Yld Loss NoTrt:	9.0%	10.2%	11.0%	4.9%	4.6%	5.5%
Yield Loss Trt:	1.4%	1.7%	2.0%	0.8%	0.8%	1.0%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	49.70	16.90	32.80
Crop loss ($/HA)	10.84	3.68	7.15

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
	Price	Loss	Yield	Loss	Yield	Benefit			Net	Area		
CROP	$/KG	%	KG/HA	%	KG/HA	Yr 1	Yr 2	Cost	Bene	HA	Yr 1	Both
MILL	0.27	9.1	277	1.4	300	6.31	7.15	7.93	5.53	8700	0.8	1.7
SORG	0.15	4.9	326	0.8	340	2.10	7.15	7.93	1.32	0	0.3	1.2

Information for run no. 4 of 14 runs.
Record code: 4 Sample message number: 160 Campaign code: CDA87
Grasshopper sample date: 28-Sep-87 Treatment date: 25-Sep-87
Location: AM ZOER AVG AMZOER BIL

Weather site code	: 10
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 25
Ha sampled	: Unknown.
Crops	: millet
Crop stage	: EPIAI-MATUR
Treated Ha	: 3320 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: OCLALAV-IRIBA

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.90	0.08	0.02	0.90	0.08	0.02
Seeded:	Jul-29	Jul-29	Jul-19	Jul-29	Jul-29	Jul-9
Seedling:	Aug-8	Aug-10	Aug-3	Aug-10	Aug-11	Jul-25
Tiller/Spike:	Aug-18	Aug-22	Aug-24	Aug-22	Aug-25	Aug-18
Milky Grain:	Sep-3	Sep-9	Sep-28	Sep-8	Sep-11	Sep-27
Dry Grain:	Oct-2	Oct-9	Oct-29	Oct-8	Oct-7	Oct-29
Harvest:	Oct-14	Oct-26	Nov-15	Oct-26	Nov-5	Nov-15
Yld Loss NoTrt:	29.2%	35.0%	39.9%	17.0%	15.6%	19.9%
Yield Loss Trt:	3.4%	4.3%	5.2%	2.1%	2.1%	2.6%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	71.40	24.10	47.30
Crop loss ($/HA)	15.57	5.25	10.31

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
	Price	Loss	Yield	Loss	Yield	Benefit			Net	Area		
CROP	$/KG	%	KG/HA	%	KG/HA	Yr 1	Yr 2	Cost	Bene	HA	Yr 1	Both
MILL	0.24	29.9	218	3.5	300	19.62	10.31	7.93	22.01	3320	2.5	3.8
SORG	0.15	16.9	289	2.1	340	7.72	10.31	7.93	10.11	0	1.0	2.3

Information for run no. 5 of 14 runs.
Record code: 5 Sample message number: 150 Campaign code: CDA87
Grasshopper sample date: 21-Sep-87 Treatment date: 20-Sep-87

Location: ADRE AVG	ADRE OUA
Weather site code	: 18
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 18
Ha sampled	: Unknown
Crops	: millet
Crop stage	: Unknown
Treated Ha	: 9955 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: KHOURY/ADRE

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.80	0.14	0.06	0.80	0.14	0.06
Seeded:	Aug-2	Aug-2	Jul-23	Aug-2	Aug-2	Jul-13
Seedling:	Aug-12	Aug-14	Aug-7	Aug-14	Aug-15	Jul-29
Tiller/Spike:	Aug-22	Aug-26	Aug-28	Aug-26	Aug-29	Aug-22
Milky Grain:	Sep-7	Sep-13	Oct-2	Sep-12	Sep-15	Oct-1
Dry Grain:	Oct-6	Oct-13	Nov-2	Oct-12	Oct-11	Nov-2
Harvest:	Oct-18	Oct-30	Nov-19	Oct-30	Nov-9	Nov-19
Yld Loss NoTrt:	23.9%	25.2%	20.6%	12.5%	11.8%	10.9%
Yield Loss Trt:	1.6%	1.6%	1.0%	0.8%	0.8%	0.5%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	45.10	25.30	19.80
Crop loss ($/HA)	9.83	5.52	4.32

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
	Price	Loss	Yield	Loss	Yield	Benefit			Net	Area		
CROP	$/KG	%	KG/HA	%	KG/HA	Yr 1	Yr 2	Cost	Bene	HA	Yr 1	Both
MILL	0.23	23.9	155	1.5	200	10.43	4.32	9.05	5.70	9955	1.2	1.6
SORG	0.15	12.3	407	0.8	460	8.00	4.32	9.05	3.26	0	0.9	1.4

Information for run no. 6 of 14 runs.
Record code: 6 Sample message number: 159 Campaign code: CDA87
Grasshopper sample date: 25-Sep-87 Treatment date: 22-Sep-87
Location: GOZ-BEIDA AVG GOZ-BEIDA OUA

Weather site code	: 33
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 30
Ha sampled	: Unknown
Crops	: millet
Crop stage	: FLOR/GRAINS
Treated Ha	: 1650 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: H.KHOURI/BILTINE

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.80	0.14	0.06	0.80	0.14	0.06
Seeded:	Aug-8	Aug-8	Jul-29	Aug-8	Aug-8	Jul-19
Seedling:	Aug-18	Aug-20	Aug-13	Aug-20	Aug-21	Aug-4
Tiller/Spike:	Aug-28	Sep-1	Sep-3	Sep-1	Sep-4	Aug-28
Milky Grain:	Sep-13	Sep-19	Oct-8	Sep-18	Sep-21	Oct-7
Dry Grain:	Oct-12	Oct-19	Nov-8	Oct-18	Oct-17	Nov-8
Harvest:	Oct-24	Nov-5	Nov-25	Nov-5	Nov-15	Nov-25
Yld Loss NoTrt:	20.3%	20.3%	8.2%	10.2%	10.1%	3.8%
Yield Loss Trt:	2.1%	2.1%	0.5%	1.0%	1.0%	0.2%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	76.50	17.10	59.40
Crop loss ($/HA)	16.68	3.73	12.95

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
	Price	Loss	Yield	Loss	Yield	Benefit			Net	Area		
CROP	$/KG	%	KG/HA	%	KG/HA	Yr 1	Yr 2	Cost	Bene	HA	Yr 1	Both
MILL	0.18	19.6	205	2.0	250	8.08	12.95	6.27	14.76	1650	1.3	3.4
SORG	0.15	9.8	419	1.0	460	6.12	12.95	6.27	12.80	0	1.0	3.0

Information for run no. 7 of 14 runs.
Record code: 7 Sample message number: 166 Campaign code: CDA87
Grasshopper sample date: 28-Sep-87 Treatment date: 29-Sep-87
Location: ABECHE ABECHE OUA

Weather site code	: 17
Grasshopper species	: OSE and SCA
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: 25 / 10 / 18
Ha sampled	: Unknown
Crops	: millet
Crop stage	: Unknown
Treated Ha	: 11620 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: H. KHOURI/ABECHE

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.80	0.14	0.06	0.80	0.14	0.06
Seeded:	Aug-2	Aug-2	Jul-23	Aug-2	Aug-2	Jul-13
Seedling:	Aug-12	Aug-14	Aug-7	Aug-14	Aug-15	Jul-29
Tiller/Spike:	Aug-22	Aug-26	Aug-28	Aug-26	Aug-29	Aug-22
Milky Grain:	Sep-7	Sep-13	Oct-2	Sep-12	Sep-15	Oct-1
Dry Grain:	Oct-6	Oct-13	Nov-2	Oct-12	Oct-11	Nov-2
Harvest:	Oct-18	Oct-30	Nov-19	Oct-30	Nov-9	Nov-19
Yld Loss NoTrt:	6.2%	7.2%	7.7%	3.6%	3.1%	3.8%
Yield Loss Trt:	0.4%	0.4%	0.4%	0.2%	0.2%	0.2%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	57.80	18.30	39.50
Crop loss ($/HA)	12.60	3.99	8.61

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
	Price	Loss	Yield	Loss	Yield	Benefit			Net	Area		
CROP	$/KG	%	KG/HA	%	KG/HA	Yr 1	Yr 2	Cost	Bene	HA	Yr 1	Both
MILL	0.30	6.4	108	0.4	115	2.08	8.61	9.12	1.57	11620	0.2	1.2
SORG	0.15	3.5	445	0.2	460	2.29	8.61	9.12	1.78	0	0.3	1.2

Information for run no. 8 of 14 runs.
Record code: 8 Sample message number: 168 Campaign code: CDA87
Grasshopper sample date: 01-Oct-87 Treatment date: 01-Oct-87
Location: OUM-HADJER AVG OUM-HADJER BAT

Weather site code	: 16
Grasshopper species	: OSE and SCA
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 35
Ha sampled	: Unknown
Crops	: millet
Crop stage	: LAIT/PATEUX
Treated Ha	: 7460 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: H.KHOURI/BATHA

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.90	0.08	0.02	0.90	0.08	0.02
Seeded:	Aug-9	Aug-9	Jul-30	Aug-9	Aug-9	Jul-20
Seedling:	Aug-20	Aug-21	Aug-14	Aug-21	Aug-22	Aug-5
Tiller/Spike:	Aug-29	Sep-2	Sep-4	Sep-2	Sep-5	Aug-28
Milky Grain:	Sep-13	Sep-19	Oct-9	Sep-19	Sep-21	Oct-8
Dry Grain:	Oct-13	Oct-21	Nov-10	Oct-19	Oct-18	Nov-10
Harvest:	Oct-25	Nov-6	Nov-26	Nov-6	Nov-16	Nov-26
Yld Loss NoTrt:	65.4%	76.7%	77.7%	39.2%	39.6%	49.3%
Yield Loss Trt:	24.7%	30.9%	40.3%	15.3%	15.8%	20.2%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	130.50	57.10	73.40
Crop loss ($/HA)	28.45	12.45	16.00

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
	Price	Loss	Yield	Loss	Yield	Benefit			Net	Area		
CROP	$/KG	%	KG/HA	%	KG/HA	Yr 1	Yr 2	Cost	Bene	HA	Yr 1	Both
MILL	0.25	66.6	112	25.5	250	34.45	16.00	7.65	42.81	7460	4.5	6.6
SORG	0.15	39.5	286	15.5	400	17.03	16.00	7.65	25.38	0	2.2	4.3

Information for run no. 9 of 14 runs.
Record code: 9 Sample message number: 170 Campaign code: CDA87
Grasshopper sample date: 03-Oct-87 Treatment date: 03-Oct-87

Location: ATI AVG	ATI	BAT
Weather site code	: 14	
Grasshopper species	: OSE	
Stages	: adult and larva.	
Densities (Max/ Min/ Avg.)	: / / 25	
Ha sampled	: Unknown	
Crops	: millet	
Crop stage	: LAIT/PATEUX	
Treated Ha	: 16600 HA	
Control agent	: MV	
Risk index	: 2.41	
Efficacy reported	: 95% (default)	
Origin of sample message	: H.KHOURI/BATHA	

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.90	0.08	0.02	0.90	0.08	0.02
Seeded:	Aug-12	Aug-12	Aug-2	Aug-12	Aug-12	Jul-23
Seedling:	Aug-22	Aug-24	Aug-17	Aug-24	Aug-25	Aug-8
Tiller/Spike:	Sep-1	Sep-5	Sep-7	Sep-5	Sep-8	Sep-1
Milky Grain:	Sep-17	Sep-23	Oct-12	Sep-22	Sep-25	Oct-11
Dry Grain:	Oct-16	Oct-23	Nov-12	Oct-22	Oct-21	Nov-12
Harvest:	Oct-28	Nov-9	Nov-29	Nov-9	Nov-19	Nov-29
Yld Loss NoTrt:	38.4%	43.3%	45.5%	21.1%	19.8%	23.7%
Yield Loss Trt:	2.4%	2.6%	2.3%	1.3%	1.2%	1.4%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	51.30	8.90	42.40
Crop loss ($/HA)	11.18	1.94	9.24

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
	Price	Loss	Yield	Loss	Yield	Benefit			Net	Area		
CROP	$/KG	%	KG/HA	%	KG/HA	Yr 1	Yr 2	Cost	Bene	HA	Yr 1	Both
MILL	0.25	38.9	219	2.5	350	32.68	9.24	7.81	34.12	16600	4.2	5.4
SORG	0.15	21.1	320	1.3	400	12.03	9.24	7.81	13.46	0	1.5	2.7

Information for run no. 10 of 14 runs.
Record code: 10 Sample message number: 172 Campaign code: CDA87
Grasshopper sample date: 09-Oct-87 Treatment date: 09-Oct-87

Location: MONGO AVG	MONGO GUE
Weather site code	: 29
Grasshopper species	: OSE and ASI
Stages	: adult and larva..
Densities (Max/ Min/ Avg.)	: / / 25
Ha sampled	: Unknown
Crops	: millet
Crop stage	: Maturite
Treated Ha	: 16185 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: A.M.YAKOUB/MONGO

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.70	0.20	0.10	0.70	0.20	0.10
Seeded:	Jul-27	Jul-27	Jul-17	Jul-27	Jul-27	Jul-7
Seedling:	Aug-6	Aug-8	Aug-1	Aug-8	Aug-9	Jul-23
Tiller/Spike:	Aug-16	Aug-20	Aug-22	Aug-20	Aug-23	Aug-16
Milky Grain:	Sep-1	Sep-7	Sep-26	Sep-6	Sep-9	Sep-25
Dry Grain:	Sep-30	Oct-7	Oct-27	Oct-6	Oct-5	Oct-27
Harvest:	Oct-12	Oct-24	Nov-13	Oct-24	Nov-3	Nov-13
Yld Loss NoTrt:	10.7%	40.3%	53.0%	20.1%	22.5%	26.5%
Yield Loss Trt:	0.6%	1.8%	2.4%	0.9%	1.0%	1.2%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	83.40	50.90	32.50
Crop loss ($/HA)	18.18	11.10	7.09

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
CROP	Price $/KG	Loss %	Yield KG/HA	Loss %	Yield KG/HA	Benefit Yr 1	Benefit Yr 2	Cost	Net Bene	Area HA	Yr 1	Both
MILL	0.20	20.9	400	1.0	500	20.06	7.09	6.23	20.92	16185	3.2	4.4
SORG	0.15	21.2	358	1.0	450	13.82	7.09	6.23	14.68	0	2.2	3.4

Information for run no. 11 of 14 runs.
Record code: 11 Sample message number: 177 Campaign code: CDA87
Grasshopper sample date: 11-Oct-87 Treatment date: 13-Oct-87
Location: BITKINE AVG Mongo GUE

Weather site code	: 39
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: 40 / 30 / 35
Ha sampled	: Unknown
Crops	: millet
Crop stage	: Unknown
Treated Ha	: 16600 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: ABDEL-WAHITE Y.

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.70	0.20	0.10	0.70	0.20	0.10
Seeded:	Jul-27	Jul-27	Jul-17	Jul-27	Jul-27	Jul-7
Seedling:	Aug-6	Aug-8	Aug-1	Aug-8	Aug-9	Jul-23
Tiller/Spike:	Aug-16	Aug-20	Aug-22	Aug-20	Aug-23	Aug-16
Milky Grain:	Sep-1	Sep-7	Sep-26	Sep-6	Sep-9	Sep-25
Dry Grain:	Sep-30	Oct-7	Oct-27	Oct-6	Oct-5	Oct-27
Harvest:	Oct-12	Oct-24	Nov-13	Oct-24	Nov-3	Nov-13
Yld Loss NoTrt:	12.9%	56.0%	73.7%	28.0%	31.5%	36.8%
Yield Loss Trt:	0.9%	2.9%	3.8%	1.4%	1.6%	1.9%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	113.20	67.70	45.50
Crop loss ($/HA)	24.68	14.76	9.92

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
	Price	Loss	Yield	Loss	Yield	Benefit			Net	Area		
CROP	$/KG	%	KG/HA	%	KG/HA	Yr 1	Yr 2	Cost	Bene	HA	Yr 1	Both
MILL	0.20	27.6	368	1.6	500	26.39	9.92	6.23	30.08	16600	4.2	5.8
SORG	0.15	29.6	322	1.5	450	19.22	9.92	6.23	22.91	0	3.1	4.7

Information for run no. 12 of 14 runs.
Record code: 12 Sample message number: 177 Campaign code: CDA87
Grasshopper sample date: 14-Oct-87 Treatment date: 14-Oct-8
Location: MANGALME AVG MANGALME GUE

Weather site code	: 31
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 45
Ha sampled	: Unknown
Crops	: millet
Crop stage	: Unknown
Treated Ha	: 16600 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	: ABDEL-WAHITE Y.

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.70	0.20	0.10	0.70	0.20	0.10
Seeded:	Jul-27	Jul-27	Jul-17	Jul-27	Jul-27	Jul-7
Seedling:	Aug-6	Aug-8	Aug-1	Aug-8	Aug-9	Jul-23
Tiller/Spike:	Aug-16	Aug-20	Aug-22	Aug-20	Aug-23	Aug-16
Milky Grain:	Sep-1	Sep-7	Sep-26	Sep-6	Sep-9	Sep-25
Dry Grain:	Sep-30	Oct-7	Oct-27	Oct-6	Oct-5	Oct-27
Harvest:	Oct-12	Oct-24	Nov-13	Oct-24	Nov-3	Nov-13
Yld Loss NoTrt:	15.5%	70.6%	77.6%	35.3%	39.8%	46.5%
Yield Loss Trt:	1.2%	3.8%	5.1%	1.9%	2.1%	2.5%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	144.60	86.10	58.50
Crop loss ($/HA)	31.39	18.77	12.62

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
CROP	Price $/KG	Loss %	Yield KG/HA	Loss %	Yield KG/HA	Benefit Yr 1	Benefit Yr 2	Cost	Net Bene	Area HA	Yr 1	Both
MILL	0.16	32.8	344	2.1	500	25.02	12.62	5.99	31.65	16600	4.2	6.3
SORG	0.15	37.3	288	2.0	450	24.31	12.62	5.99	30.94	0	4.1	6.2

Information for run no. 13 of 14 runs.
Record code: 13 Sample message number: 1 Campaign code: CDA87
Grasshopper sample date: 25-Sep-87 Treatment date: 21-OCT-87
Treatment date missing; estimated as 3 days prior to sample date
Treatment date missing; estimated from similar samples
Location: GOZ-BEIDA AVG2 GOZ-BEIDA OUA

Weather site code	: 33
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 30
Ha sampled	: Unknown
Crops	: millet
Crop stage	: Unknown
Treated Ha	: 10380 HA
Control agent	: MV
Risk index	: 2.41
Efficacy reported	: 95% (default)
Origin of sample message	:

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.80	0.14	0.06	0.80	0.14	0.06
Seeded:	Aug-8	Aug-8	Jul-29	Aug-8	Aug-8	Jul-19
Seedling:	Aug-18	Aug-20	Aug-13	Aug-20	Aug-21	Aug-4
Tiller/Spike:	Aug-28	Sep-1	Sep-3	Sep-1	Sep-4	Aug-28
Milky Grain:	Sep-13	Sep-19	Oct-8	Sep-18	Sep-21	Oct-7
Dry Grain:	Oct-12	Oct-19	Nov-8	Oct-18	Oct-17	Nov-8
Harvest:	Oct-24	Nov-5	Nov-25	Nov-5	Nov-15	Nov-25
Yld Loss NoTrt:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Yield Loss Trt:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	76.50	76.50	0.00
Crop loss ($/HA)	16.68	16.68	0.00

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
CROP	Price $/KG	Loss %	Yield KG/HA	Loss %	Yield KG/HA	Benefit Yr 1	Benefit Yr 2	Cost	Net Bene	Area HA	Yr 1	Both
MILL	0.18	0.0	250	0.0	250	0.00	0.00	6.27	-6.27	10380	0.0	0.0
SORG	0.15	0.0	460	0.0	460	0.00	0.00	6.27	-6.27	0	0.0	0.0

Information for run no. 14 of 14 runs.
Record code: 14 Sample message number: 161 Campaign code: CDA87
Grasshopper sample date: 18-Oct-87 Treatment date: 18-Oct-87
Location: BOKORO AVG BOKORO CHB

Weather site code	: 26
Grasshopper species	: OSE
Stages	: adult and larva.
Densities (Max/ Min/ Avg.)	: / / 72
Ha sampled	: Unknown
Crops	: millet
Crop stage	: Unknown
Treated Ha	: 6000 HA
Control agent	: FV
Risk index	: 2.76
Efficacy reported	: 95% (default)
Origin of sample message	: ?

Crop Information:

	Millet			Sorghum		
Variety:	75	90	110	80	90	130
Proportion:	0.70	0.20	0.10	0.70	0.20	0.10
Seeded:	Jul-31	Jul-31	Jul-21	Jul-31	Jul-31	Jul-11
Seedling:	Aug-10	Aug-12	Aug-5	Aug-12	Aug-13	Jul-27
Tiller/Spike:	Aug-20	Aug-24	Aug-26	Aug-24	Aug-27	Aug-20
Milky Grain:	Sep-5	Sep-11	Sep-30	Sep-10	Sep-13	Sep-29
Dry Grain:	Oct-4	Oct-11	Oct-31	Oct-10	Oct-9	Oct-31
Harvest:	Oct-16	Oct-28	Nov-17	Oct-28	Nov-7	Nov-17
Yld Loss NoTrt:	30.5%	59.8%	77.3%	29.9%	33.1%	41.9%
Yield Loss Trt:	3.5%	5.5%	7.6%	2.8%	2.9%	3.8%

Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey breakeven analysis) Egg density threshold: 34.4/m ; Treatment cost: $7.50/HA; Crop value $74.00/HA.

	No Treatment	Treatment	Difference
Final egg density (#/m)	235.10	90.40	144.70
Crop loss ($/HA)	41.39	19.71	21.69

RESULTS:

		No Treatment		Treatment		Treatment ($/HA)					Benefit /Cost	
CROP	Price $/KG	Loss %	Yield KG/HA	Loss %	Yield KG/HA	Benefit Yr 1	Benefit Yr 2	Cost	Net Bene	Area HA	Yr 1	Both
MILL	0.24	41.1	189	4.3	307	28.15	21.69	7.93	41.91	6000	3.6	6.3
SORG	0.15	31.7	380	2.9	540	24.07	21.69	7.93	37.83	0	3.0	5.8

The Aggregate economic analysis:

Region	#Sites	Avg Dens	Trt Code	%Yld inc	Result of Treatment ($/HA) Benefit Yr 1	Benefit Yr 2	Cost	Net Benefit	Area HA	Avg Risk	Benefit /Cost Yr 1	Benefit /Cost Both	/Risk Index
IRI	1	25	MV	50.0	30.95	5.71	11.29	25.37	4335	2.4	2.7	3.2	1.4
GUD	1	75	MV	322.5	54.69	32.38	7.93	79.14	4550	2.4	6.9	11.0	4.6
BIL	1	15	MV	8.3	6.31	7.15	7.93	5.53	8700	2.4	0.8	1.7	0.7
AMZ	1	25	MV	37.6	19.62	10.31	7.93	22.00	3320	2.4	2.5	3.8	1.6
ADR	1	18	MV	29.0	10.43	4.32	9.05	5.70	9955	2.4	1.2	1.6	0.7
GZ1	1	30	MV	22.0	8.08	12.95	6.27	14.76	1650	2.4	1.3	3.4	1.4
ABE	1	18	MV	6.5	2.08	8.61	9.12	1.57	11620	2.4	0.2	1.2	0.5
OUM	1	35	MV	123.2	34.45	16.00	7.65	42.80	7460	2.4	4.5	6.6	2.7
ATI	1	25	MV	59.8	32.68	9.24	7.81	34.11	16600	2.4	4.2	5.4	2.2
MON	1	25	MV	25.0	20.06	7.09	6.23	20.92	16185	2.4	3.2	4.4	1.8
BIT	1	35	MV	35.9	26.39	9.92	6.23	30.08	16600	2.4	4.2	5.8	2.4
MAN	1	45	MV	45.3	25.02	12.62	5.99	31.65	16600	2.4	4.2	6.3	2.6
GZ2	1	30	MV	0.0	0.00	0.00	6.27	-6.27	10380	2.4	0.0	0.0	0.0
BOK	1	72	FV	62.4	28.15	21.69	7.93	41.91	6000	2.8	3.5	6.3	2.2
Avg	14	32	N/A	47.2	20.83	9.89	7.39	23.33	133955	2.4	2.8	4.2	1.7
Stdev					18.36								

First Year Benefit: $ 2,790,838 Second Year Benefit: $ 1,324,737
Cost of Treatment : $ 989,817 Net Benefit : $ 3,125,757