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On Insect Infestation and Agricultural Productivity in Developing Countries[1]

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Abstract

The objective of this study is to examine the linkages between insect infestation and agricultural productivity. The analysis is based on data obtained mainly from EM-DAT, WDI, and FAOSTAT. Even though the frequency of insect infestations has declined in recent years, they continue to cause considerable damage. As a large majority of these infestations is confined to Low Income/ Sub-Saharan African countries, with low or stagnating agricultural productivity, their potential for damage remains high. A detailed investigation of various options in pest control and their cost-effectiveness is necessary to enhance productivity in many of the poorest countries.

Key words: insect infestation, agricultural productivity, biological pest control, cost-effectiveness.

JEL codes: Q54, Q 57, I12.

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On Insect Infestation and Agricultural Productivity in Developing Countries

1. Introduction

The objective of this study is to examine the linkages between insect infestation and agricultural productivity. To the extent that insect infestations impair agricultural productivity and cause supply shocks, an attempt will be made elsewhere to examine whether these shocks contribute to the occurrence of famines. In a larger analytical framework that takes into account these and other supply shocks that combine with market and government failures, some new light will be thrown on why famines occur and the devastation that follows.

A point of departure from the extant literature is how a ‘history’ of undernutrition and mild food production shocks can lead to famines. Contrary to the view of Sen (1982), *absence* of food supply shocks measured in terms of an aggregate index of food availability in the year of the famine (e.g. the Bengal famine of 1943) cannot be a basis of rejection of food availability decline (FAD) as a causal factor[3]. A *gradual* deterioration of food supplies over time and a few mild shocks often precipitate a famine. In the Bengal famine, for example, a large fraction of the population had lived in quasi-famine conditions for a long period. A series of supply shocks -a poor harvest in 1941, cessation of normal imports of rice from Burma in early 1942, disruption of food trade by government controls- resulted in a sharp rise in food prices and loss of food entitlements of various sections (e.g. agricultural labourers, fishermen and transport workers). So there is a case for a more elaborate and nuanced treatment in which both *levels of food*

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[3] See, for example, important recent contributions of O’Grada (2007, 2008, 2009).

availability over a period and *intensity* of shocks must be given due importance. In other words, the *history* of food availability and consumption matters a great deal. This is not a rejection of the entitlement framework, since changes in the food entitlements of various groups would still vary and this framework would help understand better why some faced greater hardships.

The scheme is as follows. First, a brief description of the data used and its sources is given in Section 2. Section 3 contains an exposition of the biology of grasshoppers, locusts and other insects to understand better the conditions that lead to swarms and the devastation that follows. This is followed by a few cross-tabulations of occurrence of insect infestations by region and level of income in Section 4. Section 5 contains a brief exposition of the Poisson regression model used to analyze the occurrence of insect infestations, and other related techniques to focus on their impact on agricultural productivity. Section 6 discusses the econometric results. Section 7 reviews the experience with biological pest control measures. Concluding observations from a broad policy perspective are made in Section 8.

2. Data

These issues are addressed with the help of a database compiled from EM-DAT, WDI, FAOSTAT, and from the website of the Kennedy School at Harvard[4]. The main component is EM-DAT which covers all countries over the entire 20th century[5]. Along with a description of the types of disasters, their dates and locations, the numbers killed, injured, made homeless and otherwise affected are reported. An event qualifies for

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[4] An important source on geographical and political regime characteristics is Gallup et al. (1999).

inclusion in the EM-DAT if it is associated with (i) 10 or more people reported killed; or (ii) 100 or more people affected, injured or homeless; or (iii) a declaration of a state of emergency and/or an appeal for international assistance made[6].

As the EM-DAT quality has improved in the 1970s and to focus better on changes in recent years, the present analysis uses the data for the period 1980-2004, with different sub-periods for specific exercises.

A recent review draws attention to the following problems/gaps in the EM-DAT[7]:

Data coverage is incomplete for several categories. The numerical data categories (e.g. numbers killed, total affected) are unsatisfactorily represented before 1970, with many recorded events having no entries for numbers killed or total affected. Even after this year, data are patchy for some countries and event types.

According to a report by Working Group 3 of the Inter-Agency Task Force of the International Strategy for Disaster Reduction (ISDR), a comparison between EM-DAT and the DesInventar disaster database (http://www.desinventar.org) for Chile, Jamaica, Panama and Colombia shows that differences in numbers of people "affected" are substantial. Differences in numbers "killed" are, however, much smaller and "generally of the same order of magnitude" (Brooks and Adger, 2005, cited on p.15). Larger discrepancies in the numbers affected are due to underreporting in DesInventar,

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[5] Annual rainfall data were obtained from Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia.

[6] As argued later, while hazards may be natural (e.g. tsunamis, cyclones, earthquakes), disasters are often man made. Death tolls in a famine or an earthquake vary with the speed of relief provided by governments, communities and donors. For elaboration, see Gaiha et al. (2007).

[7] For details, see Brooks and Adger (2005).

suggesting that EM-DAT is more reliable. In any case, a general consensus is that mortality data are more robust across different data sets[8].

The economic losses consist of direct and indirect components (Andersen, 2005). The direct losses refer to the physical destruction of assets, comprising private dwellings, small business properties, industrial facilities, and government assets including infrastructure (e.g. roads, bridges, ports, telecommunications) and public facilities (e.g. hospitals, schools). The indirect losses, on the other hand, refer to disruption of economic activities, and loss of employment and livelihoods. In addition, business pessimism could dampen investment and consequently growth. So the relationship between destruction of capital and loss of income may vary a great deal[9]. Although there has been a steady increase in economic losses, the available estimates are incomplete and unreliable. These are compiled from a variety of sources including insurance companies, multilateral institutions and the news media. It is thus plausible that insured losses are better covered and consequently there is significantly lower coverage of losses in developing countries (Andersen, 2005). Accordingly, the economic losses are not analyzed.

An issue of considerable importance is whether natural disasters in rich countries are distinguishable from those in less affluent countries. A recent World Bank study (2006) points out that there is no private insurance against natural hazard risk in most developing countries. Specifically, while about half of the costs of natural disasters are covered by insurance in the United States, less than 2 per cent of them are covered in the developing world. Besides, the costs of hedging against natural hazard risks in developing countries

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[8] For further validation, see Gaiha et al. (2007, 2009).

[9] A difficulty is that conversion of changes in capital stock to income flows should take into account pre-disaster capacity utilization, depreciation of capital stock and efficiency of replacement assets (Andersen, 2005).

often exceed the cost of simply paying for the damages when they occur. Finally, both awareness of and preparedness for such risks are much greater in rich countries. We have accordingly restricted our analysis to the sample of countries other than the rich (including OECD and non-OECD groups).

The focus of the present analysis is on the impact of insect infestations on agricultural productivity and growth. As no deaths are reported, the analysis of the impact is confined to whether agricultural productivity suffers.

3. Biology of Grasshoppers, Locusts and Other Insects

Grasshoppers are herbivorous insects. They are sometimes referred to as short-horned grasshoppers. Locusts are several species of short-horned grasshoppers. The Desert Locust is the most dangerous of the locust pests because of the ability of swarms to fly rapidly over long distances[10]. Notorious for their voracious appetite, they have devastated crops in 60 countries of the world (BBSRC, 2001, FAO, 2007). The Desert Locust spends most of its life, of about 5 months, as a shy and solitary individual, balancing its nutritional intake to match its needs[11].

In their non-swarming phase, locusts avoid each other. But, if they are crowded together even for an hour, they become gregarious. Gregarisation occurs when there is competition for dwindling food supplies after a period of abundance[12]. The switch from

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[10] The Desert Locust, *Schistocerca gregaria*, is one of about a dozen species of grasshoppers that change their behaviour in response to population density and form swarms that can migrate over long distances.

[11] A Desert Locust lives a total of about 3-5 months, depending mostly on weather and ecological conditions (FAO, 2007).

[12] Researchers at University of Oxford found that, when solitarious locusts were given access to a single clump of food or several smaller ones, they gregarised after 4 hours only when they had to compete for the single clump. When food is clumped, only a small increase in the number of

solitarious to gregarious phase results in a change in physical appearance -solitary adults are brown whereas gregarious adults are pink (immature) and yellow (mature)[13]. Just as crowding triggers gregarious behavior, removal from a crowd triggers solitarious behavior (BBSRC, 2001, FAO, 2007).

For the Desert Locust, favorable breeding conditions are (i) moist sandy or sand/clay soil to depths of 10-15 cm below the surface; (ii) bare areas for egg-laying; and (iii) green vegetation for hopper development. During quiet periods (recessions), Desert Locusts are concentrated in the semi-arid and arid deserts of Africa, the Near East and South West Asia that receive less than 200 mm of rain annually. These regions cover an area of 16 million square kilometers (km^2) and 30 countries (Showler, 1996, FAO, 2007).

Swarms and Plagues

A locust outbreak or upsurge marks the transition from the innocuous solitary phase to the plague stage. During plagues, Desert Locusts may spread over an area of 29 million km^2, extending over (parts of) 60 countries. This is more than 20 per cent of the total land surface of the world. A plague has the potential of damaging the livelihood of a tenth of the world's population (Showler, 1996, FAO, 2007)[14]. A list of insect infestations during the past two decades is given in Table 1.

(Table 1 to be inserted around here)

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locusts triggers gregarious behaviour. Field-trials show that parents in conditions of clumped vegetation produce hatchlings that were more gregarious (BBSRC, 2001).

[13] Not just the colour but also the form, physiology and behaviour change. The gregarious form is metabolically highly active, physiologically larger with bigger wings and a fatter body, nervous in behaviour and totally social (Balasubramanian, 2004).

Locust swarms can be small or huge, varying from less than one km^2 to several hundred km^2. There may be 40 - 80 million locust adults in each km^2 of a swarm. Swarms of locusts can fly 100 km in a day in the general direction of prevailing winds (Showler, 1996). In recent decades, locust swarms have been reported in many countries, including Mali, Mauritania, Kazakhstan, Uzbekistan, Russia and China (BBSRC, 2001). An outbreak in 2004 was the largest known since those of 1986-89. It affected the whole Sahel, from Senegal and Mauritania to the Red Sea, moved offshore from the Atlantic Ocean to the Canary and Cape Verde Islands and reached the Mediterranean Sea (Sanchez-Zapata et al. 2007).

In a reconstruction of the incidence of regional plagues going back to 1900, Waloff and Green (1975) report[15]. Table 2 shows that: (i) the intervals between onsets of successive plagues in the same region were highly variable; (ii) the number of plagues that occurred within an interval of less than 7 years, however, was far from negligible; and (iii) there was no periodicity when the plagues were considered in sequence, as in all the regions serial correlation of successive intervals was not significant.

(Table 2 to be inserted around here)

Further analysis, as shown in Table 3, revealed that the termination of a plague depends on how long it has already lasted. When estimates of the probabilities of a plague finishing in a particular year were calculated from the frequency distribution of plague lengths, it was found that the probability of a plague lasting 1 year was high, and

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[14] During the 20th century, Desert Locust plagues occurred in 1926-1934, 1940-1948, 1949-1963, 1967-69, and 1986-1989 (FAO, 2007).

of finishing after 2 years was low; thereafter, the longer the plague lasted, the more likely it was to end, with the probability of it lasting more than 8 years being very small indeed. The details are shown below.

(Table 3 to be inserted around here)

Plagues are of two types -short and long. The latter seem to carry seeds of their own destruction. While control measures have contributed to the termination of some recent plagues, it is also known that several ended with droughts. The tendency of the longer plagues to last a comparatively regular and seldom exceeded period is linked to deterioration of reproductive capacity of locusts due to crowding (Waloff and Green, 1975).

Damage

Locust damage is sporadic in time and patchy in space, owing to the nature of the swarms. Where swarms do not land, losses do not occur. Where they do and feed, losses can be 100 per cent within hours at the local level[16].

The Desert Locust is mobile during much of its life-cycle. During the periods of maximum mobility, the damage is distributed over a large area, and is accordingly of low intensity per unit area. Once the mobility decreases, damage in the area where the

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[15] The area from West and North Africa eastwards to Assam, and from the Middle East to Tanzania was divided into four major regions-western, eastern, north-central and south central-for the analysis summarized (Waloff and Green, 1975).

[16] While a 10 per cent loss each year is tolerable, a 100 per cent loss once in 10 years can be disastrous, even though the total loss over the period is no greater. It is this threat of total destruction that makes the locust the most dreaded of all crop pests (Bullen, 1967).

mobility decreases can be severe. Local wind convergence and low temperatures contribute to the persistence of locusts in a particular area[17].

The intensity of damage by locusts depends on the amount of vegetation eaten by a locust and the size of the locust population. A Desert Locust hopper (nymph) eats roughly its own weight of fresh vegetation per day, and an adult roughly half its own weight per day (approximately 1.0 g). An actively migrating adult swarming locust eats at least its own weight per day, and possibly three times as much. Thus a typical Desert Locust swarm 10 square miles in area, with a density of thirty locusts per square yard and a mean weight (of a locust) of 1.7 g could consume at least 1595 tonnes of fresh vegetation per day. This measures vegetation loss due to eating only. Additional damage results from stems and leaves cut through but not completely eaten, and branches broken down by the sheer weight of massed locusts (Bullen, 1967, FAO, 2007).

From available evidence, it is estimated that about 200 yd^2 of a Desert Locust swarm could eat as much vegetation per day as one native cow (about 25 lb), so that a small-to-medium swarm of about 10 square miles has the grazing capacity of 150,000 head of cattle. Thus Desert Locust swarms have devastating effects on the grazing land. These could be of a short or long-term nature. For example, during a locust infestation in Kenya in 1931, dairy production fell by 20 per cent, and, at a farm in Limuru, milk production dropped from 273 to 91 litres/day only 2 days after the infestation. The pasture recovered its full grazing potential over 3 years (Bullen, 1967).

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[17] Topographical 'cul-de-sacs' such as the Souss Valley in Morocco and parts of the Rift Valley system in East Africa trap locust swarms for longer periods. Local winds inflowing towards isolated mountain areas (e.g. Mount Kilimanjaro in East Africa) hold swarms together. Such

4. Occurrence of Insect Infestations

Here cross-classifications of insect infestations are given to focus on their frequency by region and income level over the periods 1985-94 and 1995-2004.

In Table 4, the frequency distribution is by region. First, as may be noted from the cross-classification by region, the frequency of insect infestations fell drastically during 1995-04, relative to 1985-94. The total number plummeted from 44 to 17. Second, the regional concentration also changed. During 1985-94, over 90 per cent of the infestations were confined to Middle East and North Africa, and Sub-Saharan Africa, with the majority in the latter (over 70 per cent of the total infestations in the latter). South Asia accounted for barely 7 per cent while Latin America and the Caribbean for a little over 2 per cent of the total. Third, the concentration in two sub-regions of Africa fell drastically during 1995-04- from over 90 per cent to about 64 per cent. There were two insect infestations each in Latin America and the Caribbean, East Asia and the Pacific and Europe and Central Asia, with each region accounting for about 12 per cent of the total. Finally, considering the sharp reduction in the frequency of insect infestations during the recent decade, it is not surprising that the frequency per million of population also registered a sharp reduction.

(Table 4 to be inserted around here)

The distribution by level of income in Table 5 points to an interesting but a consistent contrast. First, a vast majority of the infestations were concentrated in Low Income countries (over 77 per cent) during 1985-94, and one fifth in Lower Middle Income

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areas, with higher rainfall than the surrounding semi-desert plains, are highly vulnerable to locust damage, and are usually important settlement nodes (Bullen, 1967).

countries. Second, this pattern changed, with a reduction in the share of Low Income countries and a rise in that of Lower Middle Income countries during 1995-04. There were none in Upper Middle Income countries.

(Fig. 1 and Fig. 2 to be inserted around here)

So it follows that insect infestations are mostly an affliction of Sub-Saharan /Low Income countries. As agricultural productivity tends to be low in this region/group of countries, the damage through insect infestation could be severe. Before examining this effect, let us turn to the determinants of insect infestation.

5. Methodology

As the frequency of insect infestations is relatively small and discrete (with a preponderance of zeros), the Poisson regression model is preferred to the OLS.[18] This model has been widely used to analyze count data. It assumes that each observation ($Y_i = y_i$) is drawn from a Poisson distribution with parameter λ_i, which is related to the regressors, X_{ik}. The basic equation of the model is

$$\text{Prob}\ (Y_i = y_i) = \frac{e^{-\lambda}\lambda_i^{y_i}}{y_i!},\ y_i = 0,1,2,\ldots\ldots \qquad (1)$$

A common formulation for λ_i is

$$\ln \lambda_i = \Sigma_K \beta_K X_{ik}\ . \qquad (2)$$

The expected number of "events" (in this case, the number of insect infestations in a country over the period 1980-2004) for the i th country is $E\left[y_i / X_i\right] = \lambda = e^{\sum_K \beta_K X_{iK}}$.

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[18] For an exposition of the Poisson regression, see Wooldrige (2006, pp.604-609).

Consequently, the expected number of events will increase with the value of the kth explanatory variable if $\beta_K > 0$ and will decrease if $\beta_k < 0$.

Although Poisson MLE (maximum likelihood estimation) is a natural first step for count data, it is somewhat restrictive. All of the probabilities and higher moments of the Poisson distribution are determined entirely by the mean. In particular, the variance is equal to the mean:

$$\mathrm{Var}\,(y \mid \mathbf{X}) = \mathrm{E}\,(y \mid \mathbf{X}) \qquad (3)$$

The Poisson distribution, however, has a robustness property: whether or not the Poisson distribution holds, we get consistent, asymptotically normal estimators of the β_j. When we use the Poisson MLE but do not assume that the Poisson distribution is entirely correct, the analysis is referred to as quasi maximum likelihood estimation (QMLE). However, if the Poisson variance assumption does not hold, the standard errors need to be adjusted.

A simple adjustment when the variance is assumed to be proportional to the mean is given below:

$$\mathrm{Var}\,(y \mid \mathbf{x}) = \sigma^2\,\mathrm{E}\,(y \mid \mathbf{x})$$

where $\sigma^2 > 0$ is an unknown parameter. When $\sigma^2 = 1$, we obtain the Poisson variance assumption. When $\sigma^2 > 1$, we get the case of overdispersion, and, when $\sigma^2 < 1$, it is a case of underdispersion.

When overdispersion is indicated, a negative binomial regression could be used. Instead of assuming as before that the distribution of y, the number of events, is Poisson, we assume that y has a negative binomial distribution. This means relaxing the assumption of equality of mean and variance.

The next step is to assess the impact of insect infestations on agricultural productivity and its growth. This is done by regressing a measure of agricultural value added per hectare of arable land on a set of geographical variables, predicted frequency of insect infestation, initial rainfall (i.e. annual rainfall during 1980-81) and annual incremental rainfall. A robust regressions analysis is carried out.

6. Results

Determinants of Insect Infestations

Through several different specifications of the Poisson or negative binomial regressions, we have tried to identify the factors associated with insect infestations. The key questions are variation in the occurrence of insect infestations due to geophysical characteristics, income groups, and regional characteristics. This equation is identified by lagged insect infestations. Two sample periods are considered: 1980-2004, and 1991-2004. The dependent variable is the number of infect infestations in 1980-2004 (or 1991-2004). A vector of explanatory variables, **X**, includes: land area (km^2) and its square, dummy variables to reflect the national income level groups[19], share of land area in dry temperate, and in tropical conditions, a set of regional dummies, population density and its square, whether the country is landlocked (outside of Western and Central Europe), dummy variables to capture mean elevation or metres above sea level (or a set of dummy variables for the range of mean elevation), a soil suitability index that measures the

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[19] Countries are divided according to 2004 GNI per capita, calculated using the World Bank Atlas method. The groups are: low income, \$825 or less; lower middle income, \$826 - \$3,255; upper middle income, \$3,256 - \$10,065; and high income, \$10,066 or more and we use dummy variables for the first and the second categories as our sample does not include the last category. This is preferred to income levels in order to circumvent its endogeneity.
Source: Adapted from World Bank (2006)

degree of moisture (or, alternatively, suitability for rainfed crops)[20], mean distance to the nearest coastline, and the number of insect infestations in 1970-79[21].

(Table 6 to be inserted around here)

Table 6 presents the results for infect infestations in 1980-2004. The result in Case 1 imply that (i) large countries are more prone to insect infestation but this relationship weakens with size; (ii) each of the three regional dummies i.e., for South Asia, Middle East and North Africa, and Sub-Saharan Africa, has a significant positive coefficient (relative to the default case of Latin America and the Caribbean, and Europe and Central Asia), implying that these regions are more prone to insect infestation; (iii) neither population density nor its square has a significant coefficient; (iv) landlocked economies are likely to be more prone to insect infestation but the coefficient for these economies is weakly significant; (v) elevation, however, has a negative but weakly significant coefficient- as reported later, threshold effects of different elevation ranges cannot be ruled out; (vi) distance from a coast is unrelated to insect infestation; however, (vii) controlling for all these effects, insect infestations during 1980-04 are strongly related to number of insect infestations during 1970-80. Arguably, (lagged) insect infestations help to capture the effect of country specific characteristics in the infestations during 1980-2004. These in part could also reflect differences in state capacities for pest control.

The results of an alternative specification, shown in Case 2, point to minor changes. An additional explanatory variable used here is a soil suitability index. Among other

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[20] Soil suitability is a measure of its suitability for rainfed crops.(FAO. 1995. The Digital Soils Map of the World, Version 3.5. Rome:FAO).

21 To ensure the comparability of results from the two samples, we use the same lagged dependent variable to identify the relationship.

factors, this is linked to Desert Locust swarms, as summarized in Section 3. While all those variables with significant coefficients in Case 1 possess significant coefficients in this specification as well, that of elevation is negative but significant at the 10 per cent level. There is, however, no significant relationship between insect infestations and soil suitability.

In Case 3 of Table 6, the regional dummies are replaced with land areas in temperate or tropic zones and income dummies. Some notable changes in the results are: (i) the higher the share of land in dry temperate conditions, the lower was the vulnerability to insect infestations; (ii) both income dummies have significant positive coefficients, implying more frequent occurrence of insect infestations in lower income countries; (iii) the coefficient of elevation remains negative but ceases to be significant; (iv) as examined later, there could be significant threshold effects, depending on the ranges of elevation; and (v) as before, lagged infestations have an important role in explaining inter-country variation in insect infestations during 1980-2004. The Poisson functional form is rejected by the goodness-of-fit test in Case 3, and a negative binomial regression was tried in Case 4. The results are largely similar in terms of significant relationships.

In Case 5, there is some evidence favoring threshold effects of the ranges of elevation. While the first two ranges (i.e. less than 300m or between 300m and 600m) have positive coefficients, only the second is significant. The coefficient of landlocked economies is positive and significant, as also of lagged insect infestations. However, the Poisson functional form is rejected by the goodness-of-fit test. So a negative binomial regression was tried in Case 6. However, the results do not corroborate threshold effects of elevation.

A selection of results based on the 1991-2004 sample is given in Table 7. In general, the results with this sample are uneven and not-so-robust- in part, due to the steep decline in the frequency of insect infestations. Specifically, we note from Case 1 that the only regional dummy with a significant coefficient is South Asia[22]. Elevation has a positive effect in Case 1, but not significant. Controlling for these and other effects in this specification, only lagged insect infestations are significantly related to those during 1991-2004. In Case 2 where shares of land area in dry temperate, and in tropical conditions are included, the coefficients of share of land area in tropics, and elevation become significant. The higher the share of land in tropical conditions, the more likely is the country to experience insect infestations, as also those with a higher elevation. As in all other cases, lagged insect infestations have a significant role in explaining cross-country variation in infestations during 1991-2004. In Case 3, inclusion of a soil suitability/moisture index does not change the results substantially, as all those variables with significant effects in the previous specification retain their significance.

(Table 7 to be inserted around here)

Insect Infestations and Agricultural Productivity

Next, we examine the effect of the predicted occurrence of insect infestations on agricultural productivity[23]. A selection of results is given in Table 8. The main findings from Table 8 are: (i) there is positive relationship between agricultural productivity (defined as agricultural value added per hectare) and initial rainfall in 1980; however, the average annual growth of rainfall does not have any effect on agricultural productivity;

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[22] Note that both India and Pakistan had insect infestations during 1992-94.

[23] We have avoided analyzing total factor productivity mainly because of data constraints.

(ii) there are threshold effects of arable land area, with the dummies for the first two ranges possessing significant positive coefficients relative to the largest (default) range[24]; (iii) as in the case of arable land, there are threshold effects of elevation on agricultural productivity- productivity is lower in the first and third ranges while it is higher in the second, relative to the highest (default) category; (iv) the higher the share of land in the tropics and dry temperate zone, the lower was the productivity; (v) the productivity varied with the soil suitability index; (vi) the longer the distance from a coast, the lower was the productivity; and (vii) controlling for these effects, more frequent insect infestations lowered agricultural productivity.

(Table 8 to be inserted around here)

To the extent that frequency of insect infestations cannot be restricted but their devastation can be -as elaborated below through, for example, biological pest control- it is worthwhile to examine the orders of magnitude implied by our estimated econometric relationships. So what we have done below is to reduce the coefficient of insect infestation by three hypothetical amounts: 10 per cent, 20 per cent, and 30 per cent. Two remarks are in order. First, with a modest reduction in the devastating effect of insect infestations (say, 20 per cent), agricultural productivity rises by a small amount (i.e. it rises by a little over 1 per cent). With a more than moderate reduction (of 30 per cent), agricultural productivity is higher by a moderate amount (i.e. by over 3 per cent). In low income countries with barely subsistence levels of agricultural production and

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[24] Arable area is divided into 4 ranges: <.5 million hectares, .5 million-2.5 million hectares, 2.5million-5million hectares, and >5 million hectares.

nearly stagnant productivity, even a moderately higher agricultural productivity has the potential of enhancing substantially the welfare of the poorest segments.

7. Biological Pest Control

The major locust swarms of 1988 took several years, 1.5 million litres of chemical pesticides and US$300 million to bring them under control. Growing concerns about the effects of these pesticides on human health and the environment, and their unaffordability by small farmers have prompted experiments with biological pest control (Neuenschwander, 2004).

Classical biological control consists of the introduction, establishment and spread of natural enemies against exotic pests. A distinctive feature is that it is *self-regulating*. Unlike resistant crop varieties, biological control pits pests against their natural enemies. These parasitoids and predators offset any emerging defense mechanisms, ensuring that biological control does not break down[25].

A new biopesticide based on fungal spores, *Green Muscle*, for example, has been licensed for use against grasshoppers and locusts in many African countries[26]. Its extensive use, however, is constrained by regulatory and other hurdles (Neuenschwander,

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[25] There is some early evidence that biological control agents had undesirable effects on non-target populations but such problems are relatively rare now (Neuenschwander, 2004).

[26] Entomopathogens are microorganisms that cause diseases among anthropods, particularly insects and mites. These are widespread in the environment and include bacteria, fungi, viruses, nematodes and protoza. Most are host- specific and cause epidemics in insect populations. When entomopathogens are mass-produced and applied against pests in ways similar to insecticides (e.g. using sprays, dusts), they are called microbial pesticides. They leave no toxic residues and do not pollute the environment.

2004)[27]. Some of these hurdles are lack of production capacity, small markets, intellectual property rights issues, and harmonization of regulatory and quality control measures.

Another promising approach is to use insecticidal plant extracts, known as botanicals. Although some of these extracts are poisonous and require regulatory testing, others (e.g. *neem* seed or leaf extracts) are found to be safe. But such plant extracts continue to be used on a small scale- despite their abundance-as commercial production is limited.

Biological control agents (e.g. entomopathogens, plant extracts) share some advantages: they are compatible with new crop varieties and cultural practices, and they preserve indigenous natural enemies (Neuenschwander, 2004).

Two recent reviews of biological control-especially in the Sahel- emphasize the following eight points summarized below (Langewald and Cherry, 2000, De Groote et al., 2001). First, plant Protection Services and extension agents share the positive views of farmers about biopesticides[28]. Second, even poor farmers are willing to pay for locust control[29]. However, the amounts that they are willing to pay will cover a fraction of the production costs of biopesticides. Donor assistance is imperative, as governments spend small amounts. Third, biopesticides face stiff competition from chemical pesticides which

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[27] It has been deployed against Sahelian grasshopper outbreaks since 2000 in Mali and Niger. On a smaller scale, it has been used in field-trials in Benin, Cabo Verde and some East African countries. There have been fewer field-trials against locusts (Neuenschwander, 2004).

[28] For details, see Langewald and Cherry (2000), De Groote et al. (2001).

[29] The willingess- to- pay for grasshopper control in Maine-Soroa (Niger) was attributable to heavy losses from grasshopper infestation. The harvest in a good year (with good rains and no grasshoppers) was estimated at 1500 to 5000kg/family of 5 to 15 people (as the *Fulani* do not have a unit for area measurement). A heavy grasshopper infestation could reduce it to 300-1000 kg or a loss of 80 per cent. Farmers were willing to pay 203 sacks (of 100kg), with an estimated value of about $50. This is almost 10 per cent of the expected harvest of 30 sacks in a good year (De Groote et al. 2001).

are not only cheaper but also benefit from strong promotional efforts from their producers influencing the decisions in the national plant protection services.

Fourth, in the high value export crop sector, there are opportunities for efficient commercialized microbial products which target the major insect pests such as the cotton bollworm[30]. Some of these products are available and could be introduced under license for testing on the local markets. In the peri-urban farming sector, pest problems are diverse and pest tolerance is low. Inputs, income and turnover are high, cropping cycles are short, and the need is for fast acting, efficient products. Yet the range of pesticides in use at any one time is limited. Here, as in the cash crop sector, openings exist for commercial production. In the third sector, mainly traditional West African agriculture, there is potential for a diversity of microbial organisms, implementation routes and strategies. Success of commercial products is contingent on donor and government support. Given the diversity of target crops and pests, and low farmer incomes, non-commercial approaches such as classical microbial control merit serious consideration (Langewald and Cherr, 2000).

Fifth, in India, the government has been proactive in promoting the use of biopesticides. As a consequence, small and medium enterprises have flourished in supplying them to small markets. In striking contrast, this has yet to happen in Western Africa, with many small market niches. Sixth, although guidelines on the registration, import and release of biological pest control agents exist (FAO, 1988, 96), the framework in use in (most of) Africa remains weak and patchy. Few countries have the resources to implement and enforce the guidelines. Besides, national regulatory authorities have little

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[30] These recommendations are based on a three-fold classification of agriculture in West Africa (Langewald and Cherry, 2000).

or no experience of handling biopesticide registration, which is either dealt with by following standard chemical registration guidelines or on an *ad hoc* basis.

Seventh, more analysis is needed on the risk of locust and grasshopper attacks as perceived by farmers, how important those attacks are to them, and how much are they willing to pay for control measures. Finally, also, the relationships between the pests, the damage caused by them, and the resulting crop losses need more careful scrutiny. Detailed data will allow robust estimation of the expected economic loss. Together with data on the efficacy of different treatments and strategies, expected benefits of these strategies could be computed for comparison with their costs (De Groot et al. 2001)[31].

8. Concluding Observations

The main findings of our analysis are summarized from a broad policy perspective. Even though the frequency of insect infestations has declined in recent years, they continue to cause considerable damage. As a majority of these infestations are confined to Low Income/ Sub-Saharan African countries, with low or stagnating agricultural productivity, their potential for damage remains high. A finding that reinforces this concern is that countries which experienced more frequent insect infestations in the decade prior to the sample period, remained prone to such attacks during 1980-2004. This is partly a result of geographical and climate-related factors that favour the formation of insect swarms, but also linked to the failure of government agencies in implementing pest control measures.

The effects of insect infestation on agricultural productivity are significant. Even moderate success in restricting the damage to crops through, for example, biological pest

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[31] For a brief but an admirably lucid exposition of the benefit-cost methodology in the context of natural resource management, see Dasgupta (2007).

control could enhance growth of agricultural productivity. However, a detailed investigation of various options in pest control and their cost-effectiveness is necessary.

New biological pest control methods (e.g., biopesticides) are promising -especially since they preserve the natural enemies of the pests- but their application is constrained by regulatory and other hurdles. Specifically, the latter comprise lack of production capacity, small markets, and weak enforcement of guidelines for release of biological pest control agents. Biopesticides also face stiff competition from chemical pesticides which are cheaper and benefit from strong promotional efforts by their suppliers. There is, however, considerable potential for a diversity of microbial organisms, implementation routes and strategies. But success of commercial production is contingent upon donor and government support.

New research with more detailed data sets must analyze in greater detail the risks that farmers face of insect infestations (e.g. grasshopper and locust attacks) and how much they are willing to pay for control measures. Also, robust estimation of expected economic losses is required for comparison with expected benefits of different options in pest control.

In conclusion, while low income countries are unlikely to stop insect infestations, government and donor support could make a difference in restricting their damage.

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Table 1
Countries Where Desert Locust Infestations Occurred

1986-1989	1992-1994	1995	2004
Algeria	Algeria	Eritrea[b]	Algeria
Burkina Faso	Cape Verde	Saudi Arabia	Burkina Faso
Cameroon	Chad[d]	Sudan	Canary Islands
Cape Verde	Djibouti[d]		Cape Verde
Chad	Egypt		Chad
Eritrea[a,b,c]	Eritrea[b]		Egypt
Ethiopia[a]	Ethiopia		Gambia
Gambia	Gambia		Guinea
India	Guinea Bissau		Libyan Arab Jamahiriya
Iran	India		Mali
Iraq	Mali[a,d]		Mauritania
Jordan	Mauritania[b]		Morocco
Kuwait	Morocco		Niger
Mali	Niger[a,d]		Saudi Arabia
Mauritania[b]	Oman		Senegal
Morocco	Pakistan		Sudan
Niger	Saudi Arabia		Tunisia
Pakistan	Senegal		Yemen
Saudi Arabia	Somalia[a,d]		
Senegal	Sudan		
Sudan[a]	Yemen		
Tunisia	Western Sahara[a]		
Yemen			

[a] Countries where locust survey and/or control were limited by armed conflict.

[b] Some areas inaccessible because of land mines.

[c] Eritrea was not independent from Ethiopia in the 1980s.

[d] Locust invasions occurred but were not sprayed. Such details are not readily available for insect infestations in 1995 and 2004.

Source: Showler (1996) and FAO (2007).

Table 2

Frequency Distribution of Intervals between Onsets of Successive Regional Plagues

Interval year	<4	5-7	8-10	11-13	14-16	17-19
Frequency of occurrence	5	9	7	5	8	2

Source: Waloff and Green (1975)

Table 3
Estimated Probabilities of a Plague Finishing in a Particular Year When it Existed at the Beginning of That Year

Plague existing in year	1	2	3	4	5	6	7	8
Probability of it finishing	0.18	0.00	0.06	0.10	0.18	0.36	0.47	0.88

Source: Waloff and Green (1975)

Table 4
Insect Infestation by Region

Region	Number of Insect Infestations (85-94)	Number of Insect Infestations (95-04)	Insect Infestations per million (85-94)	Insect Infestations per million (95-04)
	%	%		
Latin America & Caribbean	1 (2.27)	2 (11.76)	0	0
South Asia	3 (6.82)	0 0.00	0	0
East Asia & Pacific	0 0.00	2 (11.76)	0	0
Europe & Central Asia	0 0.00	2 (11.76)	0	0
Middle East & North Africa	9 (20.45)	1 (5.88)	0.04	0
Sub-Saharan Africa	31 (70.45)	10 (58.82)	0.07	0.02
Total	44 (100.00)	17 (100.00)	0.12	0.03

Calculations based on EM-DAT. Note that rich OECD and non-OECD countries are excluded.

Table 5
Insect Infestation by Income

INCOME	Number of Insect Infestations (85-94) %	Number of Insect Infestations (95-04) %	Insect Infestations per million (85-94)	Insect Infestations per million (95-04)
1 Low income	34	11	0.02	0.01
	(77.27)	(64.71)		
2 Lower middle income	9	6	0	0
	(20.45)	(35.29)		
3 Upper middle income	1	0	0	0
	(2.27)	0.00		
Total	44	17	0.03	0.01
	(100.00)	(100.00)		

Calculations based on EM-DAT. Note that rich OECD and non-OECD countries are excluded.

Table 6
Occurrence of Insect Infestations (1980-2004)

Dep. Variable: Number of Insect Infestations (1980-2004)

	Case 1		Case 2		Case 3		Case 4		Case 5		Case 6	
	Poisson regression		Poisson regression		Poisson regression		Negative Binomial Regression[*2]		Poisson regression		Negative Binomial Regression[*2]	
Explanatory Variables	Coef.	Z value	Coef.	Z value	Coef.	Z value	Coef.	Z value	Coef.	Z value	Coef.	Z value
land area (km^2)	6.64E-07	(3.63) **	6.69E-07	(3.57) **	5.87E-07	(3.69) **	6.03E-07	(2.67) **	5.09E-07	(3.25) **	6.40E-07	(2.17) **
(land area)^2	-3.04E-14	(2.88) **	-3.08E-14	(2.89) **	-3.55E-14	(3.16) **	-3.61E-14	(2.57) *	-3.12E-14	(2.68) **	-3.94E-14	(2.25) **
D (Low Income countries)	-	-	-	-	2.39	(2.29) *	2.31	(2.11) *	-	-	-	-
D(Lower Middle Income countries)	-	-	-	-	2.02	(1.89) +	2.12	(1.89) +	-	-	-	-
share of land area in dry temperate (%)	-	-	-	-	-3.25	(1.87) +	-2.84	(1.43)	-	-	-	-
share of land area in tropics	-	-	-	-	0.71	(1.14)	0.56	(0.68)	-	-	-	-
D(South Asia) [*3]	1.94	(2.53) *	1.93	(2.52) *	-	-	-	-	-	-	-	-
D(Middle East and North Africa)	2.39	(4.09) **	2.45	(4.15) **	-	-	-	-	-	-	-	-
D(Sub-Saharan Africa)	2.61	(5.09) **	2.75	(5.11) **	-	-	-	-	-	-	-	-
persons/ km^2	-0.001	(1.13)	-0.00087	(0.96)	-0.001	(1.24)	-0.0009	(0.66)	-0.00085	(0.78)	-0.0004	(0.24)
(persons/ km^2)^2	2.41E-07	(0.53)	2.00E-07	(0.45)	1.08E-07	(0.15)	-1.73E-07	(0.19)	-1.75E-07	(0.24)	-4.55E-07	(0.44)
D (landlocked)	0.67	(1.58)	0.65	(1.54)	0.52	(1.26)	0.49	(0.91)	0.68	(1.65) +	0.61	(0.79)
outside of Western and Central Europe												
mean elevation (metres above sea level)	-0.000454	(1.48)	-0.0005	(1.63)$^+$	-0.0003	(1.15)	-0.0003	(0.75)	-	-	-	-
D(elevation dummy, less than 300m)	-	-	-	-	-	-	-	-	0.56	(1.34)	0.39	(0.67)
D(elevation dummy, bet. 300m & 600m)	-	-	-	-	-	-	-	-	0.55	(1.67) +	0.28	(0.54)
D(elevation dummy, bet. 600m & 900m)	-	-	-	-	-	-	-	-	0.05	(0.10)	0.08	(0.12)
soil suitability	-	-	0.02	(0.88)	0.02	(1.18)	0.022	(0.86)	-	-	-	-
mean distance to nearest coastline (km)	0.000045	(0.10)	0.0002	(0.36)	0.0002	(0.57)	0.0002	(0.37)	-1.6E-05	(0.05)	0.0003	(0.42)
No. of insect infestations in 70-79	1.11	(1.93) +	1.17	(2.02) *	1.08	(1.88) +	1.28	(1.60)	1.39	(2.40) **	1.64	(1.73)
Constant	-2.55	(3.94)	-2.92	(3.70)	-2.98	(2.65)	-3.07	(2.53)	-1.09	(2.61)	-1.28	(1.92)
No. of Obs.	89		89		89		89		89		89	
Joint Significant Test												
LR chi^2	LR chi^2(11) = 81.7**		LR chi^2(11) = 82.4**		LR chi^2(11) = 58.25**		LR chi^2(12) = 27.61**		LR chi^2(10) = 32.69**		LR chi^2(9 = 15.61+	
Prob > chi^2	0		0		0		0.0063		0.0003		0.0755	
Pseudo R^2	0.3508		0.3541		0.2503		0.1395		0.1404		0.0788	

Notes 1. **= statistically significant at 1% level. *= significant at 5% level. += significant at 10% level. 2. Dispersion is a function of the expected mean of the counts of the jth observation. 3. D stands for a dummy variable that takes the value 1 or 0.

Table 7
Occurrence of Insect Infestations (1991-2004)

Dep. Variable: Number of Insect Infestations (1991-2004)

	Case 1 Poisson regression			Case 2 Poisson regression			Case 3 Poisson regression		
Explanatory variables	Coef.	Z value		Coef.	Z value		Coef.	Z value	
land area (km^2)	3.44E-07	(1.39)		2.94E-07	(1.29)		3.06E-07	(1.29)	
(land area)^2	-7.82E-15	(-0.52)		-4.65E-15	(-0.31)		-6.94E-15	(-0.45)	
D (Low Income countries) [*2]	-	-		-	-		-	-	
D(Lower Middle Income countries)	-	-		-	-		-	-	
share of land area in dry temperate (%)	-	-		-2.041371	(-0.70)		-2.77	(-0.88)	
share of land area in tropics	-	-		2.373621	(2.30)	*	2.69	(2.44)	*
D(South Asia)	1.51	(1.88)	+	-	-		-	-	
D(Middle East and North Africa)	-0.75	(-0.64)		-	-		-	-	
D(Sub-Saharan Africa)	0.57	(0.76)		-	-		-	-	
persons/ km^2	-0.0004	(-0.28)		0.0000291	(0.02)		-0.00002	(-0.01)	
(persons/ km^2)^2	4.80E-08	(-0.09)		-6.88E-08	(-0.12)		-4.17E-08	(-0.08)	
D (landlocked)	-0.3	(0.43)		-0.3189975	(-0.47)		-0.4063012	(-0.58)	
outside of Western and Central Europe									
mean elevation (metres above sea level)	0.00063	(1.47)		0.0011908	(2.34)	*	1475	(2.29)	*
soil suitability	-0.0105	(-0.34)					0.03	(0.90)	
mean distance to nearest coastline (km)	-0.00048	(-0.54)		-0.0001962	(-0.24)		0.0001	(0.13)	
No. of insect infestations in 70-79	0.55	(2.33)	*	0.5711848	(2.86)	**	0.53	(2.70)	**
Constant	-2.52	(-2.83)		-3.525068	(-4.14)		-4.04	(-3.82)	
No. of Obs.	89			89			89		
Joint Significant Test									
LR chi^2	LR chi^2(12) = 24.40			LR chi^2(10) = 26.20			LR chi^2(11) = 26.95		
Prob > chi^2	0.0179			0.0035			0.0047		
Pseudo R^2	0.2313			0.2484			0.2555		

Notes 1. **= statistically significant at 1% level. *= significant at 5% level. += significant at 10% level. 2. D stands for a dummy variable taking either 1 or 0.

Table 8
Determinants of Agricultural Productivity (1980-2004)

Dep. Variable: agricultural value added per hectare

	Robust regression		
	Coef.	t value	
log (annual rainfall in 1980)	24.2	(2.05)	*
average growth of annual rainfall	-13.94	(-0.32)	
D(arable land <0.5 million hectares) [*3]	93.5	(3.12)	**
D(0.5 mil. <arable land <2.5 mil hectares)	82.74	(3.43)	**
D(2.5 mil. <arable land <5 mil hectares)	-4.07	(-0.16)	
share of land area in dry temperate (%)	-96.98	(-1.90)	**
share of land area in tropics	-839.66	(-12.55)	**
D(elevation dummy for range 1)	-329.04	(-10.19)	**
D(elevation dummy for range 2)	142.68	(5.80)	**
D(elevation dummy for range 3)	-242.2	(-8.07)	**
soil suitability	3.86	(3.14)	**
mean distance to nearest coastline (km)	-0.35	(-13.98)	**
predicted no. of Insect Infestation (1980-2004)	-176.69	(-13.16)	**
[predicted no. of Insect Infestation)] X [log (annual rainfall in 1980)]	-	-	
Constant	850.83	(9.42)	
No. of Obs.	1492		
Joint Significant Test			
F test	F(13, 1478)=107.97**		
Prob > F	0		
Breusch-Pagan / Cook-Weisberg test for heteroscedasticity	chi^2(1)= 692.39**		
Ho: Constant variance	Prob>chi^2= 0.0000		

Notes 1. **= statistically significant at 1% level. *= significant at 5% level. += significant at 10% level.2. D stands for a dummy variable taking either 1 or 0.

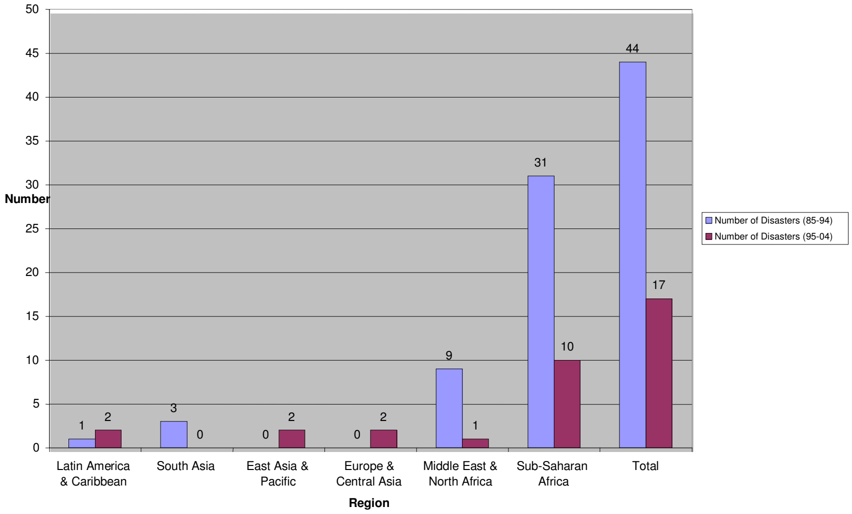

Fig.1 Insect Infestation by Region

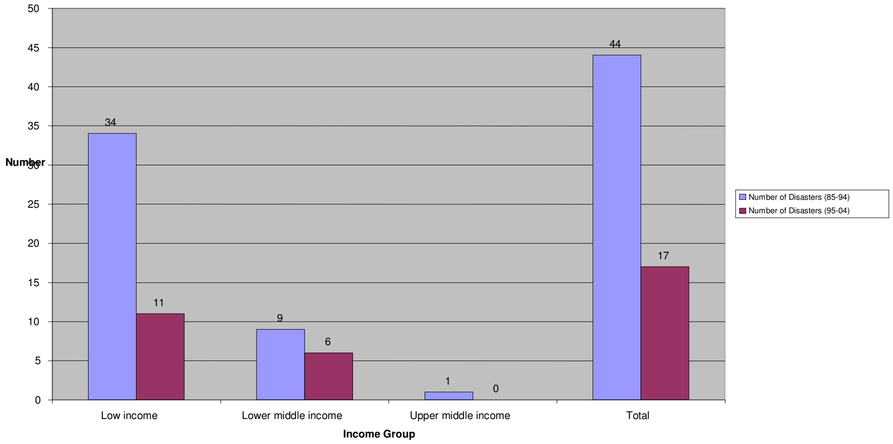

Fig.2 Insect Infestation by Level of Income