The economics of desert locust
A draft summary

Mohammed Belhaj
Environmental Economics
University of Gothenburg
E-mail: Mohammed.Belhaj@economics.gu.se
Tel (46) 31 773 2516
Fax (46) 31 773 4154

Introduction

Depending on the scarcity of reliable data to compare benefits and costs of desert locust's campaigns, to study the socioeconomic impacts of DL invasions and in order to develop policy instruments, the objective of this study (summary) is to;

- study whether the agricultural sectors in some African countries suffered from DL invasions of the eighties and nineties,
- analyse the socioeconomic impacts of DL,
- discuss the transition of DL invasions,
- study campaigns efficiency,
- develop a DL insurance,
- discuss biological pesticides and to,
- compare the benefits and costs of DL control.

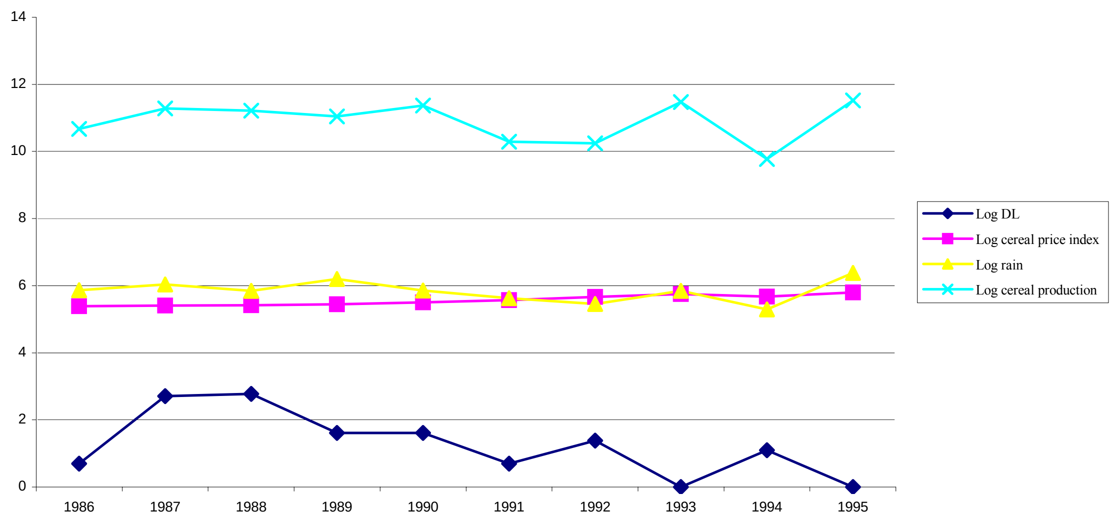
Since data related to DL invasions that were not controlled is not available the analysis as well as the results of the different sections relate to the years where control campaigns have been conducted.

1. Agricultural sectors in Morocco and Sudan

Looking at the agricultural sectors in both Morocco and Sudan the macro-data does not show any evidence of negative relationship between desert locust (DL)[1] invasions and agricultural yield.

-In Morocco the impact of rain is crucial to agricultural yield and there is no clear relation between DL invasions and cereal yield. As shown[2] in figure 1.1 and especially during the eighties where DL invasions[3] were at greatest, there is either no relationship between DL invasions and prices. One reason of the lack of correlation is that the damage caused by DL may be local and non significant at the county level. However, there is a clear correlation between cereal price index and the average magnitude of rain.

Figure 1.1: DL, Rain, Prices and cereal production in Morocco



-In the case of Sudan it is not easy to unambiguously identify any factor having a strong impact on cereal's production. As shown in figure[4] 1.2 and during the famous DL year 1988, agricultural production has been higher than

[1] In this study we do not make any distinction between DL swarms and hopper bands.

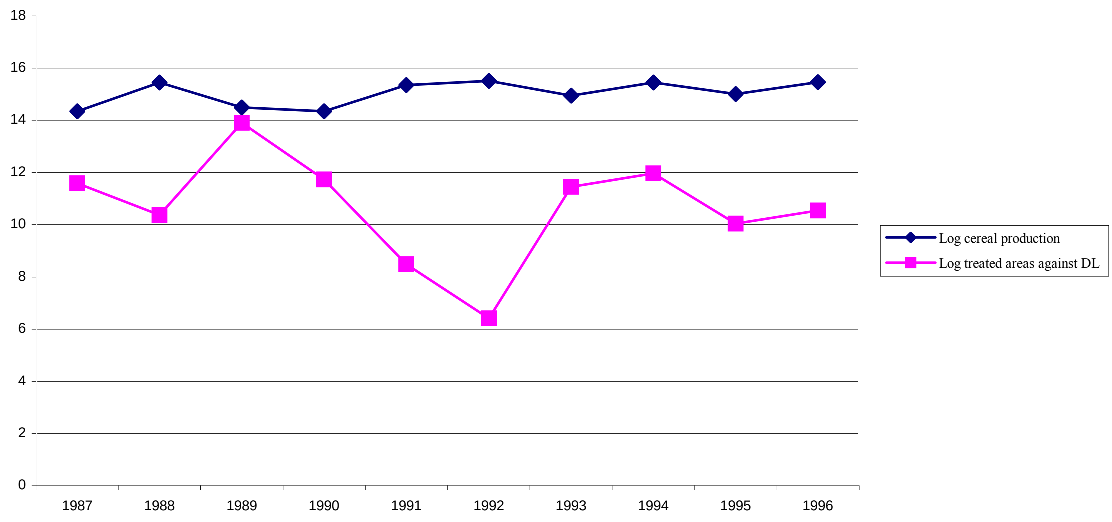
[2] The figures are in logarithmic form to ease comparison.

[3] Since data on DL intensity is lacking the share of invaded farmers is used as a proxy variable for invasions. In 1992 no campaigns were conducted against DL but some farmers stated they were invaded during this year.

[4] Since no data about DL intensity is available treated areas against DL are used as proxy variables.

the average. Here again the impact of DL may be local with no impact on the countries total production and thereby no impact on prices.

Figure 1.2: Cereal production and DL invasions in Sudan



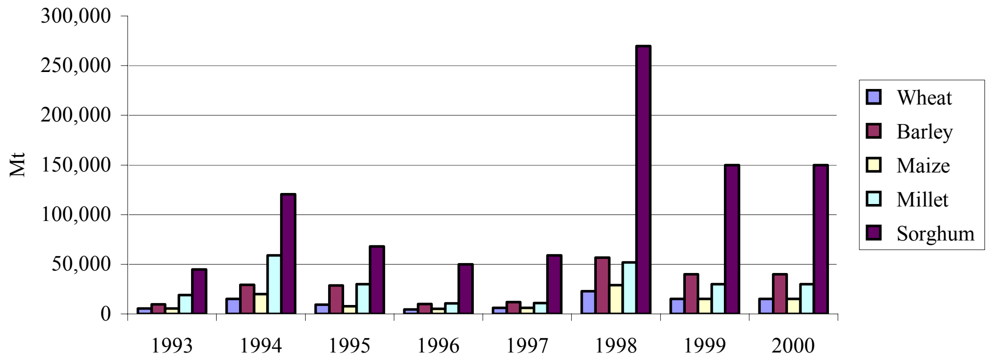
2. Agricultural sector in Eritrea[5]

2.1 Agricultural production in Eritrea

Similar to the majority of LDC economies, Eritrea's economy has two distinct and unequal parts where the traditional one is based on agriculture with a population around 80 percent of the total. The farming sector is crucial to the economy and it employs 77.5 percent (in 2000) of the working population. According to FAO prognostics, the share of this population is expected to increase at almost a constant rate until year 2010. These figures give an insight of the importance of the agricultural sector to the Eritrean economy. The traditional subsistence-farming sector is dominating where most of the holdings are small. This sector is concerned with producing basic foods and a considerable part of the cultivated land is under cereals mainly wheat, barley, maize, millet and sorghum where the production for different years is shown in figure 2. 1.

[5] The discussion here is limited to agriculture which is more relevant to the study. The industrial and service sectors will not be discussed here.

Figure 2.1: Cereal production



Source: FAO

Notice, however, that the cereal production is dominated by sorghum and the best production was achieved in year 1998, a year where the country has been invaded by DL. This evidence is confirmed by the agricultural production indices for Eritrea since the year of its independence i.e., 1993.

Table 2.1:Agricultural production indices[6]

	1993	1994	1995	1996	1997	1998	1999	2000
Cereals	83.1	278.9	162.1	83.5	92.2	487	285.2	285.2

Source: FAO

In general, crop cultivation and animal husbandry are important sources of income for all rural Eritreans accounting for about 60% of income on average in 1993-94. In the lowland rural areas, the income from livestock is significantly higher than in the rural highlands. Nearly 50% of total income is derived from livestock i.e. the sale of livestock and its products as compared to about 30% in the highlands. Moreover, both in the highlands and the lowlands, the rural population also obtains about a third of its income from off-farm activities i.e. casual employment, self employment and trade, including use of livestock for transport and hiring out.

[6] Net Production Index Number (PIN). Presents Net Production (Production - Feed - Seed) indices. All indices are calculated by the Laspeyres formula. Net production quantities of each commodity are weighted by 1989-91 average international commodity prices and summed for each year. To obtain the index, the aggregate for a given year is divided by the average aggregate for the base period 1989-91. Indices are calculated from net production data presented on a calendar year basis.

Eritrea is a drought prone country. In normal years, rainfall varies from 400-600 mm in the highlands and southwestern lowlands to 200-300 mm in the eastern areas i.e., north and southeastern lowlands. In drought years, rain magnitude may be only 200 mm in the highlands and less than 100 mm in the lowlands. In 1993-94, households were unable to survive through their own production which was badly affected by drought and had to rely on food aid and food-for-work for 6-8 months of the year. In the following year, the rain was good, and production increased to about 8 months of need. On the other hand, Eritrea belongs to the so-called central region, which often constitutes the starting point of DL invasions. Hence, except drought, Eritrea is also a DL prone country.

2.2 Agricultural input

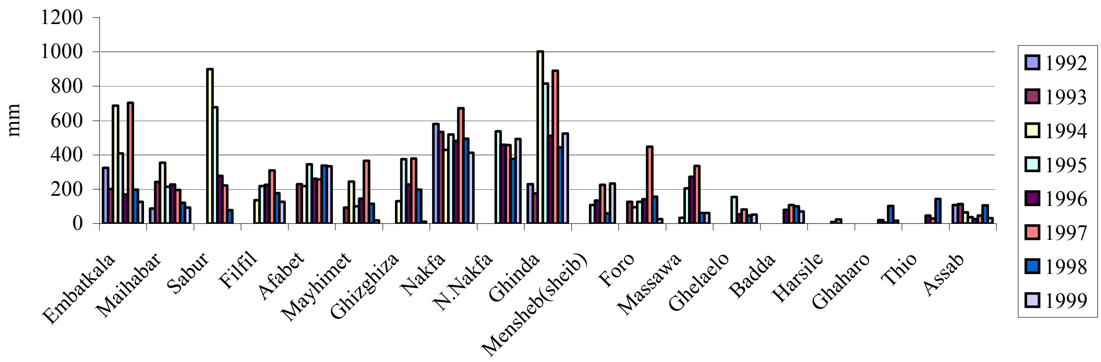
Similar to all kind of production, agriculture is dependant on a variety of input factors whose availability is a prerequisite for a stable and high yield. The inputs may be classified into two categories. The first ones are natural and constitute a precondition for all agricultural production. These inputs are labor, land and rain (seeds are of course important as well but they will not be discussed here since data is not available). The other category of inputs is used in order to increase yield and to reduce risks and instability in crop production. These inputs are fertilizers and pesticides. Fertilizers are used to nourish the crops while the pesticides are used to protect the crops against different pests such as DL.

i. Rain:

There are two rainy seasons in Eritrea. The main rains, Kerempt, last from June to September and fall almost all over the country, more in the highlands than elsewhere. The small rains, Belg, last from about December to March or April, mainly along the cost. The irregularity of rain in Eritrea is a fact that depends on its location/topography. However, when it comes to rain, the distinction is to be made between highlands and lowlands. The highlands do not in general suffer much from water scarcity. In the lowlands, rain is very irregular but these regions often benefit from water coming down from the highlands and flooding the croplands. This is an old irrigating system practiced in the lowlands.

Figure 2.2 shows the magnitude of rain in different stations located all over the country. All stations with higher peaks such as Sabur (near the capital Asmara) are located in the highlands. As concerns the lowlands with the exception of Meyhimet in the north all the 9 stations on the right hand side of the figure are to be found in the southeastern lowlands where Massawa is the second largest city in Eritrea and located on the Red Sea coast. Looking at the different years and especially at those with higher precipitations, many of these years i.e., 1993, 1995, 1997 and 1998 are DL years.

Figure 2.2: Precipitations in mm



Source: M.A Eritrea

Eritrea is also dependant on irrigation. When it comes to irrigated land it has been constant since 1993 and amounted to 22 thousand hectares. However, five seasonal river basins (Mereb, Tekeze, Anseba, Barka and Damas) some of them shared with neighboring countries have substantial potential for irrigation development (and hydroelectricity generation). Some studies (World Bank) point out that the Tekeze and Mereb river basins together have a potential irrigable area of up to 350 thousand hectares.

ii, Agricultural prerequisites

The agricultural prerequisites including machinery, fertilizers and pesticides are used to stabilize and/or increase production. In Eritrea, agricultural production, which is mainly for subsistence and in the hands of individual farmers is very low. This sector lacks in general of modern agricultural implements. Table 2.2 shows the number of agricultural machines in use. Although the number of harvesters-threshers and tractors has increased since the independence year they were 0.16 and 1.2 respectively per thousand hectares arable land in 1998. These figures are quite lower than the African average which was 0.2 and 3 respectively for harvesters-threshers and tractors in 1998.

Table 2.2: Agricultural machinery in use

	1993	1994	1995	1996	1997	1998	1998/93
Harvesters-Threshers	15	15	15	16	47	80	5.33
Tractors Agric Total	250	270	300	331	440	613	2.45

Source: FAO

As concerns fertilizers including nitrogenous and phosphate, table 2.3 shows their use since 1993. Although it has increased by more than 600 percent during this short period the use of nitrogenous and phosphate is about 10 and 3 *Mt* respectively per thousand arable land in Eritrea. The fertilizers use also remains very low compared to the average African use which was 13.42 and 5.24 for nitrogenous and phosphate respectively, in 1998.

Table 2.3: total fertilizer consumption (MT)

Fertilizers	1993	1994	1995	1996	1997	1998	1998/93
Nitrogenous	700	1100	1414	3793	5000	5000	7.14
Phosphate	0	200	200	1200	1000	1500	7.50*

Source: FAO. *)1998/94

iii, Pesticide use and DL invasions

Similar to the application of fertilizers, the use of pesticides is another key element in the Eritrean farming in order to mitigate instability and increase agricultural production. Yet, we can distinguish between two kinds of pesticide’s use. The first ones including for instance fungicides, herbicides and insecticides. These are procured by the farmers to serve their individual needs. The other kind of pesticides, which is an insecticide to be used against DL is taken care of by the country's ministry of agriculture.

However, the use of pesticides against DL involves several problems. Their impact on humans occurs not only during DL campaigns but also afterwards. During the campaigns the effects were noted mainly among pesticide handlers and applicators. When the campaigns are over large stocks of unusable, obsolete, environmentally undesirable or banned insecticides have accumulated in many DL affected countries. These stocks are a problem since they are stored in deterioring containers that may leak and they may be used for pest control when stocks of preferred pesticides are exhausted. Moreover, in addition to potential environmental and human health risks associated with spraying large stocks of unwanted pesticides, there is the problem of dealing with empty pesticide containers and their use by the general public as storage containers, including food and water (Showler, (1998)).

To use or not to use the pesticides against DL is in general DL intensity dependant[7]. In the case of Eritrea and since the outbreak of 1987 (see table 2.4) pesticides have been used in many years where the country has experienced DL invasions. In 1992 although the country has been invaded by DL their intensity has been judged to be less threatening and no pesticides were applied.

Table 2.4: Pesticides used against DL

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997 to 1998	1999	2000
Pesticides Used	yes	Yes	No	No	No	No*	Yes	No	Yes	No	Yes	No	No

Source: M.A Eritrea. *) The country experienced DL but no pesticides have been used.

The starting point of DL invasion in many cases, if not all, is very dependent on rain. In brief, solitary DL starts to develop "social" behavior when enough rain has fallen in their region. They join other solitary locust and start breading where the result after some weeks is a swarm. The swarm, depending on weather conditions including wind, starts its invasion to different regions/countries. These create a kind of

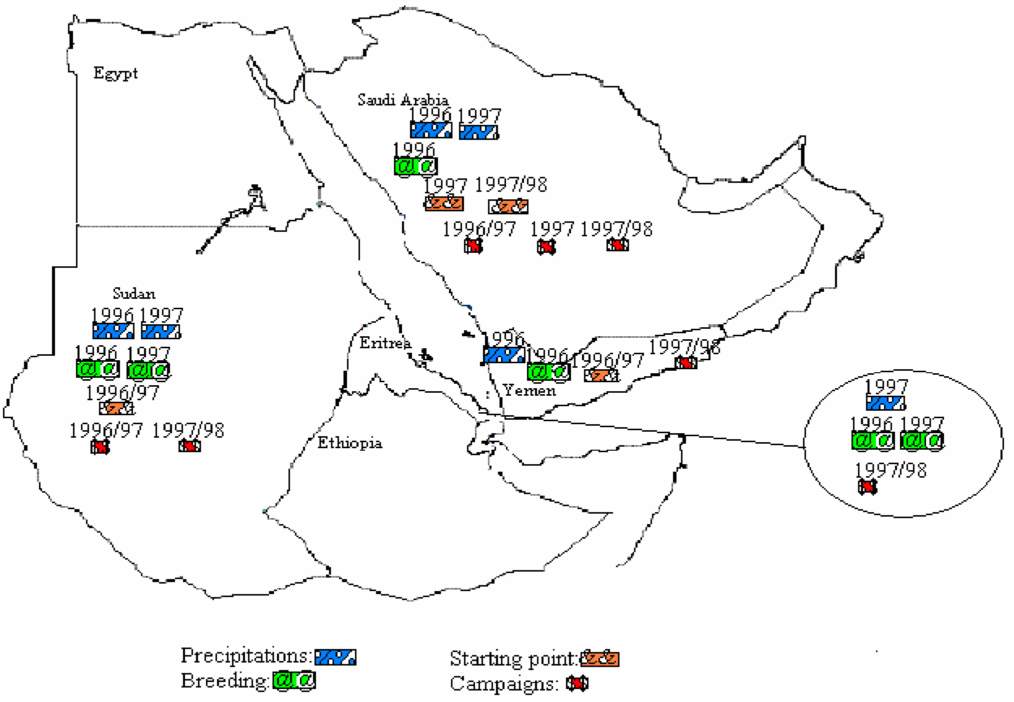
[7] According to Mr. Benhalima (EMPRES West region) control campaigns take place when the intensity is 200 DL per hectare.

interdependency as concerns the mobility of the pests. As shown in table 2.4 a DL invasion took place during the period 1997-1998 where according to farmers the invasion of 1997 as well as its impacts were worse than any other invasion since the country's independence.

2.3 DL invasions and impacts

Eritrea is a country of the central region which is often the starting point of many DL invasions. Figure 2.3 depicts the interdependency of the countries of the central region as concerns DL movements for the years 1996-1998; In October 1997 for instance heavy rainfall from central Eritrea north to the Sinai Peninsula ensured good breeding conditions along the Red Sea coasts. Swarms arrived and bred on the coast of Sudan in late October and reached northern Eritrea in early November. Hopper bands appeared in Sudan from Tokar north to Port Sudan. In northern Eritrea, bands mixed with African Migratory Locusts formed by the end of November. Some of these swarms emigrated in January across the Red Sea to the coast of Saudi Arabia and probably neighboring parts of Yemen. Others went north into Egypt. Breeding continued in Sudan and Eritrea in January 1998 (FAO).

Figure-3: Some interdependancies in the Central Region



Hence, the interdependency of these countries in this region has led to different control campaigns that are often dependant on the intensity of the swarm. Notice, however, that Saudi Arabia sprays more land than the other countries of the region. This of course may depend on the size of the invaded areas but also on the economic advantages this country possesses. Table 2.5 shows the treated areas in *ha* in different countries of the central region.

Table 2.5: Treated areas in *ha*

Country	Year	
	1996/97	1997/98
Saudi Arabia	339 360	280 107
Sudan	618	61 669
Yemen	0	18 165
Eritrea	0	18 565
Egypt	0	50 267

Source: FAO

As concerns the history of DL invasions in Eritrea since its independence it has evolved in the following manner (FAO):

-1993; December 1992 a survey on the Read Sea coast in Eritrea indicated that most of DL population has departed as the main infestation was observed from Sheib to Mersa Cuba in the lowlands.

-1995; Starting on July, various reports were received of DL entering Eritrea (i.e., the western lowlands and Senhit province) from the neighboring country, Sudan.

-1997; As a result of an unexpected breeding during November 1997 from isolated non-gregarious adults almost all Eastern Coastal region was infested by DL and migratory locusts. The first report was received from Mahmimet, the northern part of Eritrea where small swarms entered from the north (i.e., Sudan).

To summarize this part of the study one would argue that depending probably on the control campaigns conducted by the ministry of agriculture in collaboration with

EMPRES DL attacks did not have any significant impact on agricultural production reduction at the macro level. In year 1998 for instance, a DL year, cereal production has been higher than the average. These results are in accordance with the findings in Morocco and Sudan where in general cereal production in both countries did not exhibit any evidence of negative relationship between DL invasions and agricultural yield. When it comes to prices no impact of DL on cereal prices was found in the case of Morocco. In Eritrea price increases are according to the farmers subject to drought.

3. Household production function

This section analyses household production function that may give some insight on the effect of DL invasions on the Eritrean farmer's yield. To our knowledge this is the first attempt to estimate a farmer production function where DL is included as an explanatory variable.

In 2000 and 2001 and with the help of technical officers of the Ministry of Agriculture 28 villages (see table 3.1) located in southeastern and northeastern lowlands and highlands where randomly chosen to conduct a survey. Since DL invasions harm the different regions differently, where the lowlands are the most affected, the idea of including villages from different regions of Eritrea may give results that are important for policy formulations.

Table 3.1: Villages of the sample

Southeastern Lowlands	Northeastern Lowlands	Highlands
Foro 41	Meyhimet 139	Maihabar 45
Kadra 35	Karora 38	Dongolo 68
Airomale 26	G.Halib 72	Metkelabet 33
Afta 23	Kimtiwa 61	Zoba makel, Tseazega 80
Zula 53	Kezan 25	Adinahbay 36
Gelalo 8	Kubae 44	Dekitsenay 33
Menkalite 14	Gulbub 12	
Ghedem 15	Afrit 8	
Hirgigo 44	A. Galbou 11	
Engel 24	Naro 7	
Gahtelay 29		
Shieb 95		

In each village some households where selected randomly and many important questions related to the household production function were asked. The data collected is for the agricultural year 1997/98 because this year is of special interest to the study; It is a DL year and a control campaign has been conducted.

3.1 Modeling household production function

The farmer's household is modeled as producing a vector of outputs *y* from inputs *x* (i.e., land, labor including male, female and child, machinery, fertilizers, pesticides procured by the farmer, rain and soil quality), given random production disturbances (DL) denoted by $\tilde{\theta}$ with joint density $h(\theta)$ [8]. The realized output is;

$$y=y(x, \tilde{\theta})$$

where θ is a particular set of realizations of $\tilde{\theta}$. To enable the econometric estimations, a Cobb Douglas specification is used. By choosing this functional form it is assumed that the relation between crop production and the independent variables is linear in logarithms with constant return to scale. The logarithmic form also allows us to interpret the parameter estimates as elasticities.

3.2 Determinants of agricultural production

The characteristics of the sample, for all regions that were invaded by DL including southeasten lowlands, northeastern lowlands and highlands are presented in table 3.2. These characteristics concern the agricultural year 1997and relate to households that were engaged in cereal production during this year. We refer here to households whose answer related to DL invasion in 1997 was positive i.e., they were invaded by DL but the magnitude of the swarm differs between farmers where 1 is a big swarm, 2 is a medium one and 3 relates to a low level swarm. We are aware of the fact that the swarm's magnitude is subject to farmers perception about size. However, since there is not data about the size of DL swarm on each farm, the perceptions of the farmers is used as a best guess for the estimations.

[8] This is a reduced form based on Chambers (1989) in Hueth et al (1995).

The production refers to cereals in quintals and the average yield is 6.62 with a lower production in the northeastern lowlands. The cropped land by household is on average very low i.e., 1.88 hectare. As concerns labor[9] input in days it is lower in the northeastern lowlands. For many households, Oxen is seen to be an important input to increase productivity. However, depending on poverty factors the availability of oxen is in average very low i.e., 9.7 days. As discussed earlier, agricultural prerequisites including machinery, fertilizers and pesticides are very low at the country level and the shown figures reflect this evidence at the household level as well. As regards pesticides the values reported in the table concerns pesticides used on other pests rather than DL. Turning to rain's magnitudes the values are those reported by the farmers. Figures from rain stations are not included in order to avoid biases since rain magnitudes reported by a station may not reveal the true quantity of rain a specific farmer got on his cropland. When it comes to soil-quality it is reported to be better in the lowlands.

As concern DL swarms they are larger in the lowlands. In the northeastern lowlands 78 percent of the farmers stated that their cropland was sprayed in 1997. In this region the quantity of pesticides used against DL is revealed to be in average around the medium quantity. Moreover, the number of times a cropland has been sprayed is in average 2.26 in the northeastern lowlands.

[9] It is an aggregation of male, female and child labor

Table 3.2: Agriculture; 1997 output and input in different regions

Variable	South-eastern lowlands	Northeastern lowlands	Highlands	Average
Production (qt)	8.9	5.2	5.76	6.62
Land (ha)	1.52	3.21	0.91	1.88
Labour	45.45	37	48.9	43.7
Oxen (days)	14.48	5.3	9.32	9.7
Machinery (number)	0.11	0.37	0.03	0.17
Fertilizers (kg)	na*	0.24	0.37	
Pesticides (kg)	0.55	0.81	0.005	0.45
Rain (if good =1)	1.17	1.67	1.85	
DL (if large swarm = 1)	1.63	1.64	2.81	
Soil (if good =1)	1.09	1.4	1.87	
If spray	na	0.78	na	
Quantity sprayed (if large = 1)	na	1.58	na	
Number of times DL sprayed	na	2.26	na	

*)na=non available

3.3 Estimation results

Using the ordinary least squares methodology the estimation results for cereal production in the agricultural year 1997 are brought together in table 3.3. These results may be commented in two ways. The first one refers to the farmer's incentives to increase crop production. The second way relates to the impact of DL on yield.

Except for land and labor, dummy variables are used to estimate the impact of the other variables. For the variable insecticides' use and in order not to bias the results since most of the reported values were nil (i.e., do not use insecticides) a dummy variable is used.

Table 3.3: Household's production function

	Norhteastern lowland	Highland	Southeastern lowland
Variables	Elasticity (T-stat.)	Elasticity	Elasticity
Land (ha)	0.23	0.5	0.81
	(2.94)	(5.33)	7.75)
Labor(days)	0.06	0.3	0.18
	(1.25)	(5.27)	(3.50)
Oxen(days)	0.42	-0.15	0.04
	(3.16)	(-0.46)	(0.44)
Insecticides(kg)	0.1	-1.11	0.24
	(0.7)	(-3.34)	(2.44)
If large DL=1	-0.3	.	.
	(-2.45)		
If med. DL=1	.*	-0.44	-0.07
		(-3.7)	(-0.77)
If low DL=1	.	-0.47	0.51
		(-4.66)	(2.80)
Rain(if good=1)	0.55	-0.1	-0.07
	(4.58)	(-0.81)	(-0.77)
Soil (if good =1)	0.11	-0.1	0.06
	(0.92)	(-0.77)	(0.29)
Intercept	0.52	1.45	1.52
	(2.54)	(4.11)	(5.63)
Adj. R^2	0.14	0.49	0.45

*) For reasons of multicollinearity the variable is not included in the estimations.

As concerns land used to produce cereals in all regions, the parameter estimate is positive and highly significant implying an increase in cereal production if more land is available. This is an intuitive result of good importance to the policy makers in Eritrea where the low cereal production may be increased if more efforts were mobilized to enhance land management e.g., decreased deforestation and soil erosion. Looking at the elasticity of labor, although it is less in magnitude compared to land, it is positive and highly significant suggesting that more work leads to better harvest. When it comes to oxen an increase of its use would lead to better harvest in the northeastern lowlands. As concerns the elasticity of insecticides procured by the farmers the parameter estimate is positive and highly significant implying higher yield if more chemicals are used against different agricultural pests in the southeastern lowlands. When it comes to rain the elasticity of this variable is positive and significant at 5 percent level in the northeastern lowlands suggesting a higher cereal yield when sufficient quantities of rain are available.

Turning to DL impact on cereal production the outcome is as follows;

-In the northeastern lowlands large DL swarms has a significant and negative impact on cereal production; an increase in the magnitude of swarms by 1 percent would decrease cereal production by 0.3 percent.

-In the highlands medium and low level swarms have similar negative effects on cereal production.

-In the southeastern lowlands, DL impacts are non significant. This result may be seen as a paradox for a non-DL expert. However, as discussed above historically data shows that cereal production during DL years is in general higher than in years without DL. This is because rain in the highlands and the derived flooding in the lowlands are sufficient. The reasons for this outcome are several and include the farmer's incentives to make use of more land, the damage after DL is corrected as DL leave and since DL attacks are random, the average farmer may not suffer much from the invasions. However, although the average farmer in the southeastern lowlands did not suffer from DL invasions the findings may not imply that the 1997 invasion did not affect some farmers to the point that they lost everything where the outcomes may be severe socio-economic consequences?

4. Transition models

4.1 Introduction

How long time do farmers in different regions of Eritrea experience a DL invasion? How does the duration of DL attacks vary across farmers? Answers to these questions are needed for at least two reasons. First, the welfare of the farmers is surely more closely related to the time they are attacked by DL than the fact that they have been attacked. Second the length of DL attack-spells, plays a critical role in control campaigns. Any careful evaluation of the control campaigns, therefore, requires accurate information on the duration of DL attacks. An interesting method to study these issues is the hazard function, which provides a convenient definition of duration dependence. Positive duration dependence means that the probability that a spell will end shortly increases as the spell increases in length (Kiefer 1988).

The transition rate from being attacked by DL to a *status quo* situation may be given by the product of potential control campaigns and the probability that a campaign is conducted. This transition rate is the probability of DL leaving a cropland at any moment given that the cropland is still attacked by DL up to that moment. In other words, it is the hazard function for the distribution of DL-attacks duration.

In order to analyze this relation in Eritrea a non-parametric and semi-parametric models are used for the estimations. This is the first time in our knowledge this methodology[10] is used in an agricultural study in general and in the estimations of DL invasion's transition in particular.

4.2 Modelling the transition

The Kaplan-Meier estimator of the survival function will be used in this study. This estimator is non-parametric and may be interpreted as a maximum likelihood estimator of the transition function $\lambda(t)$;

$$\hat{\lambda}_i = \frac{d_i}{N_i}$$

d_i is the number of DL attacks at duration t_i and N_i is the number of farms at risk just before t_i. Moreover, the Kaplan-Meier estimator of the survival function for those farms, which have not been attacked during the observation period t is,

$$\hat{S}(t) = \prod_{t_i<t} \left| 1 - \frac{d_i}{N_i} \right|$$

A semi parametric model is used by way of a Cox proportional hazard framework as an alternative method of estimation. It is based on the following transition function for the distribution of duration "being invaded" which, is the transition rate.

[10] This method has been widely used in studying unemployment and female fertility.

$$\lambda(t) = \lambda_0(t)\, e^{\beta' x}$$

where $\lambda_0(t)$ is the baseline transition and $e^{\beta' x}$ is the relative risk associated with the regressors. That is the probability of being invaded at any moment given that the farm is not invaded by DL up to that moment**.** This is a flexible procedure since the baseline hazard is semi parametric and the risk of affecting the estimated transition is eliminated and the effect of the covariates takes a particular functional form.

4.3 The data

In order to make use of the transition model a very specific data was collected and transformed to spell format. This data concerns different events that took place previous to and during the invasion of 1997. Hence, data related to duration of DL attacks was collected i.e., the number of days farmer's agricultural land has been invaded by DL. In the survey, data was also collected for the magnitude of rain, previous DL campaigns and other variables such as agricultural production.

The average length of duration of DL invasions is summarized in table 4.1. As shown this duration is lower in the highlands and longer in the southeastern lowlands. Notice, however, that the duration varies considerably between farmers. It ranges between 1 day being the shortest duration and almost three months being the longest stay.

Table 4.1: Average length of invasions in 1997

Variable	Northeastern lowlands	Southestern lowlands	Highlands
Length of invasion (days)	11.99	13.34	4.83

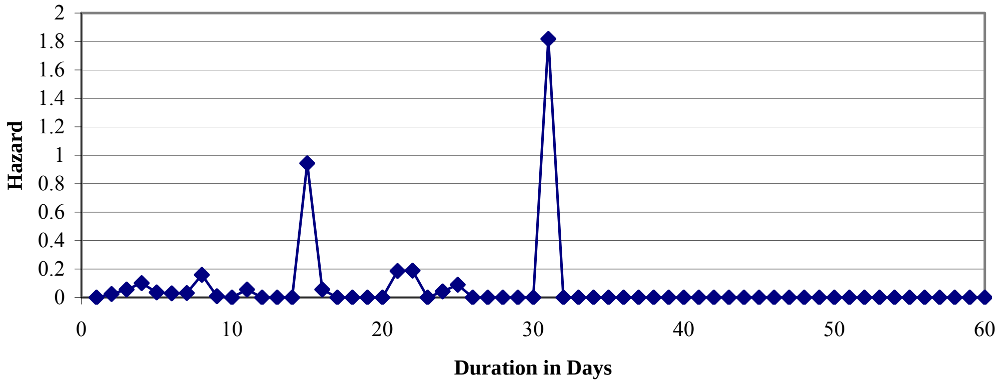
4.4 Estimation results

Starting with the non-parametric approach figures 4.1 shows the hazard rates in the southeastern lowlands[11]. The hazard rate is equal to 0.16 in day 8 and increases to

[11] (The results (not shown here) are almost identical if all regions are considered).

0.95 in day 15. The hazard rate is highest in day 31 and decreases to zero when the duration in days is higher.

Figure 4.1: The Hazard Function (southeastern lowlands)



Turning to the semi parametric estimates the results are summarized bellow. The highlands are not included since few farmers of this region have been invaded by DL.

-The northeastern lowlands; in this region only 3 variables'parameter estimates are significant (at different levels). When a cropland is rich in cereals the hazard ratio is greater than one implying a higher probability of stay if the conditions are favorable. When a cropland is small in size, duration of DL invasion is low and the transition period is high. Moreover, the number of times DL has been sprayed reduces the length of the stay.

Table 4.2: Semi parametric estimates in northeastern lowlands

Variable	Parameter Estimate	Pr > ChiSq	Hazard Ratio
Crop production	0,02	0,08	1,02
Crop land	-0,08	0,04	0,92
Labor	-0,001	0,68	0,99
If use machines	0,17	0,47	1,19
If good rain	-0,11	0,55	0,90
If good soil	0,06	0,76	1,06
If use oxen	-0,18	0,33	0,83
If large quantity sprayed	0,05	0,80	1,04
Number of times DL sprayed	-0,04	0,16	0,96

-The southeastern lowlands; Only 2 variables' parameter estimates relative to DL transitions, are significant. When cropland is relatively large in size, duration of DL invasion is high and the transition period is low. Hence, displacement within a specific area is quite slow. Moreover, soil quality impacts positively on the length of duration.

Table 4.3: Semi parametric estimates in southeastern lowlands

Variable	Parameter Estimate	Pr> ChiSq	Hazard Ratio
Crop production	-0.001	0.85	0.99
Crop land	0.10	0.18	1.11
Labour	-0.001	0.38	0.99
If good rain	-0.12	0.66	0.88
If good soil	-0.81	0.007	0.45
If use oxen	-0.27	0.22	0.76

5. Using panel data to analyze Socio-economic impacts of agricultural disasters.

5.1 Introduction

In this part of the study we will look carefully at the socioeconomic impacts of DL invasions in all regions in general and in the northeastern region in particular using a panel data and a probit model. It is, however, not easy to unambiguously distinguish between problems caused by DL and problems caused by other factors such as drought and/or quelea[12]. Moreover, since a control campaign has been conducted the results of this part are probably the product of the efforts done to mitigate the effects of DL. However, the aim of this part is to study the socioeconomic impacts of a presumably disaster caused by the DL invasion that hit Eritrea in 1997. This part of the study will especially focus on income fluctuations that followed during the invasion year i.e., 1998, 1999 and 2000 especially in the northeastern region of Eritrea.

[12] Quelea is a bird that is very common and whose damage is often compared to the damage caused by DL.

5.1 Agricultural risk and fluctuations

Income fluctuations are believed in general to lead to consumption instability where the outcome in rural areas in general may be starvation or migration to urban areas if government assistance programs such as food aid are lacking or non efficient. However, it is well known that people in general and farmers in particular behave in different ways in order to protect their consumption from income fluctuations. These range from informal community risk sharing to participating in insurance and credit markets when such opportunities exist (Binswanger et al (1987), Fafchamps et al 1998)). In the case of Africa, keeping livestock as an insurance substitute has longstanding importance. Livestock sales and purchases are used as part of farm household's consumption smoothing strategies. Also off-farm income is used in cases where circumstances dictate it.

-The southeastern lowlands and the highlands

Based on the survey conducted in 2000 an attempt is made here to describe the destiny of the farmers who started crop production in the southeastern lowlands and the highlands in 1997 and for whom the yield was nil in 1999. The idea of including both 1997 and 1999 is to try to grasp the socioeconomic consequences, if any, of the DL invasion[13].

Table 5.1 shows the number of farmers and some characteristics related to their agriculture in the southeastern lowlands. Starting with window *I* these farmers stated that they were damaged by DL at least one time during the last 20 years. The best agricultural yield these farmers ever achieved (including crops and livestock) was on average 3065 Nakfa[14]. Assuming in general that crop production constitutes 50 percent of agricultural production (the other half is livestock production) the best average crop production ever achieved is 1533 Nakfa. In 1997, although this year was a DL year and the stated damage by DL was estimated to 2776 Nakfa, the average crop yield was valued to 2100 Nakfa. In 1999, crop yield for these farmers was on

[13] It should be noted that this data does not include the farmers that may have left the region directly after DL damaged all their crops in 1997.
[14] 1 Nakfa = 10 USD in 2000

average 806 Nakfa. Hence, crop production in 1997 was on average higher than in any other previous year.

Window *II* reports the characteristics of farmers with only positive crop production. Window *III* brings together farmers that started crop production but whose crop yield was nil. Notice that the sum of farmers in *II* and *III* is equal to the number of farmers in *I*. In *II* and *III* farmers were invaded by DL at least one time during the last 20 years and the damage reported concerns that period.

Table 5.1: DL invasion and agricultural yield in the southeastern lowlands

	Farmers who started crop production I		Farmers with only positive crop yield 97 II		Farmers with zero yield; may be DL III		Farmers with zero yield 1997; stated they were invaded by DL IV		Farmers with zero yield 97 and zero income in 1999; stated they were invaded by DL V	
Variables	N	Mean*	N	Mean	N	Mean	N	Mean	N	Mean
DL damage 97	256**	2776	164	2802	92	2729	82	2682	6	3083
Crop prod. 97	321	2100	206	3284	115	0	83	0	6	0
Best agr. Yield	318	3065	206	3040	112	3110	80	3252	6	2783
Crops 1999	320	806	205	917	115	606	83	579	6	0
Livestock 1999	320	2271	205	2323	115	2179	83	2212	6	250

*) The means are in Nakfa (10 Nakfa=1 USD in 2000). **) Differences between the *N* are due to missing values.

In window *IV*, 82 farmers stated that they were invaded by DL in 1997 and their total crop damage was valued on average to 2682 Nakfa. Comparing this value to the average crop yield in 1999 one would say that these farmers have lost almost everything during the invasion of 1997.

Looking at window *V*, we are left with 6 farmers i.e., 1.5 percent of the sample with zero crop production in 1997. These 6 farmer's households are to be found in the following villages: 2 in Kadra, 2 in Menkalile and 2 in Hirgigo south of Massawa. Out of these 6 farmers, 5 farmers have had no livestock in 1999. Since these farmers may be stayed in the region depending on their ownership of land they could overcome the crisis because of private loans, sell of livestock or food aid or a combination of these.

-The highlands

In the highlands, however, only 2 farmers out of 296 have seen all their 1997 crop production damaged by DL. The stated average crop damage was valued to 4700 Nakfa. In 1999, these farmers who are from Maihabar and Dongolo located on the slopes between the capital Asmara and Massawa on the Red Sea cost, have had on average an income equal to 1375. The source of income was crop production. Notice, however, that only one of these two farmers had no livestock in 1999.

Table 5.3: DL invasion and agricultural yield in the highlands (Nakfa)

Variables	Mean	Std. D	Minimum	Maximum
DL damage 97	4700	2404	3000	6400
Crop prod. 97	0	0	0	0
Best agr. yield	2325	106	2250	2400
Crops 1999	1375	1237	500	2250
Livestock 1999	2200	3111	0	4400

-The northeastern lowlands

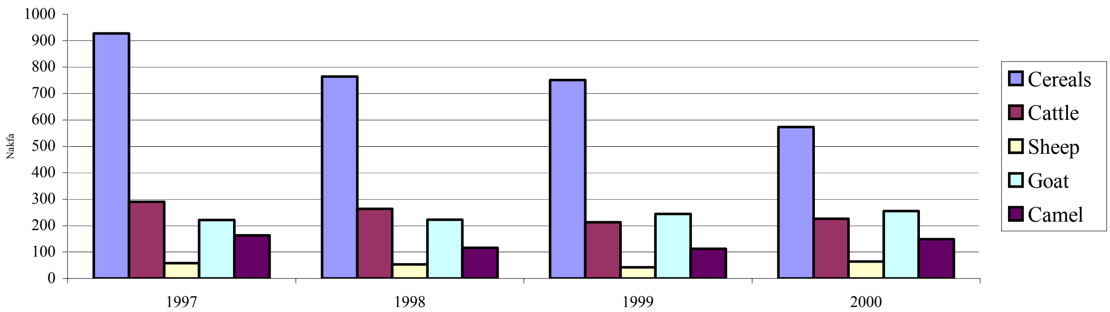
In 1997 a severe DL invasion hit the region and 265 farmers or 64 percent of the sample have been invaded by DL. However, although the northeastern region is a breeding as well as a starting place for DL invasions, the majority of farmers i.e., 61 percent have been invaded by DL only one time the last 10 years as shown in table 5.3. This is probably the result of the efforts conducted by the ministry of agriculture with the assistance of EMPRES.

Table 5.3: The number of times damaged (Northeastern lowlands)

	Mean	Std. D	Min	Max
Invaded 1 time	0.61	0.48	0	1
Invaded 2 times	0.20	0.39	0	1
Invaded 3 times	0.08	0.26	0	1
Invaded 4 times	0.005	0.07	0	1

In 2001 and in the northeastern lowlands, 85 percent of the farmers have had agriculture as the principal activity and 15 percent have had off-farm work as the principal activity. Figure 5.1 brings together the development of agricultural income during the period 1997-2000 for farmers who have been invaded by DL in 1997. In 1997 both incomes from crop production and livestock have been higher than those in the coming years where the main reason has been the abundance of rain although DL invasion that year was the most serious one since the country's independence.

Figure 5.1: Household total agr. income 1997-2000 in the notheastern lowlands (Nakfa)



During the studied period the overall agricultural income has decreased by 23 percent; crop income has decreased by 38 percent while that from livestock has decreased by 5 percent only. Since the lowlands, in general, are more prone to drought, diversification of agricultural activities are very important in order to smooth consumption and to avoid starvation as discussed above. Hence livestock production constitutes the relatively stable part of the farmer income.

During the survey farmers were asked 2 questions related to their responses in the wake of a DL invasion that would damage all crop production.

-The first question was related to what they would do themselves and,

-The second question concerns what those farmers who lost all crop production in connection with a DL invasion did.

When it comes to what the farmers themselves would do, table bellow shows the results. 47 percent revealed they would take a loan in order to compensate for the missing income, 10 percent would move to another region (or another country such as Sudan) and 38 percent would work, sell livestock or wait for food aid distributed by the government[15].

Hypothetical and factual responses in the case of total agricultural damage by DL

	What the farmer would do if totally damaged?	What the totally damaged farmer have done?
Private loan	47	12
Move to another region	10	5
Work, sell livestock or food aid	38	
Food aid		42
Work		21

As concerns what the farmers that have been totally damaged by DL have done, the answers were as follows: 42 percent received food aid, 20 percent started to work, 21 percent sold livestock, 12 percent took loans and 5 percent moved from the region. Notice, however, that 5 percent may be a biased number since different families would refer to the same family while answering the question if they know of any family who left the region after a DL invasion.

Comparing answer one and answer two gives an insight about what the farmer would do in the case his agricultural production is totally damaged by DL. The second answer shows, however, what the totally damaged farmer have done. Nevertheless, it is not evident to believe that the farmer’s behaviour in general and in the wake of a total damage implied by DL would correspond to the actions of what the totally

[15] These numbers do not sum to 100. Information on the remaining part could not be obtained.

damaged farmers have done. These farmers who lost all during a DL invasion may be the most vulnerable (e.g., old or sick or with kids that could not help or without kids at all), the poorest or a combination of these two attributes. Therefore their actions probably have been as such. The fact that 42 percent of the representative farmers received food aid confirms their vulnerability; Less vulnerable or non-poor farmers would manage the damage caused by DL through private loans, sale of livestock, off-farm work or a combination of these alternatives including food aid.

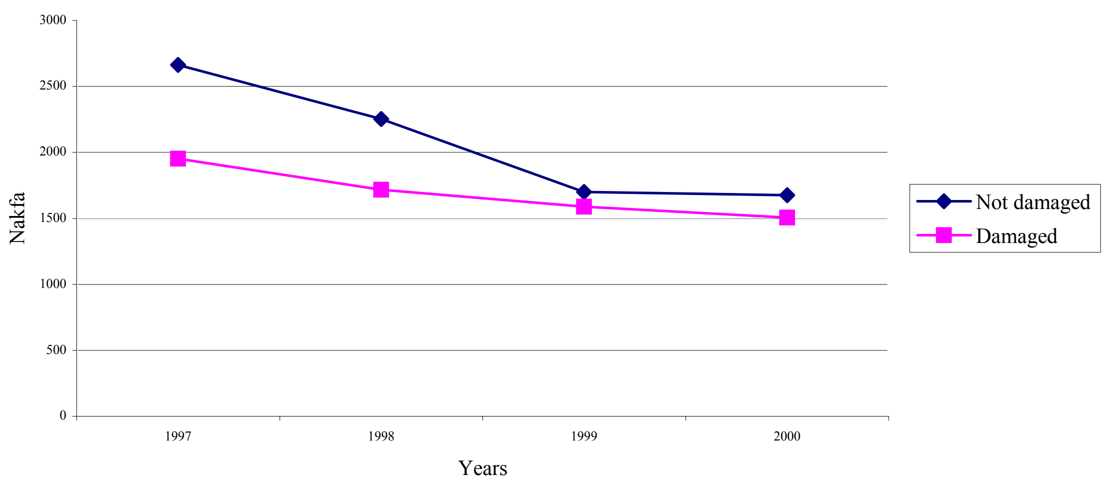
-Comparing the three regions

When comparing the data from the southeastern lowlands, the highlands and the northeastern lowlands we observe the following;

-Since we do not have any data relative to the farmer's income previous to the 1997 DL invasion two alternatives could be used as concerns the total agricultural income and the DL impacts in the northeastern lowlands.

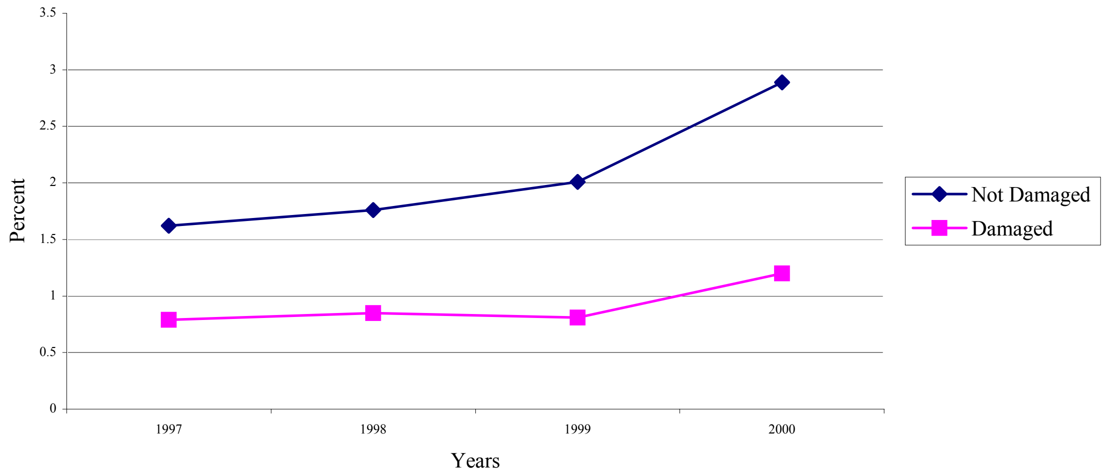
Assumption 1: the lower overall income is a result of the DL invasion of 1997;
Assumption 2: the damaged farmers are in average poorer (see figure 2) and therefore more vulnerable to DL attacks where the 1997 DL invasion have had a significant and negative impact on the overall income.

Figure 2: Agricultural income in the northeasten lowlands



-On the other hand, the share of livestock in agricultural income is believed to be higher in the southeastern lowlands and the highlands than in the northeastern lowlands. This is maybe the reason why the overall economical impacts of the 1997 DL invasion were not severe in the southeastern lowlands and the highlands. Moreover, looking at figure 3, the livestock/crop ratio is higher for those who have not been damaged by DL in 1997 and lower for those who have been damaged by DL the same year. Based on these observations one may assume the following;

Figure 3: Livestock/cereal ratio in the northeastern lowlands



Assumption 3: Reliability on crops alone may put a farmer in a fragile position where negative chocks such as DL or drought may imply disastrous consequences;

Assumption 4: Reliability on (at least) both crops and livestock where the share of livestock is higher helps to mitigate the negative impacts of different agricultural disasters.

Based on the assumptions 1-4 we will in the following use a probit model in order to understand which one of the assumptions (or a combination) is valid to explain the socioeconomic impacts of the 1997 DL invasion in the northeastern lowlands.

5.2 Coping with the 1997 DL invasion in the northeastern lowlands

Table 5.4 and 5.5 bring together the marginal effects of the probit model for the farmers who have been invaded and for farmers fully damaged by DL in 1997 where the results are rather similar.

-Farmer; as shown, being exclusively a farmer implies a significant and negative impact on the overall income. When asking the farmers of the northeastern region if they were interested of having another work, 49 percent of the respondents were looking for a job in order to enhance their economical situation. Out of the whole sample only 12 percent have had a paid work. Hence these results show not only that being exclusively a farmer is a risky business, the numbers also show that although a farmer is willing to have an off-farm work the possibilities are very limited, at least if the farmer does not move to an other region. However, most of the farmers are not willing to move to another region as discussed above (only 3 percent out of the whole sample would consider moving to another region as an alternative to increase income). The reasons for not moving to another region maybe different were land reform and food aid may be the major ones.

As concerns land, 87 percent of the farmers are “owner” of their land. In the beginning of the Eritrean independence a Land Reform Act was enacted with the purpose of ensuring all Eritreans equal access to land. The new law makes the state the owner of all land and provides life-time (and inheritable) usufruct rights to all Eritreans over the age of 18 (World Bank). The land reform replaces a variety of complex local systems of land tenure, some of which may have reduced incentives for improvements to increase productivity. Nevertheless, even though the distribution of land is relatively equitable as discussed the non-poor gets more income from crop cultivation as the poor do, suggesting that using non-land inputs such as irrigation and animal power can make a critical difference.

When it comes to food aid Eritrea may be an exception but the food aid policy gives an idea about how farmers may be passive. Estimates of the percentage of population in need of food aid also shows how vulnerable the population is: 48% of households need food aid even in a good agricultural year; this proportion rises to 80% in a bad agricultural year. Recognizing the disincentive effects that free food aid was having on incentives to produce and to work (also in other regions), the government has decided in early 1996 to monetize food aid and to provide cash assistance to those truly in need and unable to work (World Bank).

Table 5.4: Farmers invaded by DL in 1997

Variables	Parameter estimate	Marginal effect	Std	|T|	Prob>|T|
Intercept	1.28	0.40	0.20	6.50	7.53E-11
Cereals	7.11E-06	2.21E-06	1.97E-05	0.36	0.72
Cattle	0.0002	0.00005	9.21E-05	1.77	0.08
Sheep	0.0004	0.0001	0.0003	1.20	0.23
Goat	0.00006	0.00002	8.19E-05	0.73	0.46
Camel	0.0001	0.00004	0.00008	1.44	0.15
If farmer only	-0.85	-0.26	0.20	-4.24	0.00002
If farmer with a secondary occupation	0.53	0.16	0.16	3.29	0.001

-Farm and off-farm; when a farmer is not exclusively dependent on his farm income impacts on the overall revenue are positive if the farmer can rely on other resources such as off-farm work or trade activities [16]. Looking at the tables in the appendix, 27 percent of the farmers with an average lower income relied on off-farm activities while around 50 percent of those with an average higher income have had off-farm income as a second activity to increase the overall income.

Table 5.5: Farmers fully damaged in 1997

Variables	Parameter estimate	Marginal effect	Std	|T|	Prob>|T|
Intercept	1.21	0.39	0.21	5.69	1.27E-08
Cereal production	7.67E-06	2.44E-06	2.12E-05	0.36	0.72
Cattle	0.0001	4.71E-05	9.58E-05	1.54	0.12
Sheep	0.0008	0.0002	0.0004	1.78	0.07
Goat	0.00006	1.78E-05	8.46E-05	0.66	0.51
Camel	8.54E-05	2.72E-05	7.64E-05	1.11	0.27
If farmer only	-0.82	-0.26	0.22	-3.78	0.0002
If farmer with a secondary occupation	0.52	0.17	0.17	3.02	0.003

[16] Here food aid is also included as an alternative belonging to off-farm income since during the survey we had no specific question for this variable.

-Crops; such as in the case of being exclusively a farmer, being dependent only on crop production have non significant effect on total income since this business is very sensible and may fluctuate strongly depending on rain, DL invasions and other agricultural inputs. Based on the survey in the northeastern region, table 5.6 shows the main factors menacing crop yield. As shown 73 percent of the farmers consider drought being the main traitor and 11 percent believe that DL invasions imply negative effects on their crop production.

Table 5.6: Factors menacing crop yield in the northeastern region

Factors	Mean	Std. D	Minimum	Maximum
Drought	0.73	0.44	0	1
DL	0.11	0.32	0	1
Birds; e.g., quelea	0.08	0.26	0	1
Lack of fertilizers	0.002	0.05	0	1
Lack of agri. Machines	0.019	0.14	0	1
Phytosanitary problems	0.005	0.07	0	1
Others	0.03	0.17	0	1

-Livestock; Ownership of cattle, sheep and goat has a significant and positive effect on total income. However, camel ownership does not; farmers are encountering some problems with them "one camel can eat up to one hectare in one night". When it comes to cattle, it is not only a good source of income when it is sold, ownership of oxen also determines the extent and quality of crop cultivation. Turning to sheep (and goat) this livestock is in general often sold to mitigate income fluctuations.

6. Impact analysis of DL campaigns

Following Mohr (1988) the crux of impact analysis is a comparison of what did happen after implementing a program with what would have happened had the program not been implemented. This comparison may be called the impact of the program. Events in the what-would-have-happened category must obviously be troublesome sometimes since it is not know for sure what would have happened.

Here an attempt is made to give an insight of what would have happened in the southeastern regions of Eritrea (Sudan and Morocco) if no measures have been taken. Looking at the campaign years an impact analysis is a discussion of the effectiveness ratio defined such as:

Effectiveness = (average yield – average damage) / average yield

Using this simple formula, the effectiveness ratio would indicate the percentage of the estimated successes actually achieved.

Recall from the previous sections that Eritrea has been invaded by DL during the years 1993, 1995 and 1997-98. The campaign costs at the national level are shown in table 6.1. The campaign costs of 1993 and 1997-98 are almost equivalent but constitute only 66 percent of the campaign 1995. Moreover, the campaigns of 1993 and 1997-1998 that are almost equal in costs show different proportions of damaged households.

Table 6.1: Campaigns costs and damaged households 1993-1998

	1993	1995	1997-1998
Campaign cost (Nakfa)	187080	282954*	185650
Damaged households (percent)	1.7	12	32

*) For year 1995 the cost was calculated by the Eritrean Ministry of Agriculture. For the other years the figures are based on treated hectares with a cost of USD 10 per *ha*.

Turning to our efficiency measures the results are shown in table 6.2. For the average household campaign's efficiency range between 5 and 52 percent and there is no apparent correlation between campaign costs (shown above) and the efficiency ratios. One may not in this case eliminate the effect of "economies of scale" since the campaign of 1995 costing twice as high as 1993 and 1997-98, respectively, has been more efficient. Unfortunately, this statement does not hold when looking back at the results of the Sudanese campaigns in the Red Sea region where the impact of the famous 1988's campaign was not the highest even though high amounts of dollars were spent. The highest efficiency (55%) was achieved during the agricultural year

1995 with a lower cost than in 1988. Moreover, the next highest efficient campaign (52%) i.e., 1993 did not cost more than USD 900 according to PPD Sudan.

Table 6.2: Efficiency of the campaigns (southeastern lowlands)

Year	Households (percent)	Mean damage* in Nakfa (USD)	Best average yield**(USD)	Campaign efficiency (percent)
1993	1.7	1104 (110)	1166 (117)	5
1995	12	1143 (114)	2418 (242)	52
1997-98	32	1558(139)	1712 (171)	9

*) Assuming the reported damage includes cereals and livestock and cereals damage is half the overall damage.**) refers to the best yield the farmer has produced during the last 20 years.

The efficiency measure reported above concerns all farmers who stated they were invaded and damaged by DL. Recall from the section on agriculture that many of the farmers stating they were damaged by DL had a relatively high cereal production in the end of the year. Of course some of them may have lost some part of their livestock. Unfortunately, no data is available to control for livestock' loss which may not be considerable. Hence, although farmers were damaged, many of them could recover and show a high cereal production. Therefore, the efficiency rates reported above may not be the ones we are looking for. The correct ones would include only the farmers that have been damaged by DL and who lost all cereal production during the invasion year 1997.

- Sudan

Turning to the efficiency of the control campaigns represented here by Tokar in the Red Sea region of Sudan, campaign's efficiency range between 26 and 55 percent and there is no apparent correlation between campaign cost and the efficiency ratio. The impact of the famous 1988's campaign is not the highest even though big amounts of dollars were spent then. The highest efficiency (55%) was achieved during the agricultural year 1995 with a lower cost than in 1988. Moreover, the next highest efficient campaign (52%) i.e., 1993 did not cost more than USD 900 according to PPD Sudan. Moreover, notice that the damaged agricultural yield in years with control campaigns is not different from the damage implied in years without campaigns as shown in table bellow.

Efficiency[17] of the campaigns in the winter region of Sudan

Year	Mean damage in SDD	Households (Percent)	Best average yield SDD	Campaign efficiency (percent)
1988/89	103292	42 (13)	190135	46
1989/90	85961	42 (13)	138504	No campaign
1990/91	170264	14 (4)	309085	No campaign
1991/92	114361	21 (7)	199071	No campaign
1992/93	58857	14 (4)	79500	26
1993/94	72551	73 (23)	150536	52
1994/95	109417	23 (8)	229608	No campaign
1995/96	90865	82 (26)	202917	55
1996/97	78400	20 (7)	135650	42
1997/98	121034	148 (47)	231685	48
1998/99	68439	53 (17)	146517	No campaign

1 Sudanese Dinar (SDD) = 0.004 USD (1999)

- Morocco

As concerns the efficiency of the Moroccan DL campaigns, table 6.4 shows the results. Compared to Eritrea and Sudan campaigns in this country has been more successful. The higher efficiency in this country is probably dependant on the collaboration undertaken with Mauritania where Morocco is engaged in order to limit the spread of the pest.

Efficiency of DL campaigns in Morocco[18]

Year	Mean damage in MAD	Households (percent)	Campaign efficiency (percent)
1987	9 596	105(15)	64
1988	1 758	113(16)	93
1989	8 138	37(5)	70
1990	6 551	35(5)	76
1991	2 991	14(2)	89
1992	3 747	31(4)	No campaign
1993	1 778	9(1)	93
1994	3 675	24(3)	86
1995	13 000	11(1)	51

1 Moroccan dirham (MAD) = USD 10 (1998)

[17] Effictiveness = (average yield-average damage)/average yield.
[18] Since no data on best average yield is available, the average yield of 1997 is used.

7. Developing a DL insurance

7.1 Introduction

Agricultural production is subject to unpredicted, random shocks caused by weather events, pest damages and other natural disasters such as fire. The relative frequency of such problems is believed to generate significant yield instability. Therefore the agricultural sector is more in need of assistance and insurance is a policy instrument that is designed to deal with yield uncertainty.

The purpose of this part is to make a suggestion to design a DL insurance program in Eritrea where this insurance does not exist at present. The basic idea is that farmers buy the DL insurance from the government, who in turn buys a re-insurance from a private company. Moreover, buying the insurance is compulsory to the farmers.

This insurance program is proposed to protect farmers from devastating infestations of DL while making the publicly supported preventive control program more financially sound. Initiating an insurance program conditional on effective preventive control would reduce the economic inefficiencies associated with traditional control or the mixture of both classical and preventive campaigns. Furthermore, the proposed insurance program will result in reduced use of chemicals to control and thereby to reduce impacts on the environment including farmers, flora and fauna.

7.2 Insurance against DL invasions

The basic idea of DL insurance in Africa (Eritrea) would be to compensate farmers for the losses in cereal production caused by DL invasions. This insurance would be conditional on a preventive control program to be conducted in order to mitigate the impact of DL invasions. Therefore, the cost of the preventive program would be supported by the insurance fund into which farmers pay annual premium. Furthermore, insurance programs would have been mandatory rather than optional. Mandatory participation is required because preventive control concerns all lands regardless of size and ownership. Unless mandatory, “free rider” tendencies would result and an uninsured farmer could become a beneficiary to preventive control applied to DL. Another reason for promoting a mandatory DL insurance is the possibility of risk pooling. The idea of pooling is to bring several risks together for insurance purposes in order to balance the consequences of the realization of each farmer risk.

There are in general different kinds of crop insurance including the general multiple peril insurance, drought insurance and the special case of hail insurance[19]. Each of these insurances has positive and negative sides. However, the most dominant reasons for crop insurance'failure have been two types of asymmetric information problems i.e., moral hazard and adverse selection. These both rise expected indemnity payments relative to premiums, undermining the financial soundness of the insurer.

-Moral hazard refers to a situation where an insured person, without the knowledge of the insurer, changes behaviour after purchasing insurance in a way that increases the probability of receiving an indemnity payment. When it comes to DL insurance moral hazard would not emerge since farmers' individual actions cannot affect the risk of being invaded by DL. In the case of an efficient preventive control moral hazard cannot be a serious problem either since the objective of preventive control is to deal with DL in remote areas and not to conduct control on farmland.

-Adverse selection refers to the fact that people who are more likely to suffer the insured event will be more willing to insure at a given rate. However, adverse selection may not be a serious phenomena if an efficient preventive control is in place. Nevertheless, if there is no preventive control or if the applied preventive control is not efficient, adverse selection may be a serious problem.

A routine benchmark to evaluate if an insurance scheme is successful is the *loss ratio*. This ratio is generally calculated as indemnities divided by premiums. Private insurance underwriters typically design their programs to achieve an average loss ration of no more than 0.7. (Patrick, Lloyd and Cary 1985; Lloyd and Mauldon 1986). The 0.7 loss ratio is a long term aim. However, in the average year, the loss ratio should be much less than 0.7 in order to compensate for high losses during disaster

[19] For more details on different crop insurance see appendix 4.

years. This is the case of private sector or private insurance. In our case it is in general the state which insures and the aim is a long run loss ratio of 1.

On the other hand, there exist two kinds of risk related to agricultural damage:

- systemic risk is a risk that is correlated among a pool of farmers
- non-systemic risk prevails in a case where farmers do not suffer losses together.

When risks are systemic diversification of them is impossible and the insurance provider may be unable to cover losses in a given year.

However, although a significant proportion of the risks associated with DL invasions may be systemic, this fact does not imply that these risks are not subject to diversification. The reason is that although DL invade a specific region the damage is not similar for all farmers. Moreover, the fact that a land has been invaded does not mean that the yield at the end of the year is zero. As discussed in the production function and hazard function parts, cereal yield depends on several factors such as access to water, labour and the duration of the DL invasion.

7.3 Theory of insurance against DL

In the *Wealth of Nations* Adam Smith pointed out that for the supplier of insurance to be willing to provide protection to the insured individual *"(The) premium must be sufficient to compensate the common losses, to pay the expense of management, and to afford such a profit as might have been drown from an equal capital employed in any common trade"*. Hence, only if the premium is too high will the private companies supply insurance. Borch ((1989) in Goodwinn et al 1995) noted that Adam Smith's observation implies that an insurance premium offered by a private insurer has three components: the expected claim payment (or expected indemnity), the administrative expense of the insurance company and the required return on invested capital.

As concerns insurance against DL the willingness of private insurance companies to directly supply insurance in Africa is probably very limited or not possible[20]. Therefore, the government (or else[21]) has to accept the role of primary insurer and relies on reinsurance. Reinsurance[22] is a mechanism the government would use if the expected losses due to DL invasions are too great to absorb.

Since the government is not a profit maximizing institution, the total premium PT would be[23]

$$PT = Pp + exp + R$$

Where Pp is the insurance premium to the farmer, Exp is the expense component of the government (administrative cost)) and R is the government cost of reinsurance (i.e., premiums paid for reinsurance minus commissions received from reinsurers). However, in the beginning $exp + R$ is covered by the government and could be considered as a subsidy to the farmers to be phased out over a "pre-decided period", with the farmers' rates increasing by some percents per year to replace the subsidy.

The reinsurance component R, similarly is a function of a reinsurer's costs which have a similar cost structure to the "primary insurers", albeit, with differing risk functions: $R=Pp_r +exp_r + \mu_r + p_r +C$ where μ_r is an uncertainty factor added to cover against less predictable catastrophic risks or those not fully captured by the above formulae,

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20 Insurance for catastrophic natural disaster risk is in low supply and can become cost prohibitive for the poor for a variety of reasons (Skees and Barnett 1999). Since the risk from insuring natural disasters cannot be pooled (especially in developing countries) the primary insurers rely heavily on traditional reinsurance markets. Reinsurance markets are inefficient, costly, and suffer frompricing cycles that respond to major losses (Froot; Kunreuther et al. 1995, Noonan 1994, Jaffee and Russell 1997, Stipp 1997). Access to reinsurance in developing countries is also limited. Reinsurance can be expensive or impossible in many cases as most reinsurers shy away from providing their services for agricultural risk in developing countries. The international reinsurers that understand agricultural risk rightly conclude that there are problems with underwriting crop insurance in developing countries. They also understand that they can make more money concentrating on the US market that is heavily subsidized. Finally, decision makers have a cognitive problem in assessing catastrophic risk (Kunreuther and Slovic 1978, Kunreuther 1996). Thus, even when a decision maker may be able to afford the insurance, they may make the wrong assessment about the real risk and decide that the price is too high.

21 See tables in appendix where the results from the CVM studies in Morocco, Sudan and Eritrea shows that farmers' preferences as concerns who would take care of the insurance money. But may be the government of each country is the most natural actor in order to guarantee the achievement of the insurance program such as in the case of Morocco and the drought insurance.

22 The term reinsurance refers to the insuring of an insurance company's underwritten portfolio by another larger insurer (the reinsurer). That is a primary (or local) insurance company insures its policy holder's, it then 'buys' insurance for part of its portfolio from a larger (usually global) company. This is referred to as "reinsurance"; i.e., transferring of part of the original insurer's portfolio to a "reinsurer" at a price (the reinsurance premium), with the result that the reinsurer takes the risk for that part of the portfolio transferred (ref: world bank technical paper no. 495. managing catastrophic disaster risks using alternative risk financing and pooled insurance structures)

23 If the insurer were a private company, PT would be equal to $Pp + exp + \mu + p + R$, where μ is an uncertainty factor added to cover against less predictable catastrophic risks or those not fully captured by the above formulae. p is a company's minimum profit margin (world Bank No 495).

p_r is a company's minimum profit margin and C is the commission paid to "primary insurers" for passing on premiums to purchase reinsurance cover. Therefore,

$$PT=(Pp+exp) + (Pp_r +exp_r + \mu_r + p_r +C).$$

7.4 The data

In general before structuring a DL insurance, data on DL invasions and associated yield and damage should be compiled to ensure that based on historical experience a sufficient strong correlation exists between the variables. Such data compilation is essential for the structuring and pricing of the insurance contracts.

There is no official data related to DL invasions and the associated yields and damages in the case of Eritrea. Moreover, there is no data collected when it comes to DL invasions where no control has been undertaken. So the data collected here is subject to both preventive control and traditional control i.e., spraying chemicals on all land.

Based on the survey in the northeastern part of Eritrea 7.1 shows cereal income for the period 1997-2000. It was chosen to base the development of DL insurance in Eritrea on income rather than yield since insurance based on yield might not be very good compensation for income fluctuations, if prices are variable (see Roumasset (1978) for more comments).

As discussed above cereal income is very low in Eritrea. The mean and median incomes are presented for two reasons: using median income instead of mean income in developing insurance would lead to limited adverse selection by the farmers and to avoid high indemnities by the insurers. The mean and median agricultural land is 3.2 an 2 hectares, respectively.

Table 7.1: Cereal income in the northeastern part of Eritrea (Nakfa*)

1997		1998		1999		2000	
Mean	Median	Mean	Median	Mean	Median	Mean	Median
1336	750	1337	780	1666	720	1191	600

*) 10 Nakfa ≈ 1 USD

As concerns cereal damage that has been reported to be dependant on DL invasions the values are shown in table 7.2 It is also worth to mention here that the best mean and median cereal income during the last 10 years was 2280 and 1260 Nakfa, respectively.

Table 7.2: cereal damage

1992		1993		1995		1997		1998	
mean	median	mean	median	mean	Median	mean	median	mean	median
2804	2200	2583	1500	3397	1920	3016	1800	2546	1400

Comparing cereal income, cereal damage and the best cereal income during the last 10 years, it is not easy to avoid the following observations which show that we have cases of potential adverse selection among the respondents,

- the average mean and median incomes for the period 1997-2000 (i.e., 1383 and 712 Nakfa, respectively) are lower than the average mean and median damage (i.e., 2869 and 1764 Nakfa respectively);
- the cereal damage is in average higher than the best mean cereal income during the last 10 years.

Based on these observations, it could be concluded that adverse selection may be a difficult issue to deal with especially while defining damage ratio and thereby the level of indemnities. Therefore the median income is to be used for the decision of the insurance contracts. An other tool to deal with such problems is the inclusion of deductibles in the contracts.

7.5 The insurance premium in northeasten part of Eritrea

Assume A is a situation where DL invade a certain region (or a country), B is a situation that they invade a specific farm and C that DL cause total damage to this farm. Then *P(A)* is the probability of DL invading a region (a country), and *P(B/A)* is the probability that DL invade a specific farmland conditionally on the fact that DL are invading the region. Moreover, the probability that DL cause total damage which is conditional on the fact that they invade the region and the farmland is $P(C/A \cap B)$.

In this study we are mostly interested of the situation where DL invade a specific region. (The fact that DL invade a specific farm and they cause total damage to this farm is very small and will not be discussed here[24]).

Turning to the case where a specific farmer may be invaded by DL our estimates are based on the total probability theorem i.e.,

$$P(B) = P(B/A) \times P(A) + P(B/A^c) \times P(A^c)$$

Where *c* denotes complements. Since a farmer cannot be invaded if the country is not the second term on the right hand side vanishes i.e., $P(B/A^c) \times P(A^c) = 0$. Hence,

$$P(B) = P(B/A) \times P(A)$$

In the case of Eritrea these figures are shown in table bellow where *P(B)*= 0 if no campaign has been conducted although the farmers stated they were invaded[25].

Table7.3: DL probabilities in northeastern Eritrea

	Pesticide used	Households Invaded	Percent *P(B/A)*	*P(B)*
1988	Yes	1	0	0
1989	No	0	0	0
1990	No	4	0	0
1991	No	4	0	0
1992	No	13	0	0
1993	Yes	54	13	0.05
1994	No	25	0	0
1995	Yes	19	5	0.02

[24] That is $(A \cap B \cap C)$. The probability for this situation can with the help of the definition of conditional probability be written such as; $P(A \cap B \cap C) = P(C/A \cap B) \times P(A \cap B) = P(C/A \cap B) \times P(B/A)) \times P(A)$.

[25] for Tokar in Sudan a similar table is to be found in the appendix.

1996	No	18	0	0
1997	Yes	276	66	0.28
1998	Yes	99	24	0.1
1999	No	18	0	0
Mean				0.037=(0.45/12)

N=417, *P(A)* = 0.42 =(5/12)

The number of times DL invaded norhteastern Eritrea under the period 1988-1999 (12 years) is 5 times. This gives *P(A)* = 5/12 = 0.42 which is the probability that Eritrea will be invaded in a specific year (this depends of course on what is happening in Sudan and other countries such as Saudi Arabia and Yemen). Out of 417 households of the sample, 13, 5, 66 and 24 percent were invaded in 1993, 1995, 1997 and 1998, respectively, as shown in table 7.3 where *P(B)* for different years is calculated. Although the probability of a farmer to be invaded when the country is invaded is higher in 1997, the average *P(B)* for the northeastern region of the lowlands is equal to 3.7 percent in the current situation where efficiency of the campaigns is not high. However, if the preventive control is efficient (also in the other countries of the central region e.g., Sudan) the probability of being invaded by DL would be smaller in magnitude and the number of farmers loosing all crops may be non-existent.

Based on the definition of the premium discussed above and assuming diversifiable systemic risks the premium to be paid by the farmer is as follows:

Pure Premium; $Pp = f \times d \times IV$

where f is a frequency probability of hazard, d is damage ratio and it is equal to h which is a hazard intensity factor such as DL intensity and IV is insured value. In our case f equals *P(A)*. Since the damage ratio is not possible to estimate and since data on the intensity of the swarms is not available, *P(B/A)* is used as a substitute for d.

Hence, premium payment would be;

$Pp = P(B) \times IV$

As discussed in Skees 2000 different contracts can be considered. For this study, the focus is on proportional contracts. The proportional contract simply pays in percentage terms for numbers of DL over a well specified threshold. For example, suppose that a regional threshold is 1000 DL per hectare, then indemnities may be paid when the intensity of DL is greater than 1000 DL/*ha*. The indemnities will be based on the number of DL over the threshold 1000DL/*ha*. The percentage calculation would be performed as follows:

If the intensity of DL is over 1000/*ha* then indemnity percentage is

[(Current intensity – 1000) /1000]x100

For example if DL intensity is 1100/ha then the indemnity percentage would be 10 percent and all farmers would buy contracts at the median crop value i.e., 394 Nakfa. The contract to be sold to the farmers is:

Indemnity = payment percentage x median crop value.

The median farmer with 2 hectares would get an indemnity equivalent to 0.10 x 2 x 394 = 79 Nakfa.

However, the median income ranges between 172 Nakfa in A-Galabou and 513 in G. Halib as shown in table 7.4. Since the purpose of these indexed contracts is to avoid adverse selection, then they have to be calculated based on the median values[26]. Therefore farmers in A-Galabou, for instance would pay lower price than the farmers of G. Halib. However, if the farmer's income is lower because of other events such as drought or quelea, no payment will be made.

[26] The median values from different villages are given in order to give an insight of the differences in income between the villages. However, in the case of Eritrea incomes of different zobas (when the data is available and reliable), may be a better way to compute the contracts.

Table 7.4: Incomes in the status quo situation (Nakfa)

Region	Median crop income	Mean crop income
North eastern lowlands	788	1287
Meyhimet	538	1374
Karora	579	1176
G. Halib	1025	1487
Kimtiwa	585	746
Kazan	475	980
Kubae	980	2137
Gulbub	405	686
A. Galabou	343	650
Afrit	395	512
Naro	463	716

Median land = 2 hectares and median crop yield for all regions is 394 Nakfa.

On the other hand, premium payment is as follows:

Pp = P(B) x IV

Where, as discussed above, *P(B)* is the average probability of a farmer being invaded by DL and IV is the insured value. A farmer with a median crop value equal to 788 Nakfa would, for instance, pay 788 Nakfa x 0.037 = 29 Nakfa in the *status quo* situation.

At the same time data for the insurance scheme was collected a contingent valuation study in the northeastern region to assess the farmer's willingness to pay for an insurance premium to be paid per year that will be conditional on an efficient preventive control was conducted. The mean willingness to pay is estimated to 51 Nakfa per household. This value is, however, higher than the values of the insurance premium to be paid by the farmers that own 2 hectares or less.

8. Biological control

In general a biological control is a management strategy for controlling pests (including diseases and weeds) which uses naturally occurring organisms against the pest organism. When it comes to DL a biopesticide has been developed[27]. In the initial

[27] A consortium of donors (including the governmens of Canada, Switzerland, The Netherlands, Great Britain and initially also the United States), agreed to finance Lubilosa (Lutte Biologique contre les Lucusts et Saauteriaux), a research program initiated in 1989. The project is implemented by a network of collaborators from CABI Biosciences, formerly IIBC (International Institue

phase the biopesticide was developed based on the spores of a fungus. *Metarhizium flavoviride*, a natural pathogen of locusts. A production unit was set up to provide spores in sufficient quantities (Jenkens 1994), and oil-based formulation was developed. In the second phase of the project (1993-1995) field trials were carried out on different locust species in several African countries (Loumer 1997) and production was scaled up (Cherry *et al*. 1999). The results are promising, with mortality rates of 80 percent or higher, although this mortality is only reached after one to two weeks. The product is easy to store and to apply. The biopesticide turned out to be a technically powerful technology, but its economic viability is still uncertain. In the near term the costs are estimated to range between USD 10 and USD 20 per *ha*, which is somewhat higher than most chemicals. Developments in production technology, such as the use of waste biomass substrates, scale improvements, and competition, will all have the effect of lowering the price of in the medium term. However, although the product is relatively expansive, it has major economic advantages. Due to secondary pick up, only one application per season is necessary, and damage to the environment, human health, and livestock are nil. However, the slower action as compared to chemical pesticides favours their use in ecologically sensitive zones and in preventive control operations where locusts are far from crops.

Therefore, an efficient preventive control to be environmentally sound it is recommended to use biological pesticides in remote areas. In all DL potential countries (see Wiktelius) the presence of many sensitive areas dictates the use of biological control.

On the other hand, a study has been conducted by De Groute *et al* (1999) where farmers in Mali, Niger and Benin displayed a positive attitude towards the biocontrol. The results of the survey indicate that market for biopesticides against grasshoppers and locusts is emerging for cash crops in the humid areas.

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of Biological Control) IITA (International Institute of Tropical Agriculture) CILSS (Comité Permanent Interetats de Lutte Contre la Secheresse au Sahel) and GTZ (Deutzche Gesellschaft fur Technische Zusammernarbeit).

9. Concluding remarks

This study has shown that during the last years where control campaigns have been conducted DL invasions in general have had no significant effect on the Eritrrean agricultural sector. The results confirm the ones found in Morocco and Sudan. Moreover, general analyses of household production function in Eritrea do not either exhibit any negative relation between DL invasions and cereal yield during the 1997 DL invasion. However, when it comes to the socioeconomic impacts of the 1997 DL invasion in the highlands and the eastern lowlands, the general finding is that farmers who were mainly dependant on crops production were the most affected. This may be dependant on hazard but it may also depend on the fact that less poor farmers can afford to avoid and/or overcome a DL invasion.

In the northeastern region we investigate the mechanisms used by households to cope with agricultural risk in general and DL invasions in particular where the principal risk to these households is that of lower income and thereby a food shortage. Using a panel data and a Probit model the most important way in which the households deal with risk is through not being exclusively a farmer and dependant on crop production but rather having both farm income where reliability on livestock is a prerequisite to mitigate income fluctuations as well as having an off-farm revenue in order to be less vulnerable and to avoid the consequences of agricultural disasters.

Despite the lack of enough and specific data related to the different regions invaded by DL, the results of the transition model show the high dependency of DL on rain availability. This finding confirms once again the positive relation between good rain and high risk of DL invasions.

On the other hand, and depending on the non-availability of region specific DL control data, an alternative methodology has shown the lower efficiency of the campaigns in Eritrea and Sudan.

As concerns the insurance to be used to compensate the damaged farmers, it is a challenging policy instruments in this part of the world where agricultural market insurance does not exist in many countries. According to Quarantelli (1978), Davis

(1978, 1986), Anderson & Woodrow (1989) and Blaikie et al (1994) a disaster occurs when its two main components, hazard and vulnerability coincide in time and place. According to this discourse, until they are met by vulnerabilities such as an unsafe environment, fragile socioeconomic structures, or lack of disaster preparedness, hazards would remain only as natural phenomena. For example, when DL invade an uninhabited place, this is only a natural hazard not a disaster. When grasshoppers invade the farmland in the USA, they do not usually experience these as a major disaster because of the country's preparedness and mitigation measures e.g., insurance.

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Appendix 1

Farm households invaded by DL in 1997 (Nakfa)

Variable	N	Mean	Std Dev	Minimum	Maximum
Cereals97	225	927	1767	0	16000
Cattle97	226	290	1023	0	7000
Sheep97	226	58	290	0	3000
Goat97	226	221	466	0	3000
Camel97	225	163	823	0	7500
Cereal98	224	765	1277	0	9200
Cattle98	224	264	1018	0	7000
Sheep98	226	53	262	0	2000
Goat98	226	222	540	0	3000
Camel98	223	117	947	0	10000
Cereal99	226	751	4206	0	61750
Cattle99	225	213	912	0	7000
Sheep99	225	42	172	0	1000
Goat99	226	244	742	0	7600
Camel99	226	113	944	0	12000
Cereal00	225	573	1169	0	10800
Cattle00	224	226	1145	0	13000
Sheep00	225	64	277	0	3000
Goat00	226	255	659	0	4000
Camel00	226	149	962	0	12000
Loan	226	1805	4476	0	55000
Agr. Income	225	807	1236	0	7200
Agr. + off-farm income	225	517	1392	0	10000
Off-farm activity	226	0.27	0.66	0	2

Farm households **not** invaded by DL in 1997 (Nakfa)

Variable	N	Mean	Std Dev	Minimum	Maximum
Cereal97	187	877	1736	0	15000
Cattle97	187	363	1956	0	24000
Sheep97	187	199	1040	0	10000
Goat97	187	386	910	0	7000
Camel97	187	475	1396	0	10000
Cereal98	187	815	1386	0	9000
Cattle98	187	282	2260	0	30000
Sheep98	187	103	576	0	6000
Goat98	187	372	933	0	6500
Camel98	187	398	1237	0	9000
Cereal99	186	514	1182	0	7500
Cattle99	187	125	586	0	4400
Sheep99	186	100	680	0	7500
Goat99	186	361	861	0	6000
Camel99	187	450	1473	0	13500
Cereal2000	185	399	967	0	6000
Cattle2000	185	98	582	0	7000
Sheep2000	187	85	565	0	7000
Goat2000	187	475	1081	0	8000
Camel00	187	501	1353	0	6000
Loan	187	669	1398	0	10000
Agr. Income	184	510	1045	0	7000
Agr. + off-farm income	185	509	1497	0	15000
Off-farm activity	187	0.50	0.79	0	2

Appendix 2

DL probabilities in Tokar (Sudan)

	Pesticide used	Households	Percent *P(B/A)*	*P(B)*
1988	Yes	42	13	0.07
1989	No*	42	0	0
1990	No	14	0	0
1991	No	21	0	0
1992	Yes	14	4	0.02
1993	Yes	73	23	0.13
1994	No	23	0	0
1995	Yes	82	26	0.14
1996	Yes	20	7	0.04
1997	Yes	148	47	0.26
1998	No	53	0	0
Mean				0.66/11=0.06

DL year according to farmers but no campaign

Who may take care of the collected money in Morocco

Variable	N	Mean	Std Dev	Minimum	Maximum
Village	849	0.37	0.48	0	1
International organisation	849	0.20	0.40	0	1
national organisation	849	0.19	0.40	0	1
national banque	849	0.18	0.39	0	1
other	849	0.007	0.08	0	1

Who may take care of the collected money in Sudan

Variable	N	Mean	Std Dev	Minimum	Maximum
Village	626	0.18	0.39	0	1
international organisation	626	0.23	0.42	0	1
national organisation	626	0.12	0.33	0	1
national banque	626	0.46	0.50	0	1
Other	626	0.009	0.10	0	1

Who may take care of the collected money in Eritrea

Variable	N	Mean	Std Dev	Minimum	Maximum
Village	1108	0.18	0.38	0	1
International org.	1108	0.03	0.17	0	1
National org	1108	0.34	0.47	0	1
National bank	1108	0.28	0.45	0	1
Others	1108	0.09	0.29	0	1

Appendix 3

Contingent valuation

1. Morocco and Sudan

In order to estimate total benefits of not using insecticides on farmland, to conduct preventive control in remote areas and to compensate farmers in the case of DL invasion the contingent valuation method (CVM) was used[28]. The sample size in Morocco included 848 households and extends from Agadir in south to Taourirt in north. Béni Mellal a region not invaded by DL is also included to investigate whether or not farmers not damaged by DL since the fifties are willing to pay in order to avoid insecticide spraying.

In Sudan the sample size was 624 households with 314 in the Red Sea region and 310 in the River Nile region.

The results of the CVM show that instead of using insecticides on their land but rather conducting preventive control in remote areas farmers are willing to pay an amount per year of USD 21 and 8 respectively in Morocco and Sudan to a fund that can compensate them for the losses caused by desert locusts. Moreover, in the hypothetical case of no state intervention (i.e., the state would not intervene in the case of DL invasion) 40 percent of the farmers in Morocco are willing to pay a higher amount than USD 21 i.e., USD 67 per year in order to prevent DL invasion. In the case of Sudan the willingness to pay if the state does not intervene to control DL is very low. The reason for this depends, according to the Sudanese farmers, on the lack of knowledge, capability and resources.

As concerns finding solutions to DL swarms in remote areas, almost 90 percent of the representative populations have preferences for preventive control. Only 5 percent

[28] In order to value total environmental effects the contingent valuation method (CVM) is used in this study. Since many values related to desert locust phenomena are not marketable goods, CVM works by directly soliciting from a sample of the concerned population their willingness to pay for a change in the level of service flows. CVM enables, therefore, to assign economic values to these services.

supported the control strategy that is used actually i.e., spraying DL swarms everywhere by plains.

Comparing the benefits of not spraying croplands to the costs of the campaigns we found the following:

In the case of Morocco total benefits of an insurance to compensate farmers for losses caused by DL in the case of invasion would be DH 914 or USD 102 million, respectively. As shown in table bellow, this value is in the same range as the value of total DL control costs for the period 1986-95. Consequently, if DL invasions happened each year total benefits would be equivalent to DL control cost for the period 1986-95. Since DL invasions do not take place each year, total benefits would outweigh total control costs.

Benefits and costs of DL campaigns in Morocco (million)

Population	Total	Yearly total benefits		Total costs 1986-95
		DH	USD	USD
Whole farmer population	4.81	914	102	105
Potential population	0.99	188	21	
Damaged population	0.50	95	11	

In the case of Sudan total benefits for all regions are estimated to be USD 23 million per year. As shown in table bellow this value is much higher than the campaign costs of the whole period 1988-1998. In the winter and summer regions benefits of not using insecticides and to compensate farmers in the case of DL attacks are higher than the yearly campaign costs.

Benefits and costs of DL campaigns in Sudan (million)

Population	Total	Yearly total benefits		Total costs
		SD	USD	1988-1998
Whole farmer population	2.846	5837	23	16.8

Comparison of the yearly mean WTP for the whole sample in Sudan to the corresponding one in Morocco may be done by way of a benefit transfer approach. Hence, the Sudanese farmer's WTP to avoid insecticides on their cropland and to be compensated in the event of DL attacks is much higher (i.e., USD 36) than the

Moroccan case. Surprisingly, even though the Sudanese farmers are less wealthy than the Moroccan ones they are willing to contribute with high amount in order to insure themselves against DL attacks. One reason for this finding may be the higher frequency of DL invasions in Sudan and that the Sudanese farmers are high risks averse.

2. Modeling WTP for an insurance against DL attacks

We show in the previous sections that DL attacks, at least during the recent campaigns did not have any significant impact on the average farmer in Eritrea. Since the attacks by DL are random and may lead to socio-economic catastrophes for some households, farmers are willing to pay an amount of money to insure theme selves in the sake of stability and reduction of production fluctuations.

Assume the farmer's agricultural production depends not only on the customary production factors such as labour and agricultural requisites but also on the policy instruments e.g., insurance available to him.

The farmer's indirect utility function takes the following form:

$$V = (p_x, y / I_j),\ j = 1, 0$$

where p_x is cereal price, y household income and I_j is the insurance premium where $j= 1$ depicts a positive acceptance of the sum proposed and 0 reflects a situation where the farmer either he does not afford or his unwilling to pay . His unwillingness may also be a result of his believes related to the authorities responsibility i.e., the state should pay.

Recall, however, that farmers are always engaged in some kind of insurance to reduce instability of their income. This non-market insurance may take the form of having a second work, to invest in livestock or to rely on social contacts that the farmer counts on in crisis' situations. However, this kind of insurance may not be enough and the farmer is willing to pay and relay on market insurance. The market insurance often also has positive side effects that are at least two; They compensate the farmer for the lost experienced and they increase the probability to get bank loans.

Since the impact of DL invasions have a marginal effect on the average farmer, payment of an insurance premium (which of course depends on its magnitude) would reduce the farmer's income by the premiums amount. The change in income generates the following;

$$\Delta V = V(p_x, y^1 / I_1) - V(p_x, y^0 / I_0)$$

The amount of money paid for the insurance premium defines the compensation variation. This is the willingness to pay to stabilize farmer's production and thereby his income. The *WTP* is the amount of money that reduces farmer's income such as;

$$\Delta V = V(p_x, y^1 - WTP / I_1) - V(p_x, y^0 / I_0)$$

where the reduced form based on separability with respect to *WTP* is;

$$WTP = f(\beta x)$$

The equation to be estimated is;

$$WTP = \alpha + \beta x + \varepsilon$$

where *α, β* and *x* are respectively, vectors of parameters to be estimated and explanatory variables of WTP given by the farmers. *ε* is an error term.

3. Data collection

The survey

In May 2000 and with the help of technical officers of the Ministry of Agriculture, 18 villages located in the southeastern lowlands and the highlands were randomly chosen to make a survey. In each village some households where selected randomly and questions related to contingent valuation method were asked.

To start with a pilot study including 100 households was carried out. The purpose of the pilot study was twofold;

i. To discuss the questionnaire and its formulation with the interviews in order to correct misunderstanding and include other relevant questions to the study.
ii. ii. The pilot study served to decide the starting bids, which were used in the final interviews.

Using the iterative choice method 5 randomly chosen villages and 20 households in each, where asked about their willingness to pay for an insurance to compensate the farmers in the case of DL invasions. From the pilot study the median WTP for the insurance was 50 Nakfa (USD 5). The starting bids which were used in the final study were calculated so that they correspond to two lower values and two upper values arrayed around the median such as:

10	30	50 (median)	70	90

4. The questionnaire

The questionnaire was conducted face to face and a total of 702 households answered the questions. In order to understand the magnitude of DL invasions on the farmer’s agricultural production and preferences towards different control strategies some questions related to these subjects were asked; If DL are the major traitor to agricultural production, then more efforts have to be mobilized. If pesticide’ use against DL has negative impact on the farmers and their environment then alternative policies such as no spraying on farm land and/or the use of environmentally friendly insecticides has to be given priorities.

Table 3 shows the results where 99 percent of the interviewed population consider drought to be the biggest environmental problem leading to limited agricultural production. DL is not seen to constitute a major treat to cereal yield. As concerns DL control impacts on the farmers and their environment, 76 percent of the households in all regions are aware of the negative impacts these chemicals imply.

Table 3: DL and the environment

Variable	N	Mean
Drought to be the biggest environmental problem	695	0.99
If DL is the major treat to agriculture	696	0.0014
DL control impacts	695	0.76

On the other hand, if the actual control strategies i.e., spraying chemicals on all lands are seen to be the best ones to deal with DL, then investments in other strategies may be questionable. In order to know farmers preferences concerning the different strategies that can be used to control DL two different kinds of questions were asked. The first kind of question was direct and asked the farmer: What is in your opinion the best strategy to deal with DL?. In order to test for consistency a different question was presented as follows[29]: There are different methods to control DL. What is in your opinion the best one that should be used? 1, 2,.. (1 being the best).

1. Preventive control; to locate reproduction sites and destroy the eggs before they develop.
2. Strategic control; to attack DL before they arrive to agricultural land
3. Mechanic control; to kill DL with fire or abatement
4. Individual control using chemicals
5. Other strategies, what are they?

Table 4 shows that 81 percent prefers preventive control i.e., to conduct control in remote areas. 16 percent votes for the strategic one. These results are in line with the findings in Morocco and Sudan where 90 percent of the representative populations have preferences for preventive control. Surprisingly, any household does not support "others" that include the actual strategy i.e., spraying all over. In the case of Morocco and Sudan only 5 percent of the populations supported this strategy where the side effect of the chemicals is sometimes appreciated since chemicals kill other pests such as birds that damage the crops.

[29] The two kind of questions were not asked consecutively in order to avoid bias.

Table 4: Alternative controls

Variable	N	Mean
Preventive control	697	0.81
Strategic control	697	0.16
Mechanic control	697	0
Individual control	697	0.02
Others	697	0

5. Socio economic determinants of WTP

Since the iterative bidding includes a number of dichotomous choice (DC) questions to which the respondent says yes or no, we used a specific question to conduct a DC study and another one to conduct the iterative choice. This design allows at least for a partial comparison using the same respondents. However, it is also worth pointing out that the iterative bidding approach generates a scenario most similar to that encountered by Eritrean (and other developing countries) consumers in their usual market transactions. They do not face a "take it or leave it" situation when buying but rather a negotiation or a bargaining situation.

Since the southeastern lowlands is one of the most invaded region by DL, this part of the study will concentrate on it. Table 5 shows some characteristics of the sample. The number of times the average household have been damaged by DL during the last 20 years is less than one. Looking at the average yearly WTP using the iterative bidding method, the average value to be given to a found and to obtain a compensation for losses generated by DL, is 36 Nakfa that is equivalent to USD 3.6. Comparing this value among the different regions, households in the low lands, although inhabitants of a region with the lowest mean income they are willing to contribute with higher values. Since this region is a breading area for DL, it is often the starting point for DL invasions. Hence, the region is more damaged i.e., the average farmer has been damaged 0.87 times compared to 0.53 times in the highlands. Therefore farmers in the low lands are willing to pay more and to insure theme selves against DL. As concerns payments for land use the households that are engaged in this activity are very low.

Although two females were engaged in data collection in order to avoid a high men' representation, most of the respondents were men and 25 percent of them has a second occupation where this value is again higher in the low lands (30 percent in low lands and 15 in the high lands).

Table 5: Characteristics of the sample (southeastern lowlands)

Specification	N	Mean	Minimum	Maximum
Number of times damaged	397	0.87	0	3
Starting price (Nakfa)	398	52.61	10	90
Average WTP (Nakfa)	398	35.89	0	700
Age (years)	398	54.1	23	95
Marital status	398	1.13	1	5
Number of kids	398	4.69	0	15
Household size	398	7.21	0	25
Total income (Nakfa)	398	3558	0	39500
If ever damaged by DL	398	0.73	0	1
Pay for land use	398	0.04	0	1
DL major traitor to yield	398	0	0	1
If have no preferences for pesticides	398	0.63	0	1
Impact of pesticides	398	0.8	0	1
Gender; if man	398	0.95	0	1
If have a second occupation	398	0.3	0	1
Dichotomous choice	398	0.44	0	1

When it comes to farmers preferences for pesticides and the impacts of these on the farmer and his environment, 63 percent of the farmers dislike pesticides and 80 percent are aware of the negative impacts of the chemicals[30]. As concerns the

[30] The question used to study the farmers preferences for the pesticides as well as their impacts are as follows:
A12. Do you have preferences for insecticides?
1. Yes
2. No
3. Indifferent

A13. Why did you answer as such to **A12**?
…………………………………………….

A13a. Are you aware of the impacts of insecticides on humans, on plants and on livestock?
1. Yes
2. No

A13b. If the answer is yes, what are then these impacts?
1. On humans……………………………………………………………………….
2. On plants………………………………………………………………………….
3. On livestock……………………………………………………………………

A13c. Do you protect yourself while insecticides are used?
1. Yes

proportions of households replying affirmatively to the suggested bid they are 44 percent in the low lands, and 30 percent in the highlands.

6. Socio-economic determinants of WTP

Apart from the fact that we are interested in the mean WTP for insurance to be paid by the farmers, we are also interested in the variables that significantly explain these contributions where the results may have some policy implications.

Using dichotomous choice requires the use of an accurate model for estimation. In this case where the dependant variable is binary and includes a large number of zeros a Probit model is used.

As concerns the variables included in the model, there is little guidance from economic theory about which characteristics such as age, gender etc should be included for estimation. Thus, many explanatory variables, even though not significant they are included in the estimations.

Table 6 shows the estimated results for the southeastern lowlands where WTP increases with the number of times the household agricultural production has been damaged. However, the parameter estimates for the high lands are not significant. These results confirm the earlier findings where households in the low lands are the most damaged and they are the ones which are willing to contribute most for an insurance to avoid the use of chemicals on their farm land and to be compensated in the case of DL invasions. Unfortunately, the starting bid is significant. By rotating the starting bids among the respondents we tried to avoid this result but our efforts did not seem to give the desired results.

Turning to the other characteristics, the number of kids is negative and significant at 5 percent level, implying a lower WTP when the number of kids increases. These

2. No

A13d. If the answer is yes, what kind of protection do you use?

results reflect the income constrains faced by families with larger number of child. However, if the size of the household is large and includes other adults that may contribute for the living, the parameter estimate for this variable is positive and significant only in the low lands. As concerns total income it is positive and significant in all regions implying a higher WTP if incomes increase.

Table 6: Estimation results (southeastern lowlands)

Variables	Parameter estimate	Marginal effect	Std	|T|	Prob>|T|
Intercept	-0.66	-0.23	0.59	-1.12	0.26
Number of times damaged	0.69	0.24	0.19	3.62	0.0003
Starting price	-0.01	-0.004	0.003	-3.5	0.0004
Age	-0.0002	-7.5E-05	0.006	-0.03	0.97
Marital status	-0.04	-0.02	0.13	-0.36	0.72
Number of kids	-0.13	-0.04	0.06	-2.23	0.026
Household size	0.11	0.04	0.05	2.28	0.02
Total income	3.47E-05	0.000012	1.73E-05	2.01	0.04
If ever damaged by DL	-0.42	-0.15	0.27	-1.57	0.12
Pay for land use	-0.09	-0.03	0.33	-0.27	0.79
Dl major traitor to yield	-6.35	-2.19	4147.58	-0.002	0.10
If have preferences for pesticides	0.25	0.09	0.15	1.71	0.09
Impact of pesticides	0.36	0.13	0.18	2.01	0.04
Gender	-0.05	-0.02	0.36	-0.14	0.89
If have a second occupation	0.24	0.09	0.15	1.55	0.12

As concerns the variable “if ever damaged by DL” one would expect a close relation between this variable and the WTP. The parameters estimates are negative and significant at 15 percent level. Since exposure to pesticides is judged to lead to negative effects, households in the lowlands would increase their WTP in order to avoid these chemicals. Having a second occupation serves to increase income and to informally insure the farmer in the case of production instability. The parameter estimate for this variable is positive and significant at 15 percent level in the low lands.

An often asked question is related to the WTP of farmers that have seen at least one time all their cereal yield damaged by DL. We report the results for this category of farmers living in southeastern lowlands in table 7 where the findings are quite different from the estimates of the other regions. The parameter estimates related to the number of times damaged is positive and highly significant suggesting that farmers who have been totally damaged by DL are aware of this experience and they are willing to avoid it. Here the starting bid did not have any significant impact on these farmers WTP. Notice, however, that income is not significant in this case i.e., WTP is mainly dependant on the fact that the household has been damaged. These farmers are also aware of the negative impact of pesticides and they are willing to pay in order to avoid the use of these chemicals on their farmland.

Table 7: Estimation results (farmers who lost all cereal yield at least one time the last 20 years)

Specification	Parameter estimate	Marginal effects	Std	|T|	Prob>|T|
Intercept	-0.27	-0.09	1.02	-0.26	0.79
Number of times damaged	0.63	0.21	0.32	1.96	0.049
Starting price (Nakfa)	-0.006	-0.002	0.006	-0.98	0.33
Age (year)	-0.02	-0.007	0.01	-2.21	0.03
Marital status	-0.16	-0.06	0.23	-0.73	0.46
Number of kids	-0.08	-0.03	0.09	-0.83	0.41
Family size	0.09	0.03	0.09	1.05	0.29
Total income (Nakfa)	-1.6E-05	-5.46E-06	2.09E-05	-0.77	0.44
If ever damaged by DL	-0.08	-0.03	0.42	-0.18	0.86
If pay for land use	0.45	0.15	0.53	0.84	0.39
If have preferences for pesticides	0.02	0.01	0.24	0.09	0.92
Impact of pesticides	0.78	0.27	0.27	2.83	0.004
Gender	0.61	0.21	0.72	0.85	0.39
If have a second occupation	0.32	0.11	0.23	1.37	0.17

7. Comparing benefits and costs of the campaigns

i. benefits of an insurance scheme

As discussed above and using CVM an insurance contingent on an efficient preventive control in remote areas would compensate the damaged farmer in the case of DL invasions. Since CVM is a tool for cost benefit analysis its role is to provide aggregate benefits. However, expanding the sample values to the whole farmer population may imply biases if proportions of non-respondents is high (see Loomis 1987).

In this study (and may be depending on the face to face procedure to collect data), we did not experience a high rate of non-respondents. Thus, using the averages of the Probit's estimates for the farmers of table 7 i.e., Nakfa 47 (USD 4.7), the total[31] of 2063850 USD/year would be collected. One reason for aggregating over the whole Eritrean agricultural household population is based on the fact that the entire country constitutes a risk zone for DL invasions. The other reason for including all households is the positive WTP in all regions.

On the other hand one may suggest that only households in the low lands should contribute to the insurance. Assuming a population of 20 percent for lowland farmers, total benefits of not using chemicals and insuring the farmers against DL would be USD 412768

ii. DL control costs

Since most data collected is for the agricultural year 1997/98 and since we are merely interested of this year, the comparison of benefits and costs are related to the same period. There are no exact values concerning the costs of the campaigns of 1997-1998 but data on the number of treated hectares is shown in table 8.

Table 8: Treated hectares in 1996-1998

	1996/97	1997	1997/98
Hectares	0	400	18165

In the agricultural year 1997-98 a total of 18 565 *ha* were treated against DL in Eritrea. 400 *ha* were treated in 1997 and 18165 *ha* were treated in 1997/98. Assuming an average total cost of 10 USD[32] per hectare, the total campaign cost of 1997-98 is estimated to 185650 USD.

As shown in table 9 benefits of not spraying agricultural land (including crop land and pastoral land) is more than eleven times the campaign cost of 1997-1998 when

[31] Agricultural population is assumed by FAO to be 2 986 000 in year 2000. Assuming an average household of 6.80 (from this study) the total number of households would be equal to 439117.

[32] Values in the range of 10 to 16 USD are used to estimate the campaign costs per hectare. This costs include fixed costs that are used irrespective of DL invasions, and variable costs including additive efforts, pesticides …..

aggregating over all regions. When considering only the low lands the total benefits would be more than twice the costs of spraying. Based on this evidence and similar to the findings in Morocco and Sudan, using chemicals on agricultural land to control DL invasions is not an efficient policy since total benefits of not spraying is higher than total cost.

Table 9: Benefits and costs of the 1997/98 campaign (USD)

Region	Benefits	Costs	Benefits/costs
All regions	2063850	185650	11.1
Low lands	412768	185650	2.2

Appendix 4

Different types of crop insurance

-Multiple peril crop insurance is a policy instrument that is designed to deal with yield uncertainty. Many countries such as the United States, Canada, South Africa and a number of Latin American countries have had such a system. However, in nearly all cases, experience with multiple peril crop insurance has been disappointing where in no country have premiums been consistently sufficient to cover both indemnities and administrative cost. The general outcome is a loss ratio greater than one in many countries (if not all) that experienced this system. The United States, Japan, Sri Lanka, South Africa and a number of Latin American countries are examples of countries that implement multiple peril insurance with loss ratios greater than one in average. The main reasons were moral hazard and adverse selection.

-The basic idea of rain insurance is that insured farmers should receive a payout whenever rainfall in their area falls bellow a specified level. Since there is nothing to be done to influence the probability of rainfall, the problem of moral hazard is in general eliminated. Similarly, given the current state of long-term weather forecasting, there are no problems of adverse selection (even if drought were predictable in advance, this could be dealt with by allowing premiums to vary from year to year). Finally administration costs are likely to be low. However, experience from the Moroccan case during the period 1995-2000 shows that the loss ratio is greater than one even though the state's subvention of premiums was considerable. The reason for the failure of this system in Morocco is that premiums and indemnities are not based on risks in different regions. All regions are considered to be homogeneous as concerns drought and this has led to a loss ratio higher than one.

-A related form of agriculture insurance is credit insurance. Coverage is based on the amount of credit extended to a farmer, and the insurance is mandatory for access to official credit. Indemnities are equal to loan repayments less revenue from harvested crop. This type of insurance ha been used in Brazil with disastrous budgetary consequences (Lopes and Dias 1986; Crawford 1977). The loss ration for this program ranged from 2.44 to 4.2 from 1975 to 1981.

-Hail insurance belongs to the category named peril and it has operated successfully in a number of countries. Different factors specific to hail damage have led to loss ratios less than one such as in the case of South Africa where the ratio was 0.68 during the period 1970-1976. The most obvious, but perhaps the least important special feature is that hail damage risks are amenable to pooling (Quiggin (1986)). Given a moderate spread of locations the likelihood that a large proportion will suffer hail damage in any one year is fairly small. The second feature is the absence of major moral hazard problems. There is nothing that can be done to prevent a hailstorm occurring and comparatively little that can be done to mitigate its impact.