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Agricultural production in the Sahelian region of Africa is among the lowest in the world. Cyclical infestations of locusts and grasshoppers have contributed to this low productivity. The infestations appear to be triggered by heavy rainfall at the beginning of a crop season after extended drought. Because locusts and grasshoppers are migratory, their control on a local and farm by farm basis is difficult.

To combat the problem of periodic outbreaks USAID has provided direct assistance through aerial spraying of grasshoppers in a number of African countries. This includes a control program in the north African country of Chad in 1987. From the beginning concern arose as to when it is economically desirable to control grasshoppers. The International Plant Protection Center (IPPC) at Oregon State University was awarded a contract for economic evaluation of spraying in Chad which included development of a grasshopper crop loss simulation model (GHLSIM) driven by climatic factors for grasshopper and crop growth. GHLSIM's posterior analysis of the 1987 anti-grasshopper campaign produced results with a wide range of B/C ratios across the 13

sites which were evaluated. The B/C ratios ranged from 0 to 6.9.

To test GHLSIM's use beyond weather conditions of a single year (1987), a Monte Carlo simulation technique was used to generate long term (100 year) rainfall patterns at selected sites and a series of expected benefits generated. The effect of rainfall variability upon economic benefits was assessed. So also were changes in grasshopper population densities and output prices. Results are presented graphically under a number of such conditions to understand the bio-physical relationships among grasshoppers, crop, natural vegetation and rainfall as modeled by GHLSIM.

The model is sensitive to within season and to some extent between season weather variation. Rainfall appears to be the dominant variable controlling crop production, regardless of grasshopper densities. When weather is the overriding factor, changes in grasshopper density levels do not play a dominant role in affecting B/C ratios. When weather is not a constraint for crop production, grasshopper density changes can affect benefits significantly.

In its present form the GHLSIM model cannot be used as an early warning indicator. While the model appears to predict crop production quite well, model refinement which will change the qualitative prediction of grasshopper populations to a quantitative one throughout a crop season is still needed. When this is completed and both the GHLCROPS and GHLOSE submodels performance are validated against field observations, the GHLSIM model can be used as an early warning predictor. With these accomplishments GHLSIM can then be considered for use in the public policy arena for assessing what areas to spray, when and what distributional effects may be involved.

Effect of Weather Variation on Economic Results From Grasshopper Control Tactics in Chad: A Partial Validation of GHLSIM

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ACRONYMS

CIDA = Canadian International Development Agency

CIRAD = Center de Cooperation International en recherche Agronomique pour le Development

DCLO = Desert Locust Control Organization

RLCO = Red Locust Control Organization

FAO = Food and Agricultural Organization

FEWS = Famine Early Warning System

GHLSIM = Grasshopper Crop Loss Simulation Model

GTZ = Gesellschaft fuer technische Zusammenarbeit (German)

OSE = Senegalese grasshopper (*Oedaleus senegalensis*)

OCLALAV = Organization to combat Birds and Locusts

PRIFAS = Programme de Recherches Interdisciplinaire Franccaise sur les Acridiens du Sahel (French)

USAID = United States Agency for International development

EFFECT OF WEATHER VARIATION ON ECONOMIC RESULTS FROM GRASSHOPPER CONTROL TACTICS IN CHAD: A PARTIAL VALIDATION OF GHLSIM

Chapter 1

INTRODUCTION

Agricultural production in the Sub-Saharan, Central and West Sahelian regions of Africa is some of the lowest of any in the world. Agricultural production there has increased very little historically. However, rapid population growth has occurred resulting in per capita food reduction (USAID African Bureau, 1987) in the last decade and outright famine in a number of African countries during drought conditions. A number of determinants are responsible for food deficits in these countries. Cyclical infestation of grasshoppers and locusts that create periodic crop losses (USAID Africa Bureau) is a major contributing factor.

Agricultural production in these countries can be enhanced in two ways (Launois, 1986). One is to produce more and the other is to reduce crop losses. The former requires extensive technical expertise and specialities in many disciplines and development of infrastructure to conduct agricultural research, extension and training activities appropriate for the region. Reducing crop losses is of a more immediate nature, one intended to enhance economic gains within a crop production cycle. Crop losses occur both pre- and post-harvest. Pre-harvest losses come from disease, weeds, nematodes and insect pest damage that reduce both the quality and quantity of crop yield. Post harvest crop losses occur during harvest, threshing, transportation and storage and are caused by physical losses, contamination and pest consumption.

The nature of pre-harvest crop losses by pests varies by geographic region. In Saharan and Sahelian countries a principal pre-harvest danger to crops is by intermittent and cyclical plagues from locusts and grasshoppers (Acrididae species). They appear periodically with great population explosions that disrupt the farming systems in the region by destroying the growing crops. The locust and grasshopper outbreaks are triggered by rains that break extended droughts. Africa suffered locust and grasshopper outbreaks of extraordinary severity during the mid 1980's. It was the first widespread outbreak in 50 years which compounded the already low crop yields from drought. The outbreak was particularly serious in the Sub-Saharan and Sahelian countries (USAID Africa Bureau, 1987).

In Sub-Saharan and Sahelian countries in 1986 about 241,000 MT of crop production were lost to grasshopper and locust damage (OTA, 1990). While the overall crop loss accounted for only 1.4 percent of total crop production, it was an amount these countries facing drought and famine could ill afford to lose. Specific crop loss on a country by country basis varied from 1 to 8 percent of total crop production (OTA, 1990). The severe drought in the region extended from the mid 1970's to 1985. The return of rains in 1985 and 1986 was a welcome sight for increasing crop production but also resulted in heavy emergence of grasshopper and locust populations (USAID Africa Bureau, 1987). The timely rains continued into 1987 causing further grasshopper infestation and expanded grasshopper populations throughout the region.

The principal feeding targets for grasshoppers are natural vegetative grasses and crops such as millet and sorghum that belong to the grass family and are the predominant staple foods of the region.

Of the 300 or so grasshopper and locust species in Northern and Western Africa, fewer than 15 are of economic importance (Cavin, 1987). According to an AID Africa Bureau Report, five major grasshopper and locust species in Sub-Saharan and Sahelian regions are of significance. They are the Senegalese grasshopper (*Oedaleus senegalensis*), the African migratory locust (*Locusta migratoria*), the desert locust (*Schistocerca gregaria*), the brown locust (*Locusta pardalina*) and the red locust (*Patanga septemfasciata*).

Grasshopper and locust control were given high priority in each country's food plan in the Saharan and Sub-Sahelian regions. Many regional and international agencies (USAID, FAO, PRIFAS, CIRAD, CIDA, GTZ etc.) combined their efforts to assist these countries to control grasshopper and locust outbreaks. Most countries have governmental organizations to support grasshopper and locust control programs. In addition, countries in the Sahel are members of regional organizations e.g, Organization to Combat Birds and Locust (OCLALAV) in West Africa, Desert Locust Control Organization (DCLO) and Red Locust Control Organization (RLCO) for Central and Southern Africa. National crop protection services, under Agricultural Ministries, are the major units responsible for locust and grasshopper control. They conduct ground spraying if the problem is beyond local farmer control.

Because grasshoppers and locusts are migratory, their control on a local or farm by farm basis often is neither practical nor effective. Aerial spraying is done by regional and donor agencies when and where extensive and remote area infestations occur. The international donor agencies contributed large amounts during the plagues of the mid 1980's. They donated insecticides, spraying equipment, training and technical assistance, vehicles, protection cloths, spare parts, aircraft and crews.

The total assistance provided by all bilateral and multilateral international donors for the four year period from 1986 through 1989 was $275 million. Some 4.6 million hectares of land were sprayed in 10 Sahelian countries in 1986 and 1987 against grasshopper. In 1988 an additional 10 million hectares were sprayed in Northern and Western Africa against locust and grasshopper. The United States, mostly through USAID assistance, provided $58.8 million, some 20 percent of total donor contribution for grasshopper and locust control. Other bilateral contributions totalled $105.7 million and multilateral contributions were $58.6 million.

Typical of the bilateral assistance by AID was the work done with the government of Chad. In 1987 USAID/Chad arranged for aerial spraying to control Senegalese grasshopper infestation. The operation started in early September and continued through late October in which 134,000 hectares of millet and sorghum were aerially sprayed with Malathion.

Subsequent to the 1987 spraying program, USAID/Chad was interested in measuring the effectiveness of the control program and to determine the conditions under which control measures would prove to be economic. The International Plant Protection Center (IPPC) at Oregon State University was awarded a contract to provide an economic evaluation of the pesticide spray program in Chad to control grasshoppers. The contract asked IPPC to approach its economic evaluation in two phases. The first phase required a preliminary post harvest assessment of economic benefits from the 1987 grasshopper control program in Chad. It involved a crop yield comparison between sprayed and non-sprayed areas at 9 paired sites. A simple cost-benefit analysis was conducted and B/C ratios were generated for each site.

The second phase directed IPPC to develop a simulation model, called Grasshopper Crop Simulation Model (GHLSIM), that would combine grasshopper population dynamics, crop production and crop loss assessment information. The model is driven by rainfall and other climatic conditions over a crop season (Coop, 1989). From it Benefit/Cost calculations are derived. The GHLSIM model provides a within year ex-post cost-benefit analysis of the dynamics of crop production and grasshopper populations.

The use of a single year posterior cost-benefit analysis as currently done with the GHLSIM simulation model, while important to an understanding of the complex physical and biological aspects of periodical grasshopper/locust infestations, is limited as a decision tool in determining if and when to spray for different conditions. Rainfall and other climatic conditions in any given year may be quite different from those found in 1987.

The subject of this study is to extend the use of the GHLSIM model across a range of weather patterns and to assess the results generated. The purpose is to analyze the sensitivity of the model to weather pattern variation with an ultimate view, subsequent to appropriate validation, towards using GHLSIM as a predictor or indicator of potentially dangerous populations and corresponding crop damage of a magnitude which would warrant spraying.

The conduct of this study involves five additional chapters. Chapter two reviews the grasshopper/locust pest problem in Sub-Saharan and Sahelian regions of Africa. Chapter three outlines the Grasshopper Crop Loss Simulation Model (GHLSIM) developed by Oregon State University. Chapter four treats the methodology used to extend the GHLSIM model to generate economic benefits across a range of historical weather conditions. Chapter five analyzes the internal functioning of GHLSIM and the influence of rainfall variation upon the crop yield and grasshopper damage results generated. Chapter six provides conclusions from the study and recommendations for use and possible modification of GHLSIM.

Chapter 2

REVIEW OF THE SITUATION

THE GRASSHOPPER/LOCUST PROBLEM IN AFRICA

Locusts and grasshoppers have caused farmers anxiety for centuries because of their erratic and potentially devastating behavior. Their plagues have occurred since biblical times. The problem becomes serious when these pests breed rapidly, concentrate heavily and undergo a biological transformation to the gregarious phase. Locust upsurges occur episodically, while grasshopper infestations often cause damage each year. The Sahelian region is vulnerable to both.

Locust And Grasshopper Species

Several locust and grasshopper species are of potential economic significance over a large area of West Africa, Sahara, North Africa and the Sahel. Locusts live as solitary individuals when their population is small. At some point when their population increases, they change from the solitary to the gregarious form and move in dense groups called swarms. Some grasshoppers form dense groups similar to locusts. The rain and availability of new vegetation create conditions conducive for the gregarious form. The life cycle of grasshoppers and locusts consists of three stages: eggs, nymphs and adults. Eggs are viable for 10-12 weeks in moist soil, but can survive several years in dry soil then hatch when rains come. The breeding ground, biotic behavior and feeding preferences of locust and grasshopper species of economic importance in Africa are presented in the following sections.

1. The ***Oedaleus senegalensis* (OSE) or Senegalese grasshopper** is found in a band across Africa north of the equator, the Middle East and Southwest Asia, where annual rainfall ranges from 250 to 1000 mm. This grasshopper generally is found in open grassy habitat and rarely in bushes and trees. It feeds predominantly on grasses and crops in the grass family like millet and sorghum, preferring young plants and plants with maturing seed heads. In the absence of these crops this grasshopper will feed on legumes, cotton and other broad-leaf plants. It prefers to lay eggs in light sandy soils.

2. The ***Locusta migratoria* or African migratory locust** has its primary breeding ground in the Niger River basin. However, it has ability to spread to most of Sub-Saharan Africa. It lives in solitary form when at low densities. Higher densities are found in the Niger River Delta in Mali, South and Southeast Parts of Lake Chad basin and Blue Nile region of Sudan. The African Migratory locust feeds on grasses and cereal crops millet, sorghum and rice and will feed on other crops and bushes and trees when its primary food is not available. Its potential for damaging crops in the area is high.

3. The ***Schistocerca gregaria* or desert locust** has the ability to swarm and move rapidly making it a potentially dangerous species over a wide geographical area. The breeding grounds occur between 14 and 20 degrees North latitude extending South to Ethiopia, the Arabian Peninsula to Pakistan and West India. Adult swarms move to Northwestern and Northern Africa, Central and Northern parts of the

Arabian Peninsula, Middle East, Iran and sometimes to East Africa. The Desert Locust feeds on a wide range of plants including grass species of millet, sorghum, maize, wheat, barley and rice and on broad leaf plants such as cotton, grapevines and fruit trees.

4. The ***Locustana pardalina* or brown locusts** breed primarily in South Africa and Southern Namibia, generally where summer rainfall ranges from 130 to 380 mm. Its migratory invasion route extends North to the Zambezi River covering Botswana, Zimbabwe, Namibia and parts of Mozambique.

5. The ***Patanga septemfasciata* or red locusts** breeding ground is primarily in East African countries, principally two major breeding areas. The Northern breeding area includes Mozambique, Zimbabwe, Malawi and parts of Zambia. The Southern breeding area includes the Western side of Lake Victoria in Uganda, Burundi and Northern Tanzania. After heavy rainfall, flooding takes place in the lowlands. After the flood waters subside Red Locust outbreaks occur. From the Southern breeding area, locusts migrate Northwest to Zaire and Angola in April-July and then South across Zambia and Botswana to South Africa in August-October. Large populations also remain in the breeding areas. The Red Locust feeds primarily on grass but will also attack cereal crops, sugar cane and bananas.

PEST DAMAGE

Grasshoppers and locusts feed predominantly on leaves and immature grain heads of cereal crops. The emerging and grain filling stages of crops are the most vulnerable and preferred stages. In the gregarious stage, locusts will eat almost all types of vegetative growth including grasses, crops, herbs, shrubs and trees.

Each insect in a gregarious group of locusts and grasshoppers can eat the equivalent of its own weight each day. A locust swarm may contain 20 to 150 million individuals per square kilometer, spread over an area ranging from a few hectares to hundreds of kilometers (OTA, 1990). A swarm of 30 to 40 million insects can consume 80,000 tons of maize a day, enough to feed 40,000 people a year (African Farmer, 1989). A fledgling swarm of adults can travel up to 1,000 kilometers in a week. Locusts can devastate vegetation over a large area if swarms are moving slowly and stay in one place for several days (where adequate vegetation permits).

The African Migratory Locust destroyed 50 % and 40% respectively of wheat and corn crops in Kenya in 1931. In Northeast Mali crop losses to grasshopper were estimated at 20% to 30% in 1985. While crop loss may be severe in specific areas, it may or may not have significant impact on crop production on a national scale.

The severity of crop damage depends on the particular crop, susceptibility of the crop, extent of foliage destroyed and amount of grain consumed. Grain crops are highly susceptible when the seed head is at the milky and dough stages where 100% grain loss may occur even with low locust and grasshopper population density.

Infestations are usually unevenly distributed in space and time. Sometimes all vegetation is wiped out, especially in breeding areas when weather conditions confine infestations to an area for an extended period of time.

PEST CONTROL TECHNIQUES

Agricultural pest problems and actions to alleviate them date to the beginning of crop cultivation itself. The earliest record of pest control involved use of sulfur as an insecticide by ancient Summarians about 2500 B.C., a practice still in use (Pedigo, 1989). In pre-biblical times both Egyptians and Chinese used insecticides formulated from oil and herbs. Pest control techniques today, perfected from centuries of experience, include physical, cultural, biological, genetic, behavioral and chemical methods.

Physical And Cultural Control: Physical and cultural controls are the traditional measures for pest control. Physical controls include manual or mechanical removal of pests, reflectors to avoid some insects, trapping of insects and mulching with straw, sawdust, wood chips, polyethylene plastic and other materials to control and protect crops from insect and weed damage.

Cultural controls include destruction of crop refuse and crop residues, crop rotations, changes in production practices and development of resistant varieties. These methods help to control some insect pests and weeds.

Cultural methods used in Africa for grasshopper and locust control include crop replanting if infestations occur at emergence and planting short season crop varieties whose growth does not coincide with locust and grasshopper infestation. Planting of cassava, a tuber crop, serves as a security crop since locusts and grasshoppers infestations have very low preference for cassava. Other physical control methods used include driving the grasshoppers and locusts into trenches and then burning, drowning or crushing them, beating and trapping of the hoppers, digging up egg pods, plowing fields, scattering straw over roosting sites then burning, lighting fires or making noise to prevent swarm settling on crops.

Biological Control: Some biological methods have been used successfully to control insects. The classic biological control technique is to introduce **natural enemies.**

Pathogens such as microbial agents that attack insects have been used for control of noxious insects. While the use of microbial agents is in its infancy, the approach is receiving increased attention (Lindquist, 1977; Andres, 1979).

Several biological methods are used to control grasshoppers and locusts in Sub-Saharan and Sahelian regions of Africa. They include using poultry in the crop fields to serve as predators of grasshoppers and locusts and their eggs, introduction of birds that eat grasshoppers and locusts, grazing cattle in locust breeding grounds to eat the vegetation upon which the eggs are laid, and introduction of pathogens.

Genetic Control: The Genetic control technique includes **male sterility**. This technique involves rearing a large number of insects then sterilizing them with gamma rays or other sterility means and flooding the sterile males in natural untreated populations. When treated males mate with females, the resulting eggs are sterile. Consequently the next generation hatch may be low. Repetition of this method is intended to lead to natural population control. It is a long term technique and is not effective when an infestation occurs and damage potential is immediate. Also because of technical complexity and non-availability for all pests it is not widely used.

Behavioral Control: The behavioral includes use of pheromones and hormones. **Pheromones** are chemicals used for communication among insects of a given species to aid in locating the opposite sex for mating or for other purpose. Pheromones are used as attractants of one sex to trap and remove them from natural populations to reduce chances of mating and ultimately reduce the population.

Natural insect **hormones** contribute to development of the different stages in the insect life cycle i.e., molting, and development of other stages of insects. Synthetic hormones interfere with the normal development of insect growth stages resulting in abnormal insects which fail to reproduce. Synthetic hormones as growth regulators are gaining importance because of their neutral impact upon the environment.

Pesticides: Pesticide use is the most common modern control technique. A number of chemical and botanical pesticides are used to control grasshoppers and locusts in the Sub-Saharan and Sahelian regions of Africa. They include arsenic baits, organohydochlorides (BHC, dieldrin, aldrin, lindane etc) and organophosphates (malathion and genitrothion).

Pesticides are especially useful when an outbreak occurs as They can be rapidly applied and can produce rapid and measurable results. Currently pesticides serve as the primary emergency action plan when severe population explosion of grasshoppers and locusts occur.

Prior to outbreaks other techniques such as cultural and biological control techniques requiring more time but safer to apply are useful.

Public concern of human health hazards have mounted, and environmental hazards are identified as insect pests have become resistant to pesticides, greater emphasis is being placed on alternatives to pesticides for controlling insect pests (Lindquist, 1977). The success of alternative pest control methods however depend upon how quick the control is, its availability to users, its effectiveness as a control measure, its cost and its environmental impact.

GRASSHOPPER CONTROL IN AFRICA

Individual farmers in Africa typically use the control method of physically driving grasshoppers into trenches and igniting, crushing or burying them. Public grasshopper control involves application of insecticides by air or ground equipment. Use of insecticides began in the 1940's with arsenic-poison bait. Wheat bran was laced with arsenic but its high cost of distribution with ground equipment and limited access to breeding sites discouraged widespread use. Ground and aerial spraying was introduced in the late 1940's and early 1950's using BHL (benzene hexachloride) and dieldrin. These are stomach poisons which persist for 30 to 40 days. Aldrin and lindane (organochlorine) pesticides were used in the 1960s.

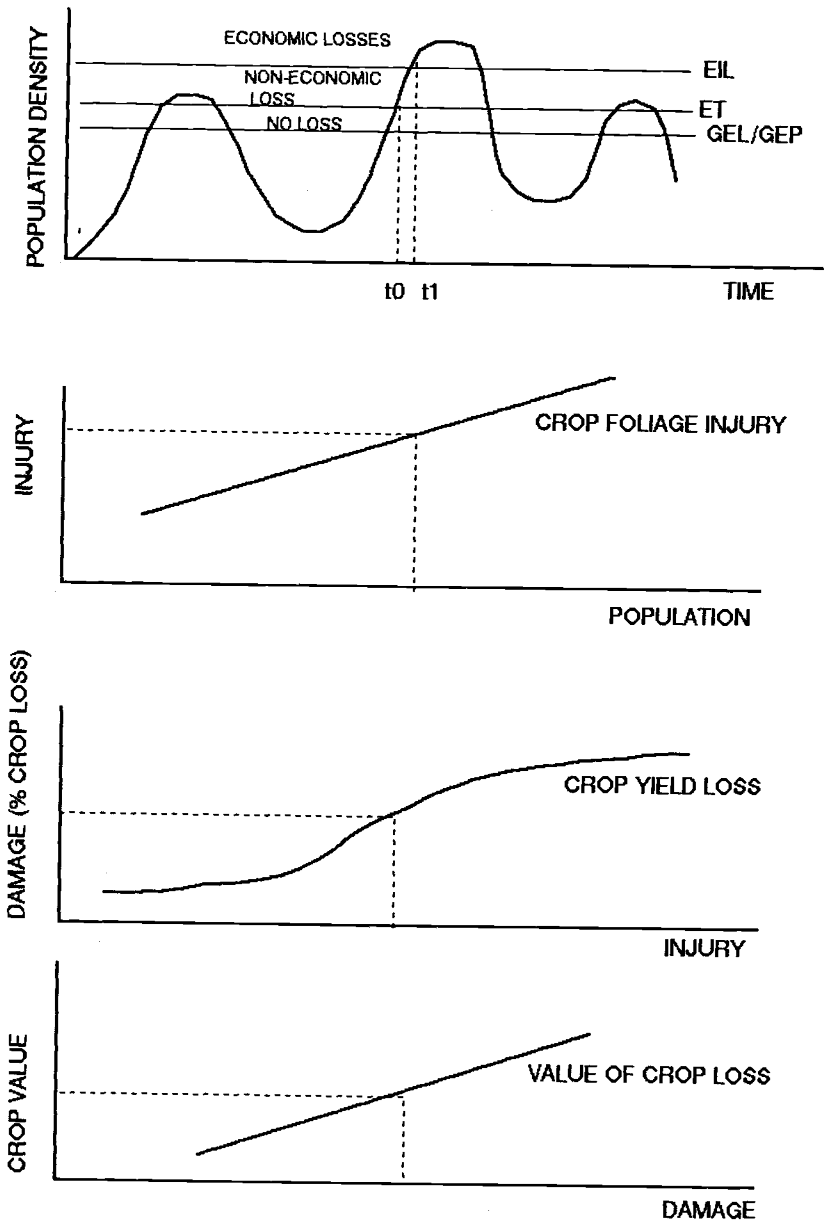
In the U.S. EPA cancelled the use of DDT in 1972 and use of dieldrin in 1974 because of their bioaccumulation in the environment where they are hazards to wild life and other fauna. Many European countries also banned their use. Pesticide use increased in third world countries throughout the 1970s and into the 1980s with few restrictions in their use. Since 1975, use of chlorinated hydrocarbons (dieldrin, lindane, BHC) on USAID overseas projects was banned and Environmental Impact Statements (EIS) were required on all USAID projects in 1978. The World Bank in 1985, with the help of US assistance, implemented a voluntary Code of Conduct for distribution and use of pesticides in third world countries. FAO continues to use dieldrin on projects because of its high level of effectiveness and low cost. Some European bilateral donors still permit use of dieldrin, lindane and BHC on their projects.

USAID has replaced organochlorines with organophosphates. The most commonly used pesticides in Africa during the recent outbreaks were malathion and fenitrothion which are contact pesticides with short residual life. Malathion has been the major pesticide component of USAID sponsored projects for grasshopper and locust control in Africa.

ECONOMICS OF PEST CONTROL

Pesticides initially were used with high dosage rates at periodic intervals to serve as insurance against outbreaks. This practice brought about adverse biological and ecological impacts and magnified control costs, sometimes with little evidence of benefit. This concern gave rise to the development of a framework by entomologists to gauge when to spray. A graphic presentation of the framework is shown in Fig 2.1 In it three concepts are presented. One is called the general equilibrium level/population (GEL/GEP). The second is called the economic injury level (EIL). A third is called the economic threshold (ET).

Fig 2.1. Economic injury levels and pest damage



The GEP as shown in Fig 2.1, is the pest density on a time scale around which the pest population fluctuates up and down in a natural state without controlling it. The EIL is the pest density on a time scale for which the value of the crop protected or saved becomes equal to or greater than the cost of control (Stern, 1966; Pedigo,1986). The EIL concept is illustrated in Fig 2.1 where the pest population reaches a level where "economic" damage begins and pest control is considered. Below the EIL level the cost of control exceeds the value of the crop being saved. The EIL is a dynamic or time sensitive concept, one in which economic injury can become more severe if control tactics are not implemented before the EIL is reached. The concept of an action threshold provides a warning of the future threat of pest population damage on the basis of some current status of pest population. The commonly used term for such an early warning mechanism for action threshold is the Economic Threshold (ET) where an action time is used for implementing control measures to reduce the risk of population levels reaching the EIL. In Fig 2.1 t_0 represents the time at which the population reaches ET. Between t0 and t1 is the time lapse when control may be initiated to prevent pests reaching the EIL. ET provides security against economic damage occurring. It varies according to risk behavior attitudes and other variables that affect the economic injury level. These variables include cost of control, value of the crop saved, crop condition, crop stages, crop variety, climatic conditions and the pest stages (Hoyt, 1979). If prices of inputs and outputs are estimated, EIL can be calculated with some degree of accuracy. By equating the cost of control to the damage, physical quantity of loss can be found. The damage can be converted to crop injury caused by pests and finally from this crop injury a certain population (pest density) can be defined that produced the damage equal to the cost of control as illustrated in Fig 2.1. Pedigo (1986) has provided the following formula for calculation of EIL.

$$EIL = C / (V * I * D)$$

where C = cost of control ($ per acre)
V = market value of produce ($ per acre)
I = injury units (percent defoliation/insect/acre)
D = damage per injury unit

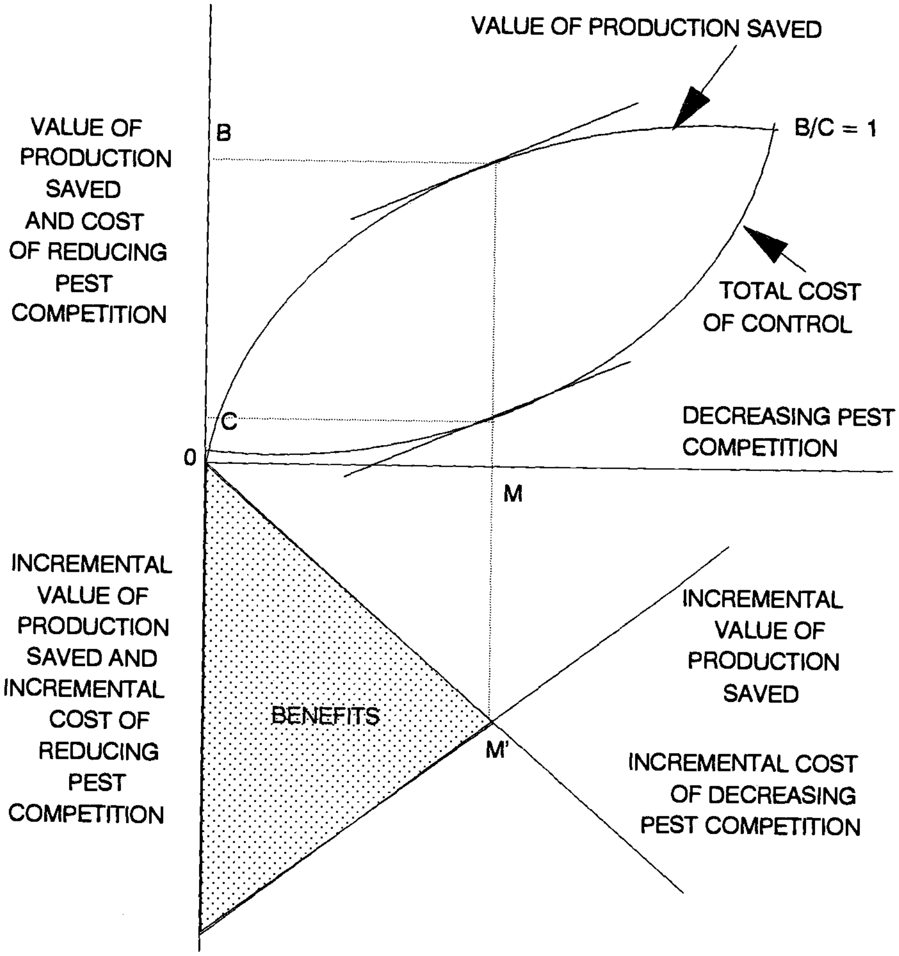
Because crop prices and control costs fluctuate, and there are many grasshopper and locust species, it is difficult to define the level of infestation that will justify control measures. However, FAO, DLCO, PREFAS and USAID have developed threshold levels and guidelines in recent years for control of grasshopper and locust in African countries (USAID Africa Bureau, 1987)

Economists have used the microeconomic theory of the firm framework to explain when to apply control tactics. Individuals are expected to apply control tactics if the expected returns are high enough to cover the cost of control tactics and the opportunity cost of capital is higher in pest control tactics than other uses of capital. Headly (1972 and 1975) explained mathematically and graphically the optimum pest control population. He introduced the concept of the value of production saved and cost of control with pest population. A graphic presentation of this concept is shown in Fig 2.2. The value of crop production saved represents the value of what would be produced in the absence of pest competition. The benefit to farmers comes from the value of damage prevented. A rational farmer wishes to maximize net returns or profit subject to a resource constraint. The producer will operate somewhere between 0 and point M in Fig 2.2 where the net benefits are maximum.

In this context a producer is not satisfied with a B/C ratio of 1 where total cost of protection is equal to total value of production saved. Rather where the difference between B and C are maximized is the point of maximum benefits. The difference will be maximized where the ratio of incremental or marginal benefits and costs are equal, at point M with unlimited capital. In this framework the economic injury level is at point M where the incremental value of production saved is equal to the incremental cost of preventing these losses. It maximizes the difference between benefits and costs, thus at point M pest population is controlled optimally in an economic sense (Headly, 1975: Thompson, 1979) under unlimited resources.

Where capital is a scarce resource, especially in the developing countries, individuals will operate between O and M depending upon their ability to afford control tactics and the opportunity cost of their resources used elsewhere. Headly (1975) has used optimizing behavior from microeconomic theory to help fine tune pest management behavior. The model assumes a static, perfect knowledge of biological and physiological aspects of pests and pest control tactics scenario. While it is a static concept which cannot be incorporated directly into the EIL framework, it does provide an important economic contribution by incorporating an opportunity cost criteria and marginal analysis upon which to judge if and when to apply control tactics. Further it provides a major distinction between the concept of B/C ratios (an averaged relationship) and at what level such ratios should be to justify control in an economic sense.

Fig 2.2. Economic costs and benefits of pest control



CROP LOSS MODELS

To predict populations over time, different dynamic population methods have been developed on the basis of ecology and biotic behavior. Jaquett (1972), Onsager (1983) and Krebs (1985) have provided guidelines to develop population dynamic models and economic threshold levels. The population dynamic models are based on phenological studies of pests and plants to predict the population over time and calculate losses caused by pests.

Mann et al (1986) developed a simulation model for population dynamics to assess alternative grasshopper control techniques. With this model next year's initial population level is estimated from this year's known population. The inputs required for the model are this year's initial population, hatch rate and daily survival rate of total hatched population.

Torell and Huddleston (1987) developed a pest population dynamics model using differential equations that predicts population levels over time. On the basis of this model Torrel et al (1987) developed a computer model to evaluate the economics of rangeland grasshopper control.

IMPACT OF CONTROL EFFORTS

To measure the economic gains from heavy investments in grasshopper outbreaks, USAID was interested in the effectiveness of controls used in the African countries during the recent grasshopper and locust outbreaks of the mid 1980's. As a pilot effort USAID chose to include, as part of its control activities in the country of Chad, the implementation of an economic measurement scheme as a component of its overall locust control activities.

Chapter 3

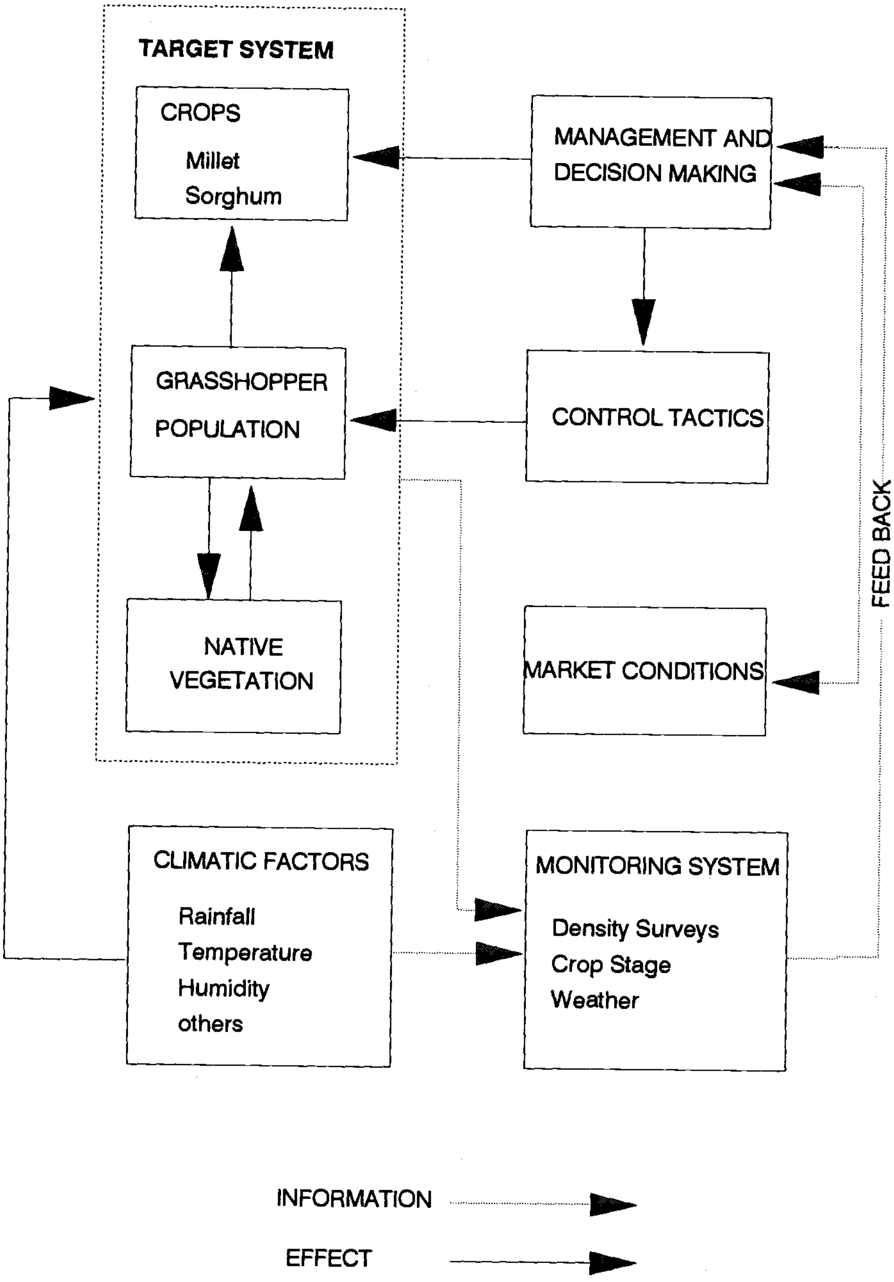
GRASSHOPPER CROP LOSS SIMULATION MODEL

The control of migratory pests like grasshoppers is complicated and involves a number of interactions. A generalized grasshopper control strategy or model is shown in Fig 3.1. The Grasshopper Crop Loss Simulation Model (GHLSIM) was developed using this generalized control framework. The target system is comprised of grasshoppers, crop and native vegetation and their interactions. Although grasshoppers attack native vegetation and crops, they prefer native vegetation to crops. The native vegetation, crop and grasshopper development are influenced by weather conditions. If there is sufficient rainfall, the native vegetation will be green and grasshoppers will feed there first so crop destruction may not be severe. In low rainfall years, however, native vegetation may be dry during grasshopper invasions so damage to crops may be increase in the absence of preferred feed.

The monitoring system provides the grasshopper sample densities (EIL, ET), crop growth and weather condition status required for decisions to apply control treatments.

The grasshopper control tactic chosen is determined by expected costs and benefits that depend on grasshoppers and crops and their dynamic status and market conditions (input and output prices).

Fig 3.1. Grasshopper damage and strategy for their control, a conceptual framework



The Grasshopper Crop Loss Simulation Model (GHLSIM) and affiliated computer software was developed in 1989 at Oregon State University (Coop, 1989). GHLSIM was designed to estimate millet and sorghum yield reduction from Senegalese grasshopper (OSE) damage in Chad. This chapter is devoted to a description of the GHLSIM model.

GHLSIM COMPONENTS

The main components of GHLSIM are shown in Fig 3.2. These components are System Inputs, Crop and Grasshopper Dynamics, Crop Loss Estimation, Economic Analysis and System Outputs.

System Inputs: System inputs include the OSE biomodel output files and the database. The OSE model (French OSE model) provides population dynamics for the Senegalese grasshopper. The database inputs include initial grasshopper sample densities before spraying, weather data (precipitation, temperature and potential evapotransporation (PET)), crop yields and varietal crop growth and yield potentials and treatment tactics (control cost and effectiveness).

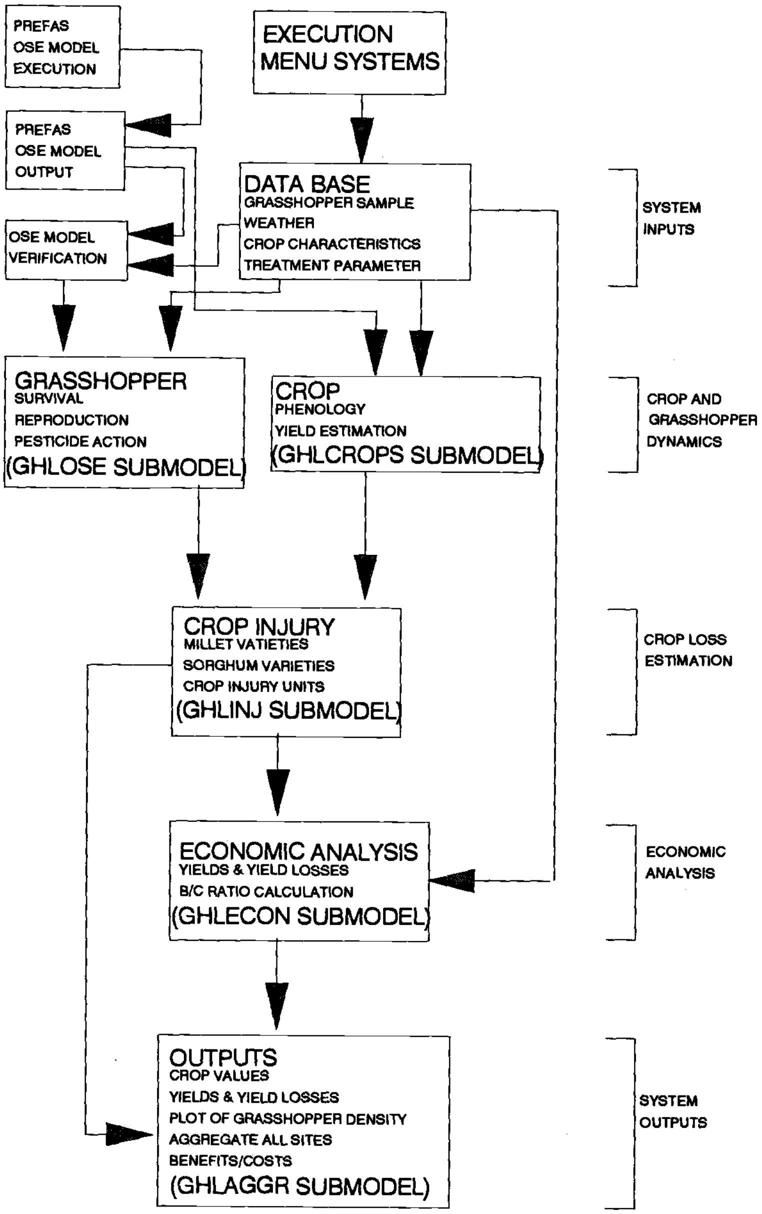
Crop and Grasshopper Dynamics: This component is comprised of two submodels GHLCROPS and GHLOSE. GHLCROPS calculates planting dates and crop yields for 3 varieties of millet and 3 varieties of sorghum from site and weather data. A vegetation greenness factor is calculated and used in the crop loss calculation. GHLOSE calculates daily grasshopper densities for both treated and untreated conditions.

Crop Loss: Crop loss is simulated in the crop injury submodel GHLINJ. GHLINJ calculates injury equivalent values for each crop variety in treated and untreated areas. Injury equivalent values are calculated as a function of grasshopper stages, their densities, their consumption rates, crop preference and crop stage susceptibility factors.

Economics: Economic analysis is conducted by the GHLECON submodel for both the current and next year. Current yield losses are calculated for both with and without treatment from GHLINJ outputs. Treatment benefit is calculated as the crop price times the difference between untreated and treated yield results. Second year benefits are calculated by breakeven analysis using first year final egg densities. GHLECON also calculates the B/C ratio for each treatment tactic. Control costs consist of materials, application and technical assistance costs and are obtained from the field. Benefits are calculated in the model by valuing the amount of crop saved as a result of control techniques applied relative to the maximum yield potential for the given weather conditions without the influence of grasshopper damage.

Systems Output: This final component of the simulation submodel GHLAGGR, aggregates and presents final results. The information on percent crop loss, B/C ratios and total costs and benefits of control action are presented.

Fig 3.2. Components of Grasshopper Crop Loss Simulation Model (GHLSIM)



Source: GHLSIM, Technical Reference (Coop, 1989)

GHLSIM SUBMODELS

Elaboration and clarification of each of the five submodels used in the simulation are presented here.

1. GHLCROPS Submodel

The GHLCROPS submodel calculates planting dates and crop yields from bio-physical characteristics of the crop for three varieties of millet and three varieties of sorghum for each of the sites. Crop growth and yield are functions of precipitation, temperature, potential evapotranspiration (PET), soil type and the crop variety potential.

Yields: Crop modelling for yields and growth uses a model developed for FAO by Doorenbos et al (FAO, 1986) that uses 10 crop growth day periods (dekads) dependent upon weather. The model has been tested and worked well in estimating yields under rainfed conditions in a number of African countries (Frere Popov,1979).

Water available to a crop is a function of precipitation, accessible soil water and soil type. The soil type was assumed to be "sandy loam" (Kramer, 1983), as site specific soil type data were not available. The model produces a WRSI (Water Requirement Satisfaction Index) that measures the cumulative water balance of the crop in successive stages. A negative water balance during any stage is assumed to stress the crop and cause irreversible yield reduction.

The maximum potential yield for a crop variety at a site is a parameter obtained from a regression of observed yields to final WRSI at that site or as an average of the three best crop yield years during the previous ten years (FAO, 1986a). The GHLSIM model assumes a 1000 kg/ha maximum yield for each of the 3 varieties of millet and sorghum (80, 90 and 120 day varieties) without grasshopper infestation. It is based on a regression of Famine Early Warning System (FEWS) reported yields. This maximum potential yield is assumed to be the same for all sites in Chad. The maximum potential yield at a site is adjusted downward using final WRSI from cumulative precipitation and available soil water. The WRSI adjustment coefficients are as follows.

if final WRSI < 50
    then % of max. yield = 20*(WRSI/100)
if final WRSI >= 50
    then % of max. yield = 182.9*(WRSI/100)-85.14

Determining Planting Dates: The GHLCROPS submodel triggers crop planting in the first dekad (a ten day period) in which 15 mm of rainfall occurs. This signals the beginning of the rainy season in which a crop can be grown. If the following dekad has less than 10 mm of rainfall then re-seeding is required as the first planting will not survive. If more than 10 of rainfalls mm no re-seeding is necessary. Crop growth for the 80, 90, 100, 120 and 130 day millet and sorghum varieties follow the schedule shown in Table 3.1. The growth schedule for these varieties does not change even if planted late as the Sahelian zone is near the equator and day length does not change during the season (ICRISAT, 1987).

Table 3.1. Millet and Sorghum phenology

Crop Stage	Millet			Sorghum		
	80	90 (days)	120	90	100 (days)	130
Seedling emergence	8	9	11	9	10	12
Seedling ends	18	21	27	21	23	29
Grain fill begin	49	33	62	33	38	71
Grain fill ends	61	67	97	65	71	107
Harvest	79	89	119	89	99	129

Source: GHLSIM technical reference (Coop, 1989)

2. GHLOSE Submodel

The GHLOSE submodel outputs a matrix of untreated and treated daily grasshopper densities. For the population dynamics of grasshoppers (OSE) GHLOSE receives output from the OSE biomodel version 2, which was developed by PRIFAS for grasshopper control. The output of the OSE biomodel is in the form of success indices that indicate the development rate for eggs, nymphs and adults. These are determined by weather conditions (mainly precipitation) as the crop season proceeds. The success indices are represented on a scale 0 to 5 with 0 indicating no development and 5 indicating high development. The success indices are converted to survival rates of grasshopper stages. Predictability of the OSE biomodel is unknown.

Survival Rates: The survival rates for each stage of the grasshopper, are used to estimate daily survival rates of grasshoppers following the Onsagar and Hewitt (1982) approach:

$$S_{1d} = S1^{(1/D1)}$$

where
S_{1d} = % survival rate per day.
S_1 = % survival rate per stage
D_1 = Duration of the stage in days.

The survival rate is used for calculation of grasshopper dynamic populations.

Grasshopper Reproduction: Grasshopper reproduction (density of offspring) is a function of success indices of mature adults, population density, the fecundity rate, success index of immigrant and ovipositing females.

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

where,
E_{sf} = the density of eggs
N_{sf} = the density of ovipositing females
f = average fecundity, 60 eggs/female
IRO = the current 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

The reproduction rates are used to calculate grasshopper population dynamic.

Effect of Treatment Tactics: After treatment daily survival rates of grasshopper depend on the maximum efficacy of treatment and the residual half-life of the tactics. The function of grasshopper survival rates is defined as:

$$S_t = 1 - \max * \exp^{(-.6931 * t/HL)}$$

where
S_t = the daily survival rate
max = the maximum efficacy of the treatment tactics
t = time in days since treatment
HL = the half-life interval of tactics (days).

These survival rates are used to calculate crop loss after treatment in treated areas.

3. GHLINJ Submodel

Crop injury is simulated in the GHLINJ submodel. It uses output from GHLCROPS and GHLOSE submodels. The accumulated crop injury units for each crop variety are calculated as follows:

$$IUS_{day} = (D_s * R_s * Cal_{s\ IV} * P_{c\ cs} * V * SUS_{cs} * PHAR_c)$$

where
IUSday = the accumulated crop injury units for the day
s = 3,4,...8; the grasshopper stages, 3=3rd instar nymph, 8=ovipositing adult.
c = crop (sorghum or millet)
cs = crop stage
D_s = current density of grasshopper
R_s = the consumption rate of the grasshopper in stage s
$Cal_{s,IV}$ = consumption calibration factor for the grasshopper stage(s) and the current index for development
$P_{c,cs}$ = crop preference factor for the crop and crop stage.
V = the current greenness factor of natural vegetation
SUS_{cs} = susceptibility of the crop stage to defoliation.
$PHAR_c$ = proportion of the crop remaining to be harvested.

Consumption Rates: OSE grasshopper consumption rates are derived from the relationship between OSE wet and dry weight at each growth stage (Van Hook, 1971; Gander, 1982).

$$Dwt = P1 * Wwt^{P2}$$

where
Dwt=dry weight
Wwt=wet weight
P1= 0.059
P2= 1.272

The consumption rate per stage is estimated by using a conversion factor of 0.35 between the dry weight of grasshopper and the dry weight of foliage consumed and listed in Table 3.2.

Table 3.2: Foliage consumption rates by stage of grasshoppers

Stage	Wet weight of OSE (mg)	Dry weight of OSE (Dwt=P1*Wwt^{P2})	Foliage consumed (C=cfac*Dwt)
Nymph3	53	9.207	3.2
Nymph4	100	20.646	7.2
Nymph5	240	62.875	22.0
Adultsoft6	180	43.607	15.3
Adultpreov7	119	25.760	9.01
Adltpostov8	100	20.646	7.2

Source: GHLSIM technical reference (Coop, 1989)

The consumption rates per stage are divided by the number of days in a stage to convert into daily consumption rates for use in GHLSIM.

The OSE biomodel produces success indices for each stage to determine development rates of grasshoppers. The higher the indices, the higher is the development rate.

Feeding Preferences: OSE tends to prefer native vegetation over millet and millet over sorghum. In the beginning of the growing season, crop seedlings may emerge earlier than native vegetation. If this happens, crop seedlings may be damaged by grasshopper defoliation. If this occurs, re-seeding may be required. When late crop seeding occurs, native vegetation greens rapidly and grasshoppers, preferring the native vegetation, will delay moving to millet and sorghum. For grasshoppers, early crop stages are less preferred than late crop stages of grain filling and maturing. The table below shows the grasshopper preference factor by crop, variety, and stage used in the simulation.

Table 3.3: Crop preference factor of grasshoppers

Crop stage	Crop preference factor Millet	 Sorghum
Emergence	0.2	0.05
Seedling	0.4	0.1
Tillering	0.3	0.075
Grainfilling	0.75	0.375
Mature/harvest	0.7	0.35

Source: Adopted after Coop (1989)

The greenness factor is directly correlated to rainfall accumulation. The greater the greenness factor of native vegetation the less vulnerable is the crop.

Crop Susceptibility Factor: Another factor influencing crop injury is the susceptibility of a specific crop to grasshopper damage at its different growth stages and its ability to compensate injury with crop regrowth. GHLSIM uses the following susceptibility values for crop injury, both for sorghum and millet.

Table 3.4: Crop susceptibility factor to grasshoppers

Crop stage	Susceptibility factor
Emergence	0.50
Seedling	0.25
Tillering	0.10
Grainfill	0.25
Mature	0.25
Harvest	0.15

Source: Adopted after Coop (1989)

Yield Loss Function: Accumulated injury units estimated from grasshopper consumption rates are converted to percent yield loss from the maximum potential yield for each crop and variety. GHLINJ currently assumes a linear relationship between crop injury units and percent yield loss until a maximum threshold is reached.

4. GHLECON Submodel

The costs and benefits of grasshopper control action are calculated by the GHLECON submodel. First year benefits are calculated as follows:

Treated yield= $Yt= Yp(1-Lt)$

where
Yp=maximum potential yield (no grasshopper impact)
Yt=the treated yield
Lt=the proportion crop loss in treated area after treatment (from GHLINJ).

Non-treated Yield= $Ynt=Yp(1-Lnt)$
where
Ynt= non-treated yield
Lnt= Proportion crop loss in non-treated area

The benefit of treatment in dollar value are estimated by the following equation:

$Bt= P*(Yt-Ynt)$

where
Bt=benefit in dollar
P=market price of the crop

Net Benefits= $NB= Bt-Ct$

Where
NB= net benefit
Ct= cost of treatment.

In GHLSIM the grasshopper control tactic costs are obtained exogenous to the model. The cost of each site was fed to the database of the GHLSIM as an exogenous variable to the model. Table 3.5 provides a detail of costs of control for each site of the treatment area in 1987. Cost components included in the analysis are as following:

i. Purchase of pesticide (Malathion 96% ULV) and transportation to N'Djamena, the capital of Chad

ii. In country transportation from N'Djamena to treatment operating sites

iii. Purchase of fuel and its transportation to operating sites

vi. Transportation of Malathion and fuel among sites during and after the treatment operation

v. Aerial spraying operation, airplane and associated spray equipment hiring charges on a per hour basis

vi. Technical assistance cost before and after the field operation

vii. Field inspection cost for regular evaluation of grasshopper densities throughout the crop season.

The costs were calculated for each site. The cost at each site was divided by the number of hectares treated to obtain the cost on a per hectare basis. The cost of each site was fed to the database of the GHLSIM as an exogenous variable to the model. The benefits are estimated within the model by the difference of yield gains in treated area as compared to non-treated area.

Table 3.5. Site data used for benefit/cost analysis of the grasshopper treatment campaign in Chad, in 1987

Location	Crop	Crop stage [a]	Density [b]	Treatment date	c area(ha)	Proportion of varietie 80day	90day	120da	Millet price ($/Kg)	Cost ($/Ha) Insecticide	Aerial applic	Tech. Assis.	Total	Annual rainfall	B/C ratio result
Iriba	Millet	Milky	25	Sep 10	4335	90%	8%	2%	0.31	2.72	5.13	3.33	11.29	314.4	2.7
Guereda	Millet	Milky	75	Sep 20	4550	90%	8%	2%	0.27	2.72	5.13	3.33	11.29	330.8	6.9
Biltine	Millet	Milky/do	15	Sep 24	8700	90%	8%	2%	0.27	2.82	3.9	1.21	7.93	186.9	0.8
Am Zore	Millet	Milky	25	Sep 25	3320	90%	8%	2%	0.27	2.82	3.9	1.21	7.93	158.6	2.5
Adre	Millet	Milky	18	Sep 20	9955	80%	14%	6%	0.23	2.83	4.5	1.72	9.05	144.4	1.2
Goz-Beida I	Millet	flor/Milky	30	Sep 22	1650	80%	14%	6%	0.18	2.82	2.23	1.72	6.27	337.8	1.3
Abeche	Millet	Milky	18	Sep 29	11620	90%	8%	2%	0.30	2.83	4.39	1.9	9.12	144.6	0.3
Oum-hadjar	Millet	Milky	35	Oct 1	7460	90%	8%	2%	0.25	2.82	3.55	1.29	7.65	340.7	4.5
Ati	Millet	Milky	25	Oct 3	16600	70%	20%	10%	0.25	2.81	3.67	1.33	7.81	311.3	4.2
Mongo	Millet	Dry	25	Oct 9	16185	20%	70%	10%	0.20	2.82	2.74	0.67	6.23	388.1	3.2
Bitkine	Millet	Milky	35	Oct 13	16600	20%	70%	10%	0.20	2.82	2.74	0.67	6.23	448.5	4.2
Mangalme	Millet	Dry	45	Oct 14	16600	20%	70%	10%	0.16	2.81	2.24	0.88	5.99	408.7	4.2
Goz-Beida I	Millet	Mature	30	Oct 21	10380	80%	14%	6%	0.18	2.82	2.23	1.21	6.27	337.8	0

a Milky=milky grain stage, Flor=flowering, dou=dough grain stage and Dry=dry grain stage.

b Grasshopper densities (# per meter square)sampled before treatment

c 6000 ha of non-crop area (rangeland) was also sprayed.

Some benefits are assumed to be carried over into the following year as grasshopper population would be lower the next year in treated areas than in non-treated areas. Over-wintering egg densities, from a sample survey taken at the end of the crop harvest of the first year, are used to estimate the potential crop yield loss in the second year. The GHLSIM assumes a linear relationship between egg densities and crop loss the second year. The difference between treated and non-treated egg densities is used to calculate second year benefits.

5. GHLAGGR Submodel

This routine presents the GHLSIM results in a tabular form. It writes and saves the results of all sites simulated in a separate file called REPORT.DAT. The information contained in the REPORT.DAT includes crop yields, percent yield loss by crop (sorghum and millet) and variety, total acreage treated, total benefits and costs and B/C ratios for each site. It also aggregates the results of all sites.

ASSUMPTIONS OF THE MODEL

Assumptions and parameters of the GHLSIM model are presented in Table 3.6. Rainfall in 1987 affected both grasshopper and crop growth. Grasshopper population densities were obtained from field survey samples at each site just before spraying. Spraying coincided with the milky stage of crop seed head development, the most vulnerable stage of crop growth, at most sites (see Table 3.5). The potential damage of various grasshopper densities between treated and non-treated areas is limited to damage differential between the two cases. Before treatment the same damage level is assumed to occur in either the treated or non-treated cases.

Table 3.6. GHLSIM model assumptions used in 1987

Parameter	Description
Crop stage at spray time	Milky grain, the most vulnerable stage to grasshoppers damage for all 3 sites
Maximum potential crop yield	1000 Kg/Ha for all millet varieties at all sites
OSE survival rate	Not available for Chad; North American species rate used for OSE
Weather influence	crop production and grasshopper population dynamics over crop season
Second year grasshopper effect	A residual egg density assumed for carryover into the second year based on egg density from sample survey
Grasshopper species	OSE at all sites
Grasshopper density	Varied by site. See Table 3.5
Proportion of varieties	Varied by site. See Table 3.5
Prices of millet grain ($/kg)	Varied by site. See Table 3.5
Control cost ($/Ha)	Varied by site. See Table 3.5

Source: GHLSIM Technical Reference (Coop, 1989).

Chapter 4

METHODOLOGY

GHLSIM models the within year dynamics of the complex interrelationship between grasshopper population and crop growth both of which are influenced by within year weather patterns occurring during a crop growing season. The model was run using actual weather in Chad during the 1987 calendar year for the 13 sites shown in Table 3.5. Benefit/Cost results generated for each of the 13 sites are provided in the same Table.

If rainfall patterns in Sahelian countries vary over time and by geographical location, only limited use can be made of the 1987 results in interpreting the need for grasshopper control in future years. Indeed weather patterns in that part of the world vary widely over time and by geographical location.

This study examines the performance of the GHLSIM model and its B/C ratio results over a range of possible weather scenarios. The generation of a range of results from different weather patterns may be useful to match against actual conditions (weather, crop production and grasshopper population) unfolding in any given year to provide the basis for validating GHLSIM's performance and ultimately to serve as a guide on whether or not to spray.

For purpose of this study, three sites from the original 13 sites used in 1987 were selected. They are Abeche, Mongo and Ati. A map of the project area and location of each of the three sites selected are shown in Fig 4.1. The sites were chosen as they represent a wide range in weather pattern variation when observing historical data across those sites. These sites were best felt to test the sensitivity of GHLSIM model results to weather pattern influences and extremes in such patterns.

USE OF HISTORICAL PRECIPITATION DATA (12 YEAR DATA SET)

Historical precipitation data is reported from weather stations, managed by the Chad Government, at each of the three sites selected. Annual station reporting however is sporadic. The precipitation data obtained is for the 11 year period from 1968 through 1978 and for the year 1987 for a 12 year total. The data is reported in 10 day increments (a dekad) and presented in Tables 4.1 through 4.3 for Abeche, Mongo and Ati respectively. While B/C ratio results also are reported, discussion of those results are treated in chapter 5.

In interpreting the rainfall results, the reader should be aware that those years represent a period of time of less than average rainfall for the region.

Fig 4.1. Map of Chad showing grasshopper treatment area

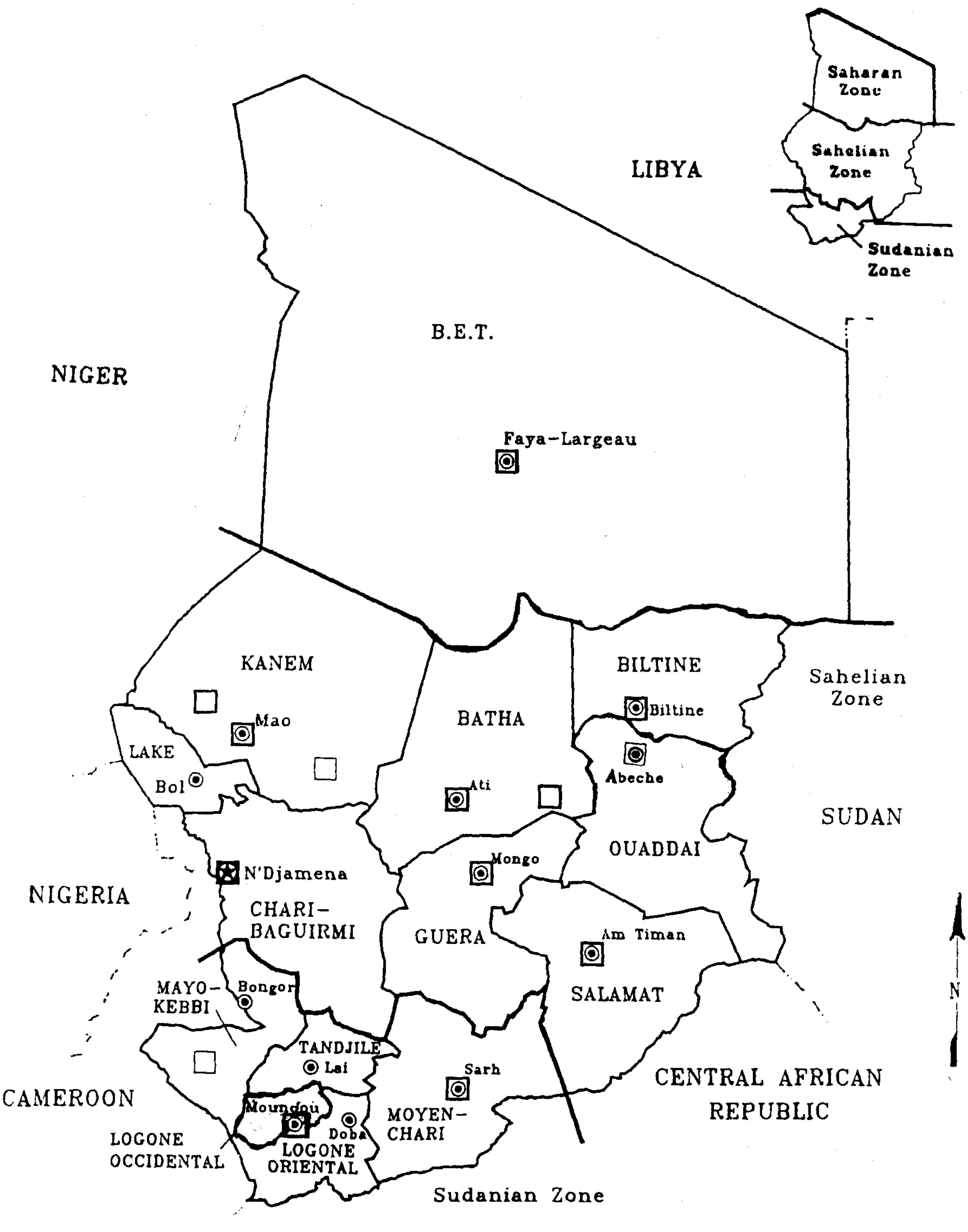


Table 4.1. Historical rainfall for Abeche site of Chad by dekad

Dekad[a]	Year													
	68	69	70	71	72	73	74	75	76	77	78	87	Mean	Sd.[b]
[c]	Rainfall mm per dekad													
13	1.8	0	0	0	0	0	0	0	0	0	0	0	0.15	0.497
14	0	9.5	0	0	28.3	0	0	0	2.6	7.9	3.2	0	4.292	7.903
15	0.6	0	0.4	0	19.7	22.4	12.9	0	0	2.6	21	3.2	6.9	8.867
16	14.4	0	0	0	9	0	8.9	2.2	9.8	5.9	6.8	4.6	5.133	4.605
17	11.8	1.9	24.3	0.4	8.8	10.5	5.1	7.6	0	0.1	21.1	0	7.633	7.911
18	29.5	58	0	3	40	8.8	0.5	0.9	9.3	39.4	15.4	0.7	17.13	18.88
19	29.2	14.1	6.2	50.2	9.7	0	35.9	26.6	4.3	0.3	63.6	1.5	20.13	20.21
20	83.9	9.7	16.3	3.6	13.3	3.5	47	19.4	17.4	32.3	73.5	13.7	27.8	25.57
21	44.6	22.1	44.6	13.8	20.3	41.5	98	44.9	16.2	2	106.8	21.3	39.68	31.16
22	2.1	19.9	56.1	61.3	14.1	44.7	17.5	69.8	102.8	128.4	15.1	7.9	44.98	38.46
23	41.8	59.3	23.8	121.5	59.5	25.1	65.1	64.5	20.6	58.9	10.7	62.1	51.08	28.46
24	27.9	62.5	61.5	27.9	34.2	1.2	122.8	99.1	16.5	46.6	83.3	23.8	50.61	34.8
25	9.8	51.2	18	33.6	5.8	25.2	8.5	50.7	4.2	59.7	14.9	NA[d]	23.47	19.74
26	1.6	33.2	56	23.8	15.6	2	19.7	34.4	2.7	15.8	41.3	5.8	20.99	16.67
27	16.7	9.1	0	3.6	9.4	0	11.4	0	24.8	6.8	0	NA	6.817	7.619
28	0	3.1	0	0	0.4	0.3	0	0	6.6	6.6	5.7	NA	1.892	2.685
29	0	6.2	0	0	0.6	1.9	0	0	2.8	0	0	NA	0.958	1.808
30	0	0	0	0	0	0	0	0	0	0	0	NA	0	0
Total	315.7	359.8	307.2	342.7	288.7	187.1	453.3	420.1	240.6	413.3	482.4	144.6	329.6	99.9
B/C ratio	1.4	0.9	1.6	2.1	0.8	0.2	2.3	3.1	3.1	1.6	1.3	0.2	1.55	0.931

Source: Unpublished data from Abeche weather station of Chad.

a: Dekad = a 10 day period/interval beginning from January 1.

b: Sd=standard deviation

c: Dekad 13 = May 1-10; dekads 1 through 12 and 30 through 36 have 0 rainfall

d: NA=not available

Table 4.2 Historical rainfall for Mongo site of Chad by dekad

Dekad [a]	Year												Mean	Sd [b]
	68	69	70	71	72	73	74	75	76	77	78	87		
[c]	[d]	Rainfall mm per dekad												
13	NA	0	0.6	0	0.4	20.5	35.7	0	1	0.9	4.1	0	5.745	11.08
14	NA	11.9	2	0	9.6	5.8	0.3	20	17.7	0	3.1	2.7	6.645	6.848
15	NA	54.8	18.6	7.1	50.8	3.3	7.9	7.9	20.8	33.4	1.4	26.1	21.1	17.71
16	NA	2.2	4	4.6	19.9	0.8	4.4	10	84.9	29	61.7	114.1	30.51	37.17
17	NA	26.9	28.8	3.7	3	10.3	4.6	2.5	38.2	22.3	37.8	9.7	17.07	13.42
18	NA	98.8	4.7	41.7	40	19.2	30.4	16.7	11.1	33.7	56.1	11.3	33.06	25.59
19	NA	49.4	27.1	38.5	64	10.6	75	98.2	51.5	63.1	38.7	1.5	47.05	26.82
20	NA	56.7	32.5	4.6	9.3	62.7	57.5	40.7	67.1	122	41.1	12.9	46.1	31.82
21	NA	48	120.2	59.6	76.3	84.3	110.7	170.5	45.4	67.8	108.7	49.9	85.58	36.87
22	NA	59.5	117.5	87.9	66.1	133.8	53.2	78.1	64.3	77.3	46.1	24.3	73.46	29.75
23	NA	22.1	223.8	153.3	144.8	85.5	89.7	62.5	40.8	119.5	56.8	47.7	95.14	57.36
24	NA	66.3	144.4	61.2	79.2	12.1	115.7	83	46.3	78.1	41	71.7	72.64	34
25	NA	158.8	53.3	46.7	20.9	30.5	37.1	116.3	47.3	67	7.2	16.2	54.66	43.36
26	NA	77.8	25.9	36.2	20.2	20.3	40.1	56.5	31.8	8.7	10	0	29.77	21.51
27	NA	64.4	15.3	7	20.8	32.5	59.2	6.5	85.2	24.3	23	0	30.75	26.02
28	NA	0	0	0.3	12.5	17	4	9.5	11.7	19.6	21	0	8.691	7.879
29	NA	7.4	0	0	9	0.3	0.6	0	36.5	0.2	11.9	0	5.991	10.51
30	NA	0.8	4.7	0.5	0	8.7	0.4	0	10.6	0	0	0	2.336	3.707
Total		805.8	823.4	552.9	646.8	558.2	726.5	778.9	712.2	766.9	569.7	388.1	666.3	129.4
B/C ratio		4.1	2.3	3.2	3.1	2	2.3	1.6	0.9	0	0	3.2	2.064	1.279

Source: Unpublished data from Abeche weather station of Chad.

a: Dekad = a 10 day period/interval beginning from January 1.

b: Sd=standard deviation

c: Dekad 13 = May 1-10; dekads 1 through 12 and 30 through 36 have 0 rainfall

d: No rainfall data for 1968

Table 4.3. Historical rainfall for Ati site of Chad by dekad

	Year												
Dekad[a]	68	69	70	71	72	73	74	75	76	77	78[b]	87	Mean	Sd[c]
[d]	Rainfall mm per dekad													
13	0	0	0	0	0	0	0	0	0.6	0		0	0.055	0.172
14	0.4	3.4	28.7	2.3	0.1	0	0	0	0	0		0.1	3.182	8.143
15	0	0.6	0	0	5	0	0	0.5	0	0		1.5	0.691	1.434
16	61.5	0	0	0	0	1.5	6.2	0	1.1	32.4		15.1	10.71	18.68
17	18.4	13	2.2	0	11.3	0	0	13.4	1.9	5.6		4.2	6.364	6.229
18	24.2	115.2	0	8.9	10.4	0.8	0	0	13.6	3.6		0	16.06	32.2
19	6	30	20.3	26.4	8.6	0	40.4	88.7	25.6	2.8		4.9	23.06	24.22
20	75	19	7.5	46.5	11.7	1.9	20	29.5	29.6	29.7		14.7	25.92	19.54
21	3.5	6.5	77.1	18.9	17	23.5	46.6	60.4	52.6	26.3		40.8	33.93	22.32
22	3.7	11	79.4	36.9	33.5	54	81.7	49.5	94.2	150.2		23.7	56.16	40.74
23	36.2	83	13.3	23.7	46.4	66.8	36.8	28.7	1.3	55.3		96.7	44.38	27.76
24	11.2	29.5	138.7	88.5	5	0	80.1	32.9	1.4	96.9		25.1	46.3	44.75
25	19.9	24.6	18	19	18.8	7.7	38.6	46	18.3	34.7		24.4	24.55	10.5
26	0	6.1	26.5	6	4.9	7	12.8	1	2.7	28.8		36.9	12.06	12.1
27	6.9	17.5	0	1	0	0	2.6	3.4	24.1	1.6		1.2	5.3	7.681
28	0	0	0	1.6	17.9	0	5.4	0.1	11.3	1.8		22	5.464	7.62
29	0	0	0	0	1.8	0	0	0	3.8	0		0	0.509	1.161
30	0	0	0	0	0	0	0	0	0	0		0	0	0
Total rain	266.9	359.4	411.7	279.7	192.4	163.2	371.2	354.1	282.1	469.7		311.3	314.7	86.69
B/C ratio	1.7	1.7	0.4	1.4	1.1	0.7	0	0	0	1.4		4.2	1.145	1.159

Source: Unpublished data from Abeche weather station of Chad.

a: Dekad = a 10 day period/interval beginning from January 1.

b: No rainfall data for 1978

c: Sd=standard deviation

d: Dekad 13 = May 1-10; dekads 1 through 12 and 30 through 36 have 0 rainfall

LONG TERM WEATHER PATTERNS: A SIMULATION

Rainfall patterns represented by the 12 years reported for the Abeche, Mongo and Ati sites may or may not represent the full range of weather pattern dispersion and mean values under long term or expected conditions. A comparison of long term expected mean values reported by FAO and shown in Table 4.4 indicates that the 12 year data base averages are on to the low side of average annual precipitation due to drought conditions prevailing during the 1970's. To account for this difference, long term rainfall patterns were derived by stochastic simulation.

The Monte Carlo simulation technique for generation of meteorological data (VanTassel, 1990) was used to simulate 100 years of annual rainfall patterns for Abeche, Mongo and Ati. The procedure used and the data source are explained below.

FAO (1984) collects and reports climatic data for selected African countries as long-term monthly and annual averages. Such data are available for the 3 sites in Chad used in this study and reported in Table 4.4. The data cover a 30-40 year period beginning after WWII. Precipitation, temperature (minimum, maximum, day and night), barometric pressure, wind speed, sunshine, radiation and evapotransporation data are reported. Additionally, FAO reports for Abeche and Mongo provide their cumulative rainfall probability distributions that are shown in Table 4.5. They are expressed as monthly rainfall levels for cumulative occurrence probabilities in 10% increments. The zero cumulative probability represents the minimum rainfall and 1.0 probability represents the maximum rainfall in any dekad.

Table 4.4. Weather data for Ati, Abeche and Mongo sites of Chad

Site: Ati	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
PRECIPITATION (mm)	0	0	0	0	17	32	118	190	64	4	0	0	425
TEMP. AVERAGE (C)	24	26.6	30.5	33.3	33.6	32.5	30.5	28.1	29.5	30.1	27.2	25	29.2
TEMP. MEAN MAX. (C)	33.7	36.7	40	41.8	41	39.1	36.1	33	35.5	38.2	36.5	35.1	37.2
TEMP. MEAN MIN (C)	14.1	16.5	20.8	24.8	26.2	26	24.7	23.2	23.5	32	18	15	21.2
TEMP. MEAN DAY (C)	27.5	30.3	33.9	36.4	36.3	34.9	32.4	29.8	31.6	33	30.5	28.6	32.1
TEMP. MEAN NIGHT (C)	20.7	23.3	27.2	30.4	31	30.2	28.3	26.2	27.2	26.8	23.5	21	26.3
VAPOUR PRESSURE	8.7	9	10.5	13.1	17.5	21	24	25.1	24.6	18.5	11.5	9.1	16.1
WIND SPEED (m/sec)	1.5	1.6	1.6	1.6	1.6	1.7	1.7	1.5	1.5	1.5	1.5	1.5	1.6
SUNSHINE %	89	89	79	80	77	67	60	52	71	85	89	91	77
TOTAL RADIATION (cal)	472	519	528	555	545	500	471	438	5.2	521	487	464	500
EVAPOTRANS. (mm)	140	152	197	211	2.8	187	166	142	154	181	151	139	2028
Site: Abeche													
PRECIPITATION (mm)	0	0	0	2	18	32	120	211	62	9	0	0	454
TEMP. AVERAGE (C)	25.3	27.7	31	32.5	32.2	31.6	28.5	26.1	27.2	29.2	28.1	26	28.8
TEMP. MEAN MAX. (C)	36	37.1	40	41.5	40.5	38.8	34.5	31.3	34.1	37.2	37.1	35.3	37
TEMP. MEAN MIN (C)	16	18	22	23.8	24.7	24.5	22.8	21.1	20.6	20.5	19.7	16.6	20.9
TEMP. MEAN DAY (C)	29.6	31	34.3	35.9	35.4	34.2	30.7	28	29.7	31.8	31.5	29.2	31.8
TEMP. MEAN NIGHT (C)	22.7	24.4	28	29.6	29.8	29.1	26.4	24.2	24.7	25.5	24.9	22.1	26
VAPOUR PRESSURE	7.6	7.3	8.5	10.5	16.5	19.8	24.2	26.1	24.5	16	10.1	8.7	15
WIND SPEED (m/sec)	2.6	2.8	2.8	2.4	2.4	2.1	1.9	1.7	1.5	2.1	2.4	2.4	2.3
SUNSHINE %	89	89	79	80	77	67	60	52	71	85	89	91	77
TOTAL RADIATION (cal)	467	516	526	556	547	5.2	473	439	501	518	482	458	498
EVAPOTRANS. (mm)	190	204	257	243	236	198	156	129	145	198	190	178	2324
Site: Mongo													
PRECIPITATION (mm)	0	0	2	12	43	73	185	304	133	26	0	0	778
TEMP. AVERAGE (C)	26.6	28.5	32.1	33.6	32.5	30.5	28	25.8	26.8	28.7	28.8	27.6	29.1
TEMP. MEAN MAX. (C)	35	37.3	39.8	40.6	39.3	36.5	33.5	31	33	36.8	36.8	36	36.3
TEMP. MEAN MIN (C)	17.8	20.5	24.7	26.8	26.2	24.5	23	21.7	21.8	21.7	20.1	18.3	22.3
TEMP. MEAN DAY (C)	29.5	32	35	36.2	35.1	32.7	30.1	28	29.4	31.9	31.4	30.3	31.8
TEMP. MEAN NIGHT (C)	23.5	26.1	29.7	31.3	30.4	28.3	26.3	24.6	25.2	26.2	25.1	23.6	26.7
VAPOUR PRESSURE	9.8	10	12.5	15.1	19	22.3	24	24.7	24.7	20.7	12.6	9.5	17.1
WIND SPEED (m/sec)	1.2	1.7	1.1	0.9	1	0.8	0.8	0.4	0.4	0.3	0.7	1.2	0.9
SUNSHINE %	86	85	73	70	70	62	51	45	59	73	80	85	69
TOTAL RADIATION (cal)	470	511	507	514	514	476	431	408	456	481	463	453	473
EVAPOTRANS. (mm)	139	164	175	166	174	146	132	113	120	131	125	137	1722

Source: Agroclimatic data for Africa, countries North of equator, FAO of United Nations, 1984.

Table 4.5. Cumulative precipitation probabilities by month for Abeche and and Mongo sites of Chad

		CUMULATIVE PROBABILITIES										
SITE	MONTH	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
		RAINFALL MM PER MONTH										
ABECHE												
	JAN	0	0	0	0	0	0	0	0	0	0	0
	FEB	0	0	0	0	0	0	0	0	0	0	0
	MAR	0	0	0	0	0	0	0	0	0	0	0
	APR	0	0	0	0	0	0	0	0	0	0	0
	MAY	0	0	0	0	6	10	15	21	31	47	74
	JUN	3	7	12	16	21	26	32	39	48	64	74
	JUL	24	41	59	75	90	106	124	146	173	217	273
	AUG	48	106	134	156	177	198	221	247	280	330	453
	SEP	0	14	25	34	43	53	63	76	94	121	170
	OCT	0	0	0	0	0	0	4	9	16	29	64
	NOV	0	0	0	0	0	0	0	0	0	0	0
	DEC	0	0	0	0	0	0	0	0	0	0	0
MONGO												
	JAN	0	0	0	0	0	0	0	0	0	0	0
	FEB	0	0	0	0	0	0	0	0	0	0	0
	MAR	0	0	0	0	0	0	0	0	0	0	14
	APR	0	0	0	3	6	8	11	15	20	29	50
	MAY	0	9	15	21	28	35	43	53	67	89	129
	JUN	3	17	29	39	49	61	74	90	111	146	190
	JUL	3	115	135	151	165	179	194	211	232	263	317
	AUG	79	159	197	228	258	288	320	356	402	472	620
	SEP	144	56	75	91	106	122	140	160	185	226	301
	OCT	39	5	9	12	16	20	26	32	40	54	60
	NOV	1	0	0	0	0	0	0	0	0	0	4
	DEC	0	0	0	0	0	0	0	0	0	0	0

Source: Agroclimatic data for Africa, volume 1, countries north of equator, FAO of United Nations, Rome, 1984

To use the monthly FAO precipitation data in the GHLSIM model, conversion of the data into the ten day dekad units was required. The monthly rainfall was divided by three to represent the middle dekad of each month. Then a linear interpolation was used between the mid-point values calculated for each dekad as shown in appendix Table 1. If the estimated precipitation for 3 dekads within a month was higher or low than the monthly average reported by FAO, individual dekads within a month were adjusted such that total average to monthly rainfall as reported was achieved. The transformed data expressed in dekads are shown in Tables 4.6 and 4.7 for Abeche and Mongo respectively.

FAO did not report a cumulative rainfall probability distribution for the Ati site. A cumulative rainfall distribution was derived directly from the 12 year rainfall data shown in Table 4.1 using a procedure reported by Law and Kent (1982). The historical among year observations (Xi) for each dekad were arranged in ascending order and each observation, using a uniform distribution, given an equal probability of occurrence. The probability of each of these observations was calculated by (i-1)/(n-1) where i is the number of observations starting from the lowest value and n is the total number of observations. The resulting cumulative distribution generated and reported by dekads is shown in Table 4.8.

Table 4.6. Cumulative precipitation probabilities by dekad for Abeche site

	CUMULATIVE PRECIPITATION PROBABILITIES										
Dekad	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	RAINFALL MM PER DEKAD										
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	1.3	2.4	3.8	5.3	8.1	11.6	23.2
14	0	0	0	0	1.8	3.2	5	7	10.7	14.9	25.4
15	0	0	0	0	2.9	4.6	6.5	8.5	12.2	20	25.4
16	0.4	1.5	2.4	3.3	4.8	6.3	7.7	10.8	12.3	15.3	16
17	0.7	1.7	3.2	4.3	5.7	7	8.9	12.2	13.5	15.3	18.6
18	1.9	3.9	6.4	8.4	10.5	12.7	15.3	16	22.3	29.4	43.3
19	6.3	10.2	15.2	20	23.9	28.5	33.7	39.8	47.2	60.3	94
20	8	12.9	18.9	24.4	29.5	35	41.3	43.5	48.7	58.2	82.7
21	10	17.9	24.9	31	36.7	42.5	49.4	57.1	67.1	83.2	96.3
22	16	34.2	39.5	43.4	57.8	66.9	72.6	81.4	92.5	109.5	136
23	18.2	40.2	50.4	64.5	65.8	81.5	90.6	96.2	102.3	119.7	151
24	13.7	31.6	40.2	52	53.4	35	67	75	85.3	100.7	165
25	0	8.4	13.6	17.7	21.5	26.1	30.3	35.5	43.7	53.5	90.1
26	0	3.1	6.5	9.6	12.3	15.4	18.6	22.7	28	37.3	43.3
27	0	2.5	4.9	7	9.2	11.6	13.7	17.8	22.2	30.2	36.6
28	0	0	0	0	0	0	2.9	6	8.9	14.7	28.6
29	0	0	0	0	0	0	0.6	1.7	4	8.2	20.2
30	0	0	0	0	0	0	0.5	1.3	3	6.2	15.2
31	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0

Source: Agroclimatic data for Africa, volume 1, countries north of equator
FAO of United Nations, Rome, 1984

Table 4.7. Cumulative precipitation probabilities by dekad for Mongo site

	CUMULATIVE PRECIPITATION PROBABILITIES										
Dekad	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	RAINFALL MM PER DEKAD										
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	1	1.9	3.8	5.5	7.5	11.1	11.7	14.6	18.5	24.7	36.8
14	1	3.2	5	7	9.3	13.6	14.3	17.7	22.4	29.7	43.5
15	1	3.9	6.2	8.5	11.1	10.4	16.9	20.8	26.1	34.5	48.6
16	1	3.5	6.8	9.6	12.6	16.2	20.1	25.1	31.5	42.5	56.9
17	1	3.9	7.6	10.8	14	17	22.4	27.8	35	47	61.9
18	1	9.6	14.6	18.6	22.4	26.8	31.5	37.2	44.5	56.5	71
19	20	31.4	37.2	41.8	45.5	50	54.7	59.8	66.3	75.6	89.9
20	27	39.9	46.2	51.3	55.6	59.8	64.7	69.7	76.3	85.1	101.3
21	31.8	43.7	51.6	57.9	63.5	70	75.2	81.7	89.3	101.9	125.7
22	48.2	53.5	65.6	75.5	85	94.5	104.5	115.8	129.6	151.2	198.1
23	53.8	57.3	67.5	82.5	93.3	104.3	115.9	128.9	146.1	170	225.4
24	41.5	48.1	60.2	70.1	79.6	89.3	99.6	111.2	126.4	147.7	196.5
25	17.4	25.3	33.1	39.4	45.8	52.3	59.4	67.3	77.3	93.2	124.3
26	12.2	17.3	23.5	28.9	33.7	38.9	44.9	51.5	59.7	73.5	98.2
27	9.4	13.4	18.3	22.7	26.5	30.8	35.8	41.2	48	59.4	78.5
28	2.8	3.3	5.5	7.2	9.3	11.2	14.1	19.8	24.1	26.5	32.4
29	0.2	1	2	2.7	3.8	4.9	6.7	9.8	12.6	14.7	16.4
30	0.1	0.7	1.6	2	2.9	3.9	5.2	2.4	3.2	11	11.2
31	0	0	0	0	0	0	0	0	0	0	2.6
32	0	0	0	0	0	0	0	0	0	0	0.8
33	0	0	0	0	0	0	0	0	0	0	0.6
34	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0

Source: Agroclimatic data for Africa, volume 1, countries north of equator
FAO of United Nations, Rome, 1984

Table 4.8. Cumulative precipitation probabilities by dekad for Ati site

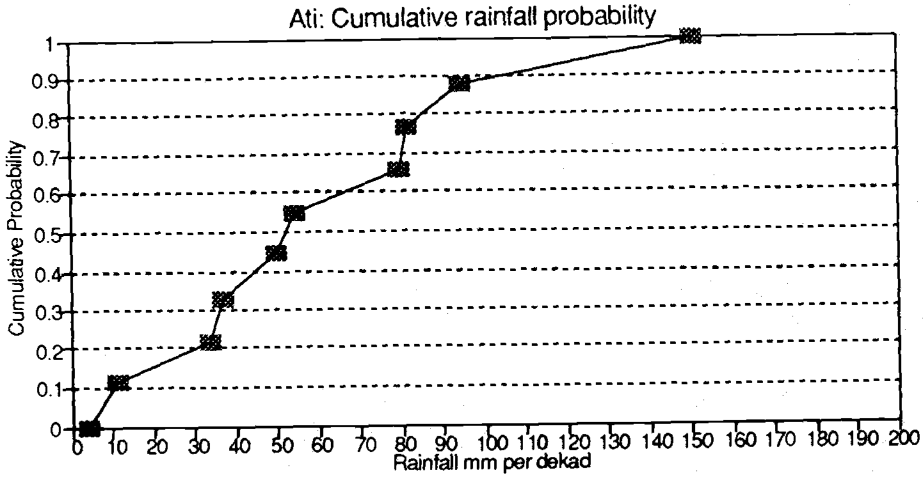
	CUMULATIVE PROBABILITIES									
Dekad	0	0.11	0.22	0.33	0.44	0.55	0.66	0.77	0.88	1
	RAINFALL MM PER DEKAD									
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	2.8
11	0	0	0	0	0	0	0	0.4	0.9	8.9
12	0	0	0	0	0	0	0	0	0	1.1
13	0	0	0	0	0	0	0	0	0	0.6
14	0	0	0	0	0	0.1	0.4	2.3	3.4	28.7
15	0	0	0	0	0	0	0	0.5	0.6	5
16	0	0	0	0	0	1.1	1.5	6.2	32.4	61.5
17	0	0	0	1.9	2.2	5.6	11.3	13	13.4	18.4
18	0	0	0	0.8	3.6	8.9	10.4	13.6	24.2	115.2
19	0	2.8	6	8.6	20.3	22.6	26.4	30	40.4	88.7
20	1.9	7.5	11.7	19	20	29.5	29.6	29.7	46.5	75
21	3.5	6.5	17	18.9	23.5	26.3	46.6	52.6	60.4	77.1
22	3.7	11	33.5	36.9	49.5	54	79.4	81.7	94.2	150.2
23	1.3	13.3	23.7	28.7	36.2	36.8	46.4	55.3	66.8	83
24	0	1.4	5	11.2	29.5	32.9	80.1	88.5	96.9	138.7
25	7.7	18	18.3	18.8	19	19.9	24.6	34.7	38.6	46
26	0	1	2.7	4.9	6	6.1	7	12.8	26.5	28.8
27	0	0	0	1	1.6	2.6	3.4	6.9	17.5	24.1
28	0	0	0	0	0.1	1.6	1.8	5.4	11.3	17.9
29	0	0	0	0	0	0	0	0	1.8	3.8
30	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0

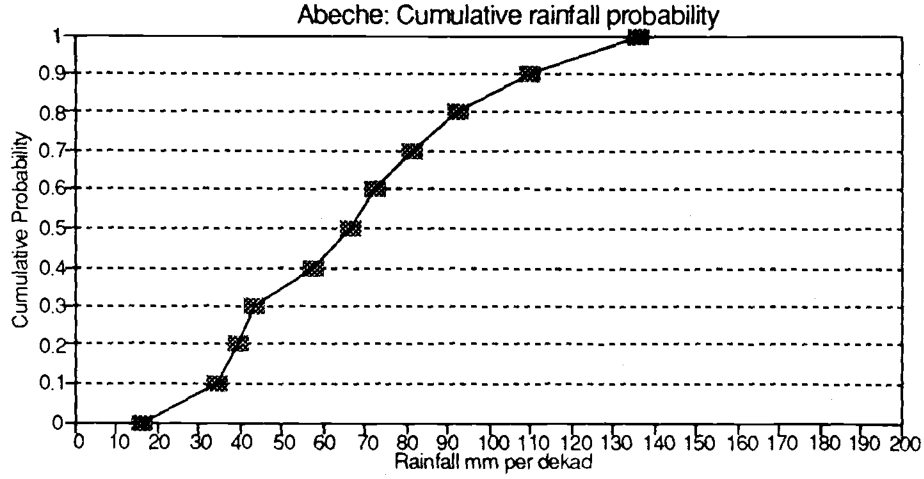
Source: Unpublished data from Abeche weather site of Chad

The next step is to apply the cumulative rainfall probabilities shown on Tables 4.6, 4.7 and 4.8 for Abeche, Mongo and Ati to generate 100 years of rainfall patterns. The procedure used is as follows. For each dekad within a crop season, a random value between 0 and 1 (representing the range of probability outcomes) was selected. That value represents the cumulative probability of a rainfall occurrence in a particular dekad. An example of the random value for dekad #22 at each of the 3 sites is shown on the cumulative rainfall probability charts in Fig 4.2. For each random value selected there is an associated rainfall level measured in millimeters per dekad which is read off the horizontal rainfall axis. For example, at Abeche site the random selection of a cumulative probability of .37 results in a rainfall level of 52 mm for dekad 22. The procedure was repeated for all dekads of a crop season at each site. The process in turn was repeated 100 times to generate 100 years of seasonal rainfall patterns for each site. The procedure assumes rainfall pattern independence among dekads, an untested assumption.

Rainfall pattern results from the 100 year simulation for Ati, Abeche and Mongo sites expressed as millimeter of rainfall by dekad are presented in appendix Tables 2, 3 and 4. The results are compared against the FAO rainfall averages reported in Table 4.4. A comparison of within year results is shown in Table 4.9 and across year results in Table 4.10. A cursory comparison for Abeche and Mongo shows long-term mean values from FAO and those generated by the simulation to be very similar. A statistical t-ratios test was run for significance. The t-ratios shown in Table 4.9 indicate that both the within year (across dekads) and between year simulated means are comparable to the FAO reported historical means for Abeche and Mongo at 99% significance level.

Fig 4.2. **Illustrative cumulative rainfall probability distribution of dekad #22 for Ati, Abeche and Mongo sites**





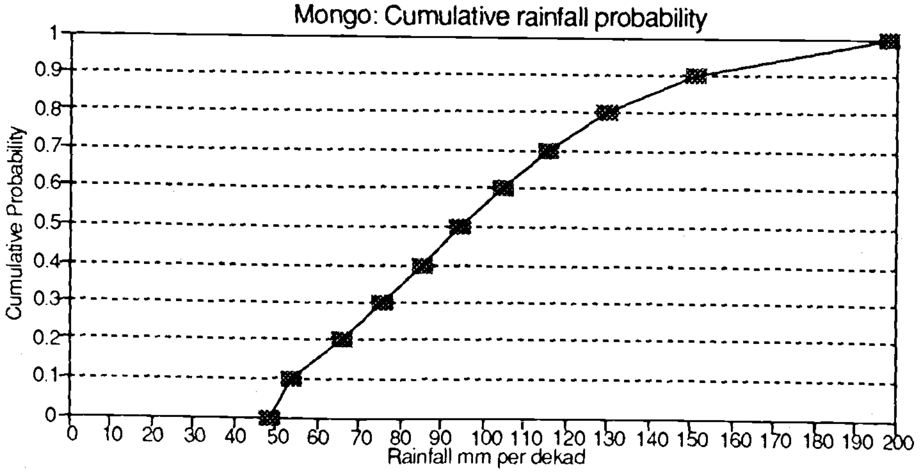


Table 4.9. Comparison of actual and simulated rainfall means by dekad

		Historical	Simulated		
Site	Dekad#[a]	Mean	Mean	Sd.	t-ratio[b]
Ati	13	0.1	0.03	0.11	0.2182
	14	3.5	2.69	6.36	0.3681
	15	0.6	0.22	0.54	0.2944
	16	10.3	10.55	17.4	0.5473
	17	6.6	5.66	6.12	0.8173
	18	17.7	15.25	25.77	0.5232
	19	24.6	18.61	16.4	0.9849
	20	27.0	27.47	17.6	1.4072
	21	33.2	33.02	21.47	1.3831
	22	59.4	61.41	32.4	1.712
	23	39.2	39.21	20.89	1.6896
	24	48.4	41.5	42.12	0.8703
	25	24.6	24.35	10.01	2.1872
	26	9.6	11.89	9.8	1.1155
	27	5.7	5.26	7.1	0.6604
	28	3.8	3.34	5	0.5918
	29	0.6	0.57	1.03	0.499
	30	0.0	0	0	
	Annual	314.7 [c]	301.03	78	1.7526
Abeche	13	5.1	4.2	5.2	-1.661
	14	6.2	5.9	6.5	-0.434
	15	7.3	7.6	7.7	0.4132
	16	7.3	7.3	4.8	-0.095
	17	8.3	8.2	5.4	-0.152
	18	15.5	14.1	10	-1.364
	19	34.5	31.4	19.3	-1.587
	20	36.6	36.9	17.4	0.1463
	21	46.9	44.9	21	-0.961
	22	68.2	65	28.9	-1.095
	23	80.0	77.5	30.4	-0.834
	24	65.4	62.7	30.1	-0.882
	25	30.9	30.2	19.8	-0.376
	26	17.9	18.6	11.5	0.6166
	27	14.2	14.6	10.4	0.4283
	28	5.6	4.9	6.8	-0.963
	29	3.2	2.3	4.6	-1.858
	30	2.4	1.9	3.6	-1.338
	Annual	455.3	438.2	63.84	2.1923
Mongo	13	11.8	10.8	8.0	-1.212
	14	14.3	13.0	8.5	-1.498
	15	16.8	15.4	11.1	-1.239
	16	19.9	17.4	13.1	-1.889
	17	22.2	20.1	14.7	-1.414
	18	30.8	32.6	17.9	1.0163
	19	52.2	53.6	15.4	0.8942
	20	61.7	60.0	17.1	-0.993
	21	71.4	68.5	19.5	-1.489
	22	99.2	96.1	32.8	-0.935
	23	110.1	110.7	41.9	0.1434
	24	94.6	95.6	38.6	0.2696
	25	56.3	58.1	24.6	0.7198
	26	42.6	45.3	18.5	1.4613
	27	34.1	32.8	18.6	-0.689
	28	13.8	13.6	7.7	-0.196
	29	6.8	6.5	5.2	-0.67
	30	5.3	4.3	4.1	-2.359
	Annual	763.9	754.6	86.8	1.1923

a: Dekad=a 10 day peeriod beginning from 1st. Jan.
b: t-value for 99% confidence level = 2.62
c: 11 year mean value for year 1968 through 1977 plus 1987

Table 4.10. **Comparison of means and variations in rainfall using 1987, 12 year historical and 100 years simulated weather conditions**

Item	Sites Ati	 Abeche (mm)	 Mongo
1987 weather			
Mean rainfall (across dekads)	311.3	144.6	388.1
Minimum rainfall (across dekad)	0	0	0
Maximum rainfall (across dekads)	150.2	62.1	114.1
Std. Dev. (across dekads)	-	-	-
Using 12 year historical weather			
Mean rainfall (across dekads)	314.7	329.6	666.3
Minimum rainfall (across dekad)	0	0	3.7
Maximum rainfall (across dekads)	56.2	51.1	57.4
Std. Dev. (across dekads)	86.7	99.9	129.4
Using 100 year simulated weather			
Mean rainfall (across years)	281.3	416.5	774.6
Minimum rainfall (across year)	144.8	291.3	528.1
Maximum rainfall (across years)	551	578	989
Std. Dev. (across years)	78	63.8	86.8
Using FAO 30-40 year data			
Mean (across years)	425	454	778

The same results held for the Ati site where only 11 years of historical rainfall data (1968 to 1978) were available for use in the simulation. Here the simulated rainfall is comparable at the 99 % level to the 11 year historical pattern. Note however from Table 10 that the 11 year pattern, occurring during a major drought period, is considerably lower than the reported FAO long term mean. Thus the simulated weather should be taken as representative of the 11 year period for Ati, not a long-term weather representation and carries a downside rainfall bias.

The simulated rainfall patterns thus represent long term rainfall for Abeche and Mongo and a decade of weather at Ati under less than normal average rainfall.

Chapter 5

RESULTS AND DISCUSSION

Each of the 100 simulated annual rainfall patterns were fed as input to GHLSIM and corresponding results generated including final benefit cost ratios for each of the three sites (at Ati, Abeche and Mongo) in Chad selected for analysis. The assumptions employed in each of the 100 weather pattern runs are listed as follows:

Assumptions the same as used for 1987:

- Milky grain crop stage at spray time
- Millet crop only
- Maximum potential crop yield of 1000 kg /ha for all millet varieties at all sites
- OSE grasshopper species only
- OSE survival rate from North American species
- Fixed grasshopper densities at spray time:
    - Ati : 25/m2
    - Abeche: : 18/m2
    - Mongo: : 25/m2
- Millet price:
    - Ati : $ .25/kg
    - Abeche : $ .30/kg
    - Mongo : $ .20/kg
- Control cost:
    - Ati : $ 7.81/ha
    - Abeche : $ 9.12/ha
    - Mongo : $ 6.23/ha
- Millet variety planting proportion between 80, 90 and 120 day maturing varieties by site:
    - Ati 90:8:2
    - Abeche 80:14:6
    - Mongo 20:70:10

Additional assumption used:

- No second year grasshopper effect from treatment

The results from the simulated rainfall pattern are reported in appendix Tables 2 through 4 for Ati, Abeche and Mongo respectively. Table 5.1 summarizes both the within season and between season rainfall variability obtained from the 100 years of simulated weather for the Ati, Abeche and Mongo sites. A brief review of the Table shows major within year and between year rainfall differences in the 3 sites. Ati is a marginal site in terms of average rainfall for crop production with extreme within year and between year variation as noted by low average annual and high standard deviations. On average only a 110 day growing season occurs with less than 300 mm annual rainfall. For Abeche average rainfall is higher (416.5 mm) with a 150 day growing season and relatively low variability. Mongo rainfall is even greater (774.6 mm average) with a 180 day growing season and low within year and between year variability.

THE EFFECT OF RAINFALL VARIATIONS UPON BENEFITS

The means and variations of benefit cost ratios summarized from the 100 simulated rainfall patterns are reported in Table 5.2 for the 3 sites. For Ati the mean value was a B/C ratio of 1.84, a range of 0 to 9 and a standard deviation of 2.03. For Abeche the mean B/C ratio was 1.9, a range of 0 to 4.4 and a standard deviation of 0.85. For Mongo the mean B/C ratio was 2.87, a range of 0 to 6.1 and a standard deviation of 1.29.

Table 5.1. Mean and standard deviation values of 100 years simulated rainfalls for Ati, Abeche and Mongo sites

	Ati		Abeche		Mongo	
Dekad	Mean (mm)	Sd.	Mean (mm)	Sd.	Mean (mm)	Sd.
13					12.1	9.1
14					13.9	10.6
15					17	11.6
16			7.34	4.69	19.3	14.5
17			8.1	5.1	23.5	16.2
18	15.25	25.65	13.71	9.28	33	17
19	18.61	16.32	31.56	19.33	52.4	16.3
20	27.47	17.51	38.07	19.06	63.3	17.8
21	33.02	21.36	46.36	21.82	72.3	20.1
22	61.41	32.23	65.83	27.17	102	38.3
23	39.21	20.78	74.37	28.7	118.2	41.8
24	41.5	41.91	58.24	27.69	93.2	39.8
25	24.35	9.96	30.3	19.34	53.8	23.4
26	11.89	9.75	17.92	10.94	44.1	21.5
27	5.26	7.07	14.62	10.33	33.7	18.5
28	3.34	4.97	5.88	7.68	12.3	7.9
29			2.27	4.55	6.3	5.5
30			1.97	3.74	4.2	4.1
Annual	281.3	78	416.5	63.84	774.6	86.8
B/C ratio	1.84	2.03	1.9	0.85	2.87	1.29

Dekad: A 10 day period starting from 1st. January.
Sd. : Standard deviation

Table 5.2. Comparison of B/C ratio results using 1987, historical and simulated weather conditions

Item	Sites		
	Ati	Abeche	Mongo
Using 1987 Weather			
B/C ratio	4.2	0.3	3.2
Std. Dev. (across years)	-	-	-
Using 12 year historical weather			
Mean B/C ratio	1.06	1.56	2.06
Minimim B/C ratio	0	0.2	0
Maximum B/C ratio	3.2	3.1	4.1
Std. Dev. (across years)	0.93	0.92	1.28
Using 100 years simulated weather			
Mean B/C ratio	1.84	1.9	2.87
Minimim B/C ratio	0	0	0
Maximum B/C ratio	9	4.4	6.1
Std. Dev. (across years)	2.03	0.85	1.29

Table 5.3. Statistical comparison of B/C ratios obtained from 1987, historical and simulated rainfall patterns

Pair of B/C means	Ati	Sites Abeche	Mongo
		t-Ratio	
Historical and 1987	14.45	5.61	2.66
Simulated and 1987	7.88	21	2.56
Historical and simulated	1.58	0.35	0.37

t-value for .99 significance level >= 2.62

A comparison was made between the 1987 B/C ratio results and those from the simulation. A visual comparison in table 5.2 already suggests major differences. A t-ratio significance test was conducted and results shown in Table 5.3. Table 5.3 also expresses major differences. The statistical comparison of B/C ratios indicate a significant difference between historical and 1987 B/C ratios and between simulated and 1987 ratios at 99 percent confidence level for all 3 sites. The 1987 year mean is different from the mean of the historical observations. The 12 year mean thus is better representative of long term conditions than those of a single year. Table 5.2 comparison of 12 year weather results with the 100 year results show lower B/C ratios, smaller ranges and generally lower standard deviations as expected reflecting again a decade of weather under less than normal average rainfall.

The t-statistic values in Table 5.3 shows there is no significant difference between simulated and historical B/C ratio means at 99 percent significance level for all three sites. Treating grasshopper density levels as a parameter in the runs contributed to this result. Rainfall is programmed in GHLSIM as an important factor causing variability in benefits (B/C ratios). Rainfall variability may be of two types: between year and within year variability. In a regression of annual rainfall on B/C ratios it was found that between year variability was not significant. This is not consistent with rainfall variability results shown in Table 5.1 or observed reality where grasshopper densities have been severe enough in only a few of the last 50 years to warrant use of control measures. Again this is due largely because the present study to this point has held the grasshopper densities constant across years. In reality grasshopper population densities are known to vary under different weather conditions. This could result in greater variability in B/C ratio results. Sensitivity of results to variation in population densities is treated and discussed in a later section of this chapter.

SCRUTINY OF WITHIN YEAR BENEFITS VARIATION

To understand the role of within year weather variation and its influence upon underlying biological and physical interrelations throughout a season, low and high B/C ratio cases are selected and reviewed for each of the 3 sites and detailed within year causal relationships examined. For this purpose B/C ratios from the 100 simulated observations were arranged in an ascending order with their respective simulated rainfall patterns, then divided into three B/C ratio range groups (presented in appendix Table 5). One case from the low end of the B/C range and one case from the high end of the B/C range were selected for intensive review of the conditions modeled by GHLSIM that produced the differences in B/C ratio results. Thus, 6 cases are analyzed intensively.

For each of the selected low and high benefit cases at each site the rainfall patterns, vegetative index, crop production calendar and yield, grasshopper load (grasshopper density of each stage multiplied by consumption rate of the stage), grasshopper injury units with and without treatment and grasshopper loss function were graphed for comparison.

A Low Benefits Case, Ati

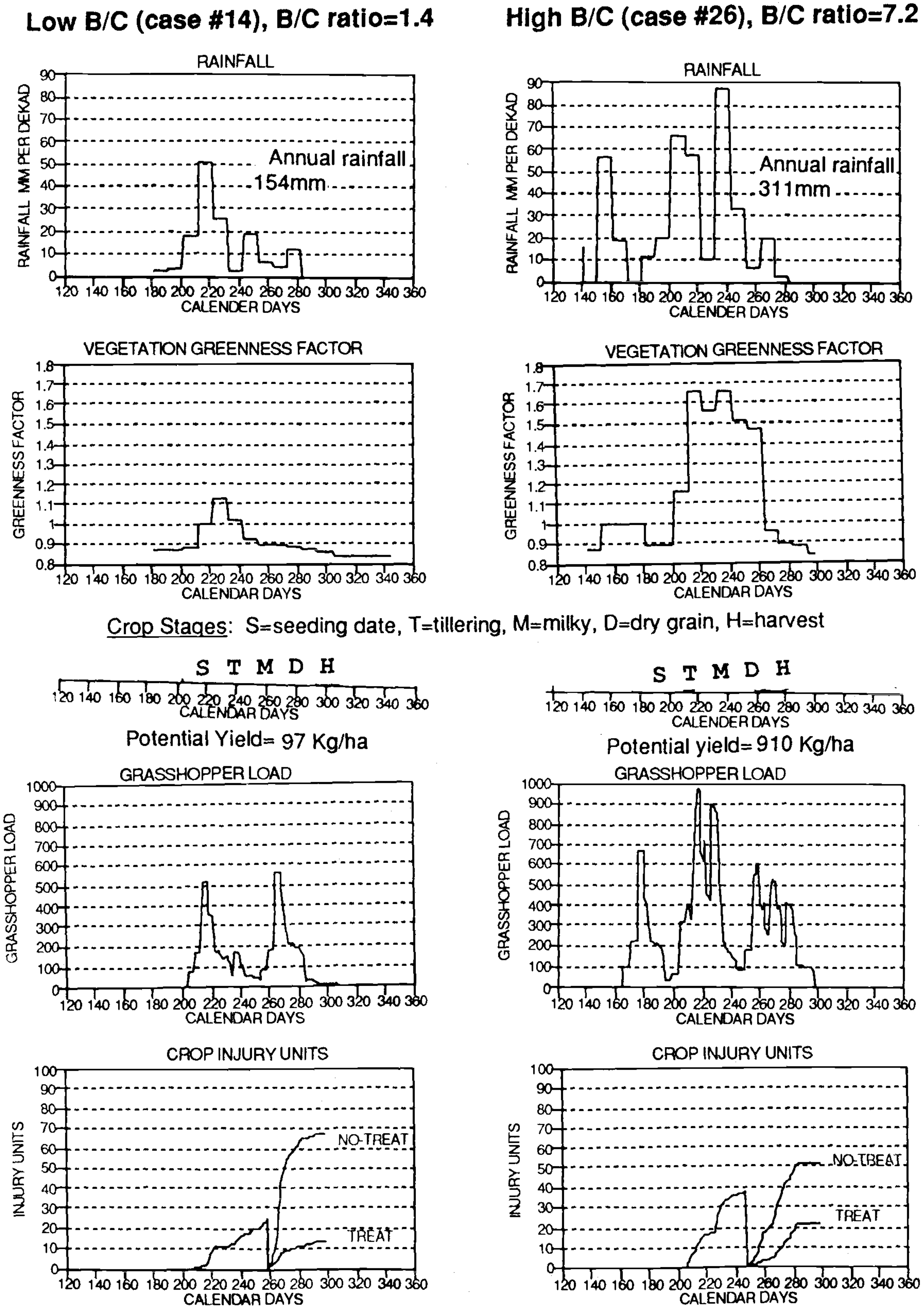
The low B/C producing case for Ati is shown in Fig 5.1 with the left hand column of the graph. Case # 14 from the simulation with a

B/C ratio of 1.4 was selected. This case received total seasonal rainfall of 154.2 mm. Crop planting was delayed until adequate rainfall for seeding occurred at day 210 resulting in a short 80 day crop season. Rainfall variability across the season was high and marginal for crop growth during much of the season. The natural vegetation greenness factor was important for only 40 days during the crop season. The implication is that natural vegetation is limited thereby providing little defensive protection from grasshoppers during the crop season, especially during the vulnerable milky dough stage of crop production. This being an extremely short season and low rainfall, the maximum potential yield attainable across the 3 varieties is 97 Kg/Ha.

Grasshopper population density expressed as grasshopper load, starts about day 200 coinciding with crop planting triggered by rainfall and continues through day 300. Two grasshopper hatches emerge as shown by the twin patterns. The grasshopper load is highest shortly after crop seeding and again from day 60 to 70 coinciding with the especially vulnerable crop milky grain stage for the predominant 80 day variety where treatment is introduced.

The crop loss by grasshoppers is expressed as crop injury units and dictated by grasshopper load, natural vegetation greenness, crop preference, crop stage and grasshopper consumption rates by stage as discussed in Chapter 3. Cumulative crop injury units beginning after treatment till harvest are translated into percent crop loss by a crop loss function shown in Fig 5.2. Before treatment the crop loss is assumed to be the same both for treated and non-treated areas.

Fig 5.1. Graphical analysis of low and high benefits cases from simulated rainfall patterns for Ati site



Low B/C (case #14), B/C ratio=1.4

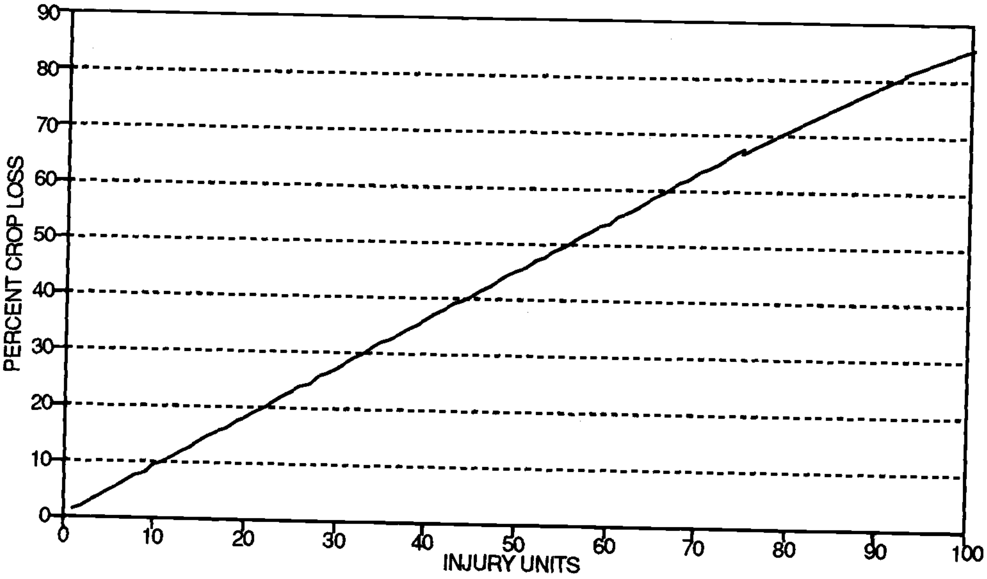
High B/C (case #26), B/C ratio=7.2

Crop Stages: S=seeding date, T=tillering, M=milky, D=dry grain, H=harvest

Potential Yield= 97 Kg/ha

Potential yield= 910 Kg/ha

Fig 5.2. Crop loss function: relationship between crop injury units and percent crop loss



In Fig 5.1 the crop injury units graph at the bottom of the page requires additional explanation. Prior to treatment on day 260, a single line pattern from day 210 to day 260 shows crop injury units accumulation. At treatment day 260, which coincides with the milky dough stage of crop development, the graph measures injury unit differentials between treated and non-treated cases. Because a comparative analysis is made the graph uses the zero value origin on the vertical axis of the graph in comparing injury units between treated and non-treated cases. In this case no treatment results in 67 crop injury units compared with 13 for the treated case, a difference of 54 crop injury units. The crop injury units are transformed into percent crop loss through the crop loss function. The no treatment case translates to a 60% crop loss while the treatment case shows about 12% crop loss. The maximum potential yield has been reduced from 97 to 86 kg/ha due to crop loss in the treatment case. In the no treatment case a 57 Kg/Ha crop loss occurs with a net crop yield of 40 Kg/Ha. The resulting B/C ratio becomes (86-40)(.25)/7.81=1.4.

A High Benefits Case, Ati

The high B/C ratio case for Ati is shown in right hand column of graphs in Fig 5.1. Case # 26 from the simulation with a B/C ratio of 7.2 was selected. This case received total seasonal rainfall of 311.4 mm starting at about day 180 and continuing through about day 270 for a 90 day growing season.

The vegetation greenness factor, which is rainfall dependent, is high most of the crop period. It is expected there may be less feeding on the crop in this situation.

The crop seeding date is about day 190 with harvest about day 280, a 90 day growing season. The maximum potential crop yield is 910 Kg/Ha.

The overall longer rainy season resulted in 3 grasshopper egg hatches as shown in the grasshopper load. Each hatch has about a 35 day growth cycle. The first hatch, occurring prior to crop seeding, was irrelevant to crop damage. The vulnerable milky dough stage of the crop comes between days 225 and 255. This coincides with the period between hatch 2 and hatch 3. The treatment date is day 250.

The cumulative crop injury units with and without treatment are shown graphically as 22 and 52 injury units respectively. The yield loss without treatment is about 46 percent and with treatment yield loss is about 20 percent. The maximum potential yield has been reduced from 910 kg to 726 kg/ha due to crop loss in the treatment case. In the no treatment case the yield is reduced to 481 kg/ha. The resulting B/C ratio becomes (726-481)(.25)/7.81=7.2.

Comparison Of Low And High Benefits Cases For Ati

Comparing the low and high B/C case (Fig 5.1), the rainfall received and its influence upon potential yield appears to be the predominant variable. Annual rainfall of 300 mm appears to be about the minimum for assuring yield to approach the maximum potential of 1000 kg/Ha. Below that, as in the low B/C case, potential crop yield is affected markedly. The natural vegetation greenness factor appears not to be a particularly important variable unless, in uncommon instances, it is low and coincides with the milky dough stage of the crop making the crop especially vulnerable. The number of grasshopper cycles and the magnitude of their load appears to be directly related to length and magnitude of the rainfall pattern. Its influence upon crop yield loss is dictated by the potential crop yield and vulnerability of the crop to grasshopper damage at milky dough stage.

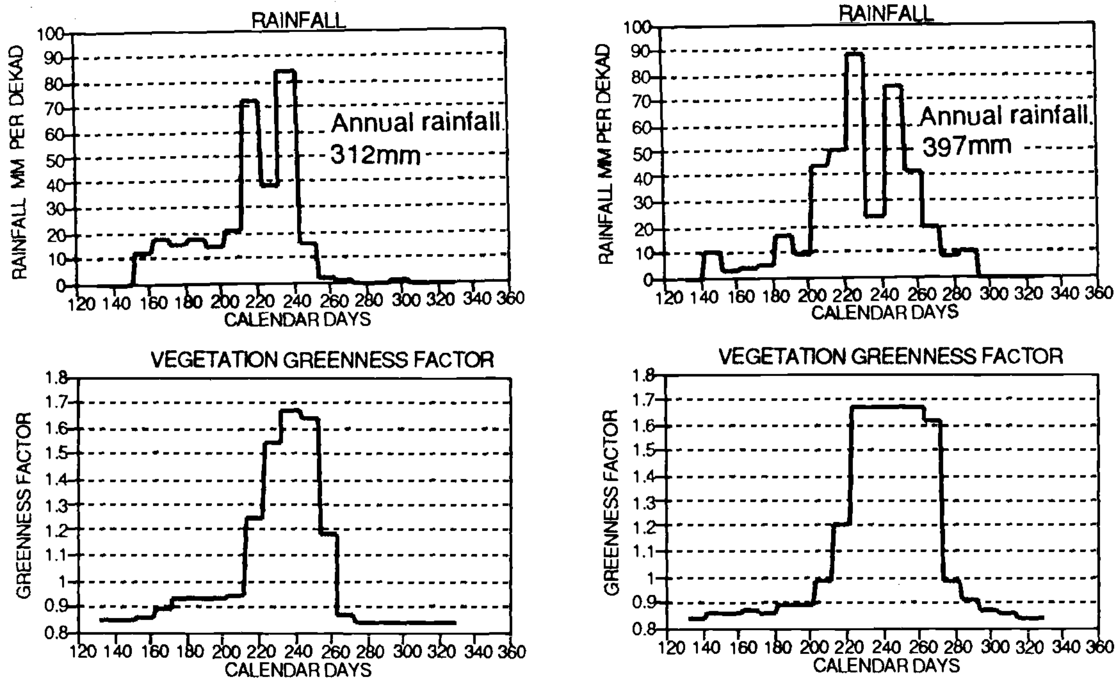
The use of crop injury units and percent crop loss that ultimately translates to a B/C ratio needs to be assessed with some caution as they all deal with relative loss that must be assessed against the potential yield as the frame of reference. In the low B/C case the crop injury units are high but relative to a very low potential crop yield. The result is a value of crop saved of \$ 11.40 in the low B/C case at a cost of \$ 7.81. In the high B/C case the value of the crop saved was \$ 61.25 at a cost of \$ 7.81.

Comparison Of Low And High Benefits Cases For Abeche

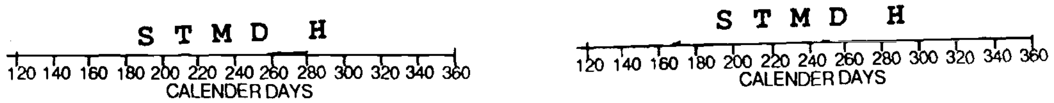
The low and high B/C ratio comparison for Abeche is shown in Fig 5.3. The low B/C ratio case selected was case # 30 while that for the high B/C case selected was case selected was case # 36. The annual rainfall in the low B/C case was 311.7 mm and that in the high B/C case was 397 mm. Overall rainfall and its seasonal distribution contributed to a maximum potential crop yield of 685 kg/ha for the low B/C case and 956 kg/ha for the high B/C case.

Fig 5.3. Graphical analysis of low and high benefits cases from simulated rainfall patterns for Abeche site

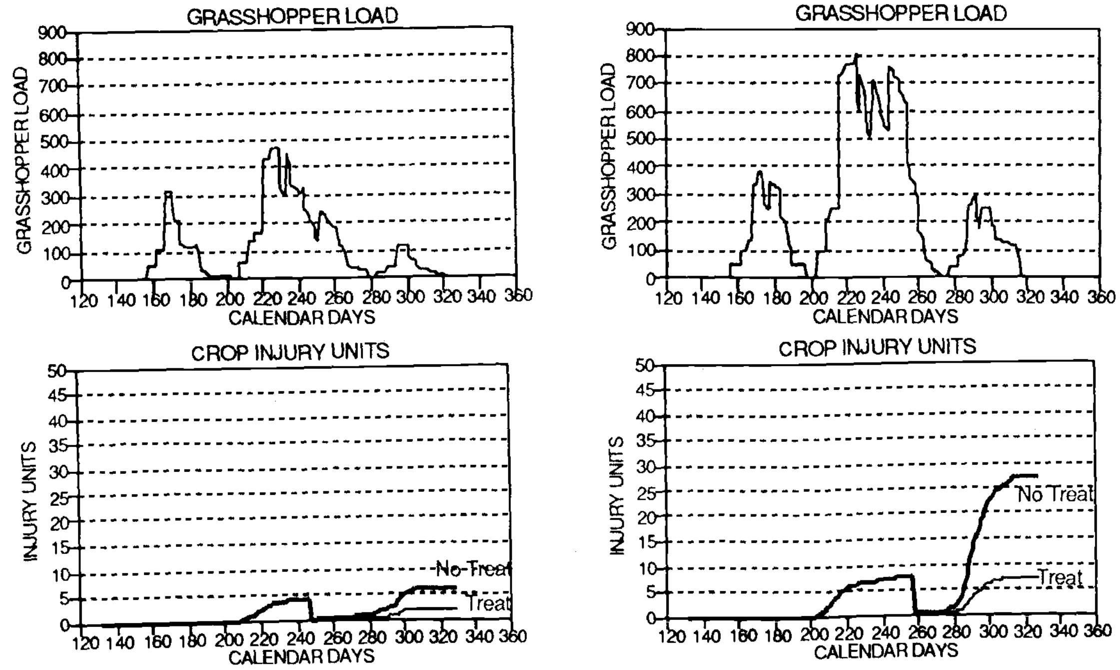
Low B/C (case #30), B/C ratio=1.5 **High B/C (case #36), B/C ratio=3.7**



Crop Stages: S=seeding date, T=tillering, M=milky, D=dry grain, H=harvest



Potential yield= 685 Kg/ha Potential Yield= 956 Kg/ha



Grasshopper load was heavier for the high B/C case resulting in more accumulated crop injury units as compared to the low B/C case. In Abeche crop injury units and resulting crop damage is influenced by grasshopper load. Although the crop injury units appear to be affected by natural vegetation greenness but this factor does not predominate. The within year rainfall distribution appears to have generated high grasshopper loads that result in high crop injury units for the high benefits case.

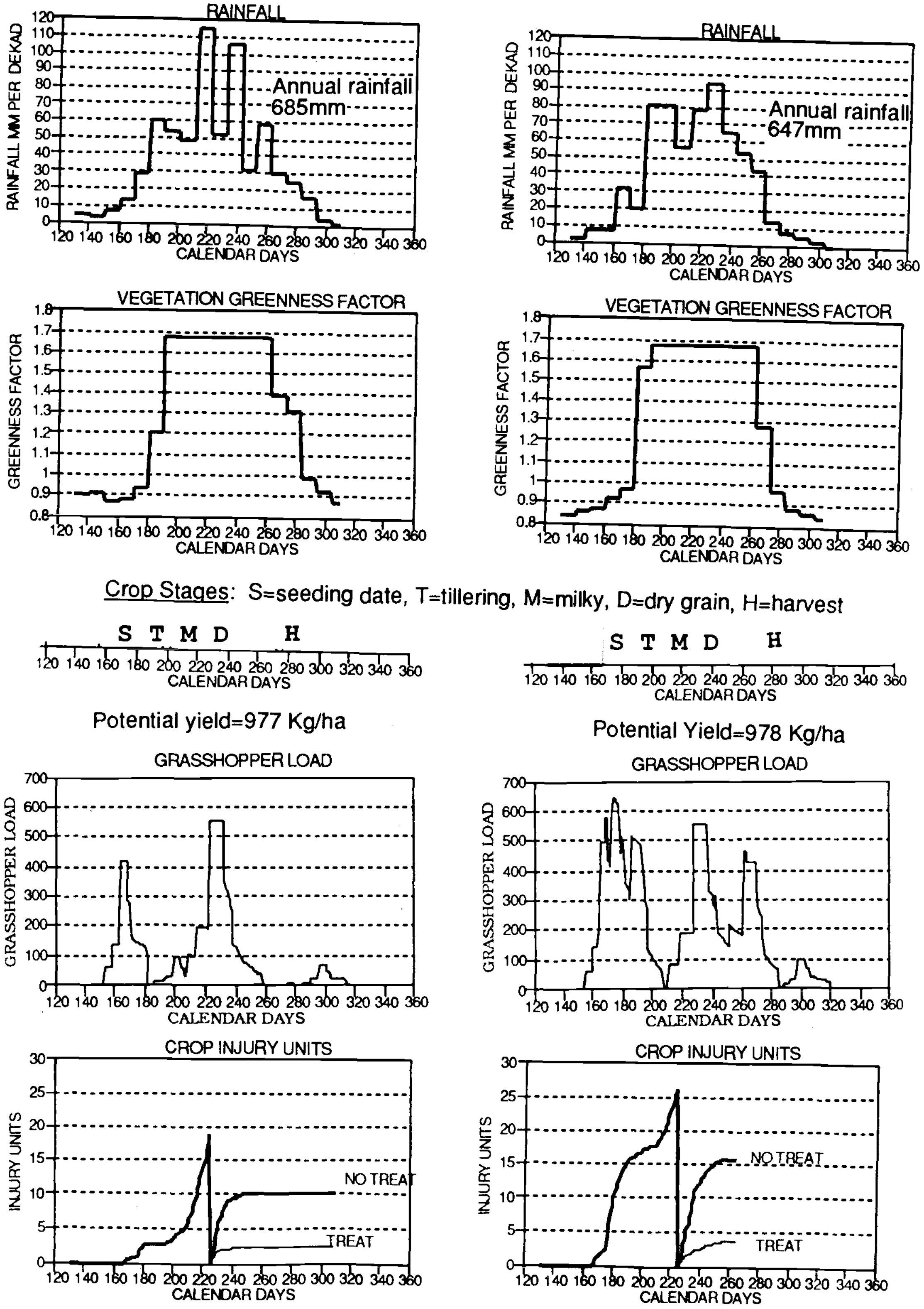
Because of grasshopper damage the crop yield for the low benefits case fell from a potential yield of 685 kg/ha to 674 kg/ha with treatment while in the no treatment case yield dropped to 625 kg/ha as a result of grasshopper damage. Benefits of treatment in the low benefits case are (674-625)(.3)=$13.62 at an application cost of $9.12 resulting in a B/C ratio of 1.5. The value of the crop saved for the high benefits case is (913-791)(.3)=$33.47 generating a B/C ratio of 33.47/9.12=3.7.

Comparison Of Low And High Benefits Cases For Mongo

The low and high benefits comparison for Mongo is shown in Fig 5.4. In the low benefits (B/C ratio of 2.3) case, Mongo received annual rainfall of 685 mm while in the high benefits (B/C ratio of 4.5) case Mongo received annual rainfall of 647.4 mm. Here annual rainfall is similar yet B/C ratio results are quite different. The vegetative greenness was nearly the same for both cases as were the crop growth stages with seeding on day 169 and harvest on day 256. Treatment was applied on day 209 at the milky stage.

Fig 5.4. Graphical analysis of low and high benefits cases from simulated rainfall patterns for Mongo site

Low B/C (case #30), B/C ratio=2.3 **High B/C (case #59), B/C ratio=4.5**



Crop Stages: S=seeding date, T=tillering, M=milky, D=dry grain, H=harvest

Potential yield=977 Kg/ha

Potential Yield=978 Kg/ha

The important difference appears to be within season rainfall distribution. Early in the season and through day 200 rainfall is high in the high B/C case. It is also high at the end of the season from day 240. In the low B/C case rainfall is low both at the beginning and end of the crop season. This rainfall pattern did not effect potential crop yield in either case as potential crop yields of 977 and 978 kg/ha were essentially the same.

The rainfall patterns did, however, affect grasshopper loads differently. The grasshopper load is greater in the high benefits case because the high rainfall through 200 day increased the grasshopper hatch for each of the 3 hatches throughout the season. The high grasshopper load in the high benefits case produced high crop injury units. This is an interesting case of within season rainfall variability resulting in different B/C ratios.

As a result of high crop injury units for high benefits case the crop yield dropped from the potential yield of 977 kg/ha to 922 kg/ha with treatment because of yield loss caused by grasshoppers. In the no treatment case the crop damage by grasshopper lowered the crop yield to 771 kg/ha from a potential yield of 922 kg/ha. The value of crop saved with treatment for high benefits amounted to (922-771)(.2)=$30.2 at cost of $6.23, a B/C ratio of about 4.5.

In the low benefits case with treatment potential crop yield is reduced to 955 kg/ha. Without treatment yield is reduced to 878 kg/ha. The value of crop saved by applying control tactics is (955-878)(.2)=$15.4 at a cost of $6.23/ha with resulting B/C ratio of 2.3.

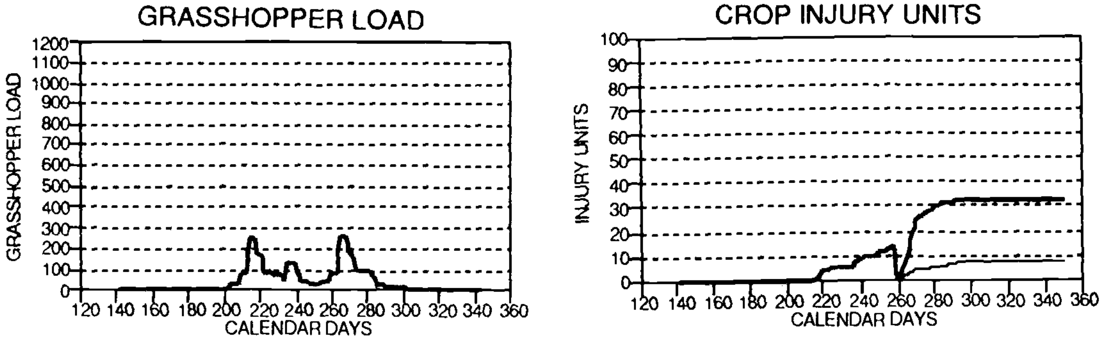
EFFECT OF GRASSHOPPER DENSITY UPON ECONOMIC BENEFITS, A REPRESENTATION OF BETWEEN YEAR VARIATION

Grasshopper populations are known to vary within and between crop seasons as influenced by changes in weather conditions. Hence, grasshopper densities may be quite different at the beginning of each crop season. Within year weather variability effect upon control tactics has been the main focus of the study to this point. In it grasshopper densities were held constant using 1987 sample densities for each of the the 100 simulated weather cases. In this section that assumption is relaxed and the effect of changes in grasshopper density on economic benefits is assessed on a limited scale.

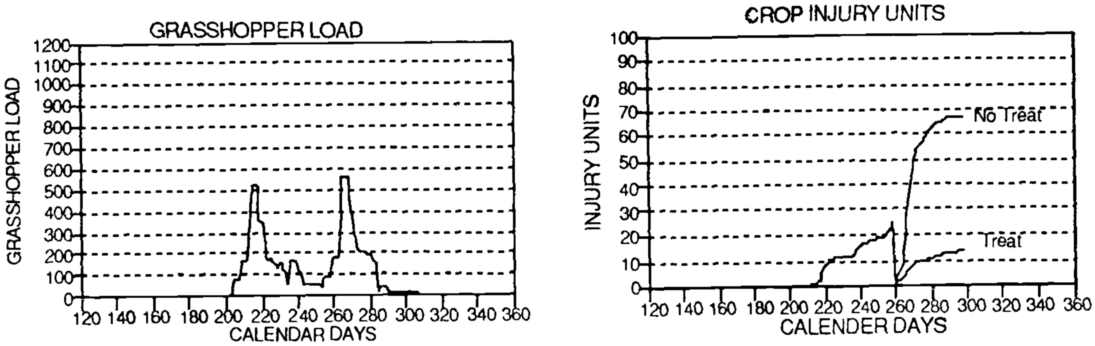
Grasshopper densities were doubled and halved from the original grasshopper densities shown in Table 3.5 for all low the high B/C cases already selected for Ati, Abeche and Mongo. The intent is to provide a preliminary assessment of the sensitivity of GHLSIM to grasshopper population density changes. The GHLSIM was run for these changed grasshopper density cases. Graphic presentation of grasshopper loads and crop injury units are shown in Fig 5.5 through 5.10. A tabular summary of B/C ratio results is presented in Table 5.4. The B/C ratios increased with the increased grasshopper density and decreased with the decreased grasshopper density. However, results were not necessarily proportional. This was particularly the case with Ati where rainfall was the controlling variable. As demonstrated in Table 5.4 and Fig 5.5 and 5.6 for Ati the grasshopper density does not influence the benefits much for low benefits case because benefits are already marginal (the crop yield potential is only 97 kg/ha). Increases or decreases in grasshopper density only marginally change the B/C ratio range from 0.7 to 1.7.

Fig 5.5. Grasshopper density effect upon grasshopper load and grasshopper injury units for low B/C ratio case #14 of Ati site

Density=12, B/C ratio=0.7



Density=25, B/C ratio=1.4



Density=50, B/C ratio=1.7

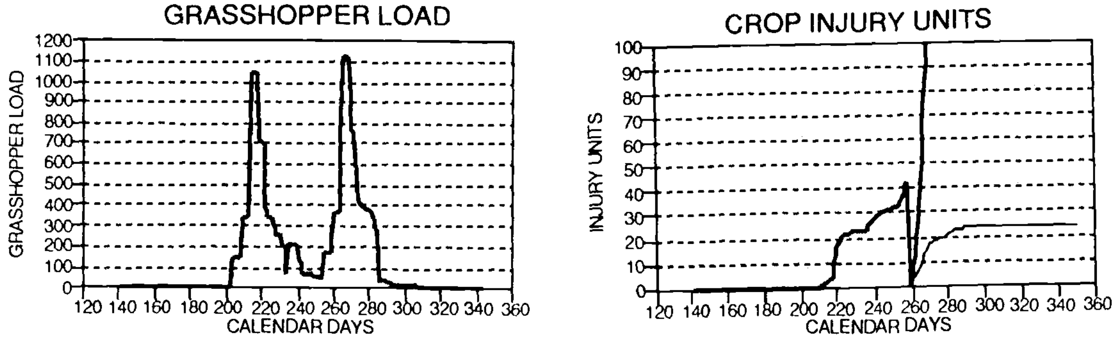
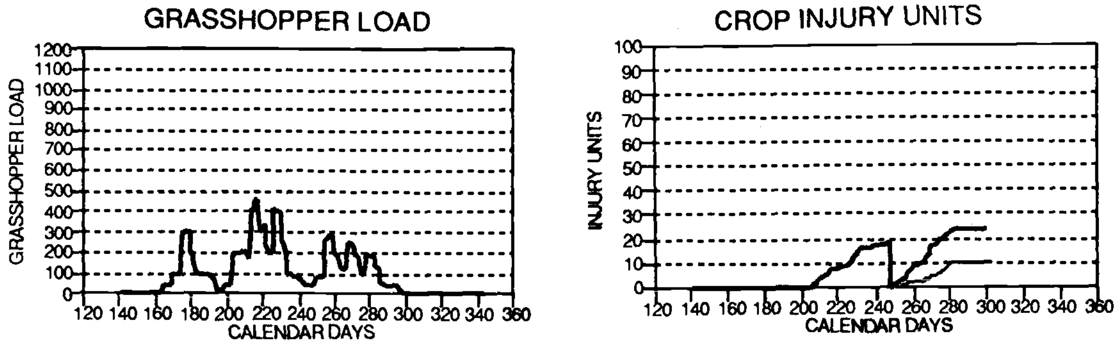
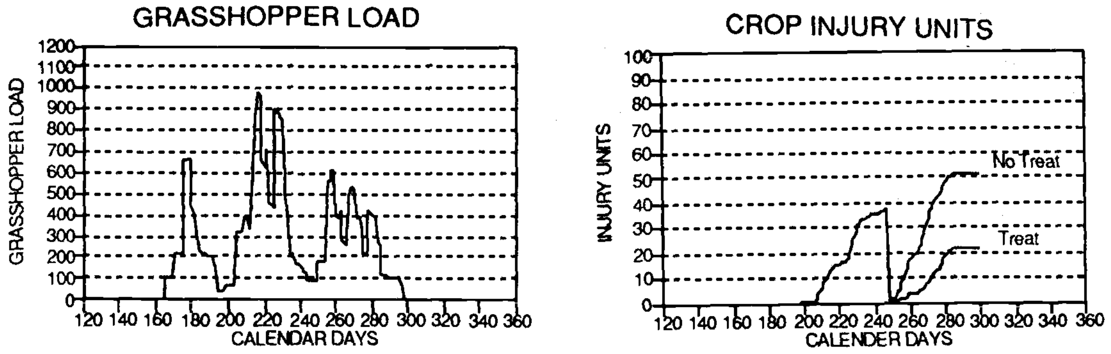


Fig 5.6. Grasshopper density effect upon grasshopper load and grasshopper injury units for high B/C ratio case #26 of Ati site

Density=12, B/C ratio=3.4



Density=25, B/C ratio=7.2



Density=50, B/C ratio=9.8

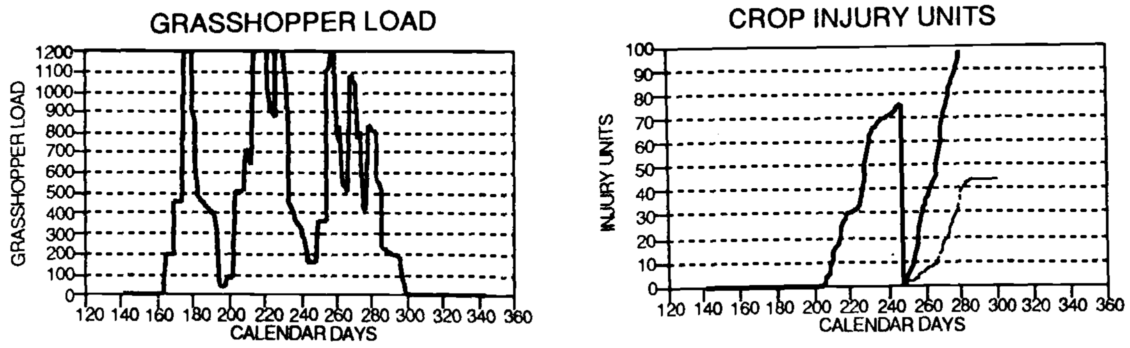
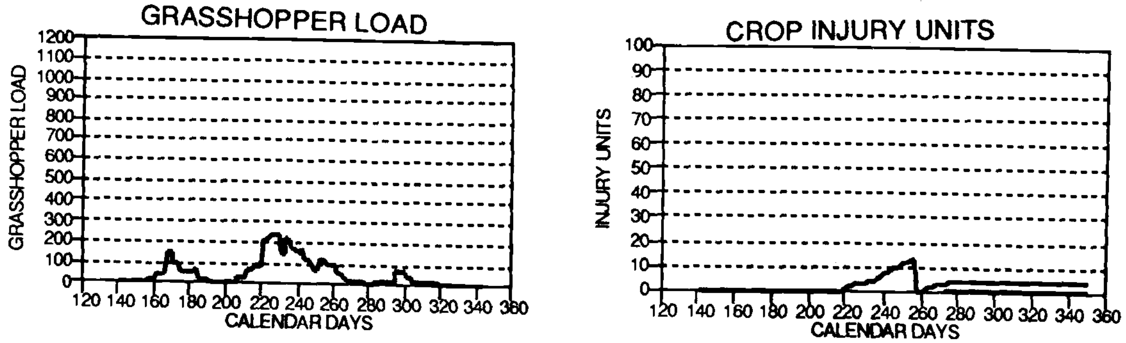
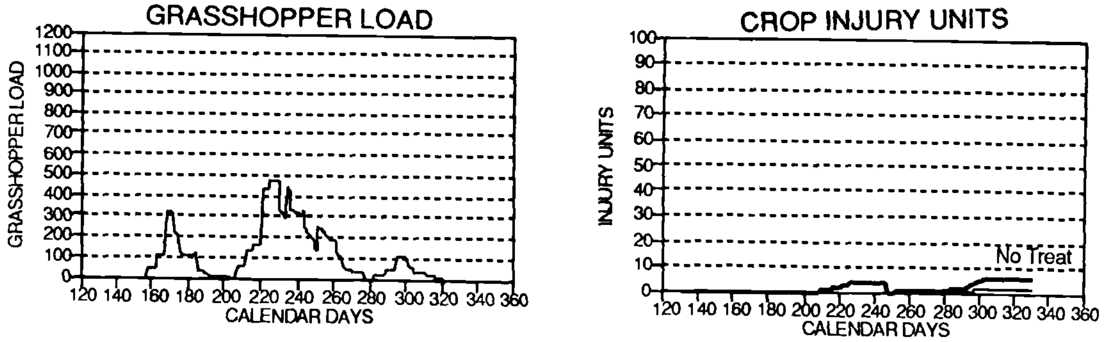


Fig 5.7. Grasshopper density effect upon grasshopper load and grasshopper injury units for low B/C ratio case #30 of Abeche site

Density=9, B/C ratio=0.7



Density=18, B/C ratio=1.5



Density=36, B/C ratio=3.0

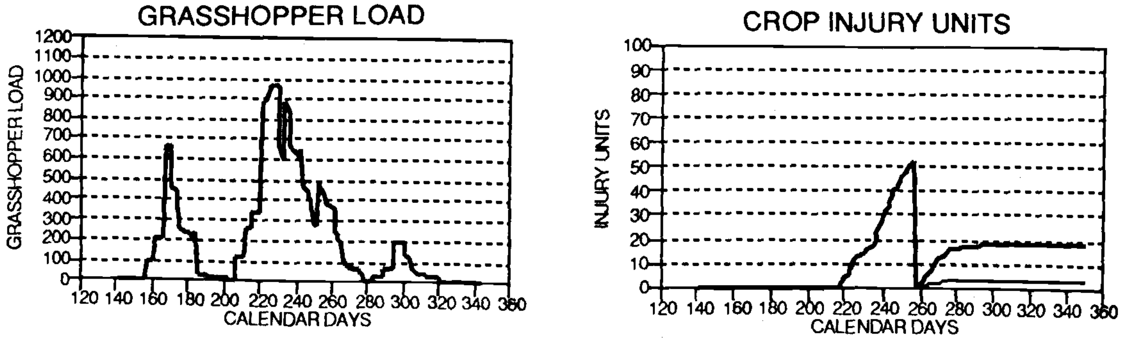
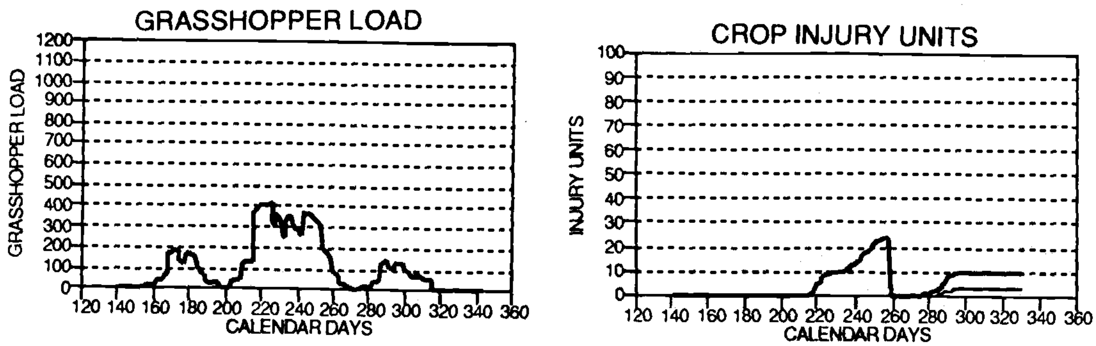
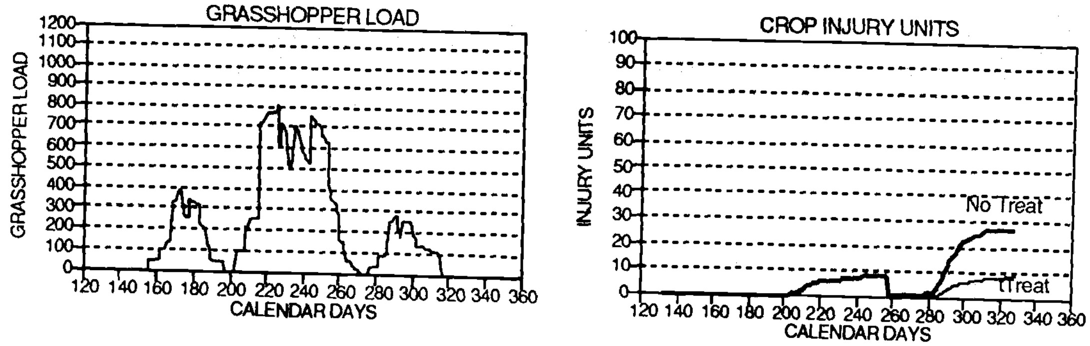


Fig 5.8. Grasshopper density effect upon grasshopper load and grasshopper injury units for high B/C ratio case #36 of Abeche site

Density=9, B/C ratio=1.8



Density=18, B/C ratio=3.5



Density=36, B/C ratio=7.3

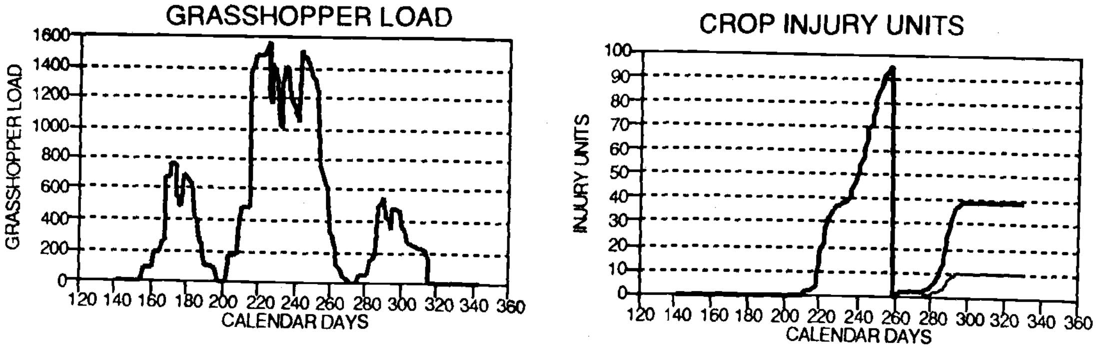
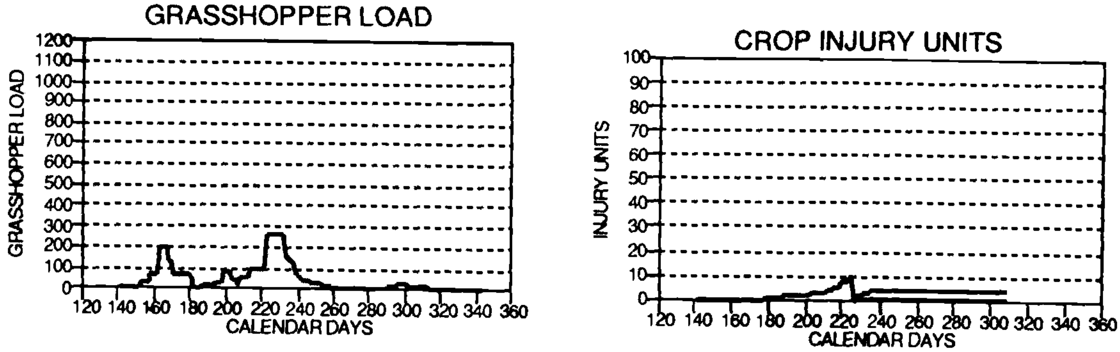
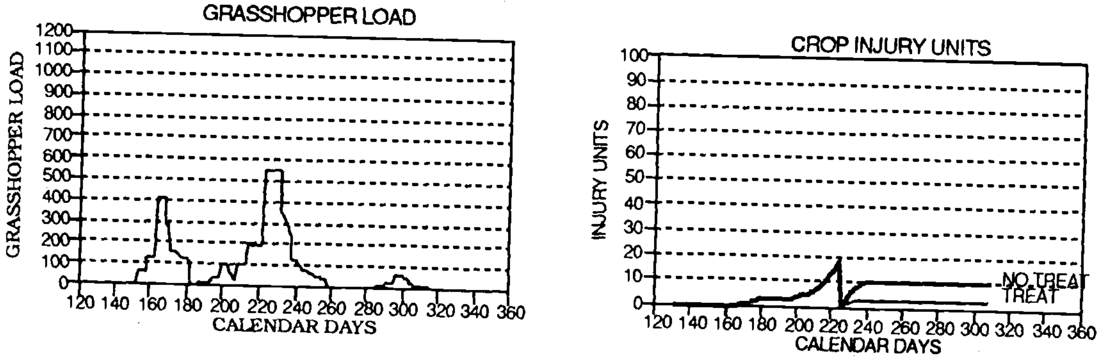


Fig 5.9. Grasshopper density effect upon grasshopper load and grasshopper injury units for low B/C ratio case #30 of Mongo site

Density=12, B/C ratio=1.1



Density=25, B/C ratio=2.3



Density=50, B/C ratio=4.6

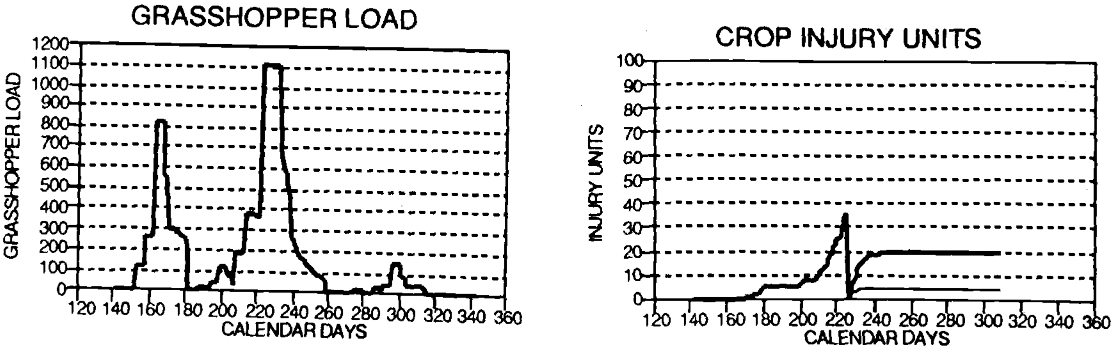
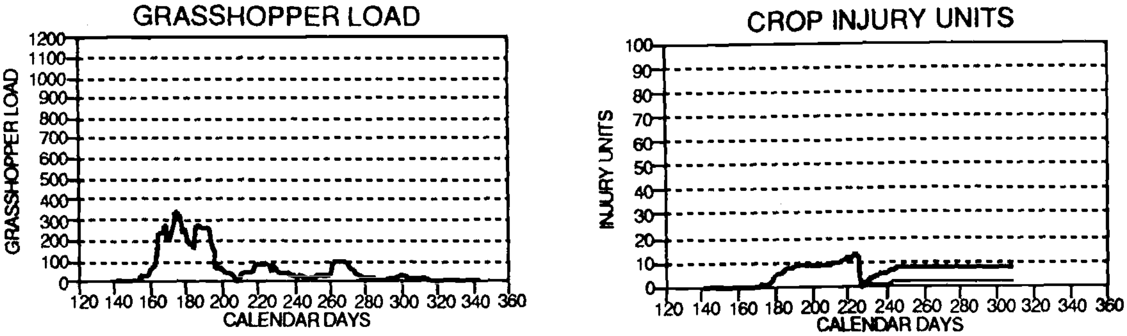
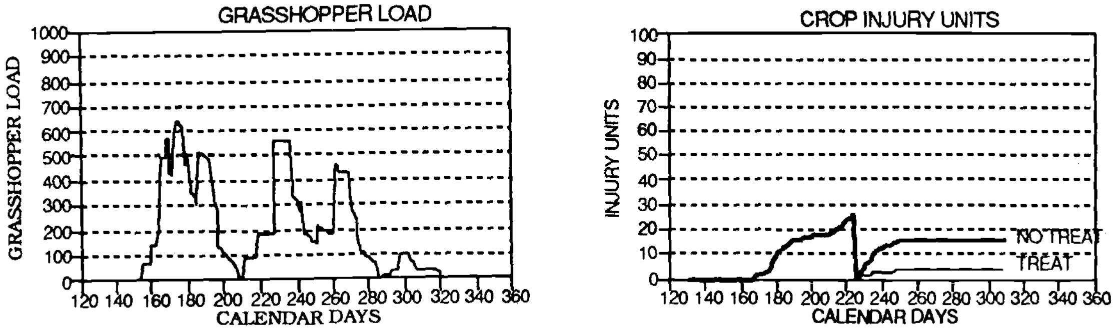


Fig 5.10. Grasshopper density effect upon grasshopper load and grasshopper injury units for high B/C ratio case #59 of Mongo site

Density=12, B/C ratio=2.2



Density=25, B/C ratio=4.5



Density=50, B/C ratio=8.9

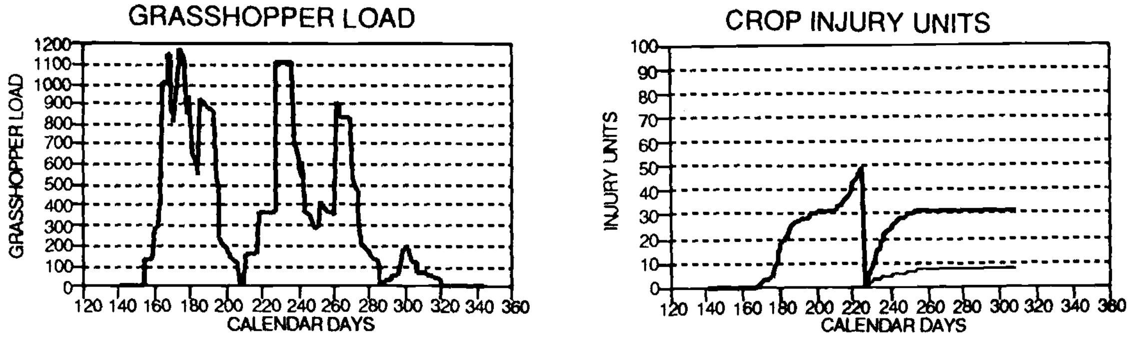


Table 5.4. Effect of grasshopper density upon benefits derived from grasshopper control tactics

Item	Sites								
	Ati			Abeche			Mongo		
Grasshopper density at spray time	12	25	50	9	18	36	12	25	50
<u>Low benefits case number</u>	14	14	14	30	30	30	30	30	30
Rainfall (mm)	154	154	154	312	312	312	685	685	685
Maximum crop yield potential (kg/ha)	97	97	97	685	685	685	977	977	977
Crop yield with spray	91	86	79	679	674	664	964	955	933
Crop Yield without spray	69	40	22	655	625	566	903	878	778
B/C ratio	0.7	1.4	1.7	0.7	1.5	3.0	1.8	2.3	4.5
<u>High benefits case number</u>	26	26	26	36	36	36	59	59	59
Rainfall	311	311	311	401	401	401	647	647	647
Maximum crop yield potential	910	910	910	956	956	956	978	978	978
Crop yield with spray	823	726	536	944	913	871	951	922	868
Crop yield without spray	706	481	203	887	791	630	878	771	568
B/C ratio	3.4	7.2	9.8	1.8	3.5	7.3	2.2	4.5	8.9

A review of the Mongo high benefits case shows that the initial grasshopper density has a considerable effect on benefits. Changing the grasshopper density from the original density of 25 to 12 and to 50/m2 resulting B/C ratio varying between 2.2 to 8.9. The amount and distribution of annual rainfall provides a near maximum potential yield of 978 kg/ha. Because rainfall is not a crop production constraint the grasshopper density substantially influences the value of crop yield that can be saved. At high density level of 50/m2 the potential high density level of 50/m2 the potential yield loss without treatment drops from 978 kg/ha to 568 kg/ha, a reduction of 410 kg/ha. The same increase in grasshopper density in the Ati low benefits case reduced the yield from 97 to 22 kg/ha a yield reduction of only 75 kg/ha. Table 5.4 shows that as potential crop yield increases because of improved rainfall, the impact of grasshopper density becomes an increasingly important factor affecting economic benefits in terms of the amount of crop saved.

With exception of the limited rainfall case at Ati, Table 5.4 and Figures 5.5 through 5.10 show that grasshopper load and crop injury units increase proportionally to the change in grasshopper density at all sites for both low and high benefits cases. In Chapter 3 the calculation of crop injury units formula include grasshopper density in a simple proportional form. Thus crop injury units will change linearly with changes in grasshopper density. The proportional change in crop injury units due to change in grasshopper density is shown in Fig 5.5 through 5.10. But the damage caused by grasshoppers with increases or decreases of grasshopper density does not necessarily change proportional to change in grasshopper density, because the crop loss function, shown in Fig 5.2, after 75 crop injury units increases with a decreasing rate. The maximum crop loss from grasshopper damage that can be reached is 85%.

EFFECT OF INPUT AND OUTPUT PRICES UPON ECONOMIC BENEFITS

Crop price and control cost changes will affect the magnitude of benefits derived from grasshopper control. This section focuses on effect of these changes on benefits derived from grasshopper control. Crop prices were arbitrarily changed 20 percent below and above the 1987 crop prices while all other variables were kept constant. The results are shown in Table 5.5 for Ati, Abeche and Mongo.

Results suggest that the impact of crop price variation on benefits is small even when potential yields are high. For the low yield case of Ati a 20% increase of crop prices raise the B/C ratio only from 1.4 to 1.68. A 20% reduction of crop prices reduces the B/C ratio from 1.4 to 1.12. Even the high benefits case of Mongo showed B/C ratio change of only from 4.5 to 5.4 with 20% price increase and a decrease of 20% crop price reduced the B/C ratio from 4.5 to 3.6.

The crop price impact on benefits is influenced by amount of crop saved. The amount of crop saved is influenced by percent loss saved on potential crop yield. The crop price change impact on benefits is greatest when potential crop yield saved is highest. Since, the actual crop price variation was not known, the exact price effect and its direction was not known.

Table 5.5. Control cost and value of crop saved from grasshopper control using simulated weather conditions for Ati, Abeche and Mongo sites of Chad

Site	Potential yield	Yield saved	Control Cost	B/C ratio under varying crop prices					
				1987 prices	B/C ratio	Lower prices	B/C ratio	Higher prices	B/C ratio
Ati									
Low B/C case	98	44	7.8	0.25	1.4	0.2	1.12	0.3	1.68
High B/C case	932	255	7.8	0.25	7.2	0.2	5.76	0.3	8.64
Abeche									
Low B/C case	765	46	9.12	0.3	1.5	0.24	1.2	0.36	1.8
High B/C case	978	112	9.12	0.3	3.7	0.24	2.96	0.36	4.44
Mongo									
Low B/C case	977	72	6.23	0.2	2.3	0.16	1.92	0.24	2.76
High B/C case	978	140	6.23	0.2	4.5	0.16	3.6	0.24	5.4

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

Historical observations and previous research studies strongly suggest that weather in the sub-saharan region of Africa plays a key role in crop production and the influence of grasshopper infestation upon it. Weather patterns, particularly rainfall, are known to influence planting dates, crop cycle, crop yields, natural vegetation greenness and grasshopper population development.

GHLSIM models these variables, their effect on crop production and grasshopper populations and the complex interaction between crop and grasshoppers. The model includes the effect of grasshoppers on crop yields and estimates economic benefits from grasshopper control.

In this thesis, the characteristics and performance of GHLSIM have been evaluated under the range of weather conditions that prevailed in 1987 across 13 field sites in Chad. These results, which produced B/C ratios ranging from 0 to 6.9, suggest that GHLSIM is sensitive to within year weather patterns. The role and importance of specific variables influencing within year GHLSIM results, the importance of between year weather influences, the interaction of weather upon crop yield and grasshopper infestation, and sensitivity to crop price change are assessed in this study. This was accomplished by simulating 100 years of rainy season weather patterns at 3 sites in Chad. The 3 sites (Ati, Abeche and Mongo) represent a wide range of weather characteristics.

CONCLUSIONS

Characteristics and Performance of GHLCROPS:

The GHLCROPS component calculates planting dates, water requirement for crop yield and natural vegetation greenness used in crop loss calculation. It is highly sensitive to within year and among year weather variation in its calculation of maximum potential crop yield.

When less than about 300 mm the potential crop yield is drastically lowered. For Ati, Abeche and Mongo when rainfall is more than 300 mm, potential yield is near the maximum attainable potential yield of 1000 kg/ha.

To attain the maximum potential yield of 1000 kg/ha the model requires 100% Water Requirement Sufficient Index (WRSI) at each stage of the crop. When rainfall is below 100% WRSI at any crop stage, yield is reduced below the 1000 kg/ha maximum potential yield. In no low or high benefits cases at Ati, Abeche and Mongo sites was the maximum potential yield of 1000 kg/ha attained. This is because the WRSI requirement was not achieved at one or more crop stages in each case.

GHLCROPS also is sensitive to within year rainfall requirements for crop production. At Ati in the high benefits example considered here the potential yield is 910 kg/ha with a 311 mm annual. In contrast at Abeche an annual rainfall of 312 mm for low benefits case generated a yield of only 685 kg/ha. Seasonal rainfall distribution produced the difference in potential yield. At Abeche rainfall at the beginning of the season from planting to tillering was at a low level, less than the WRSI requirement. At Ati rainfall at these stages was sufficient. This affects the water requirement at subsequent crop stages resulting in different yields. Thus the model is sensitive to within season rainfall variability.

Where weather is a limiting factor, changes in grasshopper density levels do not play a major or dominant role in affecting B/C ratio levels. Since potential yield is already low due to weather, grasshopper density changes have little effect on crop loss. Conversely, when weather is not a limiting factor (i.e. when yields approaches the maximum potential yield of 1000 kg/ha), grasshopper density changes can influence benefits levels substantially. When this occurs the change in benefits tends to be proportional to the change in grasshopper density.

It is concluded that modeling of the different crop stages each requiring different amounts of water as reflected by the Water Requirement Satisfaction Index (WRSI) is realistic in reflecting different within season growth requirements. The results in terms of potential crop yield are sensitive to seasonal rainfall and its distribution. High annual rainfall and an even within season distribution of rainfall results in high yields. Within season rainfall distribution, especially at Ati site, tends to be highly erratic not unlike many parts of the Sub-Sahelian region of Africa. Within season rainfall distribution and the length of a rainy season are important in deciding the varieties sown and planting time. The model selects the planting date for a given rainfall pattern. Crop variety selection is predetermined by site in accordance with a mix of varieties selected by farmers. The mixes chosen appear realistic in accordance with the long term weather patterns.

Characteristics and Performance of GHLOSE:

The GHLOSE component of the model calculates daily grasshopper densities for treated and untreated conditions and translates their effect upon crop yield through the crop injury submodel GHLINJ. Grasshopper population densities used in 1987 were those obtained from field samples at approximately the milky dough stage of grain development, the time period when the crop is most susceptible to grasshopper damage at the 13 sites. At 3 sites (Mongo, Mangalme and Goz-Beida) the sampling was done late, at the dry or mature grain stage. Because grasshopper densities were not generated endogenously in the model by weather effect, sensitivity of model performance to changes in grasshopper densities were assessed in a somewhat arbitrary fashion. This was done by first halving and then doubling grasshopper densities and re-running this model at the 3 sites with those populations. While this sensitivity analysis showed some responsiveness upon benefits to changes in population densities, the responsiveness was generally less pronounced than the effect of weather on crop yield and less uniform.

At Ati, when weather is the overriding factor, the effect of changes in grasshopper population densities on benefits generally is small because of marginal yield losses. When weather is not a predominant factor affecting crop production, grasshopper density changes are proportional to benefit changes from grasshopper control. In these situations, changes in grasshopper density has an important influence upon crop loss.

It is concluded that grasshopper population density should be linked directly to weather conditions in the GHLSIM model and the sample should be taken at the beginning of a crop season. Unless population density is linked to weather from the beginning of the season, the model is a poor predictor across seasons. Additionally, the model does not assess crop damage from crop germination to crop dough stage. The model simply assesses the potential crop loss from dough stage to harvest. The sample density taken at the beginning of season would help in assessment of damage caused by grasshopper prior to spraying.

Timing of Crop Production Vs Grasshopper Cycles:

It is concluded that the within year interaction effect between the timing of crops production and the effect of grasshopper population cycles upon the vulnerability of crop stage as modeled by GHLOSE is an important relationship.

At Mongo while the potential yield in the both low and high B/C cases are about the same, the grasshopper density effect is quite different. The main reason is that within season rainfall distributions produced different grasshopper loads resulting in different grasshopper densities affecting similar potential yields. In the high B/C case, grasshopper load is much heavier and generates greater crop loss. The natural vegetation greenness factor is approximately the same for each case. But the grasshopper load from milky stage to the end of the crop season is markedly different in each case. The second grasshopper cycle for the high benefits case is much longer dictating the severe within season crop loss effect.

Although the vegetative greenness factor is built into the model, in no case did it dominate crop loss by grasshopper in low and high benefits cases at any of the sites. Except for the low rainfall case at

Ati, in which lack of vegetative greenness exacerbated the problem, the natural vegetation greenness did not play a major role.

At the Ati site, when potential yield was low due to insufficient rainfall (the low benefit case), the grasshopper density effect was not important. The risk of crop loss due to grasshoppers is greater when crop yields are not restricted by weather. When rainfall is not the overriding factor in high benefits case at Ati, the risk of crop loss due to grasshopper is high. The risk of low crop yield at Ati is greater than at Abeche and Mongo as weather variability is greater at Ati than Abeche and Mongo.

The length of a grasshopper cycle is influenced by within season weather conditions that determine grasshopper development rates and migration. The GHLOSE models this characteristic. If conditions are conducive for development rate and immigration of grasshoppers the grasshopper cycle will be prolonged. If weather conditions are not conducive to development of the grasshopper cycle, each population generation is discrete with no population building occurring between generations.

Importance of Crop Price Changes:

Crop prices were adjusted upward and downward by an arbitrary 20 percent to provide a preliminary assessment of the relative sensitivity and hence importance of crop price changes. In general, the model was far less sensitive to prices than either weather or grasshopper density changes. Prices may or may not be important depending upon the volatility of crop prices in Chad.

General Conclusions:

In its present form The GHLSIM cannot be used as an early warning indicator that uses a specific grasshopper density to represent an economic injury level as an alert to spray. This is because we do not know specific population densities associated with specific weather patterns. It is only if grasshopper density and its variability can be correlated with specific weather patterns, the model could be used as an early warning indicator.

For a particular within season rainfall pattern the model appears to predict crop production quite well. Further refinement in the model, which changes the qualitative prediction of grasshopper population to a quantitative one throughout the season and validation of the refined model against field observations, will enable the model to be used as an early warning predictor.

The GHLAGGR submodel provides comprehensive economic information for spray and no spray situations. The GHLAGGR reports expected crop yields, crop loss due to grasshopper infestations for treated and no treated situations, crop price, control cost and net benefit. This information is important for individuals and policy makers in decision making to spray or not to spray which augment the B/C ratio results. This full set of economic results may be used in assessing policy goals once the model is validated and predictive capability determined. These may include economic and equity issues that influence the allocation of resource for grasshopper control among sites. For example, crop production risk for the country may be spread by spraying at various locations according to the aggregate value of crop saved. But if equity and avoidance of crop failure is the goal in marginal areas, the appropriate policy choice may be reversed. The areas already in food deficit may need more security in food production. This is an open question for policy makers.

RECOMMENDATIONS FOR GHLSIM MODEL

GHLSIM is a sophisticated crop production and grasshopper population dynamics model with resulting crop loss assessment. It includes interaction of a number of factors that contribute to crop yield potential and crop loss from grasshopper infestation ranging from natural factors to management practices. The model was used for crop yield estimation, crop loss assessment and economic impact of control tactics for grasshoppers under different rainfall pattern scenarios. As a part of the study, the models' predictive behavior was studied. The following difficulties were observed during the use of the model.

PRIFAS OSE Model And Sample Densities: The grasshopper population dynamics depend on OSE (French OSE model) output files that produce indices of grasshopper development and presence/nonpresence of grasshopper stages on a daily basis as climatic conditions change during a cropping season. In the GHLOSE sub-model, the qualitative results from PRIFAS/OSE are matched against the actual field sample of grasshopper population density at the milky dough crop stage when the sample was taken at each site. This match continues for an additional 30 days to compare results. If the OSE qualitative output (stating presence or non-presence) is consistent with the field sample, the model completes the calculation of B/C ratios. If the comparison is inconsistent (in the case of OSE predicting no grasshoppers but the field sample show otherwise) the GHLOSE submodel shuts down and does not calculate B/C ratios as the OSE result indicates that there is no difference between spray and no spray conditions and therefore no means to calculate a B/C ratio. Consistency occurred in 1987 at all sites in terms of GHLOSE producing some grasshopper population at each site and the field sample, as shown in Table 3.5 stating actual population ranging from 15 to 75 grasshopper densities across the sites. In the one site Goz-Beida the B/C ratio was zero, not because of inconsistency, but because the sample was taken at harvest time when no opportunity for controlling grasshopper damage remained.

In the case of the 100 year simulation where arbitrary grasshopper populations were employed, the model shuts down (saying that no grasshoppers could exist under the particular weather conditions and hence zero B/C ratios resulted) in 26 cases for Ati, 4 cases for Abeche and one case for Mongo. The relative relationship across the sites appears reasonable based upon weather differences. However, whether OSE appears to overstate or understate the conditions is not known.

It is recommended that the current procedure be replaced with a quantitative grasshopper model in which grasshopper population density is sampled at the beginning of a crop season and then grasshopper population over time is directly linked to changes in the seasonal weather patterns (just as currently is done with potential crop production).

Development Rates And Success Indicies: The OSE bio-model uses stage specific grasshopper success indices (varies from 0 to 25) to determine development rates. The higher the success index value, the faster is the grasshopper development rate. The daily consumption rates increase with the increases in success indices for each stage. If success indices are high, it takes fewer days to convert to a successive stage and more vegetation is consumed during that stage. If success indices are low then it takes more days to convert to a successive stage and less vegetative consumption occurs during the stage. GHLSIM models the consumption required for growth. It does not include heat energy required for respiration and maintenance. It is expected that the more time a grasshopper stays in a stage, the more it will consume for respiration and maintenance. If this is the case then different consumption rates for different length of a stage may be required. This would effect crop injury units that estimate crop loss due to pest invasion.

OSE Behavior: Grasshopper species perform differently across ecosystems. Mortality rates and survival rates of OSE grasshoppers have been modeled in GHLSIM using the rates from grasshopper species in North America. This is because information on OSE rates simply are not available. However, this assumes that OSE grasshopper behavior is similar to species of grasshoppers found in the U.S. This may or may not be the case. Validation of this assumption is needed.

Overlapping Generations: GHLSIM models grasshopper population dynamics starting from egg hatch and estimates population densities in successive stages. Each generation of egg hatch and grasshopper growth is discrete. GHLOSE does not provide for overlapping among generations. The model does consider immigrating populations if weather conditions are conducive, but not overlapping generations. Presence of overlapping generation and/or a full range of grasshoppers from eggs to adults of a given population drawn from a field sample would suggest that a more complex grasshopper model may be warranted.

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APPENDIX

Table 1. Transformation of monthly rainfall to dekad rainfall

Month	Rainfall	Dekad#	Rainfall
Jan	= X1	1	= X1/3
		2	
		3	
Feb	= X2	4	= X2/3
		5	
		6	
Mar	= X3	7	= X3/3
		8	
		9	
Apr	= X4	10	= X4/3
		11	
		12	
May	= X5	13	= X5/3
		14	
		15	
Jun	= X6	16	= X6/3
		17	
		18	
Jul	= X7	19	= X7/3
		20	
		21	
Aug	= X8	22	= X8/3
		23	
		24	
Sep	= X9	25	= X9/3
		26	
		27	
Oct	= X10	28	= X10/3
		29	
		30	
Nov	= X11	31	= X11/3
		32	
		33	
Dec	= X12	34	= X12/3
		35	
		36	

Dekad = ten day periods/intervals starting from 1st Jan.

Table 2. Simulated rainfall patterns and B/C ratios for Ati site of Chad

							Dekads							
Case#	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	Total	B/C
							Rainfall mm per dekad							
1	0.5	52.3	11.5	70.0	79.6	66.2	3.7	39.9	6.0	13.9	13.8	0.5	357.9	0.0
2	0.0	6.0	12.1	76.6	41.3	32.3	22.3	19.0	28.0	0.8	0.0	0.0	238.4	0.0
3	10.0	15.1	19.2	39.4	102.0	10.8	0.8	16.7	8.8	1.2	3.0	0.0	227.0	0.0
4	0.1	70.8	4.9	17.2	62.9	78.4	2.5	19.9	18.5	2.4	0.0	0.0	277.5	8.8
5	80.5	5.4	16.8	52.0	91.2	59.6	1.0	16.5	2.6	19.2	1.0	1.4	347.1	2.7
6	102.7	50.3	37.1	60.2	88.5	36.5	136.0	18.6	0.9	16.0	4.2	0.0	551.0	0.0
7	0.6	4.9	12.5	52.9	41.8	15.6	86.2	37.9	6.0	1.8	0.0	0.0	260.2	1.9
8	66.9	20.9	19.5	25.4	89.4	24.1	0.6	18.2	15.1	3.2	3.3	0.0	286.3	2.4
9	3.3	4.2	23.8	19.0	25.1	52.0	2.7	45.4	6.1	1.1	10.1	2.2	194.9	1.2
10	12.5	22.0	38.4	25.7	26.6	66.7	0.0	18.4	21.4	9.7	0.1	0.0	241.5	3.3
11	8.9	21.7	24.1	24.1	42.8	36.7	4.7	36.0	6.1	0.3	15.2	0.0	220.5	3.5
12	0.0	29.7	38.1	16.7	105.0	48.1	134.2	41.2	6.4	1.2	0.1	0.0	420.7	0.0
13	23.9	29.6	29.5	37.8	42.9	13.3	91.6	36.1	16.6	0.0	16.3	0.0	337.5	1.8
14	11.9	2.6	3.6	17.3	50.2	25.2	2.7	18.4	6.1	4.1	12.0	0.0	154.2	1.4
15	9.5	1.2	24.8	5.5	50.2	20.1	95.4	19.8	6.1	13.7	13.3	0.0	259.5	2.0
16	11.0	1.4	19.6	16.0	18.9	13.0	30.1	41.4	1.6	22.3	0.0	0.0	175.0	0.9
17	1.7	22.2	64.1	20.7	53.4	12.9	11.1	18.5	5.9	2.0	1.7	0.0	214.2	2.6
18	107.4	20.4	72.1	4.2	47.1	31.7	67.4	45.5	7.0	4.6	1.8	0.0	409.0	0.2
19	16.3	4.4	70.0	25.2	6.0	73.0	81.1	13.2	28.7	23.6	0.0	0.0	341.4	1.0
20	2.5	27.9	29.6	57.2	114.4	39.0	82.9	26.3	26.7	1.4	0.4	0.0	408.3	0.0
21	0.0	3.6	12.4	58.8	15.5	18.6	106.4	28.6	6.6	9.9	0.0	0.0	260.5	0.6
22	0.0	22.1	29.6	76.6	36.7	24.4	4.5	33.6	0.7	23.4	0.0	0.0	251.5	3.8
23	0.7	22.5	28.2	19.9	80.1	41.8	1.4	18.0	1.1	1.0	0.4	0.0	215.1	0.5
24	0.0	22.1	29.7	47.4	90.8	79.6	85.6	25.0	0.8	0.0	0.0	3.2	384.1	0.0
25	89.6	10.1	29.6	54.2	34.3	48.5	109.6	37.3	24.4	19.4	0.0	0.0	456.8	1.2
26	0.0	11.4	19.9	65.9	57.4	9.4	87.7	32.9	5.9	19.2	1.7	0.0	311.4	7.2
27	10.2	9.3	19.2	43.8	74.5	46.2	8.1	43.0	6.6	2.3	0.0	1.7	264.8	6.2
28	0.3	81.4	42.4	55.2	144.0	5.1	13.2	41.7	8.0	0.0	0.0	1.1	392.4	0.0
29	0.0	8.2	29.7	21.5	61.6	25.6	20.9	8.5	22.5	1.3	2.1	0.0	201.8	0.0
30	0.0	19.7	44.5	21.3	79.4	54.5	3.6	36.9	16.1	0.0	1.7	0.0	277.8	0.0
31	11.5	7.6	17.7	68.3	4.0	53.3	30.9	35.4	26.7	0.0	0.1	0.0	255.5	2.1
32	14.8	1.2	19.1	72.9	49.8	80.7	9.0	18.7	0.2	21.5	0.3	0.0	288.2	0.0
33	0.4	47.5	19.8	17.3	34.8	32.8	60.1	31.0	6.0	0.5	1.3	2.2	253.6	0.0
34	0.0	24.2	8.7	46.7	51.7	77.9	30.5	29.7	5.8	1.9	1.7	0.0	278.9	3.0
35	10.0	25.2	21.9	7.6	81.1	73.7	2.3	18.2	2.7	1.6	10.9	0.0	255.0	0.0
36	11.2	29.1	29.7	25.6	101.6	36.8	32.9	27.4	26.9	2.6	0.1	0.0	323.8	0.0
37	5.2	23.6	64.8	34.7	92.0	56.6	110.1	18.1	28.6	1.4	1.7	0.0	436.8	0.0
38	22.4	3.1	5.2	13.2	41.4	36.6	81.2	18.7	2.6	2.5	0.1	0.0	227.1	0.2
39	81.8	3.6	10.5	60.4	81.6	42.3	15.7	22.2	14.1	4.3	2.8	0.0	339.2	0.9
40	2.0	5.1	9.7	30.4	69.5	64.2	107.6	37.9	5.6	18.3	0.0	3.1	353.3	0.0
41	0.2	28.9	59.5	49.8	80.6	48.1	5.6	8.7	27.7	1.4	8.2	0.0	318.6	0.0
42	0.0	8.0	29.7	26.0	53.3	70.4	4.2	9.7	2.5	2.4	0.0	0.0	206.2	3.9
43	0.4	35.9	24.9	19.1	35.2	36.7	7.8	26.0	20.1	0.0	0.0	0.0	206.0	2.1
44	16.0	25.7	17.8	24.8	44.5	33.9	31.7	28.1	0.1	0.0	0.0	2.3	224.9	0.0
45	0.0	35.2	29.6	4.0	44.3	38.5	1.4	45.1	15.0	6.3	1.0	0.0	220.1	3.1
46	0.0	3.4	29.6	23.9	149.5	5.2	13.5	8.1	6.0	0.7	0.4	0.0	240.2	2.9
47	0.0	26.8	29.6	21.3	35.8	6.9	0.8	19.1	25.3	2.6	10.3	0.7	179.3	1.4
48	12.4	43.4	6.1	75.5	7.0	26.6	0.2	14.2	0.2	2.7	6.8	1.7	196.7	1.0
49	9.2	10.4	27.5	10.1	61.6	26.3	80.7	37.5	0.1	0.0	3.5	0.0	266.8	0.8
50	0.7	13.8	53.9	21.9	79.6	36.6	96.5	19.8	5.4	0.0	0.0	0.0	328.2	1.8

Table 2, continued

51	0.0	0.7	25.2	50.6	9.7	15.5	0.8	38.4	6.1	0.0	0.0	3.0	149.9	0.4
52	0.4	13.9	74.6	5.1	91.6	54.6	3.8	24.9	27.8	1.4	2.4	0.7	301.1	0.0
53	1.6	22.7	29.6	11.9	66.6	36.3	10.5	37.2	1.2	3.4	2.7	0.8	224.4	3.1
54	0.3	31.8	29.7	24.9	53.9	51.1	1.2	24.0	4.6	2.1	13.6	0.0	237.2	0.0
55	10.4	28.1	29.6	46.5	37.3	56.2	77.4	18.7	9.6	19.4	1.7	0.0	334.7	0.0
56	0.5	28.3	32.6	64.7	53.7	56.7	9.7	12.7	6.5	16.1	0.0	0.0	281.5	0.0
57	2.3	15.7	6.1	17.7	20.2	23.2	32.6	18.6	5.9	2.7	0.0	0.0	144.8	1.3
58	2.6	6.8	19.2	6.3	33.9	16.2	95.3	19.3	16.9	5.2	0.0	0.0	221.6	1.8
59	1.8	27.6	18.9	17.3	78.2	50.8	112.7	23.2	27.1	10.9	15.7	0.0	384.2	0.0
60	10.1	0.7	43.4	8.9	49.7	29.2	1.4	18.8	2.7	0.0	0.0	0.0	164.8	0.9
61	17.3	26.2	24.9	17.4	67.7	8.1	7.4	19.5	27.8	3.4	4.8	0.0	224.6	3.9
62	6.6	22.4	20.8	6.4	53.4	16.0	0.9	10.0	6.4	0.0	3.7	2.0	148.6	0.6
63	23.3	6.5	5.8	24.6	37.6	69.1	76.7	18.1	24.7	5.9	14.2	2.8	309.3	0.4
64	69.6	10.2	4.0	5.3	113.9	65.4	65.1	19.0	1.3	0.0	1.7	0.0	355.4	1.4
65	0.0	22.1	54.3	76.3	6.7	78.8	130.7	18.6	3.3	0.0	0.8	0.0	391.5	1.0
66	10.2	7.5	23.2	49.1	69.2	13.6	0.4	8.2	2.6	0.0	0.0	0.0	183.9	2.4
67	0.0	3.0	29.6	33.2	77.8	30.1	80.2	35.9	27.3	0.0	0.7	0.0	317.9	1.4
68	6.6	35.6	15.7	54.1	80.8	1.9	19.5	25.8	26.4	12.5	0.1	0.0	279.0	6.5
69	0.0	0.5	73.4	24.3	32.4	29.3	87.6	41.6	21.4	17.3	0.0	1.4	329.2	2.2
70	0.3	1.9	9.0	22.3	43.4	50.9	5.1	19.4	14.9	16.8	0.0	0.5	184.4	2.1
71	1.1	6.0	23.4	52.3	140.9	65.6	30.9	18.9	0.6	21.3	1.8	0.0	362.7	5.3
72	16.9	5.9	19.4	23.0	56.7	26.1	23.7	18.1	16.3	0.4	1.4	0.0	207.8	2.9
73	6.2	27.1	26.1	59.5	9.2	67.0	3.5	10.8	0.2	0.0	0.0	3.3	212.9	3.6
74	6.5	83.1	16.7	24.6	77.7	36.6	86.7	30.0	0.8	2.8	0.6	0.0	366.0	2.9
75	2.1	49.4	26.8	4.0	48.3	36.6	7.3	24.9	9.9	0.0	12.6	0.0	221.9	2.1
76	63.1	40.3	18.7	4.0	80.3	36.3	48.9	18.5	28.3	9.9	0.0	0.0	348.1	3.0
77	14.0	23.4	16.7	34.6	81.6	50.0	2.4	8.2	28.0	0.0	15.4	0.1	274.2	0.0
78	5.7	22.1	19.3	23.6	83.4	8.5	104.6	18.1	25.2	0.0	2.5	0.0	312.8	9.0
79	1.8	26.4	29.6	15.0	35.8	63.5	58.6	34.9	2.7	2.9	13.5	0.0	284.9	2.6
80	12.8	26.1	3.4	50.7	35.0	24.4	24.4	36.5	14.3	0.0	0.2	0.0	227.7	3.2
81	0.0	22.9	29.6	25.0	39.6	31.8	38.6	18.2	6.0	18.8	13.8	1.9	246.2	3.5
82	0.0	5.9	15.2	68.2	33.2	53.1	10.1	37.7	3.8	5.0	3.5	0.0	235.6	0.0
83	0.0	21.5	58.0	62.8	80.8	26.5	96.0	18.1	9.1	2.8	0.0	0.0	375.5	2.8
84	0.0	6.8	29.5	46.9	146.6	61.1	109.3	20.4	27.9	6.5	2.5	1.2	458.6	0.0
85	68.4	7.3	43.1	5.9	117.0	16.2	4.1	13.3	5.6	0.0	1.8	0.0	282.6	6.9
86	50.3	6.8	11.2	7.9	93.0	80.8	9.4	23.6	4.6	2.5	0.8	0.0	290.9	1.9
87	8.7	6.2	72.9	57.5	4.0	18.9	4.5	18.2	13.0	3.2	2.4	1.3	210.7	0.7
88	23.1	7.8	14.7	6.2	44.4	63.1	62.0	18.6	6.1	20.4	0.0	1.7	268.0	1.1
89	28.8	8.5	9.7	19.7	47.7	36.9	31.6	34.9	27.3	0.0	0.6	3.5	249.2	0.9
90	16.1	14.1	19.4	57.3	51.8	25.5	32.3	18.4	6.1	13.7	6.2	0.0	260.8	7.1
91	11.9	20.4	19.9	20.4	79.1	47.0	93.2	18.8	26.8	1.1	4.8	2.1	345.5	0.0
92	0.0	16.8	19.7	51.2	71.4	6.5	95.5	18.9	6.1	0.3	2.9	0.0	289.2	3.9
93	9.1	17.8	31.4	17.2	52.2	32.0	1.1	37.8	28.7	0.0	0.0	3.8	231.1	2.1
94	23.0	3.4	8.1	4.1	80.8	37.0	6.3	10.8	25.0	0.0	0.0	0.0	198.4	0.9
95	73.7	5.0	8.1	62.6	40.8	56.9	125.4	18.2	10.2	2.3	13.9	1.4	418.4	1.6
96	2.2	7.1	41.2	23.0	94.0	42.3	67.5	32.3	11.6	0.0	16.9	0.0	338.1	0.0
97	19.1	8.2	59.0	26.3	45.4	53.4	32.7	18.0	5.0	0.0	3.2	3.6	273.9	2.4
98	7.4	20.7	20.0	61.7	105.3	19.9	3.2	18.3	4.6	5.5	0.0	0.0	266.6	0.0
99	107.2	0.9	70.4	17.3	29.6	31.0	90.4	19.3	13.8	0.0	0.0	0.0	379.8	4.8
100	13.0	5.7	25.0	21.6	105.8	20.4	6.5	25.1	18.1	0.0	0.0	1.8	243.1	2.7
Avg.	15.25	18.61	27.47	33.02	61.41	39.21	41.5	24.35	11.89	5.262	3.342	0.567	281.9	1.837
Sd.	25.65	16.32	17.51	21.36	32.23	20.78	41.91	9.961	9.746	7.069	4.971	1.027	77.9	2.026

Table 3. Simulated rainfall patterns and B/C ratios for Abeche site of Chad

Case #								Dekad #									
	D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	Total	B/C ratio
							Rainfall mm per dekad										
1	11.9	8.2	9.6	32.4	47	41.2	68.9	62.4	35.8	29.5	42.1	3	6	1.2	5.5	404.7	1.7
2	10.6	7.3	18	44.7	11	29.1	73.3	63.6	118.8	11.6	11.5	4.1	0	0	0	403.6	1.4
3	15.6	8.4	2	34	26	60.3	40.4	115.4	29.2	85	32.2	18	3.3	0	13.8	483.6	2.1
4	12	3.8	12	7.9	50.5	22.5	122.4	36.4	50.2	29.6	14.6	23.1	4.8	0	0	389.8	2.3
5	5.1	16.3	11.6	46.5	25.8	94.5	91.5	92.3	53.1	36.7	10.2	3.1	0	0	5	491.7	0.8
6	5	10.8	35.6	8.5	47.4	46.7	42.6	53.6	47.8	23	16.5	3.3	11.5	10.7	0	363	1.9
7	7.4	1	12.6	30.7	32.7	91.5	69.4	42.9	52.1	3.2	27.9	20.2	1.4	0	2.4	395.4	0.8
8	2.3	7.5	13	37.4	56.2	76.2	82.3	83.2	76.5	41	11.8	10.5	3.3	0.2	0	501.4	2.3
9	7.5	10.4	18.3	25.9	19.6	53.1	120.7	47.7	90.5	34.5	18.2	13.1	14.4	0	0	473.9	
10	2	0.9	10.2	13	10.1	47.2	111.1	82.3	37	23.6	23.3	28.4	12.6	6.3	3.2	411.2	1.9
11	10.9	14.6	7.1	75.3	52.1	31.5	91	24.9	72.5	40	18.4	8.2	14.5	0	2.6	463.6	0.9
12	2.8	13.7	6.4	20.7	32.3	90.2	85.5	75.8	36.1	27.2	1.1	13.4	25.2	10.9	2.9	444.2	1.3
13	1.9	1.5	7.9	34.6	26.4	44.6	84.9	50.6	49.2	14.5	24.2	27.9	15.4	0	0	383.6	
14	9.1	15.3	35.1	38.6	80.7	32.9	70.8	86.1	53	26.7	23.9	16.6	28.3	1.4	2.7	521.2	1.7
15	11.5	10.1	17.2	14.4	11.7	68.8	57.9	75.9	14.2	15.4	5.1	30.6	0	0	0	332.8	2.9
16	13.5	1.8	10.4	10.6	14.3	27.5	63.8	109.3	90.4	24.9	8	20.4	5.6	0	4.4	404.9	1.2
17	6.4	12.2	10.5	41.5	33.8	39.3	19.3	36.3	41.7	22.9	22.2	5.2	0	0	0	291.3	3.1
18	3.3	7	2.7	34.6	43.5	39.4	42	19	14.4	2.6	38.2	29.2	10.8	6.9	0	293.6	1.3
19	1.8	12.1	31.6	30.6	50.7	24.2	45.3	134	72.8	52.3	32.7	4.4	0	3.5	0	496	2.2
20	5.8	16.7	28.1	54.6	77.1	43.5	82.3	77.6	33.5	15.4	10.9	7	0	0	0	452.5	2.2
21	7.6	0.8	10.7	28.1	67.9	10.1	41.3	18.8	144.2	9.6	27.1	21.6	0	0	0	387.8	2
22	12	16.4	15.8	32.9	46.2	69.5	119.1	87.6	90.9	22.6	16.9	15.1	0	0	0	545	0.8
23	7.6	12.6	38.9	56.1	10.4	62.9	108.7	87.1	52.6	32.1	1.7	10.9	0	0	0	481.6	3.1
24	12.7	1	12.9	15.7	51	64.2	69.7	76.9	53.1	47	3.4	0.6	0.5	0.2	0.3	409.2	2.6
25	4.7	16	22	42.9	22.2	30.9	83.5	81.5	39.5	25.3	3.8	7.2	0	5.5	0.6	385.6	1.3
26	0.6	12.6	15.5	13.5	52.5	53.2	21.2	85.3	48.7	17.6	30	5.6	15.1	0	0	371.4	1.8
27	11.5	9	5.2	29	30.5	34.6	89.7	149.3	68.3	37	1.7	7.5	0	2.6	0	475.9	1.9
28	12.5	12.6	13.1	30.2	48.9	37.3	68.1	101.8	42.4	44.2	0.8	17.2	15.8	0	2.9	447.8	1.3
29	5.7	7.9	3	36.1	37.2	53.6	42.5	105.1	36.3	39.5	29.8	6.2	4.4	1.7	13.2	422.2	1.2
30	11.7	17.1	15.8	17.6	14.3	20.3	72.5	38.7	83.6	16	2.2	0.9	0	0	1	311.7	1.5
31	6.9	10.7	22.6	45.5	46.6	34.6	38.7	82.4	124.6	30.6	19.6	23.8	0	1	14.7	502.3	2.8
32	15.7	4.9	6.4	9.4	18.2	39.8	42.4	88.8	32.4	34.9	18.7	11.2	0	0	8.6	331.4	2.6
33	7.7	1.4	7.2	37	36.6	47.4	51.3	54.4	52.9	80.8	15.3	20.2	0	0	0.7	412.9	0.6
34	1.9	4.5	11.6	7.7	48.7	33.9	50.7	97.8	63	50.2	19	34.2	3.8	0	0	427	1.6
35	12.9	6.7	12.2	17.9	24.8	74.5	38.9	64.8	37.4	26.3	0.4	9.3	0	15.1	0.3	341.5	0.4
36	2.4	4.1	4.8	16.6	9.3	43.7	49.5	88	24.2	75.5	41.8	19.4	7.3	10.4	0	397	3.7
37	15.5	11.5	2.6	8.1	21.4	22.4	61.4	82.2	88.8	11.1	11.3	16.9	6.1	0	2.1	361.4	2.5
38	4.2	6.4	11.1	29.3	61.7	39.2	112.9	40.8	53	5.2	8.7	13.9	0	16.8	0	403.2	4.4
39	2.7	3.6	11.7	59.4	8.5	21.9	62.5	92.7	40	19.1	22.7	33.6	0	0	11.5	389.9	2.2
40	7.1	16.4	15.2	51.7	72.5	23.3	22.2	141.7	52.2	5.9	28.9	21.4	6.1	10.2	0.4	475.2	1.9
41	0.5	2.3	21.3	51.5	35.9	25.2	34.5	106.4	44.8	66.9	5.8	3.3	4.4	4	0	406.8	1.7
42	3.3	12.2	19.5	83.1	21.2	32.6	105.7	84.7	84.6	28.2	11.4	5.5	0	0	2.3	494.3	1.8
43	11.9	6.1	13.4	21.3	12.2	40	31.8	46.6	52.9	10.5	8.4	33.3	13.7	0	1	303.1	1
44	3.2	16.9	3.2	50.6	37.1	41	56.2	82	52.2	28	24.5	13	8.2	0	0	416.1	1.8
45	2.6	1.4	5.1	18.3	23	57.9	121.5	118.9	77.4	16.7	24.5	5.5	17.5	16.6	0	506.9	1.1
46	1.2	9	7.2	25.9	15.6	15.4	80.5	72.4	47.1	26.2	22.5	6.3	28.1	8.8	0	366.2	2.1
47	11.1	1.2	13.6	41.4	80.3	64.8	36.7	108.9	45.7	46.9	20.6	10.3	7.2	0	0	488.7	2.9
48	6	18.3	39.9	9.6	54.3	79.7	39.6	41.6	88.4	6.1	7.9	30.9	8.2	0.1	5	435.6	1.9
49	4.8	13.2	9.8	42.3	25.2	41.3	87.3	35	35.2	17.2	22.2	29.2	0	0	0.3	363	3.1
50	0.4	5.8	12.4	45.7	26.4	58.1	61.1	81.8	56.6	18.1	14.2	4.3	15.9	0	0	400.8	3.5

Table 3, continued

51	3	16.6	27.3	31.4	48.8	26.8	86.7	108.1	87.7	5.2	21.5	2.9	0	17.8	5.8	489.6	0.9
52	0.7	9.9	13.8	9.1	39.6	31.9	79.3	32.3	123.5	29.1	33.3	5.6	9.8	0.4	0	418.3	1.3
53	5.4	12.8	5.8	21.4	44.3	25.1	48.9	64.7	36.3	34.8	6.3	0.3	0	0	2.6	308.7	0.8
54	2.6	17.3	3.3	83.6	30.1	77.7	66.5	60.9	67.7	30.8	2	1.4	0	0	2.1	446	2.8
55	13.1	5.6	28.7	44.7	12.8	24	19.5	103.4	42.3	34	25	1.2	0	0	2.7	357	1.9
56	5.4	3.1	2	53.7	32.6	48.4	72.7	64.8	52.5	26.7	42.9	22.5	5.3	0.2	0	432.8	3.2
57	6.9	1.1	29.2	92	51.2	65.2	75.5	134.2	48.9	23.4	19	17.5	0	0	13.4	577.5	0.6
58	2.2	8.4	6.6	37.8	10.9	85.2	69.1	89.8	26.2	35.2	14.5	20.7	0	2.6	0.4	409.6	1.8
59	9.1	4.5	4.3	17.4	76.4	69.8	89.5	40.8	84	16.7	23.2	17.9	0	0	11.7	465.3	0.9
60	14.5	12.6	6.7	32.4	33.3	35.6	57.7	91.2	75.6	32.3	26.9	5.9	6	0	0	430.7	2.6
61	7.2	4	11.8	44.7	54.9	79.3	92	50.3	14.9	10.3	14.8	16.4	8.9	0	0	409.5	3
62	4.2	7.6	4.6	37.3	54.1	24.8	67.3	28.3	32.8	15.9	35.2	21.1	0	0	0	333.2	1.9
63	9.9	0.9	20	20.9	32.1	56.8	30.2	19.6	52.5	43	13.5	14.5	0.7	1.3	12.9	328.8	1.7
64	11.9	10.6	7	26.9	9.9	71.5	43.3	90.9	67.8	10.7	20.9	12.1	0	19.7	6.3	409.5	2.2
65	15.8	17.7	6.6	8.8	32.8	44.9	19.9	92.5	51	4.5	14.6	13.3	8.9	0	0	331.3	1.5
66	2.2	5.4	14.6	14.1	40.5	49.4	90.2	60	29.3	44.1	16.8	11.2	1.2	0.6	0	379.6	3.4
67	15.6	5.5	10.6	25.6	44.2	41.2	79	20.4	72.1	21.5	20.8	7.9	0	0	0	364.4	3.1
68	9.8	13.6	15.9	37.2	48.8	23.6	26	93.4	53.1	18.7	34.4	4	2.9	15.7	2	399.1	1.5
69	15	10.3	20.8	55.3	33.5	11	40.4	49.1	41	35.3	22.5	12.2	0	0	0	346.4	3
70	4.9	8.3	36.6	23.9	67.5	54.4	60.9	84.2	51.2	38.6	6.2	5.9	1.5	3.4	2.5	450	1.9
71	15.5	17.1	10	29.7	44.9	57.5	43.9	63.6	108.8	78.5	7.7	2	6.3	0	0.8	486.3	2
72	8.9	1.4	14.4	15.5	20.9	33.8	108	87.8	135.8	16.2	34.2	9.2	22.1	0.4	0	508.6	0.7
73	15.9	8.8	19.9	24	32.5	15.2	109.9	84.2	92	14.7	3.8	5	0	1.3	0	427.2	1.3
74	14.5	1.1	6.2	20.9	33.8	69.3	40.6	23.6	47.4	53.4	3.8	1.2	17.9	0	0	333.7	1.6
75	3.3	6.8	5	19.9	13.6	43.2	23.6	92	36.2	57.2	12.9	35.5	3.2	3.1	14.4	369.9	0.7
76	4.1	3.3	9.7	13.4	55.5	61.8	40.8	64.1	94	50.8	38.3	35.8	0	0	0	471.6	1.3
77	1.8	4.6	15.8	24.4	39.4	88.5	73.8	30.5	59.5	33.7	1.1	32.2	0	1.1	0	406.4	3.2
78	11.6	9.9	41.3	12.4	53.3	25.7	42.8	45.1	36	42.6	25	8.3	28.4	0	0	382.4	0.8
79	0.5	6.8	20.2	15.5	32.8	10.9	67.3	44	69.6	22.2	42	10.9	0	0	0	342.7	2.9
80	15.7	11.2	15.9	16	14.2	95.2	41.3	127.1	52.5	25.5	15.1	28.1	0	0	0	457.8	2
81	5	4.4	8.5	33.1	68.3	60	40.8	65.2	83.7	51.8	17.9	20.2	13.1	1.7	0	473.7	2.3
82	0.8	3.7	2.8	87.4	81.3	59.6	36.9	89.6	51.9	84.2	7.3	5.8	22.6	0	3.5	537.4	
83	9.6	7.6	8.1	10.8	35.7	82.8	76.3	45.5	53.2	16	6.6	7.3	0	0	0	359.5	1.6
84	6.7	8.2	6.9	9.4	9.9	88	70.7	62.6	25.9	21.3	16.4	4.8	12.8	2.7	0	346.3	0.2
85	1.4	3.8	3.6	7.2	29.3	78.6	34.5	118.3	69.3	21.4	18.7	31.1	0	0	0	417.2	2.5
86	9.4	1.2	25.2	19.9	32.5	11.2	83.9	50.8	51.8	42.6	7.4	1.5	0	6.3	0.2	343.9	2.5
87	5.3	12.4	26	42.7	26.2	31	66.8	60.8	18.9	8.1	7.9	11.2	4.2	7.7	0.7	329.9	1.8
88	1.4	13.8	23	17.7	54.3	44	70.4	108.9	79.7	13	42.1	11.9	0	0	0	480.2	0.7
89	0.8	1.4	6.9	79.9	54.3	68.9	96.9	63.8	23.3	50.7	23.9	28.6	8.6	0	0.4	508.4	
90	9.4	5.3	4.9	29.1	15	29.9	75.8	81.5	40.9	58.3	25.6	13.4	0	1	0	390.1	1.5
91	6.1	5.8	11.1	28.4	79.7	33.1	40.8	79.8	53	3.1	20.9	10	5.7	0	0	377.5	0.4
92	3.1	15.4	29.6	48.3	36.4	14.7	99.4	77.4	30	0.4	14.2	34.6	0	0	0	403.5	3.5
93	5.9	6.8	7.2	16.7	35.3	47.6	73.5	78.4	43.1	32	9.6	2.3	27.6	0	0	386	1.3
94	11.2	6.2	12.5	20.3	50.3	54.5	102.5	74.9	19.3	23.1	23.4	19.4	11.3	0.9	0	429.8	3
95	13.4	6.2	3.9	17.7	75.2	50.9	39.7	87.8	45	87.1	11	31.2	15.9	0	0	485	1.7
96	3	2.9	15.3	43.4	30	13.9	63.3	94.8	82.4	12	2.7	20.7	0	0.6	0.8	385.8	2.2
97	10.6	8.6	7.7	8.7	32.7	12	109.9	92.2	48.9	29.9	24	36.1	10.4	0	0	431.7	1.3
98	3	4.5	6.2	21.6	56.4	36.2	25.8	86.5	42.5	33.4	20.1	10.8	1.7	0	0.9	349.6	1.5
99	10.2	1.1	7.9	73	23.4	52.7	101.6	75.1	103.9	51.8	25.8	34.3	11.8	0	5.7	578.3	2.1
100	11	1.6	15	20.2	32.2	41.2	99.6	88.4	133.4	29.2	9.9	16.4	0	4.3	0	502.4	2.6
50.5	7.335	8.099	13.71	31.56	38.07	46.36	65.83	74.37	58.24	30.3	17.92	14.62	5.882	2.269	1.972	416.5	1.899
28.87	4.691	5.097	9.282	19.33	19.06	21.82	27.17	28.7	27.69	19.34	10.94	10.33	7.677	4.548	3.738	63.84	0.852

Table 4. Simulated rainfall patterns and B/C ratios for Mongo site of Chad

Case								Dekad #											B/C
#	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total	ratio
								Rainfall mm per dekad												
1	14.5	8.0	10.5	13.8	27.0	29.7	40.6	79.1	83.6	49.7	114.9	199.4	96.9	48.8	36.4	23.1	4.2	1.6	881.7	2.1
2	1.6	15.2	16.8	29.2	1.5	55.2	47.9	59.0	43.1	143.7	63.5	62.5	59.8	63.6	23.8	18.2	19.0	14.1	737.5	1.1
3	27.6	1.8	5.7	17.0	17.6	17.1	66.1	81.2	60.3	141.4	167.0	108.9	35.4	59.6	28.9	6.4	6.4	3.5	851.8	3.8
4	17.3	9.0	6.7	7.7	20.5	55.1	58.7	83.4	95.4	61.9	203.6	190.8	70.2	73.3	16.6	2.3	14.1	2.6	989.0	0.6
5	24.9	3.9	31.3	13.1	12.8	62.7	40.0	57.6	101.3	128.7	156.2	78.2	34.9	29.3	29.0	6.9	9.0	1.5	821.4	3.8
6	14.6	25.1	34.9	8.9	52.0	30.0	79.8	62.6	84.4	94.2	62.4	55.2	43.4	50.8	29.0	21.3	4.5	0.3	753.5	3.7
7	11.4	13.8	21.3	36.6	8.4	21.7	94.8	72.0	82.0	105.4	98.3	124.9	40.9	36.1	65.6	9.6	1.0	0.8	844.6	3.7
8	5.1	17.5	1.4	16.8	11.2	49.4	59.2	69.9	100.9	81.9	150.9	84.7	44.1	31.1	75.5	23.2	6.2	4.0	832.9	1.7
9	6.1	15.7	13.0	22.3	25.6	62.4	52.0	69.7	94.0	85.7	139.5	62.0	65.3	14.2	31.1	11.0	3.5	18.8	791.8	3.2
10	1.0	6.9	24.7	22.9	10.5	50.3	43.4	57.1	88.9	205.1	74.0	56.5	71.3	68.7	33.9	8.5	8.8	13.0	845.8	0.2
11	1.9	5.5	40.5	15.1	6.9	30.1	44.6	92.5	53.7	84.6	187.0	172.8	65.4	71.4	13.3	13.4	4.5	2.2	905.1	3.4
12	4.1	14.1	25.5	52.8	4.5	26.5	73.8	88.7	91.3	50.2	168.1	97.2	27.0	17.5	47.6	11.7	3.5	3.3	807.1	1.1
13	5.8	4.4	10.8	18.1	63.2	62.6	51.0	58.3	49.5	98.2	96.9	75.7	96.3	18.2	43.1	6.3	6.5	2.1	766.9	4.3
14	12.4	9.1	8.5	1.7	10.7	44.4	64.3	64.2	56.5	150.7	98.9	48.1	40.7	40.0	42.8	6.1	1.2	3.3	703.5	0.9
15	11.7	11.5	9.6	7.5	14.3	39.6	55.5	43.3	90.7	63.4	85.9	124.6	72.6	50.1	13.2	24.8	1.9	4.9	724.9	2.3
16	1.9	16.1	10.7	10.8	13.0	37.9	35.9	76.9	86.2	127.5	181.2	102.0	49.3	22.4	97.9	13.6	3.1	2.8	889.0	2
17	6.0	10.4	24.1	16.8	37.7	23.3	87.1	63.4	29.7	77.1	59.6	116.9	58.8	29.0	37.8	5.6	9.6	17.9	710.7	3.3
18	11.1	7.9	8.3	12.8	1.1	25.5	37.7	31.5	81.0	70.0	96.3	113.4	29.1	68.6	37.8	2.8	12.2	1.0	648.1	0.7
19	4.7	15.9	18.8	40.8	13.8	55.7	59.2	43.6	90.7	64.5	92.5	81.8	80.0	48.3	40.1	5.9	2.2	1.7	759.9	4.2
20	5.9	20.8	34.2	24.6	28.5	22.3	47.8	30.5	58.1	115.5	54.2	62.6	38.5	45.0	41.5	7.9	3.8	5.0	646.6	3.5
21	2.9	3.0	1.8	23.7	17.1	61.1	27.5	54.4	67.1	51.8	126.9	101.0	16.5	66.4	13.3	25.5	2.4	17.0	679.3	3.4
22	4.9	5.7	8.5	4.6	1.1	5.5	31.6	84.3	42.1	123.0	66.6	53.8	46.6	30.6	13.1	3.3	1.8	1.0	528.1	1.6
23	8.7	12.7	10.8	20.0	18.8	33.1	44.9	37.8	99.5	115.2	133.8	154.5	60.5	37.5	45.7	13.7	14.1	3.0	864.1	2.2
24	4.3	2.1	7.9	17.0	14.3	19.5	43.2	49.0	70.5	77.5	155.7	50.8	49.1	51.8	25.5	19.6	2.6	4.0	664.3	3.4
25	24.3	22.0	10.4	4.4	3.2	34.8	66.3	70.3	32.4	161.8	110.5	80.7	70.1	84.7	75.7	22.7	0.5	2.7	877.4	1.3
26	12.4	9.8	25.9	27.8	20.8	18.8	52.1	52.1	47.8	98.3	108.2	46.4	78.3	64.5	18.8	21.9	5.8	0.5	709.9	3.1
27	2.8	18.7	28.4	61.7	17.7	32.3	54.8	79.6	86.7	88.7	111.6	73.9	47.7	94.1	16.2	21.0	11.3	0.5	847.4	4.2
28	18.3	6.6	32.1	2.1	20.6	63.1	58.9	48.0	57.7	113.5	138.6	198.4	97.9	49.2	22.7	3.5	2.4	6.9	940.5	2.1
29	1.7	3.9	17.3	8.3	3.0	15.8	66.2	43.3	30.0	79.1	182.7	159.7	49.1	39.8	18.3	9.8	0.9	3.9	732.8	2.1
30	28.1	4.4	3.6	7.2	13.8	28.5	59.7	53.5	48.5	114.3	52.2	106.6	31.4	59.1	30.1	24.4	16.8	2.9	685.1	2.3
31	6.3	15.3	19.7	1.4	20.1	57.2	31.5	90.6	89.3	70.9	109.0	79.3	94.9	41.3	24.8	4.2	1.2	1.8	758.7	3.1
32	14.4	16.7	38.9	8.7	21.4	29.2	71.4	67.4	86.6	96.9	172.5	66.8	79.4	81.9	13.2	12.1	1.0	3.4	881.7	2.1
33	8.3	1.3	25.6	1.8	31.1	10.7	42.7	43.6	98.2	70.5	90.6	84.4	88.4	49.2	41.1	24.2	3.4	2.6	717.8	3.4
34	17.5	1.4	1.2	6.1	25.1	51.5	67.1	28.3	56.3	181.8	133.9	83.7	90.6	32.1	19.3	7.8	6.2	1.9	811.7	4
35	18.8	13.8	31.3	19.6	13.6	48.8	34.9	64.1	86.2	86.7	88.1	100.1	25.2	31.4	43.9	23.3	1.5	1.5	732.8	3.1
36	11.6	14.0	1.7	1.1	28.9	26.0	44.8	67.8	55.0	82.3	127.1	152.3	40.7	31.1	48.0	10.7	3.5	2.9	749.5	2.8
37	12.5	9.0	1.3	13.8	18.2	56.8	37.1	44.6	76.3	116.6	123.3	92.4	32.4	35.0	39.2	26.0	10.0	3.0	747.3	3.9
38	12.5	1.8	32.4	40.5	16.6	41.9	54.1	85.9	71.9	114.1	70.0	77.8	86.4	33.7	32.9	16.9	8.4	0.7	798.6	3.2
39	6.8	13.1	24.6	9.0	23.8	53.6	28.3	40.9	70.8	101.3	83.4	47.5	25.3	41.5	15.1	8.6	19.5	4.5	617.5	2.2
40	11.8	18.8	10.5	6.2	6.0	18.1	33.0	76.4	85.2	107.3	97.2	46.6	69.5	65.6	42.4	7.3	3.8	3.4	709.0	0.8
41	5.8	8.0	6.1	36.6	4.7	1.4	43.2	26.8	95.4	57.2	200.7	84.8	14.6	43.1	13.2	1.0	17.5	4.6	664.5	1.9
42	6.8	8.4	1.5	9.1	61.1	17.8	26.6	42.6	63.7	90.8	143.6	72.7	74.3	57.7	38.4	20.4	2.5	1.2	739.0	3.4
43	6.4	3.8	29.9	38.1	33.4	42.3	58.6	53.1	66.0	102.2	129.9	103.3	94.4	30.2	15.2	21.6	9.4	2.0	839.6	3.6
44	9.2	36.4	36.0	20.8	25.4	22.1	53.7	29.3	73.0	146.2	174.6	98.9	30.3	18.4	25.2	1.8	2.0	3.3	806.5	4.9
45	12.5	1.6	2.3	7.7	2.3	61.9	75.3	54.8	100.6	83.6	148.7	53.2	34.4	65.9	31.1	7.0	11.9	7.1	761.9	1.6
46	9.9	42.2	5.3	36.9	27.0	28.3	58.6	48.0	64.3	144.9	54.5	47.2	39.6	46.7	13.8	1.6	0.4	14.7	683.8	4.2
47	17.7	13.7	22.9	19.1	36.5	30.5	62.8	88.8	34.7	64.3	89.6	108.6	85.9	27.2	23.5	16.5	7.3	4.4	753.6	3.2
48	3.5	14.4	9.1	14.4	33.5	9.9	67.5	58.5	84.1	47.2	142.2	134.5	15.5	38.8	36.7	26.4	2.6	9.5	748.4	2.6
49	5.2	14.2	6.7	13.8	10.7	35.1	74.4	60.0	73.6	65.9	114.2	96.8	53.7	24.9	61.5	4.7	4.7	4.4	724.4	1.7
50	11.2	23.5	10.6	3.4	38.8	59.0	66.4	56.9	71.0	82.2	107.5	145.4	17.7	65.2	41.8	6.8	10.5	4.1	822.0	2.9
51	13.7	17.7	20.2	33.2	49.4	33.1	71.6	75.5	91.0	124.3	109.8	49.9	48.4	28.7	56.4	1.2	11.9	1.1	837.1	4.2

Table 4. continued

51	51	13.7	17.7	20.2	33.2	49.4	33.1	71.6	75.5	91.0	124.3	109.8	49.9	48.4	28.7	56.4	1.2	11.9	1.1	837.1	4.2
52	52	19.1	27.6	10.9	14.6	60.5	25.1	42.8	48.1	62.3	143.2	150.6	95.1	50.6	15.1	70.4	22.9	3.5	12.6	875.0	3.2
53	53	26.8	13.4	10.9	5.3	60.3	43.9	55.8	94.4	72.2	85.4	119.1	46.7	58.8	37.5	23.5	4.4	19.8	3.9	782.1	1.6
54	54	10.3	14.2	18.0	8.7	11.5	16.8	30.5	43.5	38.1	169.0	87.6	82.5	29.7	56.1	29.3	10.7	4.4	4.4	665.3	0.9
55	55	5.5	33.4	22.7	41.2	6.0	16.0	66.1	76.4	68.2	97.7	155.0	47.2	61.9	59.4	26.2	2.6	4.2	0.7	790.4	3.9
56	56	5.4	37.1	24.3	8.9	24.3	40.7	35.9	56.1	65.8	189.9	87.9	52.7	70.4	67.9	27.7	25.8	1.0	3.2	825.0	3.7
57	57	4.4	14.2	37.8	1.7	28.1	58.8	51.5	41.8	54.6	64.4	93.7	111.9	40.9	13.2	23.8	13.2	15.2	2.8	672.0	2.2
58	58	3.1	13.6	10.9	9.9	13.4	32.1	74.1	55.3	97.4	98.2	68.4	182.4	34.9	52.2	13.2	25.8	2.9	4.7	792.5	1.9
59	59	1.6	1.6	7.0	7.3	31.6	20.5	81.1	80.3	56.6	78.8	93.5	66.0	53.7	43.3	13.3	6.2	4.0	1.0	647.4	4.5
60	60	39.7	36.9	1.7	16.4	21.0	29.4	70.0	78.4	101.1	78.2	164.9	146.7	56.4	27.4	40.4	5.9	1.5	2.5	918.5	4.1
61	61	12.5	13.7	11.0	2.9	54.7	29.3	34.2	51.4	63.5	57.8	98.9	194.1	98.7	15.9	42.9	7.4	4.3	8.0	801.2	3.1
62	62	11.9	4.2	23.5	46.2	12.6	35.9	35.7	88.2	67.9	46.0	97.0	107.9	19.5	44.1	13.2	9.5	5.3	1.9	670.5	3.8
63	63	16.1	8.2	9.8	8.6	4.0	57.1	47.9	53.6	101.7	52.0	81.9	178.0	55.1	80.6	14.8	23.3	1.4	2.9	797.0	0.9
64	64	42.4	18.1	8.3	11.3	49.2	15.7	31.2	71.0	96.7	169.1	57.3	96.1	88.9	26.6	17.0	22.4	8.8	1.9	832.0	0.6
65	65	27.9	39.8	6.2	35.7	32.3	53.9	45.1	47.8	73.0	132.8	117.6	96.9	46.7	39.9	18.2	11.8	3.0	3.8	832.4	0.5
66	66	11.6	3.4	4.4	58.1	9.2	50.5	57.7	77.2	87.7	106.1	149.1	56.6	74.9	36.4	49.9	1.9	2.5	3.3	840.5	4.1
67	67	3.2	35.6	34.6	35.4	3.2	58.0	42.4	36.6	49.8	177.3	69.1	74.3	43.9	51.4	22.2	9.7	1.4	15.5	763.6	3.6
68	68	29.7	5.4	11.1	41.2	10.3	47.0	37.8	67.8	58.1	89.4	68.7	120.5	37.6	27.2	74.5	9.8	17.6	4.8	758.5	4.1
69	69	9.8	8.7	10.9	11.7	16.9	18.9	53.7	49.2	101.3	127.6	163.4	76.8	55.5	97.3	22.8	0.6	2.9	0.4	828.4	2.3
70	70	11.4	5.4	11.0	31.7	50.8	18.6	38.3	48.6	51.5	68.9	148.9	162.4	31.2	80.9	14.9	7.6	4.1	1.9	788.1	4.1
71	71	14.7	3.9	35.4	19.9	25.4	22.1	36.4	50.3	63.1	183.2	181.6	137.8	27.7	38.9	30.9	13.9	14.3	2.3	901.8	3.7
72	72	5.8	19.7	7.8	15.3	31.4	17.7	42.0	54.9	90.5	126.6	192.3	80.0	16.4	17.8	57.3	17.9	0.7	1.5	795.6	6.1
73	73	1.2	9.1	10.0	14.6	43.4	5.7	32.5	70.7	49.3	97.5	133.1	70.4	35.6	24.8	81.3	8.2	11.3	15.3	714.0	6.1
74	74	1.3	21.7	18.2	6.2	11.8	26.4	51.8	63.1	93.8	58.6	154.2	74.5	22.7	31.9	25.5	5.8	0.4	1.7	669.6	0
75	75	7.6	26.7	10.0	14.0	44.0	40.0	38.1	90.6	49.5	92.9	106.4	70.2	31.9	22.9	13.1	26.2	0.6	0.6	685.3	3.9
76	76	36.8	3.9	17.2	24.0	50.1	15.7	47.1	54.4	28.8	133.7	47.1	106.7	15.6	75.7	42.7	23.4	5.3	2.9	731.1	5.1
77	77	5.0	8.1	42.8	18.7	16.1	42.5	55.1	33.8	62.1	99.8	156.9	82.7	67.7	19.5	49.6	10.6	13.1	3.0	787.1	2.3
78	78	20.4	4.6	7.9	3.1	14.6	60.2	70.9	79.7	93.3	109.7	108.2	63.5	34.2	16.5	52.7	23.6	15.3	0.5	778.9	2.3
79	79	11.4	7.8	10.6	16.9	28.2	19.0	61.0	60.8	84.8	67.2	47.8	120.6	86.9	49.2	13.2	9.7	1.1	5.1	701.3	2.2
80	80	20.5	17.3	1.8	10.6	27.9	31.1	52.5	90.1	96.0	147.3	98.4	54.5	25.6	25.9	47.6	3.5	0.6	0.5	751.7	2.9
81	81	11.5	3.5	8.0	17.7	6.7	35.7	61.9	89.2	48.0	50.7	205.1	132.4	87.4	16.0	43.6	20.8	7.4	1.8	847.4	0.8
82	82	2.0	27.9	24.9	39.8	25.8	4.2	92.2	83.8	90.5	69.7	202.1	134.5	36.1	58.7	39.1	9.8	1.0	11.7	953.8	0.8
83	83	18.5	27.6	6.6	9.2	58.1	19.2	40.1	46.2	53.2	76.0	84.5	62.5	40.2	23.9	25.8	2.1	10.3	8.2	612.2	2.7
84	84	4.4	8.7	15.3	12.5	62.5	6.8	32.8	98.6	81.6	87.2	127.9	57.7	62.3	39.8	22.0	14.3	0.4	5.1	739.9	2.5
85	85	11.3	6.0	2.7	9.2	12.8	1.9	61.3	94.9	101.0	169.9	127.3	133.2	57.8	15.5	25.1	7.3	3.9	0.4	841.5	1.3
86	86	9.6	24.5	7.0	22.6	23.2	32.7	37.3	77.3	59.7	205.8	138.6	47.9	92.5	41.4	89.0	4.2	2.3	1.3	916.9	3.9
87	87	11.6	41.0	14.3	40.5	3.9	36.2	28.7	59.8	58.0	51.7	164.9	143.2	69.7	22.0	15.9	11.3	1.9	1.6	776.2	3.9
88	88	6.6	15.4	36.8	18.4	14.7	3.9	52.9	56.0	67.5	56.8	105.4	72.9	44.0	25.9	39.2	11.7	19.9	2.3	650.3	2.8
89	89	12.0	21.6	30.9	24.1	37.7	17.8	49.7	53.0	46.5	153.8	54.4	52.0	51.3	54.8	28.0	8.1	13.1	2.9	711.7	2.4
90	90	11.3	7.5	10.9	2.2	15.4	44.4	59.7	51.1	66.4	79.1	46.6	47.5	40.7	15.4	52.1	5.3	0.5	4.7	560.8	2.3
91	91	1.6	8.5	20.0	32.2	5.5	56.8	31.1	96.6	80.4	119.7	145.5	79.0	71.0	17.5	16.5	22.7	1.8	3.0	809.4	3.2
92	92	18.1	39.6	36.2	6.4	24.9	11.7	78.2	72.6	58.1	79.9	177.9	83.4	44.8	50.4	25.7	4.1	1.3	5.6	818.9	4
93	93	11.3	6.0	8.1	34.8	48.1	26.0	40.4	76.3	74.9	83.4	84.9	87.5	41.3	95.0	54.1	6.4	5.8	2.5	786.8	4.1
94	94	3.2	12.1	17.7	54.9	39.3	29.4	33.5	66.8	69.4	137.4	187.3	49.2	85.6	62.6	18.1	26.1	14.7	2.8	910.1	4.2
95	95	11.4	3.5	30.0	21.7	16.7	43.4	89.5	91.7	88.1	85.3	121.2	62.2	30.1	17.1	26.7	11.0	9.3	3.2	762.1	3.1
96	96	35.2	2.5	18.9	5.2	24.3	12.3	48.8	65.9	37.3	141.8	92.2	47.5	90.5	78.2	18.1	8.1	0.3	4.8	731.9	2.7
97	97	15.2	42.0	34.3	18.5	39.9	13.2	40.7	56.9	95.9	89.3	124.1	96.3	91.4	57.0	15.7	9.6	10.5	2.0	852.5	3.7
98	98	23.7	4.7	16.2	15.0	24.8	31.2	40.9	72.7	100.9	84.5	49.5	89.2	72.0	13.6	13.0	22.6	5.8	2.9	683.2	3.2
99	99	11.3	10.5	41.4	60.9	30.9	54.5	66.5	65.5	76.5	58.0	104.6	65.5	51.4	66.7	36.9	3.0	13.9	2.9	820.9	5.3
100	100	38.5	5.5	42.4	35.1	1.8	22.7	89.5	83.1	101.1	114.3	127.5	50.1	35.7	93.4	51.0	10.5	16.7	7.4	926.3	4.7
Avg		12.1	13.9	17.0	19.3	23.5	33.0	52.4	63.3	72.3	102.0	118.2	93.2	53.8	44.1	33.7	12.3	6.3	4.2	774.6	2.87
Std		9.1	10.6	11.6	14.5	16.2	17.0	16.3	17.8	20.1	38.3	41.8	39.8	23.4	21.5	18.5	7.9	5.5	4.1	86.8	1.29

Table 5. B/C ratio groups and rainfall patterns for Ati Abeche and Mongo sites of Chad

Ati: B/C ratio groups and rainfall patterns

B/C							Dekad #										
range		D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	Total	Total
							Rainfall mm per dekad										
0-1.9	AVG	13.71	6.966	21.28	11.04	25.85	28.7	46.71	39.01	46.85	25.14	10.79	4.413	3.519	0.61	289.9	289.9
	STD	19.13	6.093	28.83	9.871	21.22	23.13	28.41	21.18	43.32	10.25	9.528	6.603	4.914	1.013	90.05	90.05
2-4	AVG	12.59	3.779	11.99	20.65	28.41	29.93	56.3	36.31	27.09	24.21	11.2	5.207	3.009	0.599	273.4	273.4
	STD	18.45	5.608	20.08	16.57	15.49	19.43	28.32	19.5	32.14	10.04	8.975	6.958	4.845	1.122	52.82	52.82
>4	AVG	8.812	10.54	23.92	19.72	26.14	37.48	77.58	31.41	42.24	23.27	12.08	7.937	1.556	0.186	328.9	328.9
	STD	17.5	6.605	35.68	20.48	18.23	20.4	31.97	25.25	38.31	8.725	8.818	8.235	1.875	0.525	52.92	52.92
ALL	AVG	12.64	6.066	17.71	16.12	26.95	30.28	54.48	36.96	38.01	24.52	11.12	5.174	3.067	0.554	287.7	287.7
	STD	18.72	6.367	27.01	15.26	18.69	21.49	30.42	21.19	39.52	10.01	9.223	7.054	4.662	1.025	74.36	74.36

Abeche: B/C ratio groups and rainfall patterns

							Dekad #										
B/C		D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	Total
range					Rainfall mm per dekad												
0-1.5	AVG	1.031	7.797	8.763	12.47	27.18	36.52	45.51	67.53	75.89	61.81	26.66	18.36	13.09	6.926	2.831	432.7
	STD	0.357	4.1	5.242	8.257	17.53	17.59	22.34	28	27.44	28.7	17.41	11.63	10.21	8.681	5.361	68.15
1.6-3	AVG	2.178	7.914	7.958	14.76	31.59	39.75	45.8	60.52	78.13	58.79	32.31	17.39	14.75	5.102	1.974	436.2
	STD	0.425	4.973	5.129	9.744	19	20.05	22.81	24.78	29.64	28.67	19.13	10.14	10.21	6.886	3.768	61.48
>3	AVG	3.391	4.9	8.027	14.55	36.15	32.72	47.88	77.63	56.55	46.06	27.04	18.78	17.39	2.7	2.645	402.9
	STD	0.375	3.948	4.175	10.2	14.06	14.25	17.42	26.01	23.71	14.32	19.35	13.11	10.39	4.819	5.352	47.59
ALL	AVG	1.899	7.335	8.099	13.71	31.56	38.07	46.36	65.83	74.37	58.24	30.3	17.92	14.62	5.882	2.269	433.3
	STD	0.852	4.691	5.097	9.282	19.33	19.06	21.82	27.17	28.7	27.69	19.34	10.94	10.33	7.677	4.548	64.13

Mongo Simulated rainfall patterns and B/C ratios

											Dekad #									
	B/C	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
	range										Rainfall mm per dekad									
Avg	0-2	13.4	13.9	16.2	31.8	29.9	30.3	51	59.8	67.2	95.53	111.5	78.31	46.3	47.7	38.3	9.01	7.17	4.03	728.2
Sd		11.8	11.3	11.4	16.3	16.1	15	18.6	19.6	24.04	32.69	45.61	32.89	21.8	26.4	19.7	6.99	5.27	3.86	222
Avg	2.1-	12.1	15.1	18.3	24.9	26.7	31.7	49	59.9	66.09	96.53	114.9	82.91	51.6	43.2	33.2	12.5	6.26	4.92	734.3
Sd		9.03	12.3	11.6	14.5	15.6	15.5	18.6	20	21.71	44.15	44.01	32.36	22.9	21.1	18.6	8	5.31	5.83	195.8
Avg	>4	12.5	12.5	18.3	24.4	27.8	27.2	46.8	49.9	56.75	74.35	97.66	66.29	40.8	40.5	36.8	10.3	8.03	5.93	607.5
Sd		10.3	7.8	11	12.9	14.7	16.1	21.3	21.8	26.43	44.01	46.65	24.23	22.1	21.9	16.6	6.88	6.78	7.02	289
ALL	3.2	11.8	13.7	17.8	20.1	25.1	31.6	49.9	59.1	67.9	93.7	112.2	89.0	51.9	41.9	32.9	12.3	6.5	4.4	728.3
Sd	1.2	8.3	10.3	11.5	13.9	14.8	15.9	17.5	19.7	21.7	38.9	42.7	39.7	24.1	20.6	18.0	7.8	5.6	4.7	181.6

Table 6. Printouts of GHLSIM results for selected cases of simulated weather patterns of Ati, Abeche and Mongo sites of Chad

Ati: low B/C case #14 with original grasshopper density of 25/m2

```
                Report File From GHLSIM

File created at: 18:00 on April 23, 1991

Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)       : /  / 25
Ha sampled                                     : Unknown
Crops                                          : millet
Crop stage                                     :  LAIT/PATEUX
Source of Yield data                           : Predicted
Treated Ha                                     : 16600 HA
Treatment agent                                : MV
Risk index                                     :  2.41
Efficacy reported                              : 90% (default)
Origin of sample message                       : H.KHOURI/BATHA
Remark                                         :

Modified sample and treatment dates to # days after emerge: 51
Julian day & date of sample and treatment:   260 Sep-17-87

Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE    OSE mdl:  TRUE   TRUE
 Days until match:   9

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-28  Jul-28  Jul-28  Jul-28  Jul-28  Jul-28
Seedling:          Aug-8   Aug-9  Aug-12   Aug-9  Aug-10  Aug-13
Tiller/Spike:     Aug-17  Aug-21   Sep-2  Aug-21  Aug-24   Sep-5
Milky Grain:       Sep-1   Sep-7   Oct-7   Sep-7   Sep-9  Oct-16
Dry Grain:         Oct-1   Oct-9   Nov-8   Oct-7   Oct-6  Nov-18
Harvest:          Oct-13  Oct-25  Nov-24  Oct-25   Nov-4   Dec-4
Yield (KG/HA):        98      96      66      96      84      68
Yld Loss NoTrt:    59.7%   63.1%   25.7%   31.2%   29.9%    5.6%
Yield Loss Trt:    11.8%   13.1%    7.6%    6.5%    6.3%    2.5%
```

Table 6, continued

```
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 $74.00/HA.
                                     No Treatment       Treatment      Difference
 ---------------------------------------------------------------------------
 Final egg density  (#/m )             114.40             36.90           77.50
         Crop loss  ($/HA)              24.94              8.05           16.90

Economic Information

 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  59.3    40  11.9    86   10.64   15.55  7.81 18.37 16600   1.4    3.4
 SORG  0.15  30.6    66   6.4    88    3.16   15.55  7.81 10.89     0   0.4    2.4

The Aggregate economic analysis:
                          Result of Treatment  ($/HA)                  Benefit
 Reg #Si Avg  Trt  %Yld   Benefit          Net    Area Avg    /Cost    /Risk
 ion tes Dens Code  inc  Yr 1  Yr 2  Cost  Benefit  HA   Risk  Yr 1 Both Index
------------------------------------------------------------------------------
 ATI  1   25  MV  115.0 10.64 15.55  7.81   18.38 16600  2.4   1.4   3.4   1.4
------------------------------------------------------------------------------
 Avg  1   25 N/A  115.0 10.64 15.55  7.81   18.38 16600  2.4   1.4   3.4   1.4
 Stdev                   1.00


   First Year Benefit: $ 176,624    Second Year Benefit: $ 258,130
   Cost of Treatment :$ 129,646    Net Benefit          : $ 305,108


End of the report file.
```

Table 6, continued

Ati: High B/C case #26 with original grasshopper density of 25/m2

```
                     Report File From GHLSIM

File created at: 18:14 on April 23, 1991

Information for run no. 1 of    1 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.
Grasshopper (GH) densities (Max/Min/Avg)          :  /  / 25
Ha sampled                                        : Unknown
Crops                                             : millet
Crop stage                                        :  LAIT/PATEUX
Source of Yield data                              : Predicted
Treated Ha                                        : 16600 HA
Treatment agent                                   : MV
Risk index                                        :  2.41
Efficacy reported                                 : 90% (default)
Origin of sample message                          :  H.KHOURI/BATHA
Remark                                            :

Modified sample and treatment dates to # days after emerge:    51
Julian day & date of sample and treatment:   249 Sep-6-87

Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:  11

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-17  Jul-17    Jun6  Jul-17    Jun6    Jun6
Seedling:       Jul-27  Jul-29   Jun21  Jul-29   Jun19   Jun22
Tiller/Spike:    Aug-6  Aug-10  Jul-12  Aug-10   Jul-3  Jul-15
Milky Grain:    Aug-22  Aug-28  Aug-16  Aug-27  Jul-19  Aug-25
Dry Grain:      Sep-20  Sep-27  Sep-17  Sep-26  Aug-15  Sep-27
Harvest:         Oct-2  Oct-14   Oct-3  Oct-14  Sep-13  Oct-13
Yield (KG/HA):     932     722     653     722     592     738
Yld Loss NoTrt:  46.2%   57.5%   44.9%   28.4%    6.2%   28.4%
Yield Loss Trt:  19.3%   28.8%   20.1%   14.3%    1.2%   14.2%
```

Table 6, continued

```
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 $74.00/HA.
                                    No Treatment        Treatment      Difference
 ---------------------------------------------------------------------------------
 Final egg density (#/m )              93.40              57.60          35.80
         Crop loss ($/HA)              20.36              12.56           7.81

Economic Information

 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  47.1  481  20.1  726    56.38   7.18  7.81 55.75 16600  7.2   8.1
 SORG  0.15  26.6  523  13.3  617    13.09   7.18  7.81 12.46     0  1.7   2.6

The Aggregate economic analysis:
                        Result of Treatment ($/HA)                 Benefit
 Reg #Si Avg  Trt  %Yld   Benefit          Net    Area Avg     /Cost    /Risk
 ion tes Dens Code  inc   Yr 1  Yr 2  Cost Benefit  HA  Risk  Yr 1 Both Index
-------------------------------------------------------------------------------
 ATI  1   25  MV   50.9 56.38  7.18  7.81  55.75 16600  2.4  7.2   8.1   3.4
-------------------------------------------------------------------------------
 Avg  1   25 N/A   50.9 56.38  7.18  7.81  55.75 16600  2.4  7.2   8.1   3.4
 Stdev                  1.00


   First Year Benefit: $ 935,908    Second Year Benefit: $ 119,188
   Cost of Treatment :$ 129,646   Net Benefit         : $ 925,450

End of the report file.
```

Table 6, continued

Abeche: Low B/C case #30 with original grasshopper density of 18/m2

```
                    Report File From GHLSIM

File created at: 21:33 on April 23, 1991

Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)     : 25 / 10 / 18
Ha sampled                                   : Unknown
Crops                                        : millet
Crop stage                                   : Unknown
Source of Yield data                         : Predicted
Treated Ha                                   : 11620 HA
Treatment agent                              : MV
Risk index                                   :  2.41
Efficacy reported                            : 90% (default)
Origin of sample message                     :  H. KHOURI/ABECHE
Remark                                       :

Modified sample and treatment dates to # days after emerge:    51
Julian day & date of sample and treatment:    249 Sep-6-87

Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:   0

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:           Jul-17  Jul-17  Jul-17  Jul-17  Jul-17  Jul-17
Seedling:         Jul-27  Jul-29   Aug-1  Jul-29  Jul-30   Aug-2
Tiller/Spike:      Aug-6  Aug-10  Aug-22  Aug-10  Aug-13  Aug-26
Milky Grain:      Aug-22  Aug-28  Sep-26  Aug-27  Aug-30   Oct-5
Dry Grain:        Sep-20  Sep-27  Oct-27  Sep-26  Sep-25   Nov-6
Harvest:           Oct-2  Oct-14  Nov-13  Oct-14  Oct-24  Nov-23
Yield (KG/HA):       765     487      92     487     293      72
Yld Loss NoTrt:     8.3%   11.0%   12.3%    5.4%    6.8%    5.4%
Yield Loss Trt:     1.5%    2.3%    3.4%    1.1%    1.7%    1.7%
```

Table 6, continued

```
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 $74.00/HA.
                                    No Treatment       Treatment      Difference
 ---------------------------------------------------------------------------------
 Final egg density (#/m )             21.40             17.00           4.40
          Crop loss ($/HA)             4.67              3.71           0.96

Economic Information

 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   8.9  625   1.7  674    13.62   0.88 9.12  5.38 11620  1.5   1.6
 SORG 0.15   5.6  410   1.2  429     2.61   0.88 9.12 -5.63     0  0.3   0.4

The Aggregate economic analysis:
                         Result of Treatment ($/HA)                 Benefit
 Reg #Si Avg  Trt  %Yld  Benefit          Net    Area Avg     /Cost   /Risk
 ion tes Dens Code  inc  Yr 1  Yr 2 Cost Benefit  HA  Risk  Yr 1 Both Index
-------------------------------------------------------------------------------
 ABE  1   18  MV    7.8 13.62  0.88 9.12   5.38 11620  2.4  1.5   1.6   0.7
-------------------------------------------------------------------------------
 Avg  1   18 N/A    7.8 13.62  0.88 9.12   5.38 11620  2.4  1.5   1.6   0.7
 Stdev                   1.00


   First Year Benefit: $ 158,264   Second Year Benefit: $  10,226
   Cost of Treatment :$ 105,974   Net Benefit        : $  62,516

End of the report file.
```

Table 6, continued

Abeche: **High B/C case #36 with original grasshopper density of 18/m2**

```
                    Report File From GHLSIM

File created at: 21:41 on April 23, 1991

Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)            : 25 / 10 / 18
Ha sampled                                          : Unknown
Crops                                               : millet
Crop stage                                          : Unknown
Source of Yield data                                : Predicted
Treated Ha                                          : 11620 HA
Treatment agent                                     : MV
Risk index                                          :  2.41
Efficacy reported                                   : 90% (default)
Origin of sample message                            :  H. KHOURI/ABECHE
Remark                                              :

Modified sample and treatment dates to # days after emerge:    51
Julian day & date of sample and treatment:   260 Sep-17-87

Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:  10

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:          Jul-28  Jul-7   Jul-7  Jul-7  Jul-7   Jul-7
Seedling:         Aug-8 Jul-19  Jul-22 Jul-19 Jul-20  Jul-23
Tiller/Spike:    Aug-17 Jul-31  Aug-12 Jul-31  Aug-3  Aug-16
Milky Grain:      Sep-1 Aug-18  Sep-16 Aug-17 Aug-20  Sep-25
Dry Grain:        Oct-1 Sep-17  Oct-17 Sep-16 Sep-15  Oct-27
Harvest:         Oct-13  Oct-4   Nov-3  Oct-4 Oct-14  Nov-13
Yield (KG/HA):      978    963     652    963    965     362
Yld Loss NoTrt:   17.8%   3.9%   40.9%   2.0%   9.6%   24.2%
Yield Loss Trt:    4.7%   1.0%   11.3%   0.5%   2.5%    6.7%
```

Table 6, continued

```
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 $74.00/HA.
                                        No Treatment       Treatment      Difference
 ---------------------------------------------------------------------------
 Final egg density (#/m )                38.30             31.40            6.90
         Crop loss ($/HA)                 8.35              6.85            1.50

Economic Information

 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  17.2  791   4.5  913   33.47   1.38  9.12 25.73 11620  3.7   3.8
 SORG  0.15   4.4  886   1.2  916    4.13   1.38  9.12 -3.61     0  0.5   0.6

The Aggregate economic analysis:
                      Result of Treatment ($/HA)                   Benefit
 Reg #Si Avg  Trt  %Yld  Benefit         Net   Area Avg     /Cost   /Risk
 ion tes Dens Code  inc  Yr 1  Yr 2  Cost Benefit  HA  Risk  Yr 1 Both Index
-----------------------------------------------------------------------------
-

 ABE  1   18  MV   15.4 33.47  1.38  9.12  25.73 11620  2.4  3.7   3.8   1.6
-----------------------------------------------------------------------------
-

 Avg  1   18 N/A   15.4 33.47  1.38  9.12  25.73 11620  2.4  3.7   3.8   1.6
 Stdev                  1.00


   First Year Benefit: $ 388,921   Second Year Benefit: $  16,036
   Cost of Treatment :$ 105,974   Net Benefit        : $ 298,983


End of the report file.
```

Table 6, continued

Mongo: Low B/C case #30 with original grasshopper density of 25/m2

```
                        Report File From GHLSIM

File created at: 15:23 on April 23, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)         :  /  / 25
Ha sampled                                       : Unknown
Crops                                            : millet
Crop stage                                       :  Maturite
Source of Yield data                             : Predicted
Treated Ha                                       : 16185 HA
Treatment agent                                  : MV
Risk index                                       :  2.41
Efficacy reported                                : 90% (default)
Origin of sample message                         :  A.M.YAKOUB/MONGO
Remark                                           :

Modified sample and treatment dates to # days after emerge:    59
Julian day & date of sample and treatment:   227 Aug-15-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:  18

Crop Information:
                             Millet                   Sorghum
Variety:             75      90     110      80      90     130
Proportion:        0.20    0.70    0.10    0.20    0.70    0.10
Seeded:           Jun17   Jun17   Jun17   Jun17   Jun17   Jun17
Seedling:         Jun27   Jun29   Jul-2   Jun29   Jun30   Jul-3
Tiller/Spike:     Jul-7  Jul-11  Jul-23  Jul-11  Jul-14  Jul-27
Milky Grain:     Jul-23  Jul-29  Aug-27  Jul-28  Jul-31   Sep-5
Dry Grain:       Aug-21  Aug-28  Sep-27  Aug-27  Aug-26   Oct-7
Harvest:          Sep-2  Sep-14  Oct-14  Sep-14  Sep-24  Oct-24
Yield (KG/HA):      977     978     978     978     978     978
Yld Loss NoTrt:    9.2%   10.7%    8.4%    5.2%    4.6%    2.7%
Yield Loss Trt:    2.1%    2.4%    1.6%    1.2%    1.1%    0.5%
```

Table 6, continued

```
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 $74.00/HA.
                                    No Treatment      Treatment     Difference
 -------------------------------------------------------------------------------
 Final egg density (#/m )             32.40             22.10          10.30
        Crop loss ($/HA)               7.06              4.82           2.25

Economic Information

 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  10.2  878   2.3  955   14.27   2.07  6.23 10.10 16185  2.3   2.6
 SORG  0.15   4.5  933   1.0  967    4.72   2.07  6.23  0.55     0  0.8   1.1

The Aggregate economic analysis:
                     Result of Treatment ($/HA)                     Benefit
 Reg #Si Avg  Trt  %Yld  Benefit            Net   Area Avg    /Cost   /Risk
 ion tes Dens Code  inc  Yr 1  Yr 2  Cost Benefit  HA  Risk  Yr 1 Both Index
-------------------------------------------------------------------------------
 MON  1   25  MV    8.8 14.27  2.07  6.23  10.11 16185  2.4  2.3   2.6   1.1
-------------------------------------------------------------------------------
 Avg  1   25 N/A    8.8 14.27  2.07  6.23  10.11 16185  2.4  2.3   2.6   1.1
 Stdev                  1.00


   First Year Benefit: $ 230,960   Second Year Benefit: $  33,503
   Cost of Treatment :$ 100,833   Net Benefit         : $ 163,630

End of the report file.
```

Table 6, continued

Mongo: High B/C case #59 with original grasshopper density of 25/m2

```
                 Report File From GHLSIM

File created at: 16:04 on April 23, 1991

Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)       :  /  / 25
Ha sampled                                     : Unknown
Crops                                          : millet
Crop stage                                     :  Maturite
Source of Yield data                           : Predicted
Treated Ha                                     : 16185 HA
Treatment agent                                : MV
Risk index                                     :  2.41
Efficacy reported                              : 90% (default)
Origin of sample message                       :  A.M.YAKOUB/MONGO
Remark                                         :

Modified sample and treatment dates to # days after emerge:    59
Julian day & date of sample and treatment:   227 Aug-15-87

Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:  11

Crop Information:
                         Millet                  Sorghum
Variety:            75      90     110      80      90     130
Proportion:       0.20    0.70    0.10    0.20    0.70    0.10
Seeded:          Jun17   Jun17   Jun17   Jun17   Jun17   Jun17
Seedling:        Jun27   Jun29   Jul-2   Jun29   Jun30   Jul-3
Tiller/Spike:    Jul-7  Jul-11  Jul-23  Jul-11  Jul-14  Jul-27
Milky Grain:    Jul-23  Jul-29  Aug-27  Jul-28  Jul-31   Sep-5
Dry Grain:      Aug-21  Aug-28  Sep-27  Aug-27  Aug-26   Oct-7
Harvest:         Sep-2  Sep-14  Oct-14  Sep-14  Sep-24  Oct-24
Yield (KG/HA):     978     978     978     978     978     971
Yld Loss NoTrt:  14.2%   21.4%   32.8%   10.4%   12.9%   15.6%
Yield Loss Trt:   3.1%    5.7%   10.7%    2.8%    4.1%    6.0%
```

Table 6, continued

```
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 $74.00/HA.
                                    No Treatment       Treatment      Difference
 ------------------------------------------------------------------------------
 Final egg density (#/m )             51.00             32.10          18.90
          Crop loss ($/HA)            11.12              7.00           4.12

Economic Information

 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  21.1  771   5.7  922   27.75   3.79  6.23 25.31 16185  4.5   5.1
 SORG  0.15  12.6  853   4.0  938   11.61   3.79  6.23  9.17     0  1.9   2.5

The Aggregate economic analysis:
                    Result of Treatment ($/HA)                Benefit
 Reg #Si Avg  Trt  %Yld   Benefit          Net    Area Avg    /Cost   /Risk
 ion tes Dens Code  inc  Yr 1   Yr 2  Cost Benefit  HA  Risk Yr 1 Both Index
--------------------------------------------------------------------------------
 MON  1   25  MV   19.6 27.75  3.79  6.23  25.31 16185  2.4  4.5   5.1   2.1
--------------------------------------------------------------------------------
 Avg  1   25 N/A   19.6 27.75  3.79  6.23  25.31 16185  2.4  4.5   5.1   2.1
 Stdev                  1.00


   First Year Benefit: $ 449,134   Second Year Benefit: $  61,341
   Cost of Treatment :$ 100,833   Net Benefit         : $ 409,642


End of the report file.
```

Table 6, continued

Ati: **Low B/C case #14 with lowered grasshopper density of 12/m2**

```
                      Report File From GHLSIM

File created at: 19:21 on June 20, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)         :  /  / 12
Ha sampled                                       : Unknown
Crops                                            : millet
Crop stage                                       :  LAIT/PATEUX
Source of Yield data                             : Predicted
Treated Ha                                       : 16600 HA
Treatment agent                                  : MV
Risk index                                       :  2.41
Efficacy reported                                : 90% (default)
Origin of sample message                         :  H.KHOURI/BATHA
Remark                                           :

Modified sample and treatment dates to # days after emerge:     51
Julian day & date of sample and treatment:   260 Sep-17-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE   TRUE   OSE mdl: TRUE   TRUE
 Days until match:   0

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-28   Jul-28   Jul-28   Jul-28   Jul-28   Jul-28
Seedling:          Aug-8    Aug-9   Aug-12    Aug-9   Aug-10   Aug-13
Tiller/Spike:     Aug-17   Aug-21    Sep-2   Aug-21   Aug-24    Sep-5
Milky Grain:       Sep-1    Sep-7    Oct-7    Sep-7    Sep-9   Oct-16
Dry Grain:         Oct-1    Oct-9    Nov-8    Oct-7    Oct-6   Nov-18
Harvest:          Oct-13   Oct-25   Nov-24   Oct-25    Nov-4    Dec-4
Yield (KG/HA):        98       96       66       96       84       68
Yld Loss NoTrt:    19.7%    21.8%    16.0%    10.8%    10.1%     4.2%
Yield Loss Trt:     4.3%     4.8%     4.0%     2.4%     2.3%     1.1%


Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey
breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
Crop value $74.00/HA.
                                No Treatment      Treatment      Difference
---------------------------------------------------------------------------
Final egg density (#/m²)           40.50            18.30           22.20
        Crop loss ($/HA)            8.83             3.99            4.84
```

Table 6, continued

```
 Economic Information

  RESULTS:
              No Treatment Treatment     Treatment  ($/HA)          Benefit
              ------------ ---------    ------------------------     /Cost
      Price  Loss Yield Loss Yield      Benefit        Net    Area  ---------
 CROP  $/KG   %   KG/HA  %   KG/HA    Yr 1   Yr 2  Cost  Bene    HA  Yr 1  Both
 -------------------------------------------------------------------------------
 MILL  0.25  29.0   69   6.3   91     5.10   7.46  7.81  4.75 16600  0.7   1.6
 SORG  0.15  15.1   80   3.4   91     1.51   7.46  7.81  1.16     0  0.2   1.1
The Aggregate economic analysis:
                    Result of Treatment ($/HA)                   Benefit
 Reg #Si Avg  Trt  %Yld  Benefit          Net   Area Avg      /Cost    /Risk
 ion tes Dens Code  inc  Yr 1  Yr 2  Cost Benefit  HA  Risk  Yr 1 Both Index
--------------------------------------------------------------------------------
 ATI  1   12  MV   31.9  5.10  7.46  7.81   4.75 16600  2.4  0.7   1.6   0.7
--------------------------------------------------------------------------------
 Avg  1   12 N/A   31.9  5.10  7.46  7.81   4.75 16600  2.4  0.7   1.6   0.7
 Stdev                   1.00

   First Year Benefit: $  84,660   Second Year Benefit: $ 123,836
   Cost of Treatment :$ 129,646   Net Benefit         : $  78,850

End of the report file.
```

Table 6, continued

Ati: **Low B/C case #14 with increased grasshopper density of 50/m2**

```
                     Report File From GHLSIM

File created at: 19:24 on June 20, 1991


Information for run no. 1 of     1 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
Grasshopper species                              : 14
Stages                                           :  OSE
Grasshopper (GH) densities (Max/Min/Avg)         : adult and larva.
Ha sampled                                       :  /  / 50
Crops                                            : Unknown
Crop stage                                       : millet
Source of Yield data                             :  LAIT/PATEUX
Treated Ha                                       : Predicted
Treatment agent                                  : 16600 HA
Risk index                                       : MV
Efficacy reported                                :  2.41
Origin of sample message                         : 90% (default)
Remark                                           :  H.KHOURI/BATHA
                                                 :

Modified sample and treatment dates to # days after emerge:     51
Julian day & date of sample and treatment:   260 Sep-17-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE   TRUE    OSE mdl: TRUE    TRUE
 Days until match:   0

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-28   Jul-28   Jul-28   Jul-28   Jul-28   Jul-28
Seedling:         Aug-8    Aug-9   Aug-12    Aug-9   Aug-10   Aug-13
Tiller/Spike:    Aug-17   Aug-21    Sep-2   Aug-21   Aug-24    Sep-5
Milky Grain:      Sep-1    Sep-7    Oct-7    Sep-7    Sep-9   Oct-16
Dry Grain:        Oct-1    Oct-9    Nov-8    Oct-7    Oct-6   Nov-18
Harvest:         Oct-13   Oct-25   Nov-24   Oct-25    Nov-4    Dec-4
Yield (KG/HA):       98       96       66       96       84       68
Yld Loss NoTrt:   77.3%    77.6%    69.1%    46.4%    43.6%    18.4%
Yield Loss Trt:   18.5%    20.7%    17.2%    10.2%     9.7%     4.8%


Second year benefits information

Calculation of 2nd year benefits: (Determined by preseason eggpod survey
breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
Crop value $74.00/HA.
                                 No Treatment       Treatment      Difference
------------------------------------------------------------------------------
Final egg density (#/m²)            139.10            44.60            94.50
         Crop loss ($/HA)            30.31             9.72            20.58
```

Table 6, continued

```
Economic Information

 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  77.2   22  18.7    79   13.11   18.94  7.81 24.24 16600  1.7   4.1
 SORG  0.15  45.6   51  10.0    85    4.63   18.94  7.81 15.76     0  0.6   3.0

The Aggregate economic analysis:
                    Result of Treatment ($/HA)                    Benefit
 Reg #Si Avg  Trt  %Yld   Benefit          Net    Area Avg      /Cost    /Risk
 ion tes Dens Code  inc  Yr 1  Yr 2   Cost Benefit  HA  Risk  Yr 1 Both  Index
--------------------------------------------------------------------------------
 ATI  1   50  MV   259.1 13.11 18.94  7.81  24.24 16600  2.4  1.7   4.1   1.7
--------------------------------------------------------------------------------
 Avg  1   50 N/A   259.1 13.11 18.94  7.81  24.24 16600  2.4  1.7   4.1   1.7
 Stdev                   1.00

   First Year Benefit: $ 217,626   Second Year Benefit: $ 314,404
   Cost of Treatment :$ 129,646   Net Benefit        : $ 402,384

End of the report file.
```

Table 6. continued

Ati: **High B/C case #26 with lowered grasshopper density of 12/m2**

```
                    Report File From GHLSIM

File created at: 19:08 on June 20, 1991


Information for run no. 1 of      1 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.
Grasshopper (GH) densities (Max/Min/Avg)       :  /  / 12
Ha sampled                                     : Unknown
Crops                                          : millet
Crop stage                                     :  LAIT/PATEUX
Source of Yield data                           : Predicted
Treated Ha                                     : 16600 HA
Treatment agent                                : MV
Risk index                                     :  2.41
Efficacy reported                              : 90% (default)
Origin of sample message                       :  H.KHOURI/BATHA
Remark                                         :

Modified sample and treatment dates to # days after emerge:      51
Julian day & date of sample and treatment:   249 Sep-6-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE   TRUE    OSE mdl: TRUE    TRUE
 Days until match:  11

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-17   Jul-17     Jun6   Jul-17     Jun6     Jun6
Seedling:        Jul-27   Jul-29    Jun21   Jul-29    Jun19    Jun22
Tiller/Spike:     Aug-6   Aug-10   Jul-12   Aug-10    Jul-3   Jul-15
Milky Grain:     Aug-22   Aug-28   Aug-16   Aug-27   Jul-19   Aug-25
Dry Grain:       Sep-20   Sep-27   Sep-17   Sep-26   Aug-15   Sep-27
Harvest:          Oct-2   Oct-14    Oct-3   Oct-14   Sep-13   Oct-13
Yield (KG/HA):      932      722      653      722      592      738
Yld Loss NoTrt:   21.9%    27.2%    21.3%    13.4%     3.0%    13.4%
Yield Loss Trt:    9.1%    13.6%     9.5%     6.8%     0.6%     6.7%


Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                  No Treatment       Treatment      Difference
 -----------------------------------------------------------------------------
 Final egg density (#/m²)            49.00             32.00           17.00
             Crop loss ($/HA)        10.68              6.98            3.71
```

Table 6, continued

```
Economic Information

 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  22.3  706   9.5  823    26.83   3.41  7.81 22.43 16600  3.4   3.9
 SORG 0.15  12.6  622   6.3  667     6.23   3.41  7.81  1.83     0  0.8   1.2

The Aggregate economic analysis:
                     Result of Treatment ($/HA)                   Benefit
 Reg #Si Avg  Trt  %Yld  Benefit           Net    Area Avg     /Cost   /Risk
 ion tes Dens Code  inc  Yr 1  Yr 2  Cost Benefit  HA  Risk  Yr 1 Both Index
-------------------------------------------------------------------------------
 ATI  1   12  MV   16.6 26.83  3.41  7.81  22.43 16600  2.4  3.4   3.9   1.6
-------------------------------------------------------------------------------
 Avg  1   12 N/A   16.6 26.83  3.41  7.81  22.43 16600  2.4  3.4   3.9   1.6
 Stdev                  1.00

   First Year Benefit: $ 445,378   Second Year Benefit: $  56,606
   Cost of Treatment :$ 129,646   Net Benefit         : $ 372,338

End of the report file.
```

Table 6, continued

Ati: High B/C case #26 with increased grasshopper density of 50/m2

```
+-----------------------------------------------------------------------+
|                                                                       |
|                       Report File From GHLSIM                         |
|                                                                       |
+-----------------------------------------------------------------------+
File created at: 19:01 on June 20, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)         :  /  / 50
Ha sampled                                       : Unknown
Crops                                            : millet
Crop stage                                       :  LAIT/PATEUX
Source of Yield data                             : Predicted
Treated Ha                                       : 16600 HA
Treatment agent                                  : MV
Risk index                                       :  2.41
Efficacy reported                                : 90% (default)
Origin of sample message                         :  H.KHOURI/BATHA
Remark                                           :

Modified sample and treatment dates to # days after emerge:     51
Julian day & date of sample and treatment:   249 Sep-6-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE   TRUE    OSE mdl: TRUE   TRUE
 Days until match:  11

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-17  Jul-17     Jun6  Jul-17    Jun6     Jun6
Seedling:        Jul-27  Jul-29    Jun21  Jul-29   Jun19    Jun22
Tiller/Spike:     Aug-6  Aug-10   Jul-12  Aug-10   Jul-3   Jul-15
Milky Grain:     Aug-22  Aug-28   Aug-16  Aug-27  Jul-19   Aug-25
Dry Grain:       Sep-20  Sep-27   Sep-17  Sep-26  Aug-15   Sep-27
Harvest:          Oct-2  Oct-14    Oct-3  Oct-14  Sep-13   Oct-13
Yield (KG/HA):      932     722      653     722     592      738
Yld Loss NoTrt:   77.6%   77.8%    77.5%   57.5%   12.4%    57.6%
Yield Loss Trt:   39.5%   58.9%    41.1%   29.3%    2.4%    29.0%


Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                No Treatment        Treatment      Difference
 ----------------------------------------------------------------------------
 Final egg density (#/m²)          176.50            104.30           72.20
         Crop loss ($/HA)           36.21             22.74           13.47
```

Table 6, continued

```
Economic Information

 RESULTS:
                 No Treatment Treatment     Treatment  ($/HA)              Benefit
                 ------------ ----------   ---------------------------       /Cost
       Price    Loss  Yield  Loss  Yield      Benefit          Net    Area  ------------
CROP   $/KG      %    KG/HA   %    KG/HA    Yr 1   Yr 2  Cost  Bene    HA   Yr 1   Both
----------------------------------------------------------------------------------------
MILL   0.25    77.6   203   41.1   536     76.36  12.40  7.81 80.95 16600   9.8   11.4
SORG   0.15    53.9   328   27.1   519     26.34  12.40  7.81 30.93     0   3.4    5.0
The Aggregate economic analysis:
                         Result of Treatment ($/HA)                      Benefit
Reg #Si  Avg  Trt  %Yld   Benefit             Net    Area  Avg     /Cost     /Risk
ion tes Dens  Code  inc   Yr 1   Yr 2   Cost Benefit  HA   Risk  Yr 1 Both   Index
-----------------------------------------------------------------------------------
ATI  1    50   MV  164.0 76.36 12.40   7.81   80.95 16600  2.4   9.8  11.4    4.7
-----------------------------------------------------------------------------------
Avg  1    50 N/A   164.0 76.36 12.40   7.81   80.95 16600  2.4   9.8  11.4    4.7
Stdev                     1.00


   First Year Benefit: $ 1,267,576   Second Year Benefit: $ 205,840
   Cost of Treatment :$ 129,646   Net Benefit          : $ 1,343,770

End of the report file.
```

Table 6, continued

Abeche: Low B/C case #30 with lowered grasshopper density of 9/m2

```
                       Report File From GHLSIM

File created at: 20:02 on June 20, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)     : 25 / 10 / 9
Ha sampled                                   : Unknown
Crops                                        : millet
Crop stage                                   : Unknown
Source of Yield data                         : Predicted
Treated Ha                                   : 11620 HA
Treatment agent                              : MV
Risk index                                   :  2.41
Efficacy reported                            : 90% (default)
Origin of sample message                     :  H. KHOURI/ABECHE
Remark                                       :

Modified sample and treatment dates to # days after emerge:    51
Julian day & date of sample and treatment:   249 Sep-6-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:   0

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:           Jul-17   Jul-17   Jul-17  Jul-17  Jul-17   Jul-17
Seedling:         Jul-27   Jul-29    Aug-1  Jul-29  Jul-30    Aug-2
Tiller/Spike:      Aug-6   Aug-10   Aug-22  Aug-10  Aug-13   Aug-26
Milky Grain:      Aug-22   Aug-28   Sep-26  Aug-27  Aug-30    Oct-5
Dry Grain:        Sep-20   Sep-27   Oct-27  Sep-26  Sep-25    Nov-6
Harvest:           Oct-2   Oct-14   Nov-13  Oct-14  Oct-24   Nov-23
Yield (KG/HA):       765      487       92     487     293       72
Yld Loss NoTrt:     4.1%     5.6%     6.6%    2.8%    3.6%     3.0%
Yield Loss Trt:     0.8%     1.3%     2.3%    0.7%    1.1%     1.2%


Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                No Treatment       Treatment       Difference
 ----------------------------------------------------------------------------
 Final egg density (#/m²)          14.90             12.70            2.20
         Crop loss ($/HA)           3.25              2.77            0.48
```

Table 6, continued

```
Economic Information

 RESULTS:
               No Treatment Treatment      Treatment   ($/HA)           Benefit
               ------------ ---------   ------------------------------   /Cost
       Price  Loss Yield Loss  Yield       Benefit            Net    Area  -------------
 CROP  $/KG    %   KG/HA  %    KG/HA    Yr 1    Yr 2   Cost   Bene    HA   Yr 1   Both
 ------------------------------------------------------------------------------------
 MILL  0.30   4.5  655   0.9   679      6.76    0.44   9.12  -1.92  11620  0.7    0.8
 SORG  0.15   2.9  422   0.7   431      1.28    0.44   9.12  -7.40      0  0.1    0.2
The Aggregate economic analysis:
                            Result of Treatment ($/HA)
Reg #Si Avg  Trt  %Yld   Benefit                Net                    Benefit
ion tes Dens Code  inc   Yr 1  Yr 2   Cost  Benefit  Area  Avg      /Cost    /Risk
                                                      HA   Risk   Yr 1 Both  Index
-------------------------------------------------------------------------------------
ABE  1     9  MV     3.7  6.76  0.44   9.12  -1.92  11620  2.4   0.7   0.8    0.3
-------------------------------------------------------------------------------------
Avg  1     9 N/A     3.7  6.76  0.44   9.12  -1.92  11620  2.4   0.7   0.8    0.3
Stdev                     1.00

   First Year Benefit: $  78,551   Second Year Benefit: $    5,113
   Cost of Treatment :$ 105,974   Net Benefit         : $  -22310

End of the report file.
```

Table 6, continued

Abeche: **Low B/C case #30 with increased grasshopper density of 36/m2**

```
+-------------------------------------------------------------------+
|                                                                   |
|                     Report File From GHLSIM                       |
|                                                                   |
+-------------------------------------------------------------------+
File created at: 17:53 on July 19, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)          : 25 / 10 / 36
Ha sampled                                        : Unknown
Crops                                             : millet
Crop stage                                        : Unknown
Source of Yield data                              : Predicted
Treated Ha                                        : 11620 HA
Treatment agent                                   : MV
Risk index                                        :  2.41
Efficacy reported                                 : 90% (default)
Origin of sample message                          :  H. KHOURI/ABECHE
Remark                                            :

Modified sample and treatment dates to # days after emerge:     51
Julian day & date of sample and treatment:   249 Sep-6-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:   0

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:           Jul-17  Jul-17  Jul-17  Jul-17  Jul-17  Jul-17
Seedling:         Jul-27  Jul-29   Aug-1  Jul-29  Jul-30   Aug-2
Tiller/Spike:      Aug-6  Aug-10  Aug-22  Aug-10  Aug-13  Aug-26
Milky Grain:      Aug-22  Aug-28  Sep-26  Aug-27  Aug-30   Oct-5
Dry Grain:        Sep-20  Sep-27  Oct-27  Sep-26  Sep-25   Nov-6
Harvest:           Oct-2  Oct-14  Nov-13  Oct-14  Oct-24  Nov-23
Yield (KG/HA):       765     487      92     487     293      72
Yld Loss NoTrt:    16.3%   21.3%   22.8%   10.4%   13.0%    9.8%
Yield Loss Trt:     2.9%    4.1%    5.4%    2.0%    2.8%    2.6%


Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                No Treatment       Treatment      Difference
 ----------------------------------------------------------------------------
 Final egg density (#/m²)          30.40             21.60           8.80
          Crop loss ($/HA)          6.63              4.71           1.92
```

Table 6, continued

```
Economic Information

 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  17.4  566   3.2  664    26.95    1.77  9.12 19.59 11620  3.0   3.1
 SORG  0.15  10.7  388   2.2  425     5.14    1.77  9.12 -2.21     0  0.6   0.8

The Aggregate economic analysis:
                     Result of Treatment ($/HA)                     Benefit
 Reg #Si Avg  Trt  %Yld   Benefit            Net    Area  Avg    /Cost    /Risk
 ion tes Dens Code  inc  Yr 1   Yr 2  Cost Benefit   HA   Risk Yr 1 Both  Index
 --------------------------------------------------------------------------------
 ABE  1   36  MV    17.3 26.95  1.77  9.12  19.60 11620  2.4  3.0   3.1   1.3
 --------------------------------------------------------------------------------
 Avg  1   36 N/A    17.3 26.95  1.77  9.12  19.60 11620  2.4  3.0   3.1   1.3
 Stdev                    1.00

   First Year Benefit: $ 313,159   Second Year Benefit: $  20,567
   Cost of Treatment :$ 105,974   Net Benefit         : $ 227,752

End of the report file.
```

Table 6, continued

Abeche: **High B/C case #36 with lowered grasshopper density of 9/m2**

```
                    Report File From GHLSIM

File created at: 18:03 on July 19, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)         : 25 / 10 / 9
Ha sampled                                       : Unknown
Crops                                            : millet
Crop stage                                       : Unknown
Source of Yield data                             : Predicted
Treated Ha                                       : 11620 HA
Treatment agent                                  : MV
Risk index                                       :  2.41
Efficacy reported                                : 90% (default)
Origin of sample message                         :  H. KHOURI/ABECHE
Remark                                           :

Modified sample and treatment dates to # days after emerge:    51
Julian day & date of sample and treatment:   239 Aug-27-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:  18

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:           Jul-7    Jun27    Jun27   Jun27    Jun27    Jun27
Seedling:        Jul-17    Jul-9   Jul-12   Jul-9   Jul-10   Jul-13
Tiller/Spike:    Jul-27   Jul-21    Aug-2  Jul-21   Jul-24    Aug-6
Milky Grain:     Aug-12    Aug-8    Sep-6   Aug-7   Aug-10   Sep-15
Dry Grain:       Sep-10    Sep-7    Oct-7   Sep-6    Sep-5   Oct-17
Harvest:         Sep-22   Sep-24   Oct-24  Sep-24    Oct-4    Nov-3
Yield (KG/HA):      978      978      602     978      978      301
Yld Loss NoTrt:    7.1%     6.8%     8.8%    3.4%     3.4%     3.3%
Yield Loss Trt:    1.2%     1.2%     1.7%    0.6%     0.7%     0.7%

Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                 No Treatment        Treatment      Difference
 ------------------------------------------------------------------------------
 Final egg density (#/m²)            28.50              23.40           5.10
          Crop loss ($/HA)            6.21               5.10           1.11
```

Table 6, continued

```
Economic Information

 RESULTS:
           No Treatment Treatment      Treatment  ($/HA)          Benefit
                                                                     /Cost
      Price  Loss Yield Loss Yield     Benefit          Net   Area  --------
CROP  $/KG    %   KG/HA  %   KG/HA   Yr 1    Yr 2  Cost Bene   HA  Yr 1  Both
-----------------------------------------------------------------------------
MILL  0.30   7.2  887   1.2  944    15.73   1.02  9.12  7.64 11620  1.7   1.8
SORG  0.15   3.4  905   0.6  931     3.59   1.02  9.12 -4.51     0  0.4   0.5
The Aggregate economic analysis:
                       Result of Treatment ($/HA)                 Benefit
Reg #Si Avg  Trt  %Yld   Benefit           Net   Area Avg     /Cost   /Risk
ion tes Dens Code  inc  Yr 1  Yr 2  Cost Benefit  HA  Risk  Yr 1 Both Index
-----------------------------------------------------------------------------
ABE  1    9  MV    6.4 15.73  1.02  9.12   7.63 11620  2.4  1.7   1.8   0.8
-----------------------------------------------------------------------------
Avg  1    9 N/A    6.4 15.73  1.02  9.12   7.63 11620  2.4  1.7   1.8   0.8
Stdev                  1.00

  First Year Benefit: $ 182,783   Second Year Benefit: $  11,852
  Cost of Treatment :$ 105,974   Net Benefit         : $  88,661

End of the report file.
```

Table 6, continued

Abeche: High B/C case #36 with increased grasshopper density of 36/m2

```
                  Report File From GHLSIM

File created at: 11:30 on June 29, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)       : 25 / 10 / 36
Ha sampled                                     : Unknown
Crops                                          : millet
Crop stage                                     : Unknown
Source of Yield data                           : Predicted
Treated Ha                                     : 11620 HA
Treatment agent                                : MV
Risk index                                     :  2.41
Efficacy reported                              : 90% (default)
Origin of sample message                       :  H. KHOURI/ABECHE
Remark                                         :

Modified sample and treatment dates to # days after emerge:    51
Julian day & date of sample and treatment:   260 Sep-17-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:  10

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:           Jul-28    Jul-7    Jul-7    Jul-7    Jul-7    Jul-7
Seedling:          Aug-8   Jul-19   Jul-22   Jul-19   Jul-20   Jul-23
Tiller/Spike:     Aug-17   Jul-31   Aug-12   Jul-31    Aug-3   Aug-16
Milky Grain:       Sep-1   Aug-18   Sep-16   Aug-17   Aug-20   Sep-25
Dry Grain:         Oct-1   Sep-17   Oct-17   Sep-16   Sep-15   Oct-27
Harvest:          Oct-13    Oct-4    Nov-3    Oct-4   Oct-14   Nov-13
Yield (KG/HA):       978      963      652      963      965      362
Yld Loss NoTrt:    35.4%     7.9%    77.0%     4.0%    19.2%    47.8%
Yield Loss Trt:     9.1%     2.0%    21.3%     1.0%     5.0%    12.6%


Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                 No Treatment       Treatment       Difference
 ----------------------------------------------------------------------------
 Final egg density (#/m²)           54.20             40.50            13.70
         Crop loss ($/HA)           11.82              8.83             2.99

Economic Information
```

Table 6, continued

```
            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   34.1  630   8.9  871    66.47   2.75  9.12 60.10 11620   7.3    7.6
SORG  0.15    8.7  846   2.3  906     8.27   2.75  9.12  1.89     0   0.9    1.2

The Aggregate economic analysis:
                      Result of Treatment ($/HA)                     Benefit
 Reg #Si Avg  Trt  %Yld   Benefit            Net   Area Avg      /Cost   /Risk
 ion tes Dens Code  inc  Yr 1   Yr 2  Cost Benefit  HA  Risk   Yr 1 Both Index
-----------------------------------------------------------------------------------
ABE  1   36  MV    38.3 66.47  2.75  9.12  60.10 11620  2.4   7.3    7.6   3.2
-----------------------------------------------------------------------------------
Avg  1   36 N/A    38.3 66.47  2.75  9.12  60.10 11620  2.4   7.3    7.6   3.2
Stdev                    1.00

   First Year Benefit: $ 772,381   Second Year Benefit: $  31,955
   Cost of Treatment :$ 105,974   Net Benefit         : $ 698,362

End of the report file.
```

Table 6, continued

Mongo: **Low B/C case #30 with lowered grasshopper density of 12/m2**

```
┌──────────────────────────────────────────────────────────────────────┐
│                                                                      │
│                       Report File From GHLSIM                        │
│                                                                      │
└──────────────────────────────────────────────────────────────────────┘
File created at: 20:54 on June 20, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)   :  /  / 12
Ha sampled                                 : Unknown
Crops                                      : millet
Crop stage                                 :  Maturite
Source of Yield data                       : Predicted
Treated Ha                                 : 16185 HA
Treatment agent                            : MV
Risk index                                 :  2.41
Efficacy reported                          : 90% (default)
Origin of sample message                   :  A.M.YAKOUB/MONGO
Remark                                     :

Modified sample and treatment dates to # days after emerge:    51
Julian day & date of sample and treatment:   219 Aug-7-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE   TRUE   OSE mdl: TRUE   TRUE
 Days until match:  10

Crop Information:
                          Millet                     Sorghum
Variety:             75       90      110       80       90      130
Proportion:        0.20     0.70     0.10     0.20     0.70     0.10
Seeded:           Jun17    Jun17    Jun17    Jun17    Jun17    Jun17
Seedling:         Jun27    Jun29    Jul-2    Jun29    Jun30    Jul-3
Tiller/Spike:     Jul-7   Jul-11   Jul-23   Jul-11   Jul-14   Jul-27
Milky Grain:     Jul-23   Jul-29   Aug-27   Jul-28   Jul-31    Sep-5
Dry Grain:       Aug-21   Aug-28   Sep-27   Aug-27   Aug-26    Oct-7
Harvest:          Sep-2   Sep-14   Oct-14   Sep-14   Sep-24   Oct-24
Yield (KG/HA):      977      978      978      978      978      978
Yld Loss NoTrt:    6.8%     8.1%     5.9%     4.0%     4.0%     2.6%
Yield Loss Trt:    1.3%     1.5%     0.9%     0.8%     0.8%     0.4%


Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                No Treatment       Treatment      Difference
 ___________________________________________________________________________

 Final egg density (#/m²)           8.40              4.80           3.60
         Crop loss ($/HA)           1.83              1.05           0.78
```

Table 6, continued

```
Economic Information

 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  7.6  903   1.4  964   11.13   0.72  6.23  5.62 16185  1.8   1.9
 SORG  0.15  3.9  940   0.7  971    4.24   0.72  6.23 -1.27     0  0.7   0.8

The Aggregate economic analysis:
               Result of Treatment ($/HA)                        Benefit
 Reg #Si Avg  Trt  %Yld  Benefit          Net   Area Avg     /Cost    /Risk
 ion tes Dens Code  inc  Yr 1  Yr 2  Cost Benefit  HA  Risk  Yr 1 Both Index
-----------------------------------------------------------------------------
 MON  1   12  MV    6.8 11.13  0.72  6.23   5.62 16185  2.4  1.8   1.9   0.8
-----------------------------------------------------------------------------
 Avg  1   12 N/A    6.8 11.13  0.72  6.23   5.62 16185  2.4  1.8   1.9   0.8
 Stdev                  1.00

   First Year Benefit: $ 180,139   Second Year Benefit: $  11,653
   Cost of Treatment :$ 100,833  Net Benefit        : $  90,960

End of the report file.
```

Table 6, continued

Mongo: **Low B/C case #30 with increased grasshopper density of 50/m2**

```
                     Report File From GHLSIM

File created at: 2:07 on June 26, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)         :  /  / 50
Ha sampled                                       : Unknown
Crops                                            : millet
Crop stage                                       :  Maturite
Source of Yield data                             : Predicted
Treated Ha                                       : 16185 HA
Treatment agent                                  : MV
Risk index                                       :  2.41
Efficacy reported                                : 90% (default)
Origin of sample message                         :  A.M.YAKOUB/MONGO
Remark                                           :

Modified sample and treatment dates to # days after emerge:     59
Julian day & date of sample and treatment:   227 Aug-15-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE   OSE mdl: TRUE   TRUE
 Days until match:  18

Crop Information:
                             Millet                       Sorghum
Variety:              75        90       110       80        90       130
Proportion:         0.20      0.70      0.10     0.20      0.70      0.10
Seeded:            Jun17     Jun17     Jun17    Jun17     Jun17     Jun17
Seedling:          Jun27     Jun29     Jul-2    Jun29     Jun30     Jul-3
Tiller/Spike:      Jul-7    Jul-11    Jul-23   Jul-11    Jul-14    Jul-27
Milky Grain:      Jul-23    Jul-29    Aug-27   Jul-28    Jul-31     Sep-5
Dry Grain:        Aug-21    Aug-28    Sep-27   Aug-27    Aug-26     Oct-7
Harvest:           Sep-2    Sep-14    Oct-14   Sep-14    Sep-24    Oct-24
Yield (KG/HA):       977       978       978      978       978       978
Yld Loss NoTrt:    18.4%     21.5%     16.8%    10.5%      9.2%      5.3%
Yield Loss Trt:     4.3%      4.8%      3.0%     2.4%      2.1%      1.0%

Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                No Treatment        Treatment       Difference
 ------------------------------------------------------------------------------
 Final egg density (#/m²)          48.90              28.30            20.60
         Crop loss ($/HA)          10.66               6.17             4.49
```

Table 6, continued

```
Economic Information

RESULTS:
           No Treatment Treatment        Treatment  ($/HA)            Benefit
          ------------ ------------   ----------------------------      /Cost
       Price  Loss Yield Loss  Yield      Benefit            Net   Area  ----------
CROP   $/KG    %   KG/HA  %    KG/HA    Yr 1    Yr 2   Cost  Bene   HA   Yr 1  Both
-----------------------------------------------------------------------------------
MILL   0.20  20.4  778   4.5   933     28.57    4.13   6.23 26.47 16185  4.6   5.2
SORG   0.15   9.1  889   2.1   957      9.45    4.13   6.23  7.35     0  1.5   2.2
The Aggregate economic analysis:
                         Result of Treatment ($/HA)                    Benefit
Reg #Si  Avg  Trt  %Yld    Benefit             Net   Area  Avg       /Cost   /Risk
ion tes Dens Code   inc  Yr 1   Yr 2  Cost  Benefit   HA   Risk   Yr 1 Both  Index
-----------------------------------------------------------------------------------
MON  1   50   MV   19.9 28.57  4.13   6.23   26.47 16185   2.4   4.6    5.2    2.2
-----------------------------------------------------------------------------------
Avg  1   50  N/A   19.9 28.57  4.13   6.23   26.47 16185   2.4   4.6    5.2    2.2
Stdev                    1.00

   First Year Benefit: $ 462,405   Second Year Benefit: $  66,844
   Cost of Treatment :$ 100,833   Net Benefit         : $ 428,417

End of the report file.
```

Table 6, continued

Mongo: **High B/C case #59 with lowered grasshopper density of 12/m2**

```
                    Report File From GHLSIM

File created at: 21:23 on June 20, 1991


Information for run no. 1 of     1 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.
Grasshopper (GH) densities (Max/Min/Avg)     :  /  / 12
Ha sampled                                   : Unknown
Crops                                        : millet
Crop stage                                   :  Maturite
Source of Yield data                         : Predicted
Treated Ha                                   : 16185 HA
Treatment agent                              : MV
Risk index                                   :  2.41
Efficacy reported                            : 90% (default)
Origin of sample message                     :  A.M.YAKOUB/MONGO
Remark                                       :

Modified sample and treatment dates to # days after emerge:    59
Julian day & date of sample and treatment:   227 Aug-15-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE    OSE mdl: TRUE   TRUE
 Days until match:  11

Crop Information:
                           Millet                   Sorghum
Variety:              75       90      110       80       90      130
Proportion:         0.20     0.70     0.10     0.20     0.70     0.10
Seeded:            Jun17    Jun17    Jun17    Jun17    Jun17    Jun17
Seedling:          Jun27    Jun29    Jul-2    Jun29    Jun30    Jul-3
Tiller/Spike:      Jul-7   Jul-11   Jul-23   Jul-11   Jul-14   Jul-27
Milky Grain:      Jul-23   Jul-29   Aug-27   Jul-28   Jul-31    Sep-5
Dry Grain:        Aug-21   Aug-28   Sep-27   Aug-27   Aug-26   Oct-7
Harvest:           Sep-2   Sep-14   Oct-14   Sep-14   Sep-24   Oct-24
Yield (KG/HA):       978      978      978      978      978      971
Yld Loss NoTrt:     6.8%    10.4%    16.0%     5.0%     6.2%     7.8%
Yield Loss Trt:     1.5%     2.7%     5.3%     1.4%     2.0%     3.2%


Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                No Treatment        Treatment      Difference
 ----------------------------------------------------------------------------
 Final egg density (#/m²)         30.30               21.10           9.20
        Crop loss ($/HA)           6.61                4.60           2.01
```

Table 6, continued

```
Economic Information

 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  10.2  878   2.8  951    13.42    1.85  6.23  9.04 16185  2.2   2.5
 SORG  0.15   6.2  917   2.0  958     5.64    1.85  6.23  1.26     0  0.9   1.2

The Aggregate economic analysis:
                      Result of Treatment ($/HA)                   Benefit
 Reg #Si Avg  Trt  %Yld   Benefit              Net   Area  Avg    /Cost   /Risk
 ion tes Dens Code  inc  Yr 1   Yr 2  Cost  Benefit   HA   Risk  Yr 1 Both Index
 -------------------------------------------------------------------------------
 MON  1   12  MV    8.3 13.42   1.85  6.23    9.04 16185   2.4   2.2   2.5   1.0
 -------------------------------------------------------------------------------
 Avg  1   12 N/A    8.3 13.42   1.85  6.23    9.04 16185   2.4   2.2   2.5   1.0
 Stdev                  1.00

   First Year Benefit: $ 217,203   Second Year Benefit: $  29,942
   Cost of Treatment :$ 100,833   Net Benefit         : $ 146,312

End of the report file.
```

Table 6, continued

Mongo: **High B/C case #59 with increased grasshopper density of 50/m2**

```
                         Report File From GHLSIM

File created at: 21:21 on June 20, 1991


Information for run no. 1 of      1 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.
Grasshopper (GH) densities (Max/Min/Avg)           :  /  / 50
Ha sampled                                         : Unknown
Crops                                              : millet
Crop stage                                         :  Maturite
Source of Yield data                               : Predicted
Treated Ha                                         : 16185 HA
Treatment agent                                    : MV
Risk index                                         :  2.41
Efficacy reported                                  : 90% (default)
Origin of sample message                           :  A.M.YAKOUB/MONGO
Remark                                             :

Modified sample and treatment dates to # days after emerge:     59
Julian day & date of sample and treatment:   227 Aug-15-87


Check for match between grasshopper stages for sample and OSE model
 (Nymph/Adult)  Sample: TRUE  TRUE    OSE mdl: TRUE    TRUE
 Days until match:  11

Crop Information:
                              Millet                          Sorghum
Variety:                 75       90      110       80       90      130
Proportion:            0.20     0.70     0.10     0.20     0.70     0.10
Seeded:               Jun17    Jun17    Jun17    Jun17    Jun17    Jun17
Seedling:             Jun27    Jun29    Jul-2    Jun29    Jun30    Jul-3
Tiller/Spike:         Jul-7   Jul-11   Jul-23   Jul-11   Jul-14   Jul-27
Milky Grain:         Jul-23   Jul-29   Aug-27   Jul-28   Jul-31    Sep-5
Dry Grain:           Aug-21   Aug-28   Sep-27   Aug-27   Aug-26    Oct-7
Harvest:              Sep-2   Sep-14   Oct-14   Sep-14   Sep-24   Oct-24
Yield (KG/HA):          978      978      978      978      978      971
Yld Loss NoTrt:       28.3%    42.5%    64.4%    20.7%    25.4%    30.0%
Yield Loss Trt:        6.2%    11.2%    20.7%     5.5%     8.0%    11.2%


Second year benefits information

 Calculation of 2nd year benefits: (Determined by preseason eggpod survey
 breakeven analysis) Egg density threshold: 34.4/m²; Treatment cost: $7.50/HA;
 Crop value $74.00/HA.
                                No Treatment       Treatment      Difference
 ---------------------------------------------------------------------------
 Final egg density (#/m²)          85.70             48.60           37.10
         Crop loss ($/HA)          18.68             10.60            8.09
```

Table 6, continued

```
Economic Information

 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  41.9  568  11.2  868     55.23     7.44  6.23 56.44 16185   8.9   10.1
 SORG  0.15  24.9  733   7.8  900     23.04     7.44  6.23 24.26     0   3.7    4.9

The Aggregate economic analysis:
                      Result of Treatment ($/HA)                      Benefit
Reg #Si Avg  Trt  %Yld   Benefit           Net    Area  Avg      /Cost    /Risk
ion tes Dens Code  inc   Yr 1   Yr 2  Cost Benefit  HA   Risk   Yr 1 Both  Index
-------------------------------------------------------------------------------------
MON  1   50  MV    52.8 55.23  7.44  6.23  56.44 16185  2.4    8.9  10.1   4.2
-------------------------------------------------------------------------------------
Avg  1   50 N/A    52.8 55.23  7.44  6.23  56.44 16185  2.4    8.9  10.1   4.2
Stdev                    1.00

   First Year Benefit: $ 893,898    Second Year Benefit: $ 120,416
   Cost of Treatment :$ 100,833   Net Benefit         : $ 913,481

End of the report file.
```