A technological economic assessment of _Spodoptera littoralis_ (Boisd.), a pest of irrigated crops in Cyprus.

117

by

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ABSTRACT

Appraisals of investment in pest control are complicated by the problems of predicting events in biological systems. In this study, an attempt is made to estimate the two necessary components of pest control investment appraisal, namely: the production function (decreases in crop losses with unit increases in pest control investment), and the pest damage function (relating crop damage to changing infestation variables), for attacks of the lepidopterous larvae of Spodoptera littoralis (Boisd.), on Cypriot lucerne pastures.

It is suggested, that at present the best technique available to farmers for controlling S. littoralis infestations, is the single application of one of three insecticides of proven efficacy. Consequently, the cost of successful pest control is represented by one value for a wide range of larval densities. The pest damage function is described as a dynamic relationship between a number of changing environmental and crop variables, and is presented in the form of a computer simulation. This incorporates some of the existing empirical data on pest consumption and pest and crop interaction as well as much of the additional data collected by the author.

The damage and production functions are compared, and estimates are made of the minimum larval density at various timings in the crop growth cycle, which is sufficient to cause losses equal to the treatment costs (the economic threshold of treatment). These estimates are offered as a basis for decision making on the economic control of S. littoralis in Cypriot lucerne fields.

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I wish to thank my supervisors, Professor F R Bradbury and Professor B J Loasby at Stirling University, and Dr P M Symmons of the Centre for Overseas Pest Research (C.O.P.R.) for all their help, and also Miss S Green of the C.O.P.R. for her constructive comments on Chapters 3, 4 and 5. I am also indebted to Mr C A Godley for assistance with the computer programming described in Chapter 6 and Mrs G Norton and Miss C Colquhoun for typing and technical assistance. I would like to record my gratitude to other members of the C.O.P.R. team in Cyprus for their co-operation during the field work and for making available data from their own work. Special thanks are due for the warm hospitality of the Ministry of Agriculture and Natural Resources in Cyprus and in particular Dr Th. Christou and colleagues at the Agricultural Research Institute, without whose help, effective field work would not have been possible.

I wish to state that any recommendations made in this thesis are my own, and do not necessarily coincide with the opinions of other C.O.P.R. staff on the Cyprus project.

Note on the presentation of the work and the source of data given in the text

In an attempt to maintain a coherent argument whilst drawing upon economic and technical data from a diversity of sources and fields, it was necessary to adopt a form of presentation which did not strictly conform to the conventions of either economic or scientific thesis. In particular, the descriptions of experimental methods in the text are shorter than might normally be considered appropriate, similarly, synopses rather than full results are given in text. However, full results and some further discussion of methods, along with any statistical analyses, are given in extended appendices. Since the chapters covered widely different fields, we considered it more convenient to the reader to give a list of references at the end of each chapter. The system of cross-referencing adopted used a notation for chapter sections, appendices, figures and tables, where the first digit indicated the Chapter (prefixed by an 'A' if the reference was to an appendix) and the second digit indicated the order of occurrence in the chapter. A list of the sections with their corresponding reference and page numbers is given overleaf in the index.

A good deal of the field and experimental data referred to in the text was collected by other C.O.P.R. staff on the project, or by the author in conjunction with them. Where such data are used the source is acknowledged. However, the attempt at integration in the presentation of the work makes it necessary to clearly state those data that were collected by the author and those by others.

Cypriot lucerne cultivation practice and its costs and returns, and the armyworm control methods adopted by farmers, were established with the aid of a growers' questionnaire constructed, distributed and analysed by the author (A3:1(2)). Growth rate and yield of lucerne in Cyprus, and its response to different cutting regimes were estimated by the author with a series of trials and sample harvests. The nutrient analysis of the lucerne was made by the staff of the Agricultural Research Institute (A.R.I.), Chemistry Department, and the trial involving feeding a dairy cow with larvae, was conducted by the author courtesy of the A.R.I. Animal Nutrition Department and in conjunction with Miss Harris (formerly of the C.O.P.R.). We conducted the survey aimed at establishing the pest status of S. littoralis on Cypriot lucerne (5.(3)(a)) and observed the actual infestations described in 5.(3)(b). The laboratory trials on feeding and growth were designed by the author and carried out with the assistance of Mr Paikos.[1] All analyses of the data were made by the author.

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[1] A local and temporary recruit to the C.O.P.R.

INDEX Page

CHAPTER 1: A statement of the problem and the application of technological economics to pest control research

CHAPTER 2: Agricultural production and water resources within the Cyprus economy

Page

CHAPTER 3: Crops infested by *S. littoralis*, their cultivation and profitability in Cyprus

Page

CHAPTER 4: A 'commercial screening' of the Cyprus late potato and lucerne crops, and an examination of their possible economic competitors

CHAPTER 5: A description of S. littoralis, its pest status on irrigated crops in Cyprus and some biological and ecological factors important for its control

CHAPTER 6: Crop and pest interaction: the damage function incorporated into a computer simulation

CHAPTER 7: S. littoralis control methods and their estimated cost

CHAPTER 8: Predicted crop loss and the economic threshold of treatment

APPENDICES

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(N.B.) In the notation for sections, appendices, figures and tables the first digit indicates the chapter and the second the order within the chapter (or appendix)).

CHAPTER 1

A statement of the problem and the application of technological economics to pest control research.

1.(1) Introduction

Spodoptera littoralis (Boisd.) is a noctuid moth whose larvae (known as armyworms), are pests of irrigated crops in Cyprus. The pest attacks occur only in late summer and autumn. An increasing scale of attack, coupled with developing insecticide resistance in the island's pest population was reported in the late 1960's. This led to a research project jointly operated by the Ministry of Agriculture and Natural Resources, Cyprus, and the Centre for Overseas Pest Research (C.O.P.R.), of the Ministry of Overseas Development, London.

This Ph.D. project was supported by funds from the C.O.P.R. and the Science Research Council, and is a technological economic appraisal of some aspects of armyworm control in Cyprus. It is hoped, that by a combined numerical and verbal description, the work offered will provide a fuller understanding of the armyworm problem and thus facilitate more informed decisions to be taken by the Government on the economic control of armyworms on the island.

Before any detailed description of the Cyprus armyworm situation is given, it is necessary to analyse agricultural pest control as an economic problem, and to indicate the possible role of technological economics to this field.

A working definition of agricultural pests is required to clarify any subsequent discussion. Such a definition could be that agricultural pests are animals, plants or pathogenic organisms, which compete with man for agricultural produce. They may compete with crops for the factors of primary production, or consume or spoil the useful materials the crops produce. These losses may occur either during crop growth or at the storage of the harvest.

Economic appraisals of allocations in the public sector are similar to positive propositions in economics, in that they can be tested given certain definitions about the nature of improvement in social welfare.[1] Implicit in the allocation problem is the comparison of 'welfare yield' between alternative areas of resource employment. Losses due to pests are not economic problems *per se*, unless they are at least in part avoidable. If losses are technically avoidable, an economic statement of the problem might be posed as: is the value of the commitment of resources required to save all or part of the losses due to pests, less than the value of the resulting release of resources from agricultural production? Once more, implicit in the term 'value' is the opportunity cost of the resources considered, that is the 'welfare yield' of their next best allocation. Viewed in this way, the distinction between investing to save loss, and investing to reap benefit, is seen to be a false one. Hence the

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[1] Such a definition is unnecessary if the social welfare function is of the 'Paretian type', where it is demonstrated that the proposed changes in the economic organisation make one or a number of people better off and nobody worse off. In most investment projects, however, the welfare gain is ambiguous since 'winners' have to be balanced against 'losers' and this can only be done within the context of a definition of improvement in social welfare.

loss function in pest control (reduction in loss with increasing inputs of pest control), is identical in concept with the economist's production function.

Traditional economics is more usually concerned with examining the consequences of certain types of organization, given specified production functions. Technological economics extends the analysis by scrutinizing the dynamic relationships existing within a production function, and modifying them to solutions closer to their optima. A consequence of this extended involvement is often the large technical and scientific input required for the analysis and hence the definition of technological economics by Bradbury and Loasby (1970) as: "decision making on the allocation of resources using the available technological and economic data".

In many instances the actual crop losses due to pests are considerable, and the criterion of avoidable loss is often fulfilled. However, full rationalization of pest control investment has rarely been achieved. This is in part due to the complex and specialist nature of research necessary for prediction in biological systems. This impedes the usual dialogue between economists and technicians in the applied field. We therefore suggest that the multi-disciplinary approach of technological economic appraisal might provide a useful contribution to pest control problems.

This work applies technological economic techniques to a specific problem. However, the approach taken in this study was not merely expeditious in dealing with Cyprus armyworm infestations with no general relevance to other pest problems. The methods adopted arose from the empirical requirements of the analysis and these can be stated for any pest problem. However, it is true that no single case study in pest control encounters the full range of problems and situations that would require solution before a standard practical approach could be formulated. Consequently, a brief survey of some other published work on the economic and technical aspects of pest control is presented. The review discusses the central issues relevant to a technological economic appraisal in pest control, and indicates some general biological characteristics as well as anomalies of pest crop systems.

Fig. 1:1 is a simple illustration of some of the more important interacting variables affected by pest control investment. A number of the terms in the boxes require some definition. For instance, for crop loss and control costs, it is pertinent to ask whose loss, whose costs? Similarly, crop injury, damage and loss, each have particular technical meanings. In the following review section, these terms are introduced and defined as they arise.

1.(2) Economic, technological and ecological aspects of pest control: a review and discussion

An attempt to rationalize pest control gave rise to the threshold concepts first proposed by Stern *et al.* (1959). These authors defined the 'economic injury level' as the: "lowest (pest) population density that will cause economic damage", where economic damage is the amount of pest injury causing sufficient damage to justify control expenditure.[1] In conjunction with this, they also

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[1] Clearly the economic injury level depends on the cost of effective control, and changes with changes in that cost.

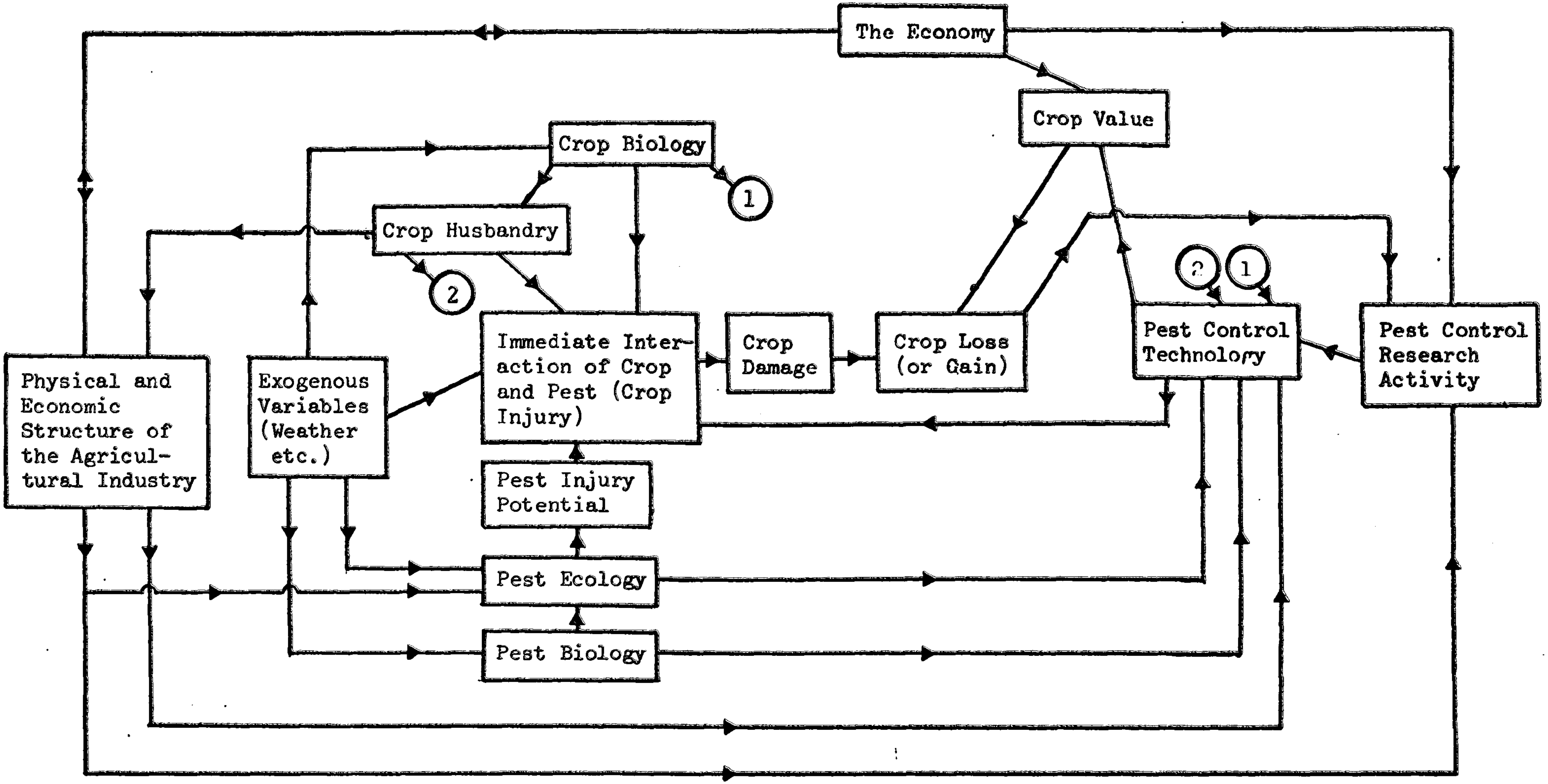

Fig. 1:1 The interaction of the main variables affecting crop protection investment

described the concept of the 'economic threshold of treatment', defined by them as: "the density (of pest) at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level". There have been frequent descriptions and redefinitions of these basic concepts, notably by: Chant (1964) (the "action threshold"), Edwards and Heath (1964), Bierne (1970), Sylven (1968) (the "critical injury threshold"), and Davidson and Norgaard (1973) (the "damage threshold").

In an algebraic statement, Headley (1972), adopts a marginal cost and revenue approach to the threshold concept, and concludes that the economic threshold population is also the economically optimal population (with respect to the maximization of net return), and redefines it as: "that (pest) population that produces incremental damage equal to the cost of preventing that damage". Other implications of the Headley model are that the economic threshold is responsive to, and determined by, prices of the product protected, and the prices of control inputs. Also the population levels where yield damage first occurs may be below the economic threshold, and finally that, unless the costs are less then the incremental value of damage prevented for the entire range of population levels, there is no economic justification for eradication policies (except a guaranteed, once and for all eradication, with a cost of maintaining zero population levels less than the cost of maintaining populations at greater than zero levels). In a critique, Hall and Norgaard (1973) point out that the timing of control, a factor emphasized by entomologists, is excluded from consideration in the Headley model. These authors extend the analysis by introducing timing as an additional variable and also, as a consequence of this they include a cost of control function.

The importance of control costs versus the value of the crops being protected, is borne out by observation. Bullen (1970) has indicated that, whereas control costs (when using pesticide) are fairly standard for a large variety of crops, crop yield value is not. This author has shown that the adoption of control practices increases markedly for crops over a certain value (for those crops yielding more than $50/acre (Ibid., p.69)).

The economic threshold concept, especially as defined by Headley, is a useful statement of the ideal investment in pest control. However, it does have a severe practical limitation. This is that there is rarely a way of predicting, with any confidence, the precise relationship between pest density and the resultant economic crop loss without becoming involved in a great deal of technical field work. Whereas the relationship between pesticide dosage and pest mortality has been established as highly sigmoid (Hillebrandt, 1960) from both laboratory (Bullen, 1970) and field observations (Mathews and Tunstall, 1968), a simple direct relationship between pest density and resultant crop loss is generally the exception rather than the rule. There is need, firstly, to consider the effects of a pest size and maturity, and the role of any exogenous variables on individual consumption demands by the pest. It is shown later in this work that the age distribution of a lepidopterous larval infestation is of prime importance in determining its injury potential, with larger larvae consuming at a rate two orders of magnitude higher than smaller ones (5.(3)(c)). Secondly, there is the relationship between pest density and the immediate physical effect of the pest on the plant (crop injury). Correspondingly, there is the effect of this injury on the quality and quantity of the crop harvested (damage), and finally the impact of quality and quantity changes in the crop on the market price (gain or loss) and correspondingly the farmer's gross revenue. Ultimately the relationship between pest density and gain or loss will depend on the functions relating these intermediate factors.

To the first approximation, the pest density/crop injury relationship is rectilinear over a considerable range of densities. For example, with the polyphytophagous locust swarms, crop injury has been described as a direct function of food intake per locust in a given time, the density of the locust population, and also the persistence of the swarm (Bullen, 1972). However, for more sedentary pests it is to be expected that intraspecific competition will affect the injury function when populations become dense. This may be due to pests being forced to feed on less favourable sites on the crop (with respect to their preferences, not necessarily from the point of view of economic damage), reducing their individual intakes, or by affecting a range of physiological and behavioural factors known to respond to population density.

The relationship between pest density and crop damage may also be rectilinear. Such a relationship has been observed for the estimated yield losses in E. African maize due to varying densities of stalk borer (Busseola fusca) larvae (Walker, 1960). However, such observations are generally uncommon. Due to the compensating response of injured plants and vegetative competition, a complex relationship exists between injury and damage. In some instances, early crop injury caused by fairly dense pest populations has resulted in increased crop yields. For example, the 'thinning' of developing cotton fruiting 'squares' by flea hoppers and other insects has resulted in increased cotton harvests (Hamner, 1941; McKinlay and Geering, 1957). A similar result has been reported for frit fly 'pruning' of unproductive oats and barley tillers (Znamensky, 1926). Conversely, a small pest population occurring at a critical time in the crop growth cycle may cause considerable losses at harvest. For example, considerable damage may occur when young cotton plants are attacked by small numbers of crickets (Tashkir Ahmad, 1954), or when the inflorescences of mature seed crop lucerne pastures are destroyed by small numbers of S. littoralis larvae; the result may be total losses of seed harvests (Vermes, pers. comm.). Bullen (1970) has cited the example of grasshopper injury to wheatat the drying out stage. At this late stage in the crop growth period, grasshoppers concentrate their attack upon the small section of still-moist stem just below the ear causing it to fall, resulting in severe crop damage.

In some crops the density of pest determines whether there are increases or decreases in the crop yield at harvest. In Sweden, Möllerström (1963), showed that low density infestations of mangold fly larvae (Pegomyia betae) on sugar beet caused an increase in yield, whereas higher densities resulted in significant damage.

Often the size and maturity of a plant is a more important determinant of damage than variations in pest density. For instance, a mature plant can generally suffer a much larger pest population and injury to its vegetative growth than a young one, and not demonstrate significant yield reductions. They are able to do this by growing new leaves (Jones, 1953) or tillers (Jessop, 1969) or relying for longer on older leaves (Taylor and Bardner, 1968).

At the more general level, cultural practice, physical environment, and interaction between pests, will all play a part in determining the crop loss due to a given severity of pest infestation.

The relationship between yield loss at harvest and farmer's loss of revenue will only occur on a pro rata basis, if the amount of crop the farm supplies has a negligible effect on the total marketed quantity and if any quality reductions in the product are sufficiently unimportant to escape price discrimination. Ordish (1968(a)) has indicated that the demand for staple food products (potatoes, cereals etc.) tends to be inelastic, and a successful pest control innovation in such an industry may well result in reduced net revenues due to a fall in unit price. This situation is contrasted with the typically elastic demand situation for luxury crop products (notably soft and hard fruits), where relatively large increases in quantities supplied do not result in substantial unit price reductions. However, loss of revenue by increased supply of inelastic demand products is a short run situation only, since in the long run a substantial price recovery may be brought about by a reduction in the size of the industry and a reallocation of released resources, not by the discontinuation of effective pest control measures.

When pest injury occurs at the site of the marketed product, such as codling moth in apples or carrot fly larvae on carrots, extra costs may be incurred in grading the product, or where this is not feasible the damaged harvest is sold as substandard products. For example, partially defoliated lucerne converted into alfalfa meal is sold as a lower grade feed additive, due to its lower percentage protein content than leafy lucerne alfalfa meal (N.A.S., 1971). A similar situation occurs in the international markets for cotton and cereals. In some cases there may be a discrete 'cut off point'. For instance, frozen food processing companies contracting with British vegetable growers, accept green bean harvests with up to 7% of the pods infected with Botrytis green mould. If the level is higher than this they reject the crop (Kovachich, 1970). The farmer is therefore faced with zero pest losses at less than 7% damage and a 100% loss for anything over this figure (assuming he doesn't use the crop for livestock feed etc.).

Pest induced quality differences may not only be the result of visible crop product damage. The production in potatoes is determined by the numbers of potatoes per plant and the mean weight of these potatoes. Artificial damage work on Cyprus potatoes, conducted by the author (unpublished), indicated that the numbers of potatoes per plant is determined early in the growth cycle and is related to foliage weight. Further development is by individual tuber growth, which is also determined, at least in part, by foliage weight. Equivalent amounts of early and late foliage injury may result not only in different yields, but may also influence the quality of yield, since small numbers of large potatoes and large numbers of small potatoes may have a different market impact.

It would therefore appear that general models of the economic threshold concept defined in terms of pest density, are not of any practical value unless the actual relationship between pest density and ultimate crop loss can be expressed accurately. Given the present knowledge of ecology and crop injury response, and uncertainties in demand schedules, such a relationship must necessarily be empirically derived for each pest problem, and may require expansion to include at least one more variable such as pest age distribution, crop growth stage or environmental temperature.

Due to the interacting nature of variables such as temperature in pest food consumption and maturation rate, the addition of a single variable of this type to a function of crop loss general increases its mathematical complexity by a power. An empirical function combining any more than two such interdependent variables will not be convenient for an operational control scheme, unless it is incorporated into a useable form, such as a computer simulation.

So far there has been no explicit consideration of who is investing in pest control or the equity of benefit from such an investment. It has been tacitly assumed by references to yield loss and crop product unit price that the individual farmer is the sole investor and main beneficiary. This is indeed the most usual case since the majority of the world's agricultural communities are highly decentralized, with each farmer an entrepreneur, using pest control techniques as just another production factor input. However, nearly all pest control research agencies are government-sponsored and are therefore presumably committed to maximizing community benefit. Given certain social value judgements, this may result in pest control measures which do not necessarily maximize individual farm revenues, or programmes requiring a co-operative response from the farming community, situations both of which are unlikely to occur spontaneously from free enterprise. Some discussion is therefore necessary to explore the implications of investment by different groups on both the type and outcome of the techniques employed.

Individual farm investment will be considered first. Collectively, farming enterprises hold considerable investment capital, but rarely can individual operators afford to fund research and development programmes in pest control. This has led to the development of pest control techniques by large industrial corporations which offer materials, generally pesticide, to farmers. Farmers therefore have access to crop protection on a low fixed cost, high variable cost basis. Although not without their problems, pesticides have been popular with both manufacturers and farmers. To the chemical industry pesticides are patentable, bulk-produced products arising from well established patterns of resource investment in research and development. They are popular with farmers due to their demonstrable qualities as crop protection agents and flexibility of usage.

The application of pesticide materials cannot be described as pest control in any general sense, since the main objective is to save the crop to which they are applied, and little cognizance is taken of the impact of these crop protection measures on the population dynamics of the pest (Southwood, 1968). Indeed it has been shown that crop protection and pest control can be antagonistic processes (Watt, 1968).

Pesticides are supplied to farmers with recommended application rates which are determined to give a high percentage kill of the pest. Due to the sigmoid form of the dosage mortality response curve to pesticides, an increase in the concentration of pesticide would not necessarily result in a marked improvement in infestation control, but could result in phytotoxicity in the crop and increased operator hazard. Conversely, a reduction in the dosage may render the pesticide almost totally ineffective. The farmer is therefore faced with the problem of applying the compound at the stated dosage or not at all. Except for extremely high value crops such as bananas (Ordish, 1968(a)) or cut flowers, this decision is further simplified into that of deciding whether to apply pesticide to the crop once, or not at all. The cost of control, in the economic threshold model, to the individual farmer is therefore a single step function of zero for no control, or the accounted costs of one dose of pesticide and its application. This has been termed the 'yes' or 'no' situation (Ibid., p.345).

As already stated, the pest loss function is not so easily estimated, and each pest problem has specific characteristics which may even be significant at the farm level (Strickland, 1970). Frequently it is only possible to be certain of making the correct investment decision when infestations are obviously severe and damaging, or when the pest is at a negligible level. There exists a broad range of infestation, or threatened infestation situations, where losses cannot be predicted with any accuracy. However, to adopt or reject the use of a pesticide the rational farmer has at least implicitly made some estimate of future loss. This estimate will normally be based on: the incidence and severity of pest infestations and their effect on yield, the role and state of any exogenous variables such as weather, any external agency advice or forecasts, and the likely market price of the crop if saved. By comparing this estimate with his control costs a farmer can postulate whether the infestation is above or below the economic threshold.

In situations where the costs of control are low and the possible crop losses are high, farmers may minimize total costs by routinely treating. An example of this is the use of cereal fungicidal and insecticidal seed dressings for cereal crops. In Britain, a total of more than 98% of all wheat acreages are treated with some form of seed dressing for either seed borne diseases, wireworms or wheat bulb fly. The estimated cost of this treatment (in 1967) was £0.05/acre (Strickland, 1967). Although this results in some diseases being kept under continuous control (such as bunt, Tilletia caries, Strickland (1970(b)), it is certainly true that in the absence of seed dressings some crops would escape attack naturally. These applications are therefore a form of insurance by the farmers who do not assess the probabilities of economic damage for each cropping.

Farmers generally tend to under-utilize pesticides. Headley (1968), using an aggregate production function analysis, estimated that the marginal value of a one dollar expenditure for chemical pesticide in U.S. agriculture was $4. A similar figure of $5 was estimated for British agriculture (Strickland, 1970). However, there appears to be considerable variation between crops, Carlson (1970) has estimated a mean of £2.25 for U.S. cotton farms, but only $0.95 for cotton farms larger than 100 acres. This under-utilization can be explained by the perhaps understandable reluctance by farmers to expend real cash resources for a problematical crop yield increase, even though the odds of a net gain may be in their favour.

One way of reducing the number of wrong decisions on control applications is to make the farmer better informed about how to recognize the economic threshold. This may require applied research into the pest problem, more extension work, or the establishing of a pest damage forecasting service. The cost of these activities is the cost of reducing error, and can legitimately be included in the cost of control function (even if the farmer does not pay, the community does). Bradbury & Loasby (1970) have described the research and development investment problem as an optimization scheme, where the costs of error fall in a diminishing returns law fashion with unit rises in research costs. The summation of the two represent the costs of uncertainty, and the optimum investment level is given by the lowest point on this curve. It is usual in pest control research that error is not greatly reduced until a useful forecasting technique has been developed. In this event, the costs of error fall to a negligible level. An example of this is the British Sugar Corporation spray warning scheme which is based on fly trap and meteorological data, and provides accurate predictions of the likely incidence of mangold fly, black aphids, and the aphid vectors of Sugar Beet Yellows Virus (Hull, 1968). However, in some instances, the costs of uncertainty are minimized with no research effort. For example, it costs about £5 per site in soil sampling and analysis to determine whether wireworms will cause economic damage in a wheat field. Although there may be considerable 'spin off' advantages in such a survey in terms of information on other pests and diseases and innate soil fertility, if a farmer has to spend more than £3 on diagnosis he is paying more than the cost of treating a 5 hectare field (Strickland, 1966).

One way of reducing uncertainty for the farmer is by contract growing, where the market price of the crop product is fixed before sowing. This at least reduces one source of loss variation, and although it merely moves the market risk onto the contractor, it does encourage the farmer to rationalize more fully his crop protection investment.

The previous discussion has been centred on crop protection investment by farmers in the developed countries. In the tropical developing countries the incidence and severity of pest damage tends to be higher. This is due to the greater diversity of pest species and their faster growth rate in these areas, coupled with a generally low level of pest control organization and investment. For instance, in 1968 stem borer (*Busseola fusca*) caused an estimated 27% loss of all cereal harvests in Tanzania, and in the same year the bollworm (*Heliothos sp.*) caused 20% losses in cereals in Kenya. Combined cereal losses due to all pests amounted to 340,000 long tons (equivalent to 450,000 ha.), in Tanzania, and 523,000 long tons (equivalent to 448,000 ha.), in Kenya, (all data from Walker, 1967). Where crop protection is practised, returns are generally high. Ingram (1965) surveyed cotton spraying in Uganda and estimated that the responses to treatment gave yield increases varying from 12-125% with an average of 27 ± 11%. It is therefore not unlikely that the return on the marginal crop protection dollar in these countries is an order of magnitude higher than that estimated for British and U.S. farms. It is probably not, as is commonly thought, widespread ignorance by farmers of the value of pesticide which prevents more extensive use of chemicals in these countries, but the lack of credit facilities coupled with subsistence agriculture (Strong, 1970). This peculiar form of market failure presents an altogether different problem to agricultural industries in these countries, and can only be resolved by some form of centralized pest control programme, or government subsidy and loan schemes to individual farmers.

When the role of crop protection is taken out of the hands of individual farmers by a community sponsored agency, two major differences occur. Firstly, the scope, flexibility and sophistication of the crop protection measures may increase, facilitating 'pest control' or 'pest management'. Secondly, the economic evaluation of a pest control strategy is complicated by the need to adopt a cost benefit analysis type of approach to the investment appraisal.

A major advantage in increasing the scope for pest control is that it can result in a lowering of the economic injury level by producing cheaper or more effective crop protection methods. Even in its least developed form, community sponsored pest control enjoys some economies of scale. For example, aerial spraying reduces fixed costs of application, resulting in a lower cost/acre of pesticide treatment. However, centralized activity also facilitates a more holistic approach to the problem. The concept of 'integrated control' developed by R.F. Smith and others (Smith, 1962, 1966, 1967) is an example of this approach, and is defined as "a pest population management system that, in the context of the associated environmental and population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible, and maintains the pest population at levels below those causing economic injury". Such methods do not preclude the use of chemical pesticides but relegate them from the status of sole crop protection agents, to the role of one input to be used judiciously in combination with other methods. The range of other methods is increasingly rapidly and can be broadly divided into biological control: the introduction, encouragement or mass culture and dissemination of pest parasites, predators or competitors; or the use of alternative treatments applied to crops, including: antifeedants, attractants and repellants (including pheromones), hormones and microbial agents. A further discussion of these control methods can be found in De Bach (1965), and Huffaker (1974).

The cost benefit analysis approach to investment appraisal adopted by community sponsored bodies differs from the conventional commercial project appraisal in two major ways. Firstly, the costs and benefits to all members of society are included, and not just the monetary expenditures and receipts of the responsible agency, and secondly the rate at which future benefits are discounted (social discount rate) may differ from the rate used by private investment.

The evaluation of costs and benefits to society is ideally made by identifying all parties affected by the project and valuing the effect on their welfare in monetary terms. An estimate must also be made of the timing of any costs or benefits, and the overall income distribution effects of the investment. In any pest control scheme, one group who are always affected is the farming community. Possible disruption of the industry as a result of crop product unit price reductions following a successful pest management innovation, will be a legitimate cost of any such scheme, which should be set against the benefits of immediately increasing crop yields.

Another difficulty arising from this kind of analysis in pest control, is in the valuation of intangible costs and benefits, usually associated with an increase or decrease in the amount of pesticide released into the environment. The problems of assessing and incorporating them into any analysis are immense, since the biological, medical, or aesthetic significance of this form of pollution is extremely difficult to establish in many cases. Even with a scientific statement of environmental impact, the valuation of any detrimental effects on a common property resource, is fraught with difficulty. In practice 'value' is often set to reflect the strength of any political lobbying, rather than by conventional demand analysis. In some instances, a range of investment choices is offered with approximately equal cost benefit ratios. In these cases, the option resulting in least pollution is chosen. However, the problem is rarely structured so conveniently, and often the choice is a direct confrontation between the continuation of a practice or its discontinuation on environmental grounds. Such an example is the banning of D.D.T. for a large number of agricultural usages on U.S. farms, the full costs and benefits of which have never been satisfactorily estimated.

The comparative advantage between a quick return crop protection policy (such as chemical control) and those offering a return in the future (such as a sterile male release, eradication programme), can be estimated by discounting any future costs and benefits at the social discount rate to arrive at a net present value (N.P.V.) for each investment. The estimation of the social discount rate is the subject of considerable academic controversy (see Layard, 1972). In principle, it should be set at a weighted average of the preferences for consumption today versus consumption tomorrow, for all people affected by the investment. There are obvious problems in estimating this, and a common practice is to adopt the market rate of interest. However, taxation and risk in the private sector may operate to make this rate higher than the actual appropriate rate for a cost benefit analysis appraisal. Also, since real rates of return will be assessed in the appraisal, inflation may have an opposite effect. The problem can be avoided to some extent by making explicit the implications of each rate of interest in terms of its overall effect on growth, and the level of present consumption, and then presenting these estimates to an elected decision making body.

It is not necessary to discuss further the application and role of cost benefit analysis in centralized investment appraisal; this is done elsewhere: Mishan (1971), Prest and Turvey (1965), Walsh and Williams (1971) and Layard (1972), and with reference to pest control: Headley (1973) and Bradbury and Loasby (1975). However, where specific factors appear to be important for S. littoralis control in Cyprus, they will be discussed more fully in context.

1.(3) A general scheme for pest control research action, and a description of the approach adopted in this study

Having outlined some of the major problems associated with a technological economic appraisal of pest control, it is useful to suggest a general scheme for research which embraces these. It is assumed that the research agency is community sponsored and does not represent any particular sectional interests.

An initial task would be to examine the agricultural sector of the economy, and in particular to identify the main resource constraints. This would give some indication of the long term 'commercial security' of the pest host crops, and also provide information on the feasibility of any control methods. For instance, aerial spraying programmes for lakeside cotton plantations in Malaŵi, although showing a high return for cotton growers were found to be incompatible with the stated government objective of a development on the lake fisheries industry (Gloyne, pers. comm.). If it is established that crop protection is possible, some preliminary survey of the present scale of crop loss is required. Coupled with estimates of the crop product demand elasticities, this will give some indication of the potential cash returns from a successful pest control innovation. A preliminary costing of the proposed techniques, including discounting to reflect the timing of costs and returns, will give a crude measure of the returns on preventing avoidable loss before any considerably research effort has been expended.

Assuming that the decision is taken to continue at this stage, the agency will need to consider whether their control recommendations are to be deployed from some centralized body or adopted by individual producers. In a highly unstructured research programme it may not be possible to make any final decisions until a working pest control technique has been established. However, a number of general points will be clear from the outset. For instance, if pest outbreaks are erratic and unpredictable the flexibility of action by individual producers will weigh in favour of a decentralized control programme. Conversely, the more complex integrated control schemes often require a continual level of specialist judgement and a broad view sometimes resulting in decisions disadvantageous to individuals. Under these circumstances a scheme would be unworkable unless centrally directed (see for instance the scheme for integrated control in Peruvian cotton, Ordish (1968(b)). An early decision on the method of deployment is advantageous since it allows time to prepare for any possible extension work or legislation for a tax or subsidy which may be necessary to make any recommendations attractive to producers. Furthermore, the readiness with which farmers will adopt innovations depends not merely on a demonstration of their profitability. Other components of the innovation such as its novelty or complexity have also been shown to be of considerable importance (Bohlen, et al., 1959; Rogers and Shoemaker, 1971), and any fully co-ordinated research programme will wish to take account of the problems of rural extension work not only in formulating its recommendations, but also in designing its research.

In devising the control technique it is necessary to develop both a crop damage function, relating crop damage to incremental changes in at least one, possibly more pest variables, and also the production function: incremental crop losses saved for unit control inputs. Although the production function may be estimated with fair accuracy, a prediction of crop loss is often uncertain. However, unless infestations are sufficiently damaging to justify routine treatments, some predictive model is required for the analysis; this will ideally be based on the available field data collected and interpreted by experienced practitioners of applied ecology.

The author's approach to the Cyprus armyworm problem and subsequent presentation of this work follows this general scheme. In Chapter 2 the agricultural sector in the Cyprus economy is examined, and the critical importance of irrigated crops and their water supply is discussed. Chapter 3 gives a miscellany of information relevant to the estimation of crop value and crop loss. Chapter 4 is the 'commercial screening' of armyworm host crops and Chapter 5 presents biological and ecological data on the pest necessary for estimating the crop damage function. This function is derived empirically by comparing pest consumption modified by growth and mortality, with the compensating growth response by the crop, and is presented in a convenient format as a computer simulation. In Chapter 7 the control costs are estimated. Chapter 8 offers a scheme for estimating the economic threshold of treatment from the control costs and the crop damage function, and in the appendix values for the economic threshold are given for different damage and treatment costs.

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CHAPTER 2

Agricultural production and water resources within the Cyprus economy

2.(1) Introduction

Shortly after preparing this chapter, war on the island caused Cyprus to be partitioned and brought about the collapse of the economy. One of the worst hit sectors appears to be agriculture, with many hundreds of square miles of forestry destroyed by napalm, and citrus and other irrigated crops lost through neglect. The priority in the Greek sector is the refugee problem, meanwhile the Turks are establishing a political and administrative infrastructure to support their military presence in the north of the island. The reports of activities in the agricultural sectors of both Greek and Turkish held areas indicate that the lack of raw materials, extensive communications damage and the disruption of a large number of agricultural communities has led to a chaotic situation from which rehabilitation will necessarily be slow.

The improvement in the control of armyworm infestations on the island, would, until July, have contributed to the economic strength of the island's key agricultural sector. In the present position of uncertainty, so many gross changes are apparent that an economic assessment of the value of increased pest control efficiency would not be possible, indeed the increase in efficiency might not even be technically feasible.

What is clear in the present situation is that whoever does ultimately control Cyprus, will be faced with the same physical constraints (geographical position, natural resources etc.) as the previous regime. Future governments on the island will therefore encounter broadly the same agricultural problems and opportunities as those existing in 1973. It is assumed that some of the economic data used in the pre-war draft of this chapter reflected these non-political constraints, and since the alternative is no data at all, the chapter is presented in essentially its original form.

The chapter presents a brief review of those factors which have a particular bearing on the type, possible outcome and value of S. littoralis control research on the island. The principal role of agriculture in the economy is discussed. Then specific factors, such as land values, fragmentation, water availability and irrigation costs will be examined more closely in support of discussions in later chapters.

2.(2) Cyprus: its position and economy

Cyprus is the second largest island in the Mediterranean; it has a population of approximately 650,000 and an area of 3,572 square miles. The island holds a key position in the eastern Mediterranean and has suffered (and continues to suffer), a stormy history of repeated invasion. From 1960 until July 1974 it enjoyed a precarious independence, at the expense of a *de facto* division between the minority Turkish Cypriot community (18% of the population), and the predominant Greek Cypriot community (80% of the population). Friction between the two communities has resulted in the stationing of 7,000 troops of the United Nations peace-keeping force on the island since 1964.

1971 marked the last year of the government's second 'Five Year Plan'. The government's attitude during that period was cautious. Foreign exchange reserves were steadily built up, almost doubling in the quinquennium. The Central Bank exerted tight control over the banking system, and liquidity ratios were high: over 35% in 1971. Even with this cautious attitude to investment, the Gross Domestic Product (G.D.P.) at constant factor costs increased each year from 1966-1971 (Table 2:1). Owing to the vagaries of weather the agricultural sector showed a variable increase in production

Table 2:1 Percentage increase over previous year of G.D.P. by industrial origin at constant factor cost of 1958

Sector	1966	1967	1968	1969	1970	1971
(1) Agriculture, Forestry, Fishing and Hunting	-5.5	26.1	-6.0	13.5	-11.3	26.4
(2) Mining and Quarrying	-4.6	32.2	-4.9	6.4	3.6	4.7
(3) Manufacturing	11.3	10.1	8.6	8.5	8.3	10.8
(4) Construction	13.8	12.1	10.8	12.2	8.7	9.0
(5) Electricity, gas and water	19.2	19.4	5.4	10.3	16.3	4.0
(6) Transportation, storage and communication	1.7	20.2	8.4	3.9	8.1	7.5
(7) Wholesale and retail trade	7.1	10.7	9.2	13.9	3.0	10.4
(8) Banking, insurance and real estate	42.1	18.5	6.3	8.8	32.4	4.1
(9) Ownership of dwellings	0.9	1.8	1.8	1.7	1.7	3.3
(10) Public administration and defence	8.5	3.9	8.8	14.9	4.0	13.5
(11) Services	8.3	5.9	10.4	7.2	10.1	11.0
G.D.P. at constant factor cost excluding agriculture	10.8	13.5	6.5	8.9	9.6	7.8
G.D.P. at constant factor cost	4.7	14.9	4.0	9.8	3.5	12.1

Modified from: Min.of Finance (1972).

through the same period; however, it did maintain a fairly high growth rate not much inferior to other sectors (average increase of 7.2% per year as opposed to 9.5% for all other sectors).

There was a recent boom in tourism; in 1971 178,000 people visited the island and their estimated total expenditure was C£13.6 millions (Min. of Finance, 1972). The balance of payments position also showed an increasing surplus in the period 1966-71, and stood at C£17.9 millions in 1971.

However, this apparently secure economic position masked a structural weakness. Import/export figures for the same period indicated an annually widening trade gap (Table 2:2). This was expected to widen still further with the decline in the mining and quarrying industry.

Table 2:2 Import/export figures for Cyprus 1968-71, in C£1.0 millions (C.I.F.)

	1968	1969	1970	1971
Imports	70.9	86.5	98.2	106.9
Exports	37.0	40.9	45.2	47.3
Trade Gap	33.9	45.6	53.0	59.6

(Data: Min. of Finance, 1972).

Minerals, principally copper and asbestos, had provided between 30-60% of exports in the past. Exhaustion of some of these reserves could mean a reduction of export earnings by this sector to as little as 12% of total exports. The heavy dependence on imports (including energy sources) laid the island open to imported inflation.

This poor trading position was protected up until 1974 by the receipt of invisibles. These totalled C£73.3 millions in 1971, and were largely due to foreign military expenditure. This was contributed by: the British sovereign bases, the U.N. peace-keeping force and the Turkish garrison (supported from Ankara).

Unemployment on the island between 1966-71 was low. 0.95-1.31% of the economically active population were registered at labour exchanges at any one time during the period (Ibid.).

Agriculture was the key sector in the economy being the largest contributor to G.D.P. (Table 2:3), and also to exports (58% of total).

Table 2:3 Industrial origin of G.D.P. at constant factor cost of 1958 (C£ million)

Sector	1966	1967	1968	1969	1970	1971
(1) Agriculture, Forestry, Fishing and Hunting	27.6	34.8	32.7	37.1	32.9	41.6
(2) Mining and Quarrying	6.2	8.2	7.8	8.3	8.6	9.0
(3) Manufacturing	15.8	17.4	18.9	20.5	22.2	24.6
(4) Construction	6.6	7.4	8.2	9.2	10.0	10.9
(5) Electricity, Gas and Water	3.1	3.7	3.9	4.3	5.0	5.2
(6) Transportation, storage and communication	11.9	14.3	15.5	16.1	17.4	18.7
(7) Wholesale and Retail trade	19.6	21.7	23.7	27.0	27.8	30.7
(8) Banking, Insurance and Real Estate	5.4	6.4	6.8	7.4	9.8	10.2
(9) Ownership of dwellings	11.2	11.4	11.6	11.8	12.0	12.4
(10) Public administration and defence	7.7	8.0	8.7	10.0	10.4	11.8
(11) Services	11.8	12.5	13.8	14.8	16.3	18.1
G.D.P. at constant factor cost	126.9	145.8	151.6	166.5	172.4	193.2

(Data: Min. of Finance, 1972)

It was the largest single employer of labour: in 1971 35.2% of the economically active population were employed in agriculture. The main constraint to further development appeared to be the availability of irrigated land. 12% of the total agricultural land was irrigated, but it has contributed over 50% of the total production, and 60% of the agricultural exports (largely citrus and spring potatoes) in the past. In spite of the rise in production in this sector, Cyprus was not self-sufficient in certain foods and meat and milk products to the value of C£3 million were imported each year.

The pre-war government was anxious to improve its trading position by increasing agriculture exports and producing more import substitutes, particularly in the dairying and livestock industry. Pressure on businessmen was for more initiative in 'modern' sector industries with the view to establishing export capacity in manufacturing.

Apart from the general disruption caused by the war in all sectors, the lucrative tourist industry will have been badly hit for a number of years. The possible withdrawal of the U.N. troops will cause further reductions in the invisible receipts, andthe mooted North Atlantic Treaty Organization (N.A.T.O.) defence cuts may reduce the contribution by the sovereign bases. Although the present partition may lead to a more rational exploitation of some hitherto shared resources (particularly irrigation water), the effects of the war damage and the other factors mentioned above have held back economic growth in Cyprus and will continue to do so.

Although it is impossible to predict with any accuracy the future economic policy of either sector, it is clear that agriculture, and particularly that part associated with irrigated crops, will play an important role in the rehabilitation and future development of Cyprus. In view of this, and the fact that armyworms are pests of the valuable irrigated crops, the nature and constraints of the agricultural resources on the island will be briefly examined, with particular reference to irrigation water.

2.(3) Land and water

The ownership of agricultural land in Cyprus was distributed within: the private sector (85%), state ownership (10%), church ownership (4%) and communally-held land (1%) (Karouzis, 1970).

Generally, agronomic qualities and climate determine the range of crops which can be grown on a piece of land. Its position (with respect to communications development), and size of individual ownerships, will affect the degree to which scale economies can be exploited, in particular the crop's harvesting and marketing costs. These two groups of factors largely determine the value of land for agricultural purposes.

2.(3)(a) Climate, agronomic quality of land and water resources of Cyprus

Cyprus enjoys an extreme development of the Mediterranean type climate, with long hot and sunny summers, and a short wet season from December to February. Cold spells are not unusual during the period December to March. In the coastal area the climate is more humid than in the Central Mesaoria region and at higher elevations lower temperatures and heavier winter rainfall are experienced.

The three important agronomic qualities of land in Cyprus are soil fertility, availability of irrigation water and improvements such as levelling and terracing.

Soil fertility on the island is generally good, for both the plains and the hills. The soils are derived largely from weathered limestone and volcanic rock. These volcanic soils reach their highest state of development in the S.E. tip of the island where they produce a rich clay loam of a characteristic red colour.

Levelling and terracing is required for hillside vine production and deciduous trees. Agriculture has been practised in Cyprus since Neolithic times and, except in areas served by modern irrigation schemes, most of these basic improvements have already been made.

In Cyprus, the most important determinant of agricultural land value is the availability of irrigation water. The estimates of the available water have varied over the years as most were based on incomplete data. A recent study (Min. of Agric. and

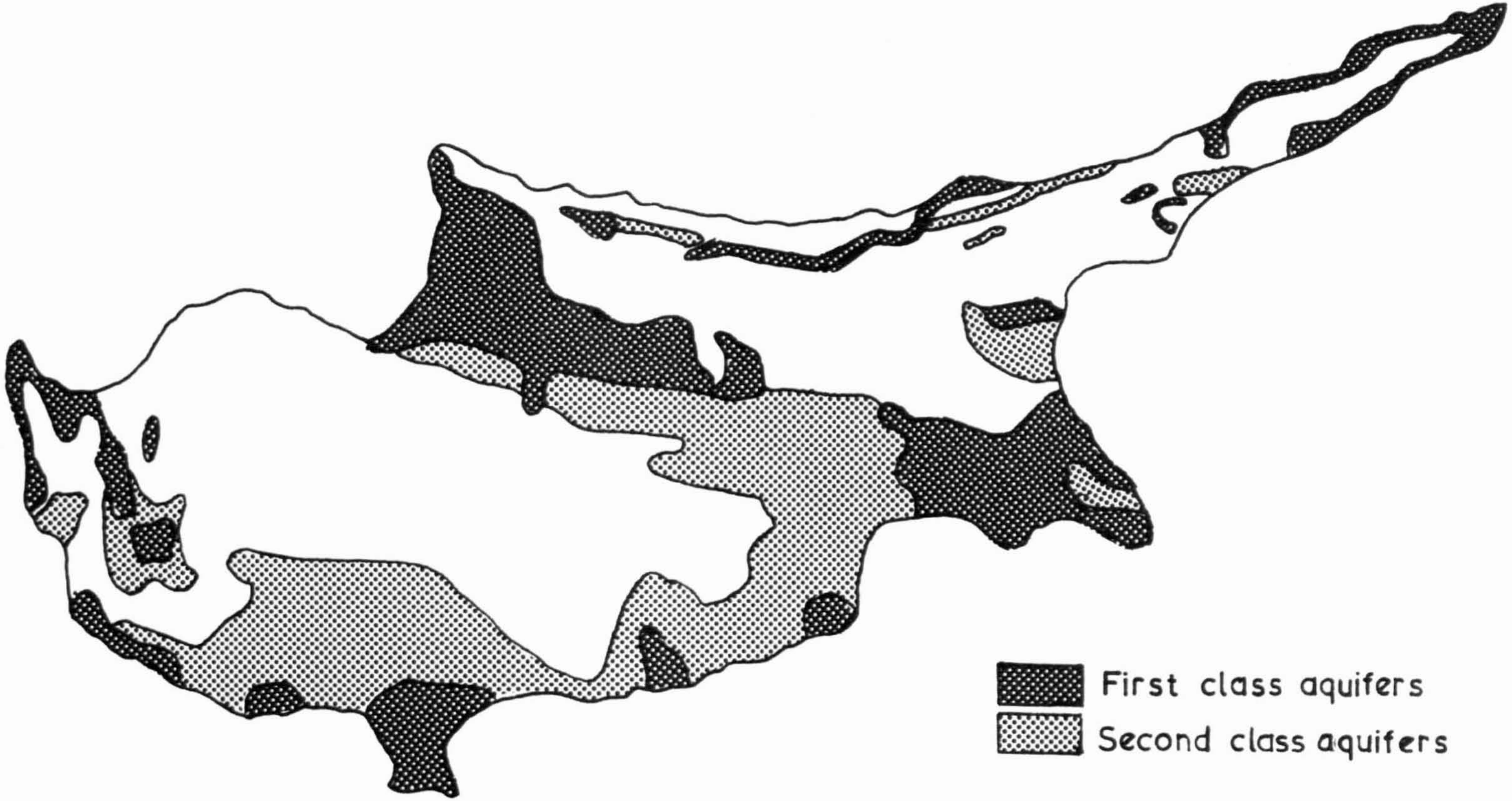
Nat. Res., 1972) computed an average water crop of 1,300 million $m.^3$/yr. of which an estimated 350 million $m.^3$/yr. reached groundwater basins.

The degree of percolation, and retention of precipitation in any one area, depends on the geology of that area and the relief gradient. In certain parts of Cyprus groundwater is retained in permeable rocks termed aquifers. There are nine major areas which are classified according to output and water quality into first and second class aquifers (Fig. 2:1).

In the Central Mesaoria, where the majority of the lucerne crop is cultivated, there are three distinguishable aquiferous zones: the classic aquifer, gypsum aquifer and river alluvium (Toufexis and Jacovides, 1971). The classic aquifer yields fresh water but in fairly low quantities. The gypsum aquifer yields a low volume of high salinity (low quality) water. Especially important in this area are the alluvial deposits of the Yialias river which supply quality irrigation water for dairying in the villages of Dhali, Potamia and Nisou, and also contribute to the Nicosia domestic water supply.

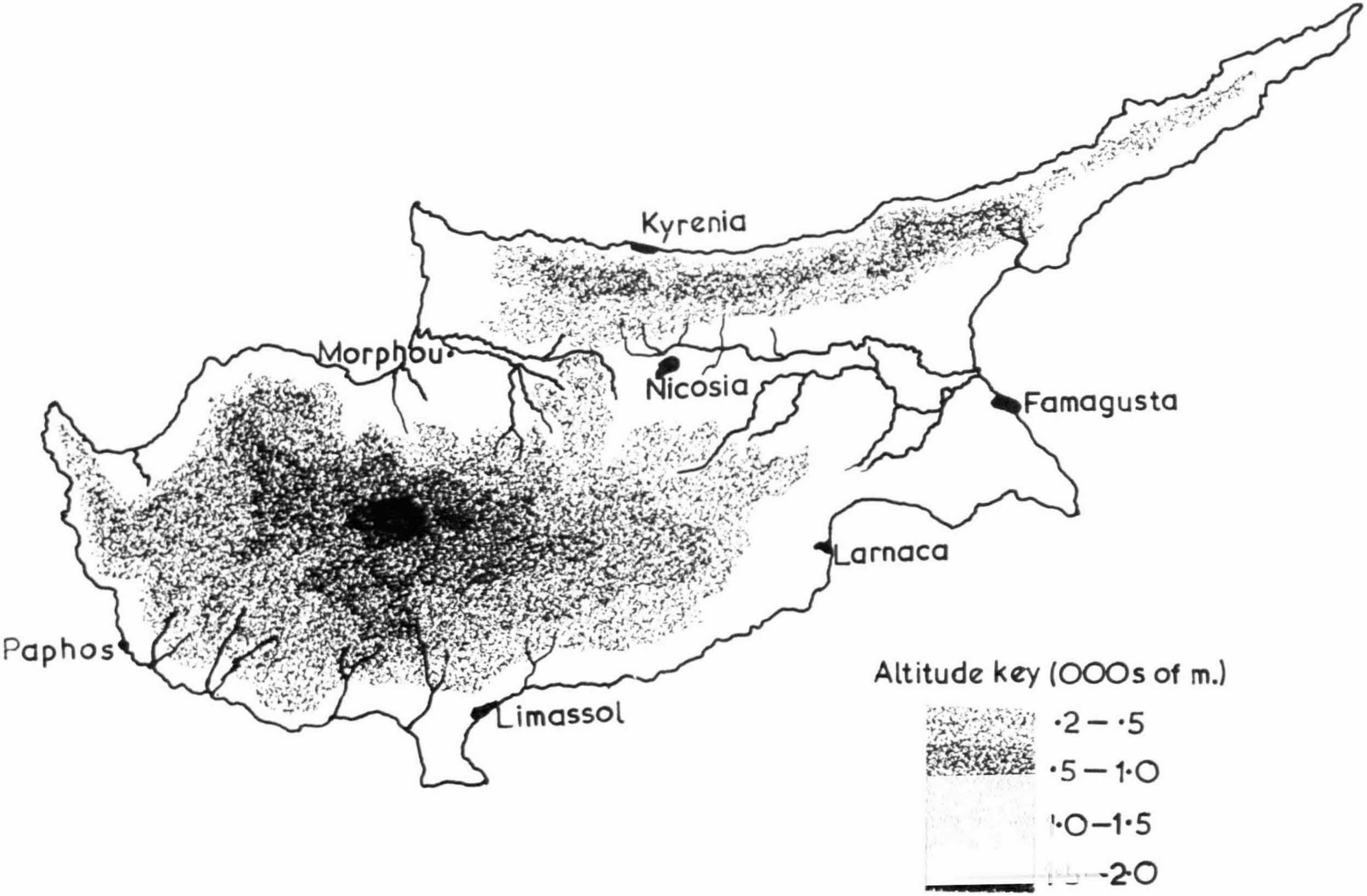
The island's most extensive and high yielding aquifer is situated in the N.W. of Cyprus, around the town of Morphou (Fig. 2:2). This highly productive aquifer, which extends to 100m. in depth at the richest point of its development, supports the largest citrus growing area in Cyprus.

Fig. 2:1 Groundwater sources in Cyprus.



(After the Water Development Department, Cyprus)

Fig. 2:2 The topography and main rivers and towns of Cyprus.



The S.E. Mesaoria aquifers are of three types; limestone, gypsum and sandstone. The sandstone aquifer contains 99% of the water available in the area and is of appreciable thickness. It is bounded on the south and easy by the sea (Ibid). This aquifer is important for its support of the large spring potato crop which is mainly grown for export (3.(3)). In the summer and autumn, water from this aquifer is used for the late potato crop and other vegetables grown for home consumption.

Table 2:4 shows the present extraction levels of groundwater sources in Cyprus. Although the two main aquifers are overpumped, there is an overall surplus of groundwater in the island. The overpumping at the first two areas listed is causing serious problems in the S.E. Mesaoria. The cones of depression of the water table correspond very closely to the pumping pattern (Pepis, pers comm.).

Table 2:4 Groundwater sources in Cyprus by Region (1972)

Region	Annual Replenishment (millions m.^{3}/yr)	Present Extraction (millions m.^{3}/yr)
W. Mesaoria	68.4	88.6*
S.E. Mesaoria	25	4.7*
Central Mesaoria	14	14
Karapass Peninsula	20	8
Limassol	101.5	36
Larnaca	36	9
Polis	25	5
Paphos	26	9
Kyrenia Coast	36.5	20.5
Total	352.4	237.1

*Aquifers suffering from sea water intrusion.

(Data reproduced from: Min. of Agric. and Nat. Res., 1972).

The aquiferous units are becoming more and more isolated, and are exploitable only at the richer places of their development. The greatest declines in the water table in 1971, were near the villages of Liopetri, north of Phrenaros, Avgorou and Kalopsidha. All of these are important potato growing areas, Liopetri being the second most important village for potatoes on the island.

This over-exploitation situation has irreversible effects: the aquifers bounded by the sea suffer sea water intrusion when pumping reduces the level of the groundwater to below sea level. This has occurred quite extensively in the S.E. Mesaoria region causing the destruction of some citrus groves and the formation of infertile sodic soils.[1]

The water problem is especially important in this study, since it is the basis for concluding that the late potato crop (a major armyworm host crop in Cyprus) may not have a long term viability (4.(2)). It is therefore necessary, in support of these arguments, to digress and briefly examine the possibility that alternative irrigation water sources will be made available at an economic rate in the areas of over-exploitation, in particular the S.E. Mesaoria.

Three systems are possible. These are the transportation of pumped water from areas of present surplus, increasing the catchment of runoff by more damming, or the desalination of sea water.

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[1] A situation resulting from saline water irrigation or sea water intrusion, where the soil loses its crumb structure due to its anionic exchange capacity being totally occupied by sodium.

The author considers it unlikely that areas at present enjoying a surplus of groundwater will in future supplement areas where there is an irrigation water deficit. This is because the one area with a considerable surplus - Limassol, and the three areas with a moderate surplus, Larnaca, Polis and Paphos - are all agricultural, and have a growing demand for irrigation water. In addition, the transportation of water involves some considerable extra costs in the form of losses in transport, pumping costs[1] and the capital and maintenance costs of conveyance to the farms, including distribution canals and pipes. Irrigation water transported for any considerable distance may therefore be quite costly, and farmers using the water may find their crop prices uncompetitive (both at home and for export) with crops produced from locally pumped water.

The possibility of a pipeline carrying a large amount of freshwater from mainland Turkey has been discussed on the island, and this may now be politically feasible. However, if the pipeline were constructed, it is doubtful, given the present political climate, whether it would be used to augment supplies in the predominantly Greek Cypriot S.E. Mesaoria area.

The amount of water runoff dammed on the island has increased considerably and steadily, from a dam accumulated storage capacity of 6.2 million m^3 in 1961 to 47.7 million m^3 in 1972 (Konteatis, 1973). However, of the 67 dams in use on the island in 1971, fully 27 were in the S.E. Mesaoria area, and of these, 9 were

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[1] Of conveyance only, since the extraction pumping costs will not be incurred by recipient farmers.

classified as major recharge dams (Ibid., p.23). It seems improbable that the remaining potential dam sites in this area, would provide a sufficient extra catchment significantly to ameliorate the water problems of the S.E. Mesaoria.

The final possibility is for some form of desalination plant on the island. Short of the serendipidous discovery of a filtering membrane or similar such system, desalination plants on a scale sufficient for irrigation purposes would require considerable energy supplies. It is assumed, that since Cyprus is dependent on imported fossil fuels, and with the recent worldwide increases in fuel prices, that the government would not contemplate desalination plants powered by these energy sources. The much-advocated plans for nuclear desalination plants in the Middle East, are not now seen as the cheap method of "making desert lands bloom for human need" (quoted from: Eisenhower, 1968). Nuclear plants would generate electricity and have undoubted economies of scale. However, the size of plant required to produce water at that price determined to be economically viable for irrigation purposes[1] would be enormous, generating electricity in excess of 3.5 million k.w.h. per year. This is far greater than the needs of any Middle Eastern country. Built-in power consumers such as agro-industrial complexes have been suggested. However, such ventures would require an extremely high initial capital input and a continuing standard of technical skill for maintenance that is not at present available outside Europe and the United States. It therefore seems improbable

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[1] Estimated at 10 cents per 1,000 gallons (Clawson et al., 1969)

that a nuclear powered desalination plant would show any favourable return in the Cyprus economy.

In conclusion, there appears to be no short term solution to the problem of alternative irrigation water supplies for those areas at present suffering a deficit.

2.(3)(b) Land and irrigation water ownership

Although the private sector is the largest ownership category, individuals rarely possessed a large amount of land. 60% of the landowners owned less than 1 ha. and 85% less than 3 ha. (Karouzis, 1970). Due to the traditional dowry system of inheritance these small ownerships were continually divided at each generation into smaller and more scattered plots. In the Morphou region land division ranged from 1-189 plots per ownership, and over 30% of the total number of owners possessed 5 or more plots (Ibid.). According to the existing Land Property Law, the minimum size of perennially irrigable land that can be owned by one person is set at 1 donum (0.134 ha.). Fragmention has continued to this limit, and now land is jointly owned. In the village of Akaki in the Morphou district, where both lucerne and potatoes are grown, the average ownership was 2.15 ha./landowner, fragmented into an average number of 11 plots, giving a mean plot size of 0.19 ha. (Ibid.). The conclusion is that the existing land tenure system causes considerable fragmentation in land ownership, dispersal of plots, small average size of plots and irregular shaped plots. This results in inefficient operation with limited scope for mechanization. There is also considerable waste of agricultural land by the numerous boundary lines and access tracks.

Similarly, the groundwater resources and control of wells in an area are subject to private ownership. These ownerships are often shared; those with the water rights using the wells according to their entitled share. The ownership of wells and water rights, is often independent of the individual's ownership of land or the proximity of the wall to any land he may have. As with land inheritence, rights change hands and are fragmented through the dowry inheritence system. On the larger farms, landowners often negotiated and purchased the exclusive rights to a well. However, the general picture amongst the smaller holdings is one of co-ownership of wells.

This situation is exemplified by the position in the village of Akaki. In Akaki in 1970, there was a chain of eight wells. The number of co-owners of each well ranged from 10-145 (Ibid.). The period of irrigation entitlement ranged from 1-30 hours usage once each eight to twenty day cycle. 34% of the co-owners of all eight wells had rights to only 1-3 hrs usage per cycle, the majority (85.5%) were entitled to 10 hrs or less each cycle. Some co-owners leased part or all of their water rights (Ibid.).

Farmers with access to water from government-sponsored irrigation schemes could utilize the water by purchasing it from the government at a rate fixed for each irrigation scheme.

The irrigation water from groundwater sources and dams was applied to the crops by either direct gravity feed (flooding) or by pumping through sprinkler pipes. The costs of each system are estimated in Appendix 2:1.

2.(4) Conclusion

Agriculture, particularly the export production from irrigated crops, made a major contribution to the prosperity of Cyprus before July 1974. We consider that in the present situation it is important that the cause of the constraints to the further expansion of the irrigated crop sector be identified and the problems tackled. It appears that land fragmentation and the inefficient exploitation of the limited irrigation water resources are two major candidates for further investigation.

SUMMARY - CHAPTER 2

The present and future economic position in Cyprus is unclear and uncertain following the events of July 1974. However, the situation existing before this period is discussed and the assumption is made that the state of the economy then reflected many resource constraints which were largely independent of the political situation and which consequently, may have a continuing impact on future developments on the island.

The economy in 1971 was bouyant and showed a steady annual real rise in G.D.P. However, the overall surplus of foreign exchange was dependent on the receipt of invisibles which masked an annually widening trade-gap. Agriculture was the key sector in the economy being the largest contributor to G.D.P. and also to exports. Within this sector, irrigated crops contributed more than half the total production and exports, although they absorbed only 12% of the total agricultural land.

Irrigation water in Cyprus was over-exploited in two areas where important export crops were grown. Other possible sources of water for these crops are discussed and it is concluded that with the present economic constraints these areas will probably not be supplemented by alternative sources.

CHAPTER 2 - REFERENCES

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CHAPTER 3

Crops infested by S. littoralis, their cultivation and profitability in Cyprus

3.(1) Introduction

S. littoralis utilizes a wide variety of food plants both cultivated and uncultivated (Chapter 5 section 5.(2)), and has been reported on most irrigated crops in Cyprus. The most important attacks occurred on the foliage of the lucerne and late potato crops. In addition, tomatoes, beans and artichokes were occasionally damaged. This chapter describes the production of lucerne in Cyprus and discusses some of the agronomic and economic factors which have a bearing on possible pest control methods. Some other crops attacked by S. littoralis are also briefly discussed.

3.(2) Lucerne

3.(2)(a) Introduction

Lucerne or alfalfa, is a forage crop which originated in Asia and was first cultivated in Iran. The genus includes a wide range of cultivars from two species: Medicago saliva and Medicago falcata. Lucerne is grown from high latitudes, where it encounters low temperatures and variable photoperiod, to the warm and constant climate of the equator. In general, higher air temperatures and light intensities promote both vegetative and reproductive growth.

3.(2)(b) Lucerne cultivation in Cyprus

In Cyprus, the Flemish variety of M. saliva is cultivated. This type is purple flowered, responds quickly to cropping and is only moderately winter hardy.

An estimated 800 ha. of lucerne were grown in Cyprus, all of this required summer irrigation. The Central Mesaoria aquifer, to the south east of Nicosia, supported approximately half the total amount of lucerne grown in Cyprus. The remainder was grown to the west of Nicosia and in the coastal districts of Larnaca, Limassol and Paphos.

Data from a questionnaire sent to lucerne and vegetable growers (Appendix 3:1), indicated that the majority of lucerne producers cultivated less than 1.0 ha. However, 93% of the growers had some farm animals; of these 55% had sheep and/or goats and 56% had dairy cattle. 68% of the farmers used all their own lucerne for their domestic livestock, 20% sold some and used some, and only 12.5% sold all of their crop. Of those who did sell lucerne, 42% sold it to their neighbours, 44% sold it in the market and the remaining 14% converted their lucerne into meal at the government sponsored drier at Vatyli. Dried meal was purchased by the Cyprus Co-operative Bank as a concentrate feed additive.

Amongst those who sold lucerne at the markets, were a small number of larger scale producers who converted their lucerne into hay for a cash crop. These farmers, henceforth referred to as type 1 farmers, were typified by their mechanization of the lucerne production process, including the use of sprinkler irrigation. They generally followed the recommended practice of the A.R.I.[1] in lucerne production and mowed their pasture when the tillers exhibited approximately one third bloom. This cutting regime resulted in a summer growth cycle of 24-28 days pasture growth, extending up to 40 days in late autumn, giving an average of nine harvest per year. The first of these was in April, collecting the accumulated winter and spring growth, then eight irrigated growth cycles followed; terminating in a prewinter harvest in early November.

Lucerne hay making in hot climates is frequently accompanied by loss of leaf due to 'leaf shatter' on baling. In Cyprus, type 1 farmers mowed in the early morning and baled before noon to reduce their losses due to 'leaf shatter'.

Sprinkler irrigations, at the rate of 700 m^3/ha. were applied twice for each of these eight cycles resulting in a total annual water usage of 11,200 m^3/ha.

Type 1 farmers ploughed up and replanted their perennial pastures once every four years. A mature stand of lucerne pasture under this regime is shown in Fig. 3:1(a).

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[1] The Agricultural Research Institute farm at Athalassa; this produced some 60 ha. of lucerne, some for its own livestock unit, and some as a cash crop.

A common characteristic of leguminous plants is atmospheric nitrogen fixation by bacteria in symbiotic association with the roots. This property largely obviates the need for nitrogenous enrichment of lucerne pastures.[1] However, other forms of fertilizer applications were necessary; type 1 farmers reported that they gave their pastures a double dressing of potash and triple phosphate.

The lucerne production practice adopted by the large number of small scale producers (henceforth referred to as type 2 farmers) was identified through the questionnaire returns[2], and general observations whilst touring the island.

The lucerne growth cycle interval reported in the questionnaire appeared to be fairly constant (mean 26 days in July-September), comparing closely with the recommended rate. It was observed that type 2 farmers generally staggered their harvests so that their plots exhibited a range of maturity, enabling the farmer to crop daily for the maintenance of his livestock. Cutting was invariably by hand using a sickle or knife (Fig. 3:1(b)).

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[1] Lesham (pers. comm.) has found some evidence suggesting that under certain conditions of cultivation, lucerne pastures in Israel do respond to nitrogenous enrichment by increasing vegetative yield.

[2] Since only one ownership reported in the questionnaire was above 5 ha. it is assumed that the questionnaire was returned exclusively by type 2 farmers.

Fig. 3:1(a) A mature type 1 lucerne pasture.

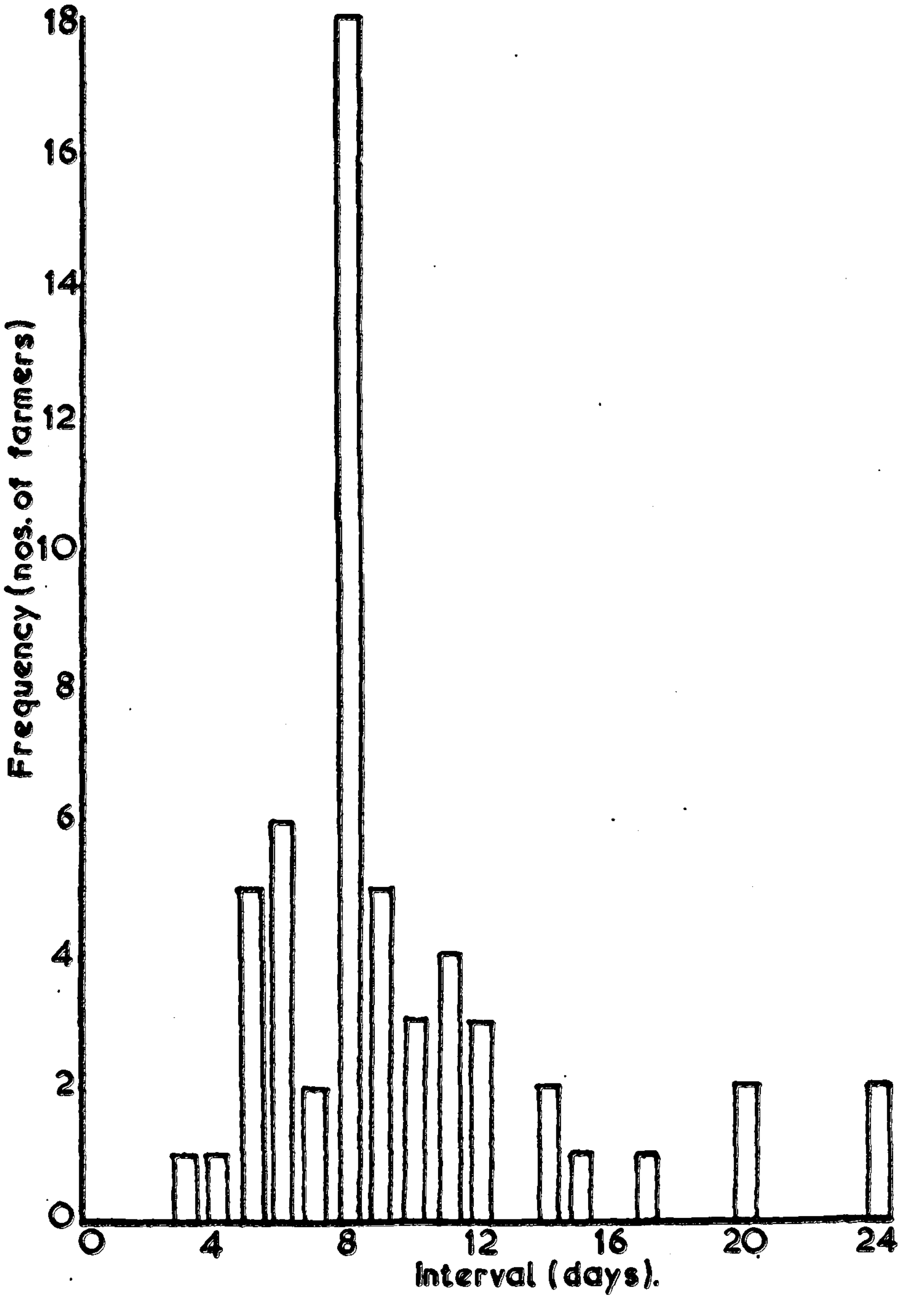
Fig. 3 1(b) Harvesting a type 2 lucerne pasture.

These farmers also tended to replant their pastures once every four to five years. However, on visits to individual farms, pasture stands were found which were up to nine years old. These appeared patchy and individual plants had woody root-stocks and crowns. These pastures developed a richer fauna; notably more woodlice (Isopoda) and ants (Hymenoptera). An attempt to correlate the incidence of S. littoralis infestations and age of pasture stand, using the questionnaire data, failed to show any significant relationship.

The irrigation regime, as reported by the questionnaire returns, showed an average interval between irrigations of 10 days. This mean figure was associated with quite a high variance (st. dev. 5.7 days), which probably reflected the difficulties encountered by farmers in gaining access to water at the most appropriate times. This view is further supported by the positively skewed nature of the distribution (Fig. 3:2). In this situation the mode datum value of 8 days between irrigations was probably the most reliable indicator of general irrigation practice within the type 2 farmer group.

Irrigation by sprinkler was adopted by only 14% of the type 2 lucerne growers who returned the questionnaire. Assuming that this figure was representative, then some explanation is required as to why the remaining 86% of lucerne growers favoured the flood irrigation method. Both economic and agronomic considerations are postulated for this.

Fig. 3:2 The interval between summer irrigations as reported in questionnaire returns.



To date, there have been no recognized costings of flood and sprinkler irrigation methods in Cyprus for the various sizes of lucerne growing enterprises. However, preliminary estimates, based on reasonable values for capital and labour cost inputs of both systems (Appendix 2:1), indicated that the advantages of sprinkler irrigation were manifested as a lower annual cost of irrigation only when the total area to be irrigated exceeded 0.3 ha. (Fig. 3:3). A large proportion of Cypriot lucerne plot ownerships were smaller than this, and consequently, in the absence of any financial incentive for adopting sprinklers, farmers favoured the retention of the simpler and cheaper flood irrigation method.

Agronomic considerations restricted the use of sprinklers to areas where good quality irrigation water was available. Brackish water sprinkled onto crops resulted in a salty deposit forming on the leaves which causes scorching of the plant in bright sunshine. Poor quality (brackish) water irrigation demands additional amounts of water in excess of the direct physiological requirements of the plant to leach the soil of accumulated salts. Since the economic advantage of sprinklers rests on their efficiency in meeting the plant's water requirements, they have no advantage under these circumstances. Poor quality water was in widespread use in lucerne cultivation, particularly in the Central Mesaoria villages of Athienou and Vatyli, which were both important dairying centres.

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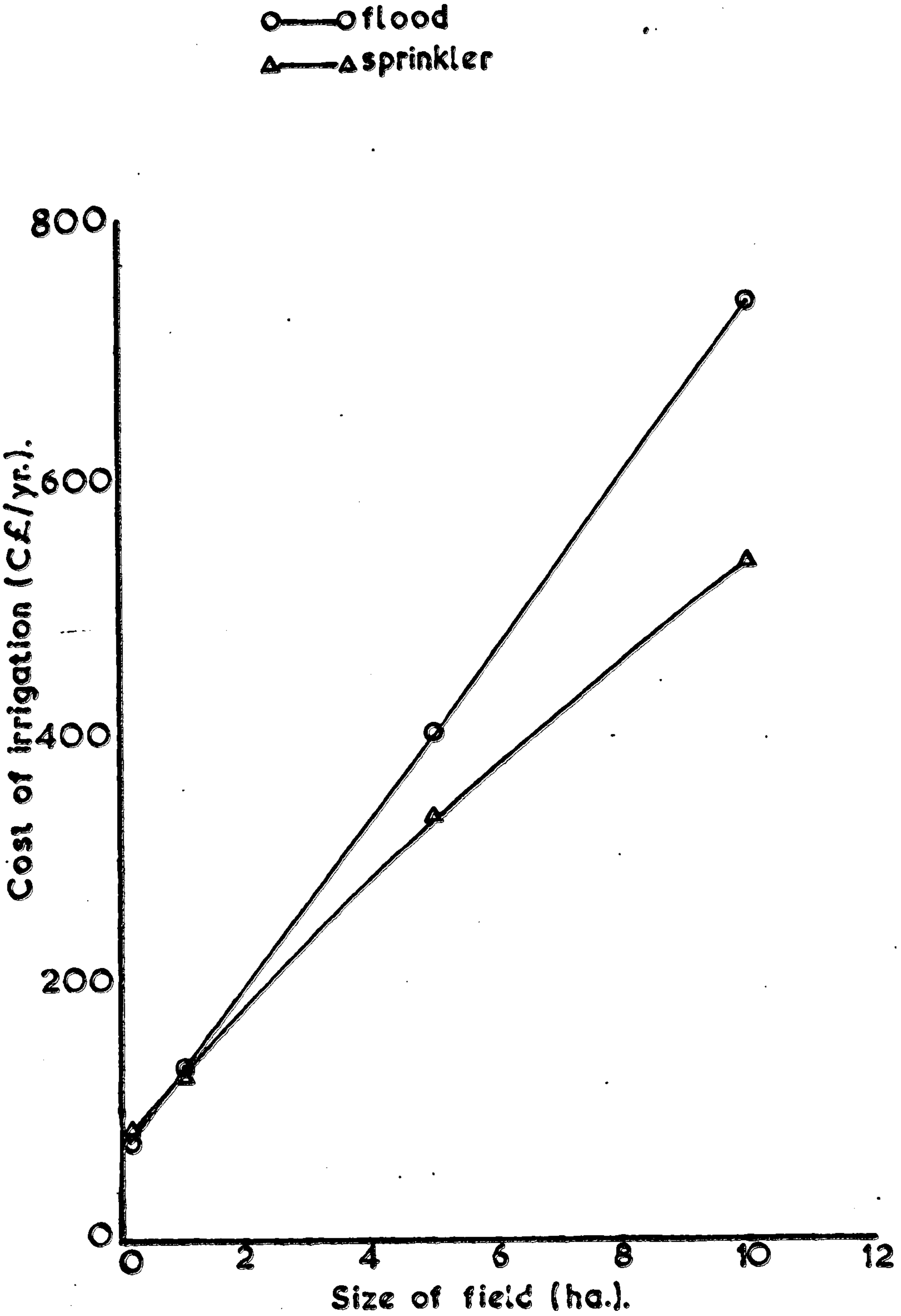
[1] The area of the lucerne crop may not be the only consideration Sprinkler irrigation is used for a large number of crops, hence the investment decision will be based on the total area of irrigable land controlled by the potential investor. Unfortunately no data was collected on the farmers total ownership of irrigable land.

Fig. 3·3 Estimated cost of flood & sprinkler irrigation for a range of sizes of lucerne fields.



3.(2)(c) Growth and yield of lucerne in Cyprus

A number of 0.25 m^2 quadrat samples of harvest maturity (1/3 bloom) lucerne were taken from types 1 and 2 farmers' plots during the months August to October. The mean yields in g/m^2 dry weight of lucerne are given in Table 3:1. The difference in mean yield between type 1 and type 2 farmers plots indicate a higher level of production by type 2 farmers. However, the difference was not statistically significant, neither were the differences in yields of samples taken in different months, therefore the mean yield for all plots was taken as representative for both types of farming. However, we suspect that the failure to detect yield differences may have been a result of insufficient sampling. Consequently, a more systematic and comprehensive series of trials is required to clarify this point.

The growth of the lucerne pasture was monitored by collecting a series of sample harvests through the regrowth period, from different areas in a type 2 pasture during September and October 1973 (Appendix 3:2). On each of the collecting dates, four 0.25 m^2 samples were taken, then dried for forty-eight hours in an oven at 70°C, and the dry weights of each sample determined. Fig. 3:4 is a plot of the data. The line drawn through these points was derived from the logistic growth equation adjusted to fit these data (Equation 6:1).

Apart from the apparent conformity of the data, there may be some theoretical justification for accepting the population growth equation as being appropriate for the growth of a single

TABLE 3:1 Lucerne field in g. Dry Weight/m^2 at harvest for types 1 and 2 farming, August - October

Plot	Month	[1]Dry Wt. g/m^2	Village	Mean and Standard Error of the Mean		
				Type 1 Farming	Type 2 Farming	Total for both types
1	7	134.8	Athalassa	$\bar{X}$ = 150.5g $S\bar{x}$ = 11.2g	▨	$\bar{X}$ = 163.3 $S\bar{x}$ = 6.12
1	8	176.4				
1	9	105.6				
1	10	133.6				
1*	9	160.0				
1*	10	160.0				
1*	8	183.0				
2	8	170.8	Dhali	▨	$\bar{X}$ = 170.4g $S\bar{x}$ = 7.03g	
2	9	192.8				
2	10	156.9				
3	8	219.0				
3	9	163.9				
3	10	174.9				
4	8	143.3	Potamia			
4	9	147.0				
4	10	133.4				
5	8	205.5				
5	9	171.9				
5	10	159.1				
6	10	174.0	Ayios Andronicus			

[1] Each dry wt. figure is a mean of 4 x 0.25m^2 quadrats

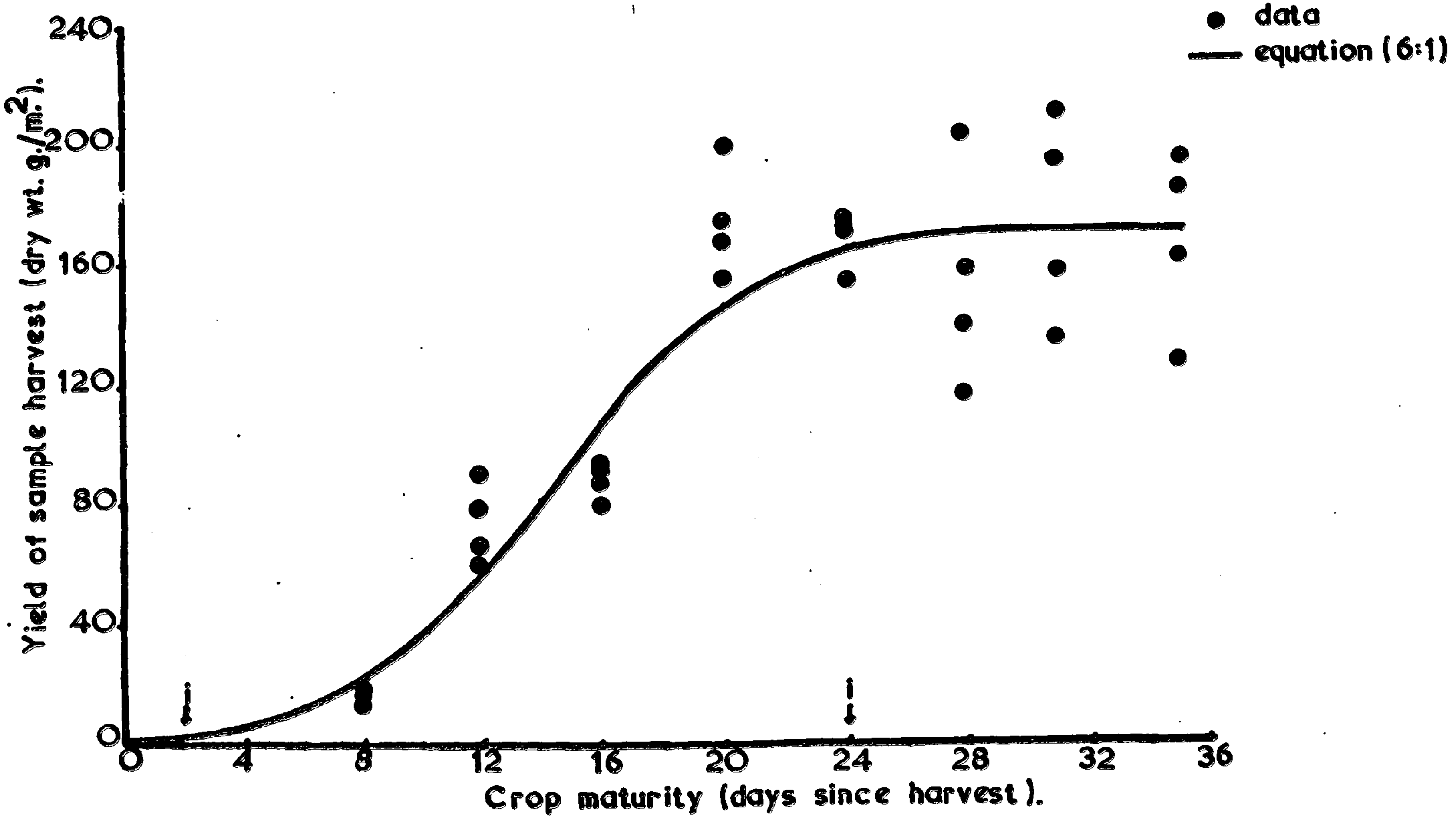
* Data courtesy Tucker and Hodson (C.O.P.R.)

organism such as the lucerne plant. This _a priori_ argument relies on the assumption that the rate of production of photosynthetic products is largely determined by the total photosynthetic area (when there are no environmental factors limiting). It is observed that during the vegetative regrowth stage the plant proportions remain fairly stable (leaf and stem ratio of 1:1). If the growth of leaf and stem is constrained by the availability of the products of photosynthesis, the rate of vegetative increase will be limited by the extent of previous photosynthetic activity. This situation is analogous to animal population growth as exemplified by bacteria or yeast cultures. It might be further postulated that the inflexion point and subsequent decline in growth rate are due to the mutual shading of leaves and resultant reduction in photosynthetic efficiency with increasing leaf area. A similar description of plant growth has been given by Fogg (1967).

Sigmoid growth curves for herbaceous plants have been observed by other workers, notably Kreusler _et al_. (1887-1879). His voluminous data on the growth of _Zea mays_ in Germany, have recently been analysed and presented by Evans (1972).

Other studies on lucerne growth in Cyprus (C.O.P.R., 1974) did not detect any early slow growth phase. This difference may be in part due to the difference in experimental method employed by these workers and the present author (Appendix 3:2). However, it is possible that the root reserves are particularly important at

Fig. 3·4 Yields of a series of sample harvests of lucerne taken at different periods after last complete harvest.



i=irrigation

this time, and are mobilized to give a rapid response to cropping by releasing the early constraints on the availability of photosynthetic products. If this is the case, then the initial regrowth lag might not occur. In view of the fundamental importance of the form of lucerne regrowth on the evaluation of crop and pest interaction (see Chapter 6), more studies in this area are needed.

3.(2)(d) <u>Pasture stand vigour</u>

Nearly all studies in lucerne management have indicated that frequency of cropping or grazing is an important determinant of lucerne production. Lucerne has a rhythmic accumulation and depletion of reserves. It has been shown with New Zealand varieties (Keoghan, 1967) that root nitrogen and soluble carbohydrate build up to high levels during vegetative growth. This energy is normally converted into flower and seed. If the ontogenic progression is disrupted by cropping, or severe grazing before inflorescence, the energy reserves are directed towards regrowth of tillers from crown buds on the rootstock, or apical and lateral buds on any remaining stubble. Overcropping depletes root reserves so that both immediate and possibly chronic effects of decreased pasture vigour will occur, depending on the intensity and duration of the overcropping regime. This is the basis for the recommendation that farmers harvest at the start of inflorescence.

For a full appraisal of pest damage it is important to establish the possible chronic effects on the pasture of defoliation by S. littoralis infestations. Due to the low incidence of infestations in the years 1971-73 it was not possible to observe this effect directly in commercial fields in Cyprus.

Plants growing in dry light soils have a higher proportion of roots to tops, than those growing in wet dense soils (Willard, 1951). Consequently, in areas with a dry climate, or in dry seasons, both irrigated and non-irrigated lucerne can be cut at an earlier stage of growth without demonstrating any immediate, or chronic inimical effects on regrowth vigour (Keoghan, 1967). Observations on stand vigour in infested pastures in other areas are therefore unlikely to be useful because of the over-riding importance of soil type and climate on lucerne pasture habit.

One method of exploring these effects in Cyprus, would be through an elaborate artificial damage experiment where pastures were defoliated in a manner which mimicked S. littoralis larval grazing. This was considered impracticable. Instead, preliminary trials on cropping rates of lucerne were conducted using a five replicate randomized block experiment. It was thought that these experiments would indicate crudely, the tolerance of Cypriot lucerne pastures to premature defoliation. However, it is acknowledged that the impact of sudden foliage removal may be somewhat different from progressive armyworm damage.

The four cropping regimes were:

(1) Plots left uncropped for the total period of 125 days
(2) Plots cropped at intervals corresponding to the recommended rate (5 times in 125 days)

(3) One extra cropping in the 125 day period (6 times in 125 days)

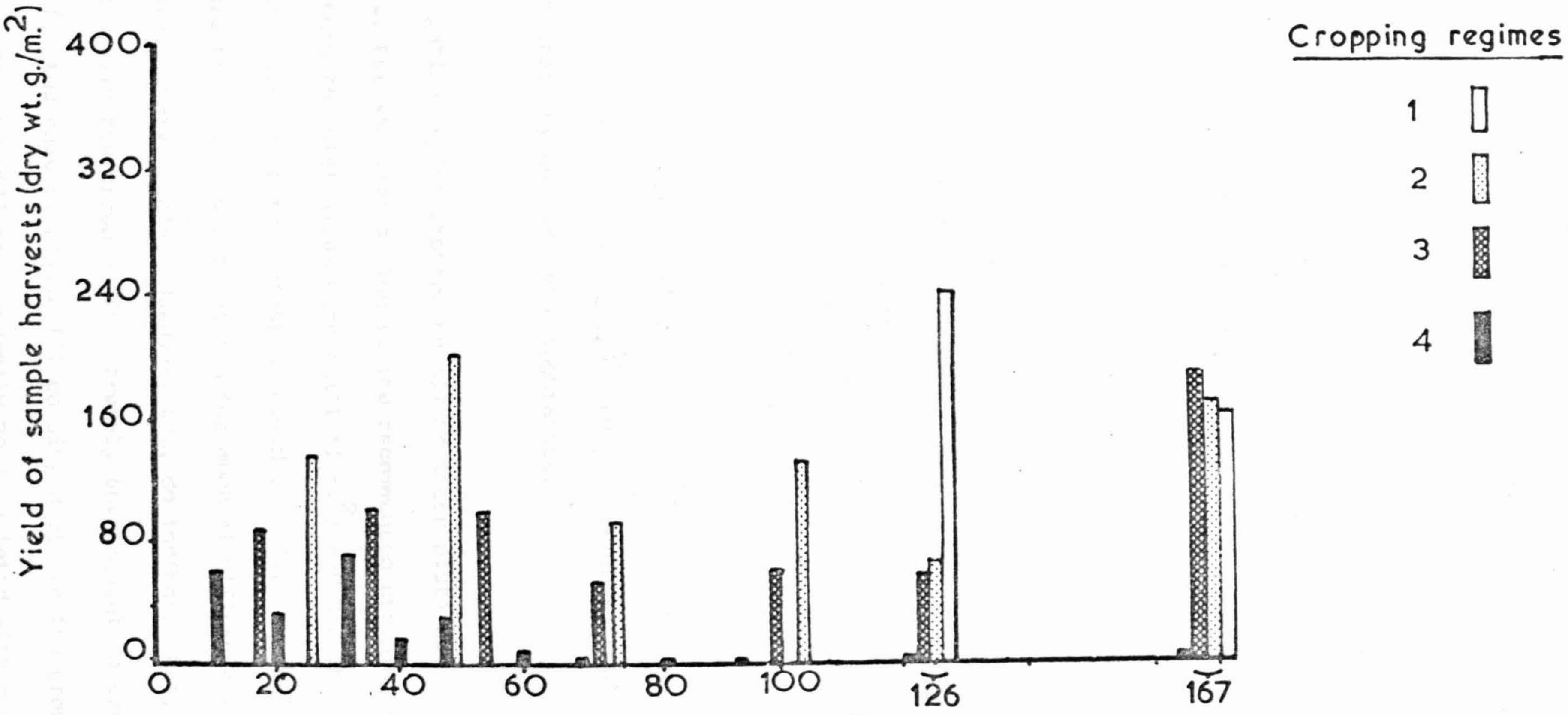
(4) Severe overcropping (11 times in 125 days)

Further experimental details and the results of these trials are given in Appendix 3:3, the individual mean harvest yields are given in Fig. 3:5.

In the moderately overcropped pasture (regime (3)), harvests were all lower than those from the recommended cutting rate, regime (2). There was also a decline in the mean yield of harvests under the regime (3) through the season. However, this was no more than was observed for the pasture cropped at the recommended rate, and it was considered consistent with the onset of lower temperatures in early autumn, slowing down the rate of plant growth. The severely overcropped pasture (regime (4)) declined rapidly in regrowth vigour and demonstrated the lowest total yield for the 125 day period. The highest mean total yield was obtained from the recommended cropping rate regime (2); this was significantly higher than all the other three regimes (Appendix 3:3 table A3:3(3)). The plots which were left uncropped throughout the 125 day period (regime (1)), developed inflorescence and seed setting occurred. These plots did not demonstrate the vigorous tillering and vegetative growth apparent in regimes (2) and (3).

When all the plots were harvested on the 125th day of the experiment (8.11.73), they were left for a further 42 days, whereupon the final harvest was taken. These harvest yields were recorded,

Fig. 3:5 Yields of sample harvests[1] of lucerne under four cropping regimes.



([1] Each yield estimate is the mean of 5×0·25m.^{2} subsamples.)

then the lucerne was chemically analysed for its nutrient composition (Appendix 3:4 tables A3:3(1) and A3:3(2)). In the severely overcropped pasture (regime (4)), the crowns had perished and no further regrowth occurred.

Statistical analysis (Appendix 3:3 tables A3:3(3) and A3:3(4)), indicated small, but significant, differences in regrowth vigour, favouring the moderately overcropped pasture (regime (2)) and the recommended cropping regime (2), over the plots left uncropped (regime (1)). Furthermore a slight increase in regrowth vigour was also detected between the moderately overcropped regime and the one cropped at the recommended rate (significance < 10% probability). In addition, the chemical analysis revealed that this trend in increased regrowth vigour was also associated with a significant increase in percentage dry matter. This higher dry matter content appeared to be distributed proportionately amongst the major plant constituents, since no significant differences could be found amongst any one of these substances.

The irrigation regime imposed on all of these plots was constant, but was more suited to the recommended cropping rate. Furthermore the plot sizes were small (1 $m.^2$) and had an associated risk or border effects (C.A.B., 1966). It would therefore be injudicious to attach too much significance to these preliminary trials. However, they do indicate that, whereas severe overcropping is extremely detrimental to crop vigour (in the case of regime (4) causing death to the crown), an extra cropping will not generally be associated with reduced vigour. Instead there appears to be some adaptation by the rootstock which results in a more vigorous vegetative response after cropping. In addition, these trials indicate that any immediate reductions in vigour, manifested as a slower regrowth in the growth cycle immediately following a premature harvest, are probably negligible.

As stated above extrapolating the results of these trials to defoliation by grazing larvae, is making the assumption that the effects on the lucerne rootstock and regenerative processes of the pasture, caused by either a harvest cropping, or a defoliation by larvae, are approximately equal. This is an oversimplification, however, the notion is discussed at greater length in (6.(7)), where it is tentatively concluded there that the effects may not be widely different.

There is also some evidence that there may be beneficial effects on the pasture due to animal grazing. Inversen (1967), commenting on lucerne pasture growth in New Zealand states: "Severe grazing[1] to zero L.A.I.[2], say for four days, results in spectacular recovery growth with lucerne taking advantage of the soluble nitrates

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[1] Inversen is referring to livestock grazing, however, the principle is the same for any animal grazing and defaecating on the same pasture. Indeed there may be better distribution of nutrients from larval defaecation.

[2] Leaf Area Index: a quantitative ratio of leaf to ground area.

returned by the grazing animal".[1] This effect has been observed in graminaceous pastures after severe Spodoptera exempta armyworm infestations (Brown and Mohamed, 1972).

In conclusion, it was assumed that two, or even three severe infestations by S. littoralis larvae on an established lucerne pasture, or a similar number of premature harvests during one season, would produce negligible inimical effects on the short or the long term viability of the pasture. Consequently, damage estimates were confined to considering the results of grazing injury within one growth cycle.

3.(2)(e) The deterioration of lucerne feed value due to S. littoralis larval infestations

The general qualities of lucerne as a feed for livestock are examined in comparison with other alternative fodders in 4.(3). From the point of view of the relationship between pest injury and economic damage, it is important to examine the devaluation of the lucerne as a livestock food source due to the influence of pest attack.

S. littoralis larvae attack pastures of all stages of maturity, but only consume the leaves, buds and flowers. To measure the relative nutrient loss due to this selective grazing, stem samples were taken from undamaged pastures and the nutrient composition of the leaves, buds and flowers determined separately from that of the stems.

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[1] It is possible that New Zealand's varieties of lucerne benefit more than the Cypriot type from grazing. This is due to the problems of establishing adequate root nodulation in N.Z. lucernes, making their response to exogenous supplies of soluble nitrates more marked.

1 m^2 sample harvests of lucerne were taken at three stages of regrowth maturity, from pastures growing both early (July), and late (November), in the armyworm season. The stems were stripped of their leaves and any flowers, and the dry weights of each determined. The resulting yields and the nutrient composition of each of these samples are given in Table 3:2.

Table 3:2 indicates that the leaf to stem weight ratio was approximately 1:1 from 12 days growth in the summer and from 14 days growth in autumn. This ratio has been found by other workers (C.O.P.R., 1974), although individual instances of 'stemmy' lucerne have been noted (Green, pers. comm.). The total yields for each sample harvest, when compared with the estimated growth form of lucerne shown in Fig. 3:4, supported the observed trend of a rapid growth phase at intermediate maturity, becoming slower as the pasture approached harvest maturity. They also indicated that the growth rate of the pasture declined through the season.

Comparison of the nutrient composition of leaves and stems from a pasture at harvest maturity, showed that leaves had a higher proportion of valuable nutrients than the stems, at the expense of a lower crude fibre content. If it is accepted that the normal leaf to stem weight ratio was 1:1 then leaves contributed twice as much protein and fat and significantly more minerals (measured by ash), on a weight for weight basis than did the stems. Comparisons with the protein content of other fodders (4.(3)), indicated that mature, but defoliated lucerne stems, with an estimated digestibility of 70%, were an average protein source, inferior to maize on a weight for weight basis, but superior to sorghum and pasture grasses.

TABLE 3:2 Yields and nutrient composition[1] (as %age of total dry weight) of leaf and stem samples of Cypriot lucerne, cut at (a) three stages of maturity and (b) in summer and autumn

Pasture maturity in days growth since last harvest	Yield			Chemical Analysis of Nutrients				
	Wet Wt./m^2 Total Sample	Dry Wt./m^2 (48 hrs at 70^{o}C)	Total Dry Wt./m^2	Protein (N x 6.25)	Crude Fibre	Crude Fat	Ash	W.S.N.F.* extract
Sampled in July 1973								
12 days	510g	Leaf 51g	101g	44.77%	7.39%	5.34%		
		Stem 50g		17.32%	22.47%	3.16%		
19 days	522g	Leaf 76g	149g	38.43%	8.23%	5.44%	12.24%	36.59%
		Stem 73g		16.03%	32.73%	2.60%	11.40%	36.79%
26 days (Harvest maturity)	928g	Leaf 91g	192g	34.81%	10.26%	5.86%	12.82%	35.64%
		Stem 101g		13.55%	37.34%	2.21%	9.99%	36.45%
Sampled in November 1973								
14 days	260g	Leaf 43g	90g	49.02%	10.71%	4.24%	11.99%	24.52%
		Stem 48g		42.35%	16.84%	2.89%	14.95%	24.47%
30 days	744g	Leaf 78g	152g	49.37g	9.28%	5.52%	12.58%	22.49%
		Stem 74g		32.97%	21.77%	2.49%	17.69%	22.99%
45 days (Harvest maturity)	825g	Leaf 98g	188g	35.32%	10.76%	5.13%	14.37%	33.95%
		Stem 90g		16.34%	34.59%	2.25%	11.70%	34.25%

*Water soluble, N. free extract is a measure of carbohydrate

[1] Chemical analysis of all samples courtesy of A.R.I., Dept. of Chemistry

The total energy available in a pasture is determined by the amounts of digestible carbohydrate and fats, and to a lesser extent proteins.[1] Although stem digestibility (and probably palatability) would have been lower than that of the leaf, due to the high crude fibre content of the former, it is probable that the total energy value of the leaves and the stems were not significantly different. This assertion is based on the equal carbohydrate levels recorded for both the leaf and the stem, which were sufficiently high to compensate for the inbalance in fat content. Hence, the desirable nutritional qualities of lucerne, which influenced its standing as the preferred crop of small scale livestock producers in Cyprus, resided in its contribution of concentrated protein in the leaves. Totally defoliated lucerne not only supplied just half the yield, but also constituted a poorer quality feed.

The cost to a farmer of lucerne defoliation on his plot was determined largely by the type of livestock he kept, the available alternative protein sources and the extent of the damage. The costs associated with loss of crop quality were therefore best estimated by market proxy. Since the majority of the lucerne produced did not reach the markets, damaged lucerne was rarely offered for sale and data on selling prices of lucerne in this condition was not collected. This point is discussed further in Chapter 8 where provision is made for calculating the losses associated with reduced quality.

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[1] From the hydrocarbon residues after deamination.

Another possible source of adverse interference by the pest with the quality of the host crop as a food source, was by livestock ingesting larvae along with the feed. The East African armyworm (Spodoptera exempta), has caused lethal toxicity amongst cattle grazing on heavily infested pasture (Brown and Mohamed, 1972; Mohamed and Young, 1972). This is a pest of the range grasslands, and these deaths occurred amongst unsupervised animals. It is unlikely that Cypriot farmers would expose their cattle to heavily infested pastures. However, a number of larvae must, from time to time, be ingested along with freshly cropped lucerne, or be taken in by grazing animals. In order to investigate any possible ill effects from ingesting larvae, a Friesian cow from the A.R.I. dairy unit was established on a lucerne diet, and then some larvae were introduced with the feed.[1] The animal did not demonstrate any acute toxicity symptoms and there appeared to be no significant effect on the milk yield, either during this feeding regime or immediately after it (Appendix 3:4).

3.(2)(f) Costs and returns of lucerne cultivation

Since the production process used by types 1 and 2 farmers differed in a number of respects, a costs and returns table for each type of farming is presented.

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[1] This work was carried out in conjunction with J. Harris (formerly of C.O.P.R.) with the co-operation of the A.R.I., Dept. of Animal Nutrition.

(i) Returns

The gross return from lucerne cultivation to either type of farmer was the value of those livestock products directly attributable to lucerne feeding, or the price raised by the crop on the market. As lucerne was one of the many, albeit important, production factors in the livestock industry, it is more convenient to use the market price of lucerne than to attempt to isolate the specific contribution to livestock profits that the crop made.

There are, however, some problems in adopting this approach. It has been stated that the major share of the harvested fodder did not reach the market, but was consumed by domestic livestock on the farms on which it is produced. In years of fodder shortages, demand for the marketed surplus resulted in extremely high prices, as farmers sought to maintain their stock with purchased fodders. Similarly, when the price of other feeds rose, demand for lucerne increased. This situation occurred in 1973 when the lack of rainfall caused the failure of the winter field crops. As a result, grain based concentrates rose in price increasing demand for lucerne and other partial substitutes of concentrates. In that year, the marketed surplus of lucerne sold at over C£70/tonne.

It is clear that when prices were high, they did reflect the true opportunity cost of feeding domestic livestock, since farmers could have realised a high revenue by cash cropping. However, these prices were a result of temporary reductions in the supply of feedstuffs, and were often exacerbated by a natural reduction in the marketed quota of lucerne in years of scarcity. Farmers who may have sold their animals and converted to cash cropping may have been quickly faced with reductions in lucerne prices. Too great a fall may have caused them to regret their decision when faced with establishing new herds or flocks, or discontinuing to grow lucerne. Therefore in practice, farmers tended not to respond immediately to feed costs by reducing their livestock commitment. They relied on the growing demand in Cyprus for livestock products to accept some price increases when production factor costs rose, and a constant supply of lucerne fodder from their own pastures to tide them over. The more usual price of lucerne, as exemplified by the 1972 price, was taken as the standard for the purposes of estimating costs and returns in this study.

No differences were found between the yields of type 1 and 2 farmers' plots and consequently the revenues given in Table 3:3 were common to both groups.

(ii) Costs

Those costs to be included in the assessment of crop returns, depend on the choice that is being considered. For instance, all costs need to be included when a farmer is considering establishing himself in lucerne cultivation. Once he is established in the enterprise he may be faced with the prospect of additional investment such as whether to apply pest control at a given time to save his crop. In this event, he will not be interested in the production costs he has already incurred, but in those he has yet to commit himself to. Since both these problems are posed in later chapters

TABLE 3:3 Gross revenue from fresh and conserved lucerne at three levels of production

State of Conservation	Yield/yr.					
	Low		Mean		High	
	tonne/ha.	C£/ha.	tonne/ha.	C£/ha.	tonne/ha.	C£/ha
Fresh	68.9	380	80.3	449	94.0	526
Hay	17.8	392	21.3	468	24.7	544
Meal	12.3	394	14.7	470	17.1	547

all of the costs of lucerne cultivation were estimated and presented separately. This enabled certain items to be omitted where they were not relevant to a decision.

The costs of the various production factor inputs are itemized for type 1 and type 2 farming processes in Appendix 3:5. However, some discussion of the two major inputs: machinery costs and labour costs, is necessary to clarify the reasons for the values given in Appendix 3:5.

The total cost of using agricultural machinery include the capital investment costs and interest on that capital, plus the variable costs of running the machine. It is frequently the case that one machine can be used for a number of crops (tractors, ploughs, sprinklers etc.). The costs attributable to using it will depend on whether the initial decision to invest in the machinery took into consideration its employment for a particular job. If the investment had been entirely justified for other crops then the farmer need only assign variable costs to its employment in the proposed task. It will be assumed that type 1 and 2 farmers have anticipated the use of their machinery for lucerne production and that a fixed cost component was included in the original investment appraisal. In normal circumstances, the capital investment costs of machinery are charged as an annual depreciation cost set by the estimated useful life of the plant or the agreed payback period of any loan capital used in its purchase. In agriculture, much of the machinery, such as tractors, mowers and balers, have a useful life which is largely dependent on the frequency with which they are used. Hence, the depreciation costs can be added as a variable cost component. The only remaining fixed cost component is the interest on operating capital. This will remain constant (assuming stable prices) for a given level of capital investment however frequently tractors, balers etc. are replaced. To arrive at a cost rate for using machinery, some assumptions on hours use per year for each machine are made; these are stated in Appendix 3:5.

A confusion arises when the allocation of permanent labour is costed. The time type 2 farmers in particular, spend on lucerne cultivation is considerable, and the imputed labour rate which is assigned to this work is likely to have a marked effect on overall profitability. For this reason a word of justification is required for the inclusion of the rates specified in Appendix 3:5.

The ultimate objective of economic activity is usually considered to be consumption and leisure. A distinction therefore needs to be drawn between voluntary and involuntary idleness. If an idle worker has opportunities for employment he is implicitly valuing his leisure at the current employment rate. He may value it higher than this and enjoy a consumer surplus, however he values it at least at this rate, which represents the opportunity cost of his time. An idle farm owner is valuing his leisure at the marginal product of labour (M.P.L.) on his farm; that is the income that would accrue through profits if he were self-employed for that period. If there is free mobility of labour in the agricultural sector, farm owners have an opportunity to hire their labour to others and therefore the M.P.L. will ideally equal the wage rate.

In conditions where there are no employment opportunities, one or both of two situations occurs, either involuntary unemployment or underemployment. A farm owner frequently employs his family on the farm but due to their position as dependents they are retained when their M.P.L. falls below the value of their consumption. They will therefore produce a situation of underemployment. This arises only when no alternative employment opportunities are offered, since in more favourable economic conditions, a farmer could increase the profitability of the enterprise by hiring out his dependents' surplus labour, and thus increasing both his income, and the M.P.L. of those left on the farm.

In Cyprus registered unemployment was extremely low, ranging from 1.31% of the economically active population in 1966 to 0.90% in 1970. There was a slight seasonality of unemployment, 1.15% in March 1971 and 0.98% in June, probably reflecting the demand from the agricultural sector for increased labour for summer harvests.

Underemployment in the Cypriot agricultural sector is unlikely to be prevalent for two main reasons. Firstly there is a large and growing 'modern' sector to the economy which would rapidly absorb the underemployed surplus. In fact, the agricultural sector has only declined from employing 38.5% of the economically active population in 1966 to 35.2% in 1971. This small reduction is consistent with technical, labour saving improvements over the five year period, and does not indicate large scale underemployment. Secondly the increases in real rates of pay in the various sectors of the Cyprus economy show a higher rate than average in the agricultural sector. Two 'modern' sector industries with lower rates include the manufacturing and service industries. This indicates a continuing high labour demand in agriculture.

There is therefore, a case for 'shadow' pricing labour used in lucerne cultivation. It would appear further that in this situation of high employment the rate should be set at the going rate of agricultural labouring which was C£.200/hr. However, the quality of permanent labour may vary. For instance, there will be a difference in utility to the farmer between labour available on a daily basis, and his own wife or son fitting in farm chores between housework or school. The latter types of labour are available for only limited times of the day and probably possess only the small skills necessary for the more menial tasks. Although their contributions to the farm are useful, it is doubtful whether the opportunity cost of their labour is as high as C£.200/hr, in fact it may well be zero. Conversely, it is argued that if this work was not done by this form of labour it would be done by labour with the standard C£.200/hr. value.

In the evaluation of input-output figures for lucerne cultivation the rate of C£0.200/hr was charged to those jobs requiring a modicum of skill or simple jobs requiring a fixed and regular time commitment. Such jobs include those using equipment or those involving the application of treatments such as seeding, irrigation or pest control. For jobs which were simple, divisible and did not have critical time limits on their completion, imputed labour rates were used in order to examine the sensitivity of overall profitability to this factor. In lucerne cultivation the only job in this category was harvesting by type 2 farmers. Farmers frequently arranged a gradation of maturity in their plots by an initial differential cutting regime. This enabled them to harvest mature lucerne on a daily basis to feed green to their domestic livestock. The amounts involved each day were small, one or two bundles, and it was invariably the responsibility of the wife or son to collect them. Harvesting costs incurred by type 2 farmers were therefore estimated using a range of imputed permanent labour. Harvesting and conservation costs were assumed to be directly proportional to yield and consequently varied with productivity (Appendix 3:5).

(iii) Costs and returns table

By combining the cost estimates in Appendix 3:5, and the yield estimates in Table 3:3, a table of costs and returns for both types of farming has been drawn up (table 3:4).

TABLE 3:4 Costs and returns of lucerne production by types 1 and 2 methods

	Yields from 1 Hectare of Pasture					
	Type 1 Farmers - Hay			Type 2 Farmers - Fresh		
	Low	Mean	High	Low	Mean	High
Tonne/yr.	17.8	21.3	24.7	68.9	80.3	94.0
C£/tonne	22	22	22	5.6	5.6	5.6
GROSS REVENUE	392	468	544	386	449	526
VARIABLE COSTS						
(1) Land preparation	10.083	10.083	10.083	9.821	9.821	9.821
(2) Fertilizers	89.200	89.200	89.200	88.600	88.600	88.600
(3) Irrigation[1]	53.000	53.000	53.000	73.830	73.830	73.830
(4) Harvesting	5.005	6.156	6.876	(included in permanent labour)		
(5) Conservation	12.417	14.472	16.163	(not conserved)		
TOTAL VARIABLE COSTS (V.C.)	169.705	172.911	175.322	172.251	172.251	172.251
GROSS PROFIT	322	295	369	214	277	454
FIXED COSTS						
(1) Permanent labour	10.149	11.675	12.939	(a) 50.580	58.250	64.568
				(b) 27.416	31.250	34.409
				(c) 4.250	4.250	4.250
(2) Rent	22.400	22.400	22.400	20.000	20.000	20.000
TOTAL FIXED COSTS (F.C.)	32.549	34.075	35.339	-	-	-
V.C. + F.C.	202.254	206.986	210.661	-	-	-
NET PROFIT in C£/ha. yr.	190	261	333	(a) 143	198	269
				(b) 166	225	299
				(c) 189	252	329

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[1] Irrigation costs also include a fixed cost component

This table indicated that, although the variable cost items for the two types of farming were approximately equal, giving a similar gross profit, the net profit of the type 2 farming system was very sensitive to the shadow price of wages used for permanent labour. The table also indicated that the average profitability of lucerne was in the order of C£200-250/ha/hr; the lucerne crop therefore compared favourably with other irrigated vegetable crops in Cyprus (Papachristodoulou, 1970).

3.(3) The potato crop: its cultivation in Cyprus

Although one in every four Cypriot farmers grew potatoes, a concentration of more than half the total production was found in the S.E. corner of the island (Savvides, 1965). Potato growing was characteristically a small scale enterprise, 84% of the farmers grew less than 0.6 hectares. These small plots represented 45% of the total production (Savvides, 1965). In the spring, the varieties Arran Banner (76% of total) and Up-to-Date (20%) were grown from virus-free seed imported from Scotland; the second cropping in the autumn used spring crop potatoes as seed. The spring crop was planted in January and harvested in June and the late crop was planted in August and harvested in November. Consequently, it was only the late crop that was susceptible to S. littoralis infestations.

Since 1960 there has been a rapid rise in potato production for the export market. However, this rise was entirely confined to the spring crop, the majority of which was exported to the U.K.

early potato markets. The *per capita* consumption of home grown potatoes had remained fairly constant resulting in a domestic consumption of around 20,000 tonnes per year. Half of this was supplied by each crop. The mean monthly prices of home grown potatoes in Nicosia ranged from C£0.035/kg. just after harvesting, to C£0.063/kg. just prior to harvest. This was a small fluctuation in price when compared to another high *per capita* consumption vegetable such as tomatoes (Fig. 3:6). This was probably due in part, to the easy storage properties of potatoes, which enabled farmers to release and store them in response to price fluctuations.

The growers' questionnaire (Appendix 3:1 revealed that the mean planting date of late potatoes was the 10th of August (st. dev. of 12 days) and the mean harvesting date was the 28th of November (st. dev. 13 days), giving an average growth interval of 108 days. Since there were only small incentives for an early harvest of the late crop, the variation around the harvesting date was neither very marked nor skewed. Approximately 90 of the 108 days growth interval were associated with aerial parts of the potato, vulnerable to *S. littoralis* attack. During the growing season late potatoes were irrigated approximately once per week (mean of 7.7 days, st. dev. 3 days) by either flooding or sprinkler methods.

3.(4) Tomatoes

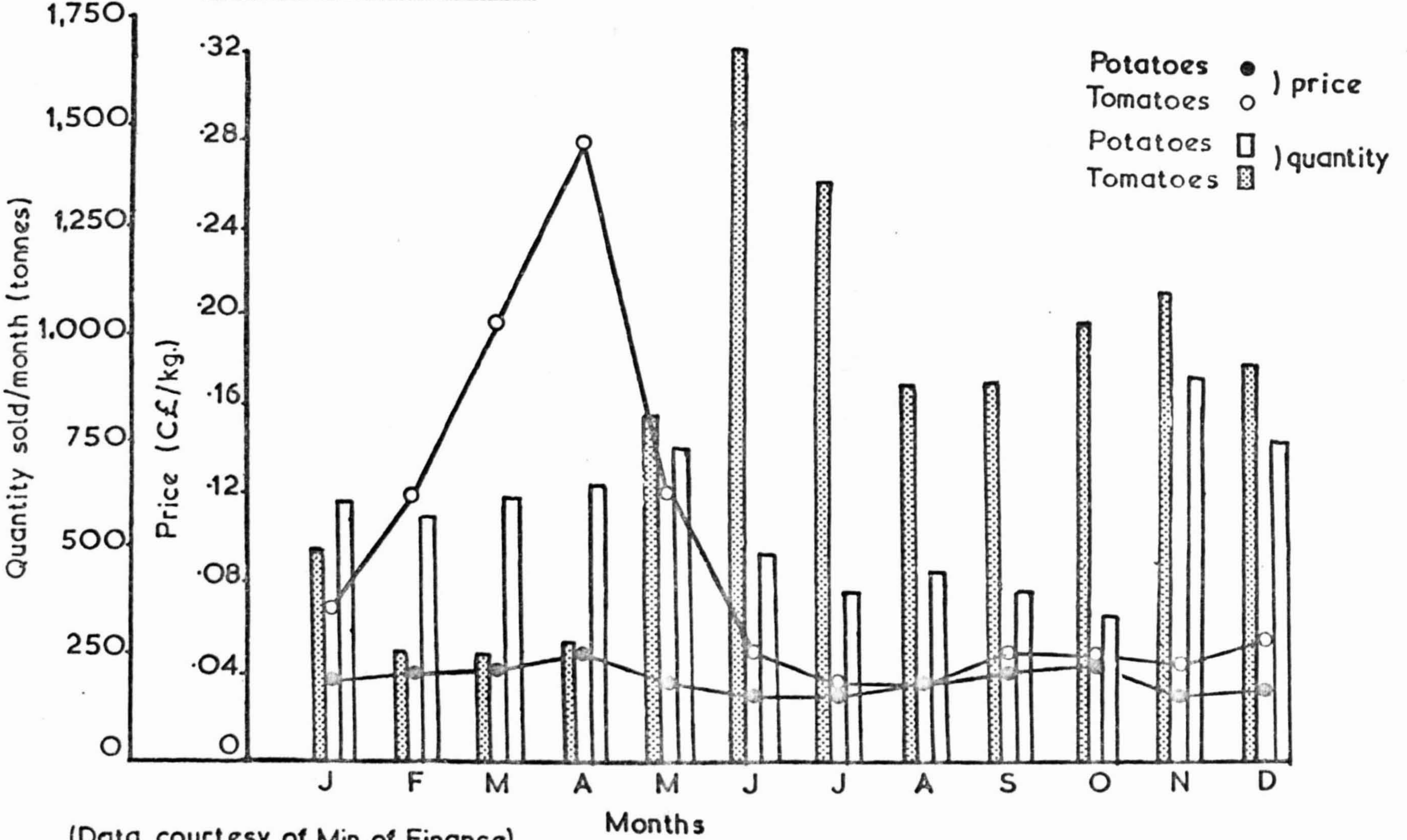
In 1960, 9,000 tonnes of tomatoes were harvested in Cyprus. Since

TABLE 3:5 Costs and returns of 1 hectare of spring and autumn potatoes (1970)

	Yield					
	Spring			Autumn		
	Low	Mean	High	Low	Mean	High
Yield in tonnes/ ha	15.00	26.25	37.50	11.25	18.75	26.25
Price C£/tonne	25.000	25.000	25.000	20.000	20.000	20.000
GROSS REVENUE	375.000	626.250	937.500	225.000	375.000	525.000
VARIABLE COSTS						
(i) Seed	70.312	117.180	164.062	33.750	56.250	78.750
(ii) Fertilizer	23.925	26.025	28.125	23.925	26.025	28.125
(iii) Irrigation	80.000	80.000	80.000	140.000	140.000	140.000
(iv) Power and Irrigation	36.397	36.397	36.397	32.392	32.392	32.392
(v) Seasonal Labour	22.500	45.000	67.500	18.000	31.500	45.000
(vi) Misc.	22.500	22.500	22.500	15.000	15.000	15.000
TOTAL V.C.	255.634	327.102	398.584	263.067	301.167	339.267
GROSS PROFIT	119.366	329.148	538.916	-38.067	73.833	185.733
FIXED COSTS						
(i) Permanent Labour	61.650	61.650	61.650	74.812	74.812	74.812
(ii) Rent	22.500	22.500	22.500	22.500	22.500	22.500
TOTAL F.C.	84.150	84.150	84.150	97.312	97.312	97.312
V.C. + F.C.	339.784	411.252	482.734	360.379	398.479	436.579
NET PROFIT	35.216	244.998	454.766	-135.379	-23.479	88.421

Data - modified from Papachristodoulou (1970)

Fig. 3:6 Mean quantity & price of potatoes & tomatoes delivered to the main municipal markets in Cyprus from 1966-70.



(Data courtesy of Min. of Finance)

that date tomato cultivation has increased, and in 1969 22,000 tonnes were harvested. Of these only 33 tonnes were exported indicating a marked rise in domestic consumption. Price fluctuations were large and seasonal, offering strong incentives for early harvests. During the months of S. littoralis larval infestations on tomatoes (August-October), tomato prices were at their lowest and control measures were not usually justified.

3.(5) Other crops

The incidence and severity of S. littoralis attack on beans, artichokes or other irrigated crops in the seasons covered by the project appeared to be extremely low. While it is possible that some of these crops may sustain economic damage in 'bad armyworm years', no data on damage were collected by the author. They are therefore excluded from further consideration.

SUMMARY - CHAPTER 3

The production, marketing and consumption of lucerne in Cyprus is described for two types of lucerne farmer: those cultivating lucerne extensively as a cash crop (type 1), and those cultivating lucerne on a small scale, usually as a zero grazing crop for their domestic livestock (type 2).

The growth form and yield of lucerne is estimated and an assessment made of the effect of differential cropping regimes on yield. The results of a chemical nutrient analysis of the leaves and stems of lucerne tillers are given. These indicate that the leaves (that part consumed by armyworm larvae) were twice as rich in protein on a weight for weight basis as the stems, however, the overall energy value of stems and leaves did not differ significantly.

A costs and returns table for types 1 and 2 lucerne farmers is presented, and it is concluded that the profitability to both types of grower at average production compares favourably with the returns from other irrigated vegetable crops.

A final section describes the production, marketing and returns from spring and autumn potatoes and indicates the low profitability of the autumn crop.

CHAPTER 3 - REFERENCES

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CHAPTER 4

A 'commercial screening' of the Cyprus late potato and lucerne crops, and an examination of their possible economic competitors

4.(1) Introduction

It is suggested in Chapter 1 that it may be prudent to examine the commercial security of a crop to which pest control research resources are to be allocated. Such preliminary analysis is justified, since a major proportion of the research effort in most pest problems yields highly specific information about one particular pest/crop system, and investors look for an increase in crop yields (or a lower crop product cost function) to recover their costs. If the crop is becoming increasingly unattractive to growers,[1] it is pertinent to ask what will the long run production level be, and will there be an emergence of substitute or alternative crops?

The static theory of supply suggests that crop products will be produced at the desired quantities by the cheapest methods (with a given state of technology). Any random departures from this position will result in price changes which exert pressure to restore supply to this 'equilibrium level'. Consequently, the normal situation in

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[1] It is of course possible that a pest problem is the major factor affecting the farmer's decision to discontinue cultivation. In this case, a pest control innovation may cause a crop to be reinstated. Examples of pests having this degree of impact are coffee rust (Hemileia vastatrix) which prevented the continuation of coffee growing in Ceylon in the 1870's

agriculture, for a given crop, is an annual oscillation in supply (modified by weather, pests etc.) resulting in alternate years of small surplus and shortage.

However, the equilibrium supply position frequently changes. This may result from a move downwards in the crop product cost function, due to a successful innovation, or by a change in demand. Changes in demand may be a result of an increase or decrease in per capita real incomes, or income distribution. Demand also responds to prevailing taste or fashion and to the introduction of substitute or complementary goods. The speed with which the economic system adjusts to changes in the equilibrium supply position will depend on a number of factors. Included in these are the size of the change, the state of knowledge concerning the shift, and the supply lag.[1]

A general characteristic of agriculture in less developed countries is the poor state of farm book-keeping. Farm accounts should contain a number of imputed items, such as permanent labour, land rent or water use; in practice farmers rarely include them. Furthermore, crop products are frequently exchanged or consumed at home and therefore farmers may very often have a poor idea of the profitability of a particular crop. A combination of these factors causes the system to respond sluggishly and imperfectly to shifts in the equilibrium supply position.

In this situation, it is to be expected that an instantaneous picture of the economy would reveal that supernormal profits were being made

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[1] Defined as "the gap between a change in the desire to produce goods and a change in their actual production" Lipsey (1967).

by pioneer farmers exploiting new techniques, or responding to a positive change in demand, and similarly, a large number of farmers were continuing to cultivate some crops that were in a situation of falling demand, and thus realizing below normal profits. Such market failure may result in legislation for or against a particular crop. It would therefore be reasonable to strutinize pest host crops before beginning any control work, and furthermore, the agricultural planner may well look within the existing crop range for emergent alternative crops.

4.(2) The late potato crop in Cyprus

Chapter 3 gives a summary of the cultivation methods, export and home consumption of the Cyprus potato crops. In section 3.(3) of that chapter, a cost and returns table is given for each crop at 1970 prices (Table 3:5).

Table 3:5 indicates that whereas spring potatoes demonstrated a good return (for average yielding plots: C£245/ha), autumn potatoes were unprofitable at average production (-C£23/ha). Yield trials in experimental plots in Cyprus, indicated that the yields given for the commercial autumn crop plots in Table 3:5 were rather lower than might actually be the case (Green, pers. comm.), but there is no doubt that autumn potatoes were not a profitable crop in Cyprus. Even when the highest published yield figures were compared with average yields of other vegetables, the returns of this crop in C£/unit area, C£/labour hour, and C£/m^3 of irrigation water are much lower than other common vegetable crops (Table 4:1).

return per donum[1], per m.^{3} of irrigation water and per labour hour

Vegetable Crop	Return/Donum		Return/m.^{3} Water		Return/Labour Hour	
	C£	Order of Profitability	C£	Order of Profitability	C£	Order of Profitability
Potatoes						
Spring	32.69	13	0.097	5	0.496	6
Autumn	12.40	20	0.016	20	0.121	22
Carrots	49.99	10	0.130	3	0.375	11
Tomatoes	-5.23	22	0.009	22	0.122	21
Cucumbers	24.87	16	0.038	17	0.273	15
Squashes	36.56	12	0.050	12	0.328	14
Water Melons	32.21	14	0.044	15	0.458	9
Melons	53.44	9	0.065	10	0.716	1
Peppers	57.90	6	0.056	11	0.382	10
Egg Plants	54.90	8	0.050	13	0.342	12
Okra	91.39	3	0.085	7	0.577	4
Cabbages	74.79	4	0.148	2	0.600	3
Cauliflowers	59.79	5	0.120	4	0.506	5
Celery	16.33	19	0.027	19	0.197	18
Haricot Beans)	21.87	18	0.043	16	0.226	17
Broad Beans) Green	3.39	21	0.015	21	0.153	20
Peas)	24.19	17	0.074	8	0.266	16
Artichokes.	55.59	7	0.097	6	0.469	8
Asparagus	43.62	11	0.046	14	0.337	13
Kolocassi	158.03	1	0.073	9	0.486	7
Onions	125.91	2	0.183	1	0.705	2
Strawberries	30.60	15	0.033	18	0.177	19

Modifed from data in: Papachristodoulou (1970)

[1] donum = 0.134 hectares

It seems valid to ask why autumn crop potatoes were still being grown in 1973 after their unprofitability has been clearly demonstrated? A possible explanation might be that late potatoes were mainly grown on the same land as spring crop potatoes. This was the S.E. tip of the island which had suitable soils and an irrigation water supply. Farmers in these areas were therefore equipped to grow potatoes, and had a great deal of experience in cultivating, harvesting and marketing their crop. Furthermore, there appeared to be a positive net return in cultivating under these circumstances. It is not likely that all the land given over to late potatoes could have been utilized by extending any of the currently grown vegetable crops, although a decrease in late potatoes would certainly have been associated with an increase in some of these. A more realistic question to pose is therefore: did the growing of late potatoes by spring potato farmers add more to their revenue than their costs? This question assumes a commitment to spring potato growing and introduces the possibility of farmers being able to ignore some of the costs in Table 3:5. If it is further assumed that for most farmers the alternative to late potatoes would involve at least some fields being left fallow in the autumn, then items such as own labour and rent cease to have an opportunity cost.[1] Thus, by extracting the fixed cost components (rent and permanent labour), the 'profitability' of the late crop, at average production is increased to C£73.83/ha./yr., providing a positive incentive to these spring crop farmers to continue late potato production. It is emphasized that this incentive for late potato growing only exists for farmers growing an early crop of some sort, which has a sufficient return to

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[1] Assuming farmers would not seek employment off their farms during this time.

offset some, or all of the annual fixed costs of resources common to it and the late potato crop. This precondition largely precludes the possibility of the emergence of an extensive late potato growing area in any other locality on the island (given the present cost and returns structure).

However, there is an argument for restricting late potato cultivation which may justify government intervention. This is the uneconomic use of irrigation water by the crop. Both the spring and the late crop relied on the irrigation water supplied from the aquifers in the S.E. tip of the island (Fig. 2:1, section 2.(3)(a)). For a number of years groundwater extraction from this aquifer has exceeded supply. Government attempts to slow down the exploitation rate by restricting the number of bore-holes has done little to prevent the continuing deterioration of the groundwater sources. Spring crop potatoes gave five times the return/m^3 of this water compared to late crop potatoes. In addition, the bulk of the spring crop was exported generating valuable foreign exchange (section 2.(2)). Since there appeared to be no economically viable alternative to locally pumped water for irrigation purposes (2.(3))a)) the government would have naturally preferred to see this limited water supply in the S.E. potato areas rationally exploited to produce more future harvest of spring crop potatoes, at the expense of a large part of the present autumn crop. Although the farmers were aware of the irrigation water situation, they could not collectively restrict their use of water. Consequently, each farmer maximized his own usage by growing a spring crop and an autumn crop.

Any campaign to encourage farmers to abandon late potatoes and use some of the released land to grow the more profitable autumn vegetable crops illustrated in Table 4:1, or legislation to conserve the aquifer for the spring crop, would have to be based on some assumptions about the elasticity of demand for potatoes and any of the possible substitute crops. Unfortunately figures for these elasticities were not available, and a meaningful estimate of them was outside the scope of this study. However, a brief examination of the characteristics of the crop and some recent economic trends on the island, indicates the possible future demand and market responses to change.

Potatoes are a nutritious and palatable staple food, which provided the main carbohydrate source in most Cypriot households. It is to be expected that the demand for potatoes was affected by the availability of other carbohydrate foods such as sweet potato, kolocassi, aubergines, bread, rice, and to a lesser extent, by other vegetables such as squashes, beans, onions and peppers. The lower the price of the substitude foods in relation to the price of potatoes, the greater would be any substitution effect on demand. At present, any attempt to increase the profitability of the crop by raising the price would most probably demonstrate a highly inelastic demand situation as consumers substitute their diet with other carbohydrates.

Potatoes are usually considered to be inferior goods. An increase in real incomes on the island might therefore be associated with a fall in demand for potatoes.[1] In fact there has been a rise of over 5%/yr. in real incomes in Cyprus since 1967 (and prior to July 1974). This had been associated with a 30% rise in the domestic production of sheep, goats and pigs (table 4:2) and also an increase in imported food, including meat, by 60% over this period. Curiously, this substantial rise in consumption of quality food products had not been associated with a marked reduction in potato consumption, which had remained around 20,000 tonnes/yr. It is possible that the substantial increase in the tourist traffic had masked some real changes in patterns of domestic food consumption.

Since the infrastructure for the production of the much larger spring crop of potatoes was established, any response of increase in quantity demanded could not be exploited by economies of scale. Lowering the price of late crop potatoes would therefore erode profit margins still further.

Any government intervention in the matter of a rational exploitation of the aquifer, would require complex decisions embracing social, political, as well as technological economic considerations. In the short term, late potatoes will probably be encouraged as a temporary expedient in the refugee problem. However, in the long run some government intervention is anticipated to safeguard water supplies for Cyprus' second largest export: the spring crop. In anticipation of further study, and possible legislative action

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[1] Real incomes in Cyprus prior to July 1974, were quite high and the upward sloping demand curve for inferior goods as apparently observed by Giffen in the Irish potato market during the nineteenth century, is not likely to occur.

concerning the late crop, we argue that the expenditure of pest control research resources in order to collect specific information on the protection of this crop is not at present justified.[1]

4.(3) The lucerne crop and alternative fodders

It is generally true that dairy or meat products derived from different, but suitable, livestock foodstuffs, are indistinguishable to the consumer. The demand for these products will therefore be unaffected by the production process. Feeds are livestock production factors and are largely substituted for one another in response to price changes, or in the case of home grown fodders and forages, changes in production costs. In determining the 'commercial security' of lucerne in its present role as a fodder and forage crop in the Cypriot livestock industry, it is necessary to attempt to predict the impact of any trends in that industry on the importance of lucerne growing. It is also necessary to examine the possibility of an alternative role for the crop, such as industrial seed production, however, it is important to note that such a change may result in a modified cultivation practice which in turn may change the complexion of the pest problem (Fig. 1:1).

In Cyprus, the livestock industry has grown in response to an increase in domestic demand (table 4:2). However, in spite of this rise in production, imports of meat have also risen (see above: 4.(2)).

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[1] Bearing in mind that S. littoralis do not occur at the time when the spring crop is growing (1.(1)).

TABLE 4:2 Livestock production in Cyprus (1967-1971)

Products	Unit	1967	1968	1969	1970	1971
Milk (sheep, goat and dairy cattle)	tons	50,000	55,000	60,000	64,000	74,600
Eggs	1,000 doz	8,000	9,000	9,000	9,500	9,600
Wool	tons	500	560	680	693	738
Pork	tons	7,500	8,000	11,000	12,000	12,500
Poultry meat	tons	5,500	6,750	9,000	9,200	9,850
Sheep and goat meat	tons	5,450	6,050	6,750	7,830	8,650
Beef and veal	tons	2,700	2,800	2,900	3,000	3,200

data: Min. of Finance (1971)

Fundamentally, there are two sectors to the livestock industry in Cyprus, a predominant small ruminant (sheep and goats) sector, which is mainly under the control of peasant farmers and non-land owning shepherds, and a growing intensive livestock unit concentrating on the production of pork, poultry, and increasingly, milk and milk products from foreign cattle breeds (notably the Friesian).

Traditionally, small ruminants have been reared on natural vegetation (rough grazing) from the early winter to the end of April, green vicos, lucerne, and other legumes (notably favetta) during April and May, and field crops stubble from May to September, with hand feeding of barley, legumes (including lucerne), seeds and straw during the late summer until early winter (Obradovic, 1965). However, the move towards intensive livestock production has increased the need for a secure nutritional base to the industry (Abu-Sharr, 1965), and in particular the replacement of fallow grazing by forage. This has been recognized, and there has been a call for the "introduction of new industrial forage crops resistant to weeds and insect pests, as well as the hot and dry, and sometimes cold and wet Cypriot weather" (Obradovic, 1965). It might be added that breeds such as the Friesian are high yielding animals and require commensurate feeding; the problem is not merely maintaining supplies of currently available feedstuffs, but increasing their quality.

In Cyprus, concentrate feeds are prepared on the island under the Government Co-operative Bank scheme from home grown produce such as barley grain and carobs. However, there is a limited supply of these concentrates and in years when the winter rains fail (as in 1973) prices rise, causing the price of lucerne and other partial substitutes to rise also. Apart from the risk of failure of supply, there are two further undesirable aspects of basing the future livestock industry on home grown concentrates, these are firstly, that the concentrates produced in Cyprus are high energy foods, but are deficient in proteins, consequently, high value protein based feedstuffs are imported to balance the concentrate rations, secondly, the home produced concentrate constituents have a considerable export earning potential. For instance, since 1966 carobs have been Cyprus' fifth agricultural export, generating an annual average of C£1,033,000 of foreign exchange. Similarly, Cyprus has exported an average of C£134,000 worth of barley grain each year since 1966 (Min. of Finance, 1972). A well-managed irrigated fodder/forage crop industry which met the requirements of the Cypriot livestock would increase the efficiency and stability of livestock industry and, in a number of ways, would help to alleviate the island's balance of payments problem (2.(2)). It would also be consistent with trends in other developing countries (Mather, 1963).

The major barrier to the development of such a fodder/forage base has been the high opportunity cost of irrigable land (Obradovic, 1965). To date, vegetable cash crops have appeared more attractive to farmers than forage/fodder production. However, in 3.(2)(f) it is shown that the return from lucerne (in 1972, a 'normal' year) was competitive with many of the commonly grown cash crops, and farmers may well adopt irrigated fodder/forage production more readily in the future.

Having established that an irrigated fodder/forage base to the livestock industry is desirable, and may be economically viable, it is necessary to consider whether lucerne production will develop further to occupy this role, or dwindle as farmers adopt alternative crops.

It is not the intention of this section to review the entire range of possible fodder/forage crops and their potential role as the basis of the Cypriot livestock industry, since the Ministry of Agriculture and Natural Resources have a considerable research effort in this direction. However, some discussion is offered on the performance of lucerne compared to other irrigated fodder/forage crops. This discussion is centred on the crop yields, and ultimately the livestock yields, derived from a unit of irrigation water. This single factor analysis may be justified as a preliminary screening of comparative crop productivity, in a situation such as Cyprus, where irrigation water is so scarce and in demand.[1] However, it is emphasized that a full comparative analysis would include the different requirements of the crops and their efficiency of utilization of other input factors such as labour, capital and such items as fertilizer and plant protection chemicals.

Preliminary trials with other irrigated fodders in 1972 indicated that maize (Zea mays), sorghum and sorghum derived hybrids were competitive on an annual yield per unit area basis with lucerne, although they only occupied the ground for half the year (table 4:3). Unfortunately, the irrigation regime on these plots was generous and did not provide information on their performance under conditions of water stress. However, earlier work (Abu-Shar, 1965) showed that sorghum, sudan grass and maize produced more than lucerne at certain times of the year.

A similar situation of hot climate and limited irrigation resources is experienced by Israel's dairy industry. Considerably more work has been done in this country than in Cyprus, towards establishing a low water budget livestock industry. Although it would be unwise to extrapolate directly from Israel to the Cypriot situation, the similarity of physical conditions indicates that Cyprus might benefit from a closer scrutiny of Israel's experience in this field.

Table 4:4 is a summary of yields and irrigation requirements of some of the main fodder crops grown in Israel in 1969. It is important to notice from this table the similarity of yield and

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[1] The value of good quality irrigable land may be five times as high as fertile but dry land (Papachristodoulou, 1970).

	Cropping date	Mean yield tonne/ha.	Totals tonne/ha.	Total dry wts. tonne/ha.	Water utilization m^3/ha.	No. of croppings	Days growth per year
HYBRID MAIZE (Spaced) (Neveh Yaar 170)	13.7	66.51					
	21.9	56.35	122.86	19.58	10,680	2	150
HYBRID SORGHUM (6078)	18.7	65.36					
	21.9	55.05	120.41	26.27	10,680	2	150
VIDAN (697) (Sorghum x Sudan grass)	16.6	22.93					
	13.7	20.32					
	23.8	22.44					
	14.10	8.37	74.06	11.75	16,000	4	180
SWEET SIOUX (Sorghum x Sudan grass)	17.6	29.56					
	13.7	23.34					
	29.8	30.74					
	14.10	8.85	92.50	17.95	16,000	4	180
SUDAN GRASS (Piper)	26.6	24.11					
	9.8	26.07					
	27.9	14.34	64.54	16.48	13,350	3	160
LUCERNE			72.27	19.17	11,200	9	360

Sowing date: 27.4

Sowing dates: maize: 27.4, 20.7

All data except lucerne yields, from Mr. A. Hadjichristodoulou, A.R.I. Cyprus irrigation requirements between lucerne pastures in Israel and in Cyprus. This is some indication that the agronomic conditions in the two countries are similar. The crops giving the highest return per unit of irrigation water were: Maize, Rhodes grass (*Chloris gayana*) and fodder beets (*Beta vulgaris*). The yield of dense maize under this restricted irrigation regime showed the highest return per unit of irrigation water. The crop giving the lowest return per unit area per day, and also the lowest return on irrigation water was lucerne. No information was available on the fodder sorghum varieties although it was stated (Lesham, pers. comm.) that these were probably higher yielding than maize in droughty conditions.

TABLE 4:4 Yield and water requirements of some Israeli fodder crops

Crop		Dry Wt Yield Tonne/ha.	Water Usage m^3/ha.	Days Growth per year	Dry Wt Yield per m^3 water
Summer	(*Maize (Dense 2 crops)	32	6,000	120	5.3
	(*Maize (Spaced 1 crop)	10	4,000	80	2.5
Perennial	(Rhodes Grass	25	9,000	365	2.7
	(Lucerne	18	10,000	365	1.8
Winter	(Beets	27	6,000	240	4.5
	(Berseem	13	6,500	210	2.0
	(Rye Grass	13	6,500	180	2.0

*Neveh Yaar variety

Data: courtesy Lesham, Bet Dagan, Israel.

If it is assumed that these results could be closely reproduced in Cyprus, it may be concluded that lucerne is not the most efficient converter of irrigation water into the products of photosynthesis. However, before its replacement as the main fodder crop base to the livestock industry is recommended, it is necessary to establish further that it is not the most efficient converter of irrigation water into milk, meat, work or any of the other desired livestock products. This will depend not only on the amount of photosynthetic products produced, but also on their quality as feeds.

Feeds can be classified according to palatability (how much of it an animal can be induced to consume), and also by nutritious qualities, that is the quantity, digestibility and composition of its nutrients. All of these factors can change markedly within a crop depending on its maturity, cultivation regime or form of presentation (conserved or unconserved).

The two major variables of nutrient composition are the amounts of energy compounds available to the animal (carbohydrates and fats), and the amount of available proteins. Generally, energy is required for maintenance and work, and protein for production. It is not necessary to present all the data on the nutrient composition of the crops mentioned above as this is published elsewhere (N.A.S., 1971). However, the energy and protein content of the fodders are given in Table 4:5. These data indicate that the energy yields of all the crops fell into a fairly narrow range, the majority between

TABLE 4:5 Basic nutritional qualities of some fodder crops

Crop	Protein Percentage Dry Weight	Digestibility by Cattle	
		Digestible Protein Percentage Dry Weight	Digestible Energy M.cals/kg. Dry Weight
LUCERNE[1]	22.00*	16.50	2.58
MAIZE (Densely grown, cut at bloom)	12.29*	8.60	2.97
SORGHUM (Densely grown, cut at milk stage)	7.50*	3.0	2.48
SUDAN GRASS (Piper)	10.09*	6.00	3.01
SUDAN GRASS (Sweet Sioux)	13.31*	7.20	2.48
RHODES GRASS (Mature Hay)	5.90	2.00	2.61
FODDER BEETS (Roots)	12.30	7.30	3.54
RYE GRASS	8.10	4.10	2.21
SORGHUM (Ensiled with Molasses)	10.50	5.80	2.20
SUDAN GRASS (Ensiled with Molasses)	13.31	7.2	2.48

*Own Data; the rest reproduced from N.A.S., 1971

[1] Berseem, a form of annual lucerne, is approximately equal to lucerne in all categories.

2-3 M.cals/kg. dry weight of fodder. Those crops contributing the greatest energy yield per unit of irrigation water were beets, maize and Rhodes grass. Lucerne gave a low energy return on water, but produced nearly twice as much protein per unit dry weight as the next best protein crop: maize. However, reference to Table 4:4 indicates that yields of protein per unit volume of water were as high in maize as they were in lucerne.

Lucerne fed fresh, as hay, or combined in concentrates in meal form, is an extremely palatable food to cattle, sheep, goats and pigs. Correspondingly, voluntary intake (V.I.) of lucerne, conserved or unconserved, is very high. Maize on the other hand, is woody, and when fed either fresh or sun dried, the V.I. is found to be considerably lower on a weight for weight basis than lucerne. The V.I. of maize can be increased by chopping, and in practice it is usually presented chopped and green or in a silage form. However, even in these prepared states, it is extremely difficult to raise V.I. levels to establish the same protein ration as can be achieved by _ad lib._ lucerne hay feeding. Maize is therefore _ipso facto_ a second-rate protein source.

Sorghum and sudan grasses, grown under droughty conditions, contain the cyanogenic glycoside 'dhurrin', which when hydrolized yields hydrogen cyanide. 0.5g. of this compound is sufficient to cause lethal acute toxicity in cattle. These feeds are only completely safe as fodders after hydrolysis by conservation methods such as ensiling. Due to its high water content the V.I. of silage tends to be lower than hay when estimated on a dry weight basis.

Fodder beets, like maize, produce as much protein per unit of irrigation water as lucerne. However, again there are problems of inducing sufficient intake to realize a high level of protein in the diet, and unless they are crushed, dried and fed as cake, they are inferior to lucerne hay.

Rhodes grass is extensively used as a forage pasture and hay fodder crop in Israel. This crop produces nearly twice the digestible energy per unit of irrigation water as lucerne, but is extremely poor in protein. However, it is to be expected that the V.I. on a weight for weight basis for Rhodes grass hay is not substantially below lucerne hay, but again the protein ration will be lower since more Rhodes grass hay is needed for a given unit of protein intake.

It appears that for livestock, such as dairy cattle, that require both maintenance and production, the V.I. of these possible alternative fodder crops would not be sufficient to meet their production requirements. A change from lucerne to another fodder would therefore almost certainly be associated with the need for protein supplementation. This would be a decisive factor weighing against such a scheme if it were not for the potential use of non-protein nitrogen (N.P.N.) for ruminant feeding.

When a N.P.N. source, such as urea, is added to a feed and ingested by ruminants, it is rapidly dissolved and hydrolysed to ammonia by bacterial urease. This ammonia can be utilized by the symbiotic bacteria for the synthesis of amino-acids required for their growth. When ammonia is produced too rapidly in the rumen, or its concentration becomes too high, appreciable amounts are absorbed directly into the bloodstream, reconverted to urea in the liver and excreted as urine through the kidneys. However, it has been discovered that natural (i.e. feedstuffs) protein sources are utilized before any supplemented N.P.N., and urea will be wasted to the extent that the feed contains enough protein to meet the needs of the animal (Loosli and McDonald, 1968).

The addition of starch, molasses, or other suitable energy sources with the N.P.N. supplemented feed, provides energy for the micro-organisms to quickly convert and utilize the urea. Such energy supplementation of fodder hays and silages enables livestock owners to increase the N.P.N. ration without danger of ammonia toxicity. There have been many applications of this now standard technique including the N.P.N. supplementation of low quality forages (Altona _et al._,1960), and it has been successfully used with sorghum silage fed to lactating dairy cattle (Ryley, 1961).

There appears therefore to be a _prima facie_ case for replacing a substantial part of the lucerne crop with other high energy/low protein forages that require less irrigation water. In Israel, lucerne is not used as a dairy fodder crop for reasons of water economy. It is grown in areas where irrigation water is more plentiful, and over 80% is harvested for a cash crop as meal. This meal is used as a feed additive in concentrates for the pig and broiler industry. The dairy industry in Israel is largely based on perennial Rhodes grass pastures. On some farms, annual fodder crops such as winter berseem, fed as hay, alternating with two summer maize harvests provide the main fodder base. Concentrates with N.P.N. additives are used throughout the year to supplement this diet.

We conclude that such a system would be advantageous to Cyprus only after considerable land reform and integration of livestock production. In the medium term, differences in the structure of the industry in Cyprus and in Israel will make a direct change away from lucerne fodder cultivation in Cyprus an unlikely event. In Israel, much of the livestock production is controlled by the Kibbutzim. These organizations have sufficient capital and production capacity to invest in maize and sorghum stem cutting machines, beet crushers, silage towers, hot air driers and other machinery required to handle these fodder crops. They also have a directed labour force that can harvest quickly such labour intensive crops as fodder beets. The large herds on the kibbutz farms make small savings per animal in feeding costs attractive. In Cyprus the pattern of land ownership (2.(3)(b)), makes for small scale production and fragmented plots. Peasant farmers gain a tremendous utility from lucerne as a perennial source of a nearly perfectly balanced diet for their sheep and goats. The crop requires little attention and no special treatment after harvesting. Indeed, many town dwelling Cypriots who have inherited plots of irrigable land through the dowry system grow lucerne, and keep a few animals for just these reasons. The future possibility of using more Rhodes grass with protein supplementation cannot be ruled out, but at the moment at least, the convenience of type 2 lucerne production as a basis for the support of domestic, particularly small ruminant, livestock in the dry season, is a decisive factor favouring the continued cultivation of lucerne on the island.

For the larger intensively reared livestock in Cyprus, lucerne will continue to be an important fodder base until such times as the legislation banning the use of N.P.N. feed supplementation is repealed. If this occurred, it would introduce an incentive for an alternative graminaceous fodder base to the industry, which may result in some reduction in type 1 lucerne growing. However, as is shown in Table 2:4 there is still an overall surplus of irrigation water on the island and the exploitation of these under-utilized sources may see the development of an important lucerne meal, or seed industry, similar to that in Israel.

In any event, it is most probable that lucerne will play a major part in Cypriot agriculture in the immediate future, and might become increasingly important in the longer term. Thus, the commercial security of lucerne is less in doubt than that of the late potato crop.

4.(4) Conclusion

In accordance with arguments advanced in this chapter the remainder of the work in this study is devoted to examining the effects of S. littoralis infestations on the island's lucerne crop.

SUMMARY - CHAPTER 4

The 'commercial security' of the autumn potato and perennial lucerne crops is examined in order to establish their long run viability and consequently their claim as candidates for pest control research expenditure.

It is suggested that the autumn potato crop is not a secure crop in Cyprus due to its low profitability and uneconomic use of scarce irrigation water. The lucerne crop is examined as the major nutritional base to the livestock industry in Cyprus and found to be a high yielding and convenient fodder crop popular with dairy farmers. It is concluded that of the two, only lucerne has a probable long term viability and consequently further work in this study is confined to that crop.

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CHAPTER 5

A description of S. littoralis, its pest status on irrigated crops in Cyprus and some biological and ecological factors important for its control

5.(1) Introduction

This chapter deals with the taxonomy, world distribution, life cycle and behaviour of S. littoralis. A larval population survey and observations of actual infestations are described. The results of some feeding and growth studies are presented and finally, estimates of the natural mortality of the larvae are given. Much of the quantitative data is utilized in the infestation simulation described in Chapter 6.

5.(2) Spodoptera littoralis taxonomy, distribution and life history

S. littoralis, in common with the majority of the important Lepidopterous pests in Cyprus, belongs to the family: Noctuidae. The general characteristics of moths of this family are broad tapering bodies and wide wings, these are usually dark brown or grey with markings peculiar to each species. The Noctuidae includes some of the most destructive pests in the world, including S. littoralis (the Egyptian cotton leaf worm),[1] Heliothus armigera (the cotton boll worm), Plusia ni (the cabbage looper), Spodoptera exigua (the lesser army worm), Spodoptera exempta (the African armyworm), and Busseola fusca (the E. African stem borer). The two commonest Noctuid pests

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[1] Referred to in this study as armyworms.

in Cyprus are *S. littoralis* and *S. exigua*, although other species such as *Heliothus peltigera*, *H. armigera*, *Agrotis ypsilon*, *Plusia ni* and *Plusia gamma* are also well represented.

S. littoralis has a wide occasional distribution. Specimens have been collected in India (Dewhurst, pers. comm.), and in the United Kingdom, where it is an infrequent pest of greenhouse chrysanthemums. The species' characteristic range is the Mediterranean coast, S.W. Africa, E. Africa and eastwards to Iran. Early literature refers to the pest as *Prodenia litura*, which was thought to extend as a single species eastwards to Japan. However, morphological differences detected in the genitalia (Viette, 1963),and larval head capsule (Mochida, 1972),indicated two separate species: the westerly *Spodoptera littoralis*, and the easterly *Spodoptera litura*.

The moths are nocturnal in habit, hiding by day and actively flying for food, mating and ovipositing at night. Females have been observed to oviposit on almost any broad leafed plant found within their range, but they have marked preferences which appear to vary with location. These preferences may be the result of local adaptation to the prevailing host plant (Vermes, pers. comm.) with gravid moths orientating to the host plant on which they were reared. This has given rise to a confusing number of regional names for *S. littoralis*. For instance, in Egypt it is the cotton leaf worm, in Malaŵi the tobacco caterpillar, in Rhodesia the tomato caterpillar and in Mauritius the bean armyworm. In Cyprus all of the host crops to which these regional names refer are in fact grown, but of those mentioned *S. littoralis* appears to be only a pest of beans and tomatoes.

Legend for fig. 5:1

(a) Male *S. littoralis* moth (x1½)

(b) Female *S. littoralis* moth (x1½)

(c) Two *S. littoralis* eggs (x50)

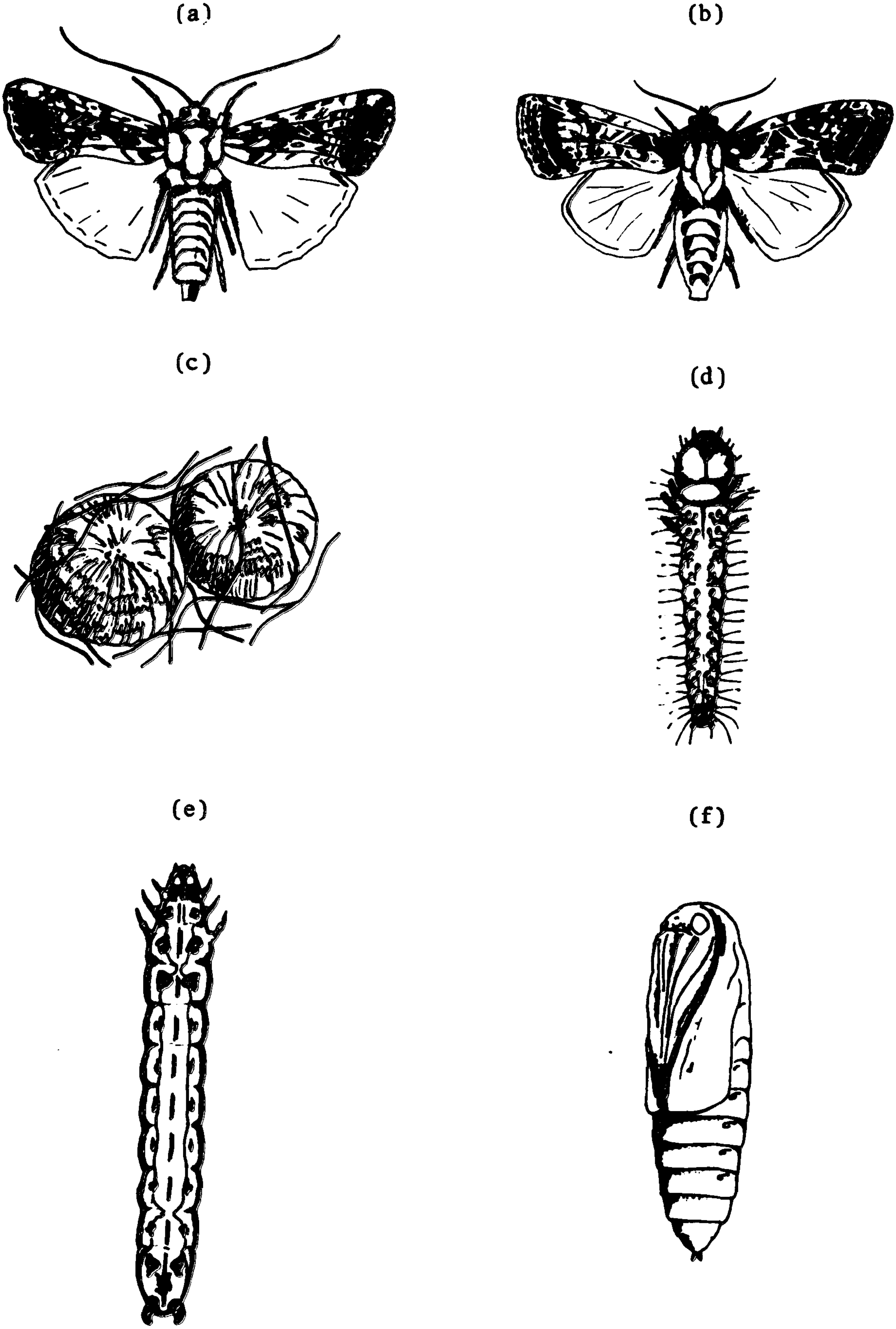
(d) *S. littoralis* first instar stage (x35)

(e) *S. littoralis* sixth instar stage (x2)

(f) *S. littoralis* pupa (x3)

(NB. figs. a, b, d, e and f after Bishara (1934),
fig. c from a photograph by the author)

Fig 5:1 Life stages of S. littoralis



The mean number of eggs laid by a single female moth is 1,200 (Bishara, 1934). These are distributed amongst 4-7 egg masses. There is some evidence that moths are attracted to oviposit in freshly irrigated fields (Ibid., p. 314 and Abul-Nasr et al., 1972(a)). However, in situations of heavy egg-laying, egg masses are frequently found on inappropriate sites such as irrigation pipes, tree trunks and walls and fences. The eggs are laid closely together in regular rows up to three layers deep. They are light green or creamy when they are laid, but assume a greyish hue as they develop.

There are six larval instars.[1] These can be identified by six ranges of head capsule width, which in the third and sixth instars are discrete (see Table 5:1). The first instar larvae are small (1-2mm in length). They have a relatively large shiny black head

TABLE 5:1 Head capsule width in S. littoralis larval instars

Instar	Sample Size	Head Capsule Width in mm	Range	St. Dev.
1	42	0.275	0.250 - 0.297	-
2	31	0.441	0.378 - 0.477	-
3	84	0.684	0.408 - 0.882	0.076
4	73	1.170	0.984 - 1.332	0.078
5	76	1.692	1.440 - 1.920	0.118
6	71	2.509	2.244 - 2.739	0.124

data from McKinley (1970).

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[1] Instars are growth stages between each insect moult.

and a translucent white body. The second instar is usually olive green in colour with a characteristic black spot on each side of the first abdominal segment. The third instar is of the same general colour, but has a second pair of dark spots on the last abdominal segment. Later instars generally develop a deeper greyish colouring and display more, but smaller spots and lines, on other segments of the body. The sixth, and final instar may grow up to four centimetres in length before pupation (fig. 5:1).

The first and second instar larvae feed gregariously on a plant leaf at the site of the egg mass. These early instars remain attached to the leaves by threads which help to prevent them from being shaken off the plant by the wind, but which may also have the reverse function of distributing them if they become airborne. Later instars appear to be sensitive to light and temperature. These larvae are generally only found on the apices of the plants after dusk and when the ambient temperature is between 15°C and 26°C. In bright sunshine, fourth, fifth and sixth instar larvae may be found buried in the leaf and stem litter of a lucerne pasture, or buried into the soil in potato fields (Ellis and Veigh, unpublished C.O.P.R. report).

Prepupal sixth instar larvae cease feeding, lose weight and burrow into the ground in preparation for pupation. Newly formed pupae are green with a rosy hue on the abdomen. The abdominal rosy hue deepens and spreads, and the pupae rapidly assumed a characteristic deep reddish colour.

5.(3) Pest status of S. littoralis in Cyprus and some biological and ecological data relevant to its control

5.(3)(a) Assessment of pest status

An initial task in assessing the pest status of S. littoralis in Cyprus was to determine the range of crops attacked and to establish its damage contribution as distinct from other similar pests. A list of cash crop reported damaged by a number of unspecified Noctuid pests (Zyngas, et al., 1964) consisted of: tomatoes, aubergines, peppers, lettuce, celery, spinach, cabbage, cauliflower, onions, garlic, leeks, haricot beans, broad beans, cow peas, artichokes and late potatoes. These authors only estimated the value of crop losses for haricot beans (at C£25,800/yr.) and late potatoes (at C£712,800/yr.). Although there is no comparative data with which to check these figures, it is clear that an estimated loss of C£712,800 for the late potato crop was a gross over-estimate, since the total late crop was valued at below C£500,000/yr.

Communication with crop protection agencies on the island indicated that the crops most affected by these pests were lucerne, tomatoes, beans, artichokes and late potatoes. It was also revealed that the vast majority of the damage occurred as a result of S. littoralis and S. exigua infestations, and suggested that for equal pest populations, the higher consumption demands of S. littoralis caused it to be the more destructive of the two.

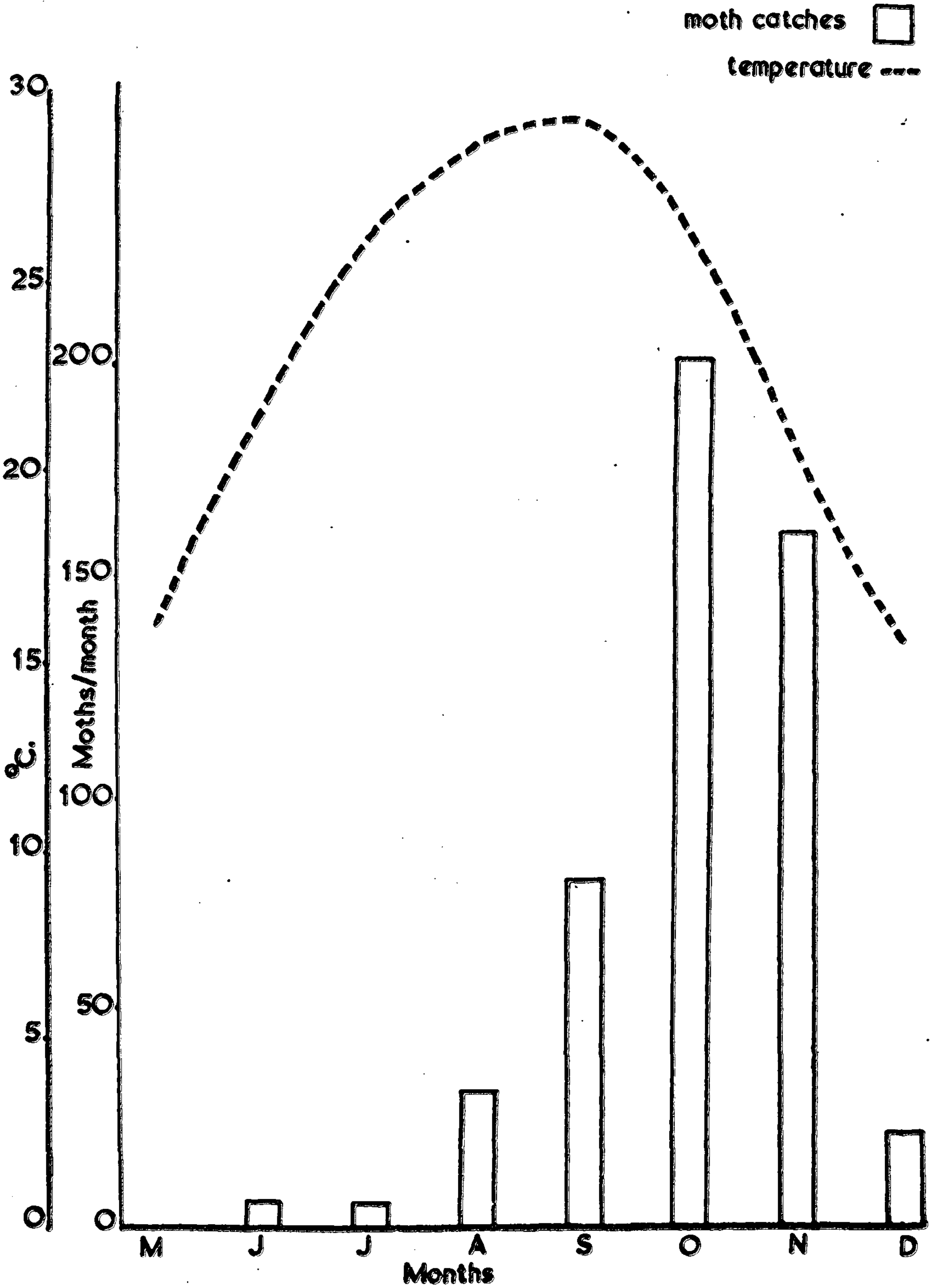
There would appear to be two variables which determine a pest's economic status, namely the frequency and the severity of infestations. Implicit in severity is a measure of the crop damage caused by the infestation and the value of this loss (1.(2)).

S. littoralis infestations occurred during July to November in Cyprus, with a peak of activity in September and October. It is generally thought that the island population increased in response to the warm summer temperatures and decreased to a low 'over-wintering' level in November (Ingram, pers. comm.) when temperatures fall again. Records of moth catches from pheromone traps during 1973, indicated the seasonal rise in the populations and lent support to the notion of population control by temperature (fig. 5:1, data courtesy of Campion, C.O.P.R.). However, this is made less certain by the estimation techniques, since, even assuming a constant efficiency of pheromone trapping with changes in temperature, the possibility of a temperature effect on the insects flight propensity (Johnson, 1969; Dry and Taylor, 1970) was not eliminated.

We attempted to measure the incidence and severity of larval infestations in the peak season (August-October) by a dual survey incorporating a pest damage questionnaire sent to individual producers, and a regular inspection of a number of trial crop sites.

The damage questionnaire was included with the growers questionnaire described in 3:1(2), and reproduced in Appendix 3:2. As stated in

Fig. 5:2 Monthly catches of male *S. littoralis* moths in pheromone traps in Cyprus & mean ambient temperature.



that section the response by the growers was disappointingly low and those questionnaires which were returned appeared to be biased towards farmers who had experienced pest damage. The data was therefore considered too unreliable to be used to assess the normal incidence and severity of pest damage.

The aim of the regular inspection survey was to establish a fairly detailed pest history for a range of insecticide treated and untreated commercial plots in different localities on the island. It was hoped by this method to establish the natural incidence of infestations, to evaluate the effect of insecticide treatment on this incidence, and possibly to identify a number of environmental factors predisposing the crop to attack. A further aim was to measure crop damage so that some empirical relationship might be derived relating crop loss with pest density (with possibly another variable such as larval size).

The sites were all lucerne pastures located in important lucerne growing villages (fig. 5:3). Seven of these sites were composed of two adjacent plots, one treated with insecticide prior to 24.8.72[1] and one untreated. A further two single plot sites were also inspected, one which had been treated and one that had not. These 16 sites were regularly inspected by the author throughout August to September 1972; this covered from two to three pasture harvests, providing data on a total of 43 growth cycles.

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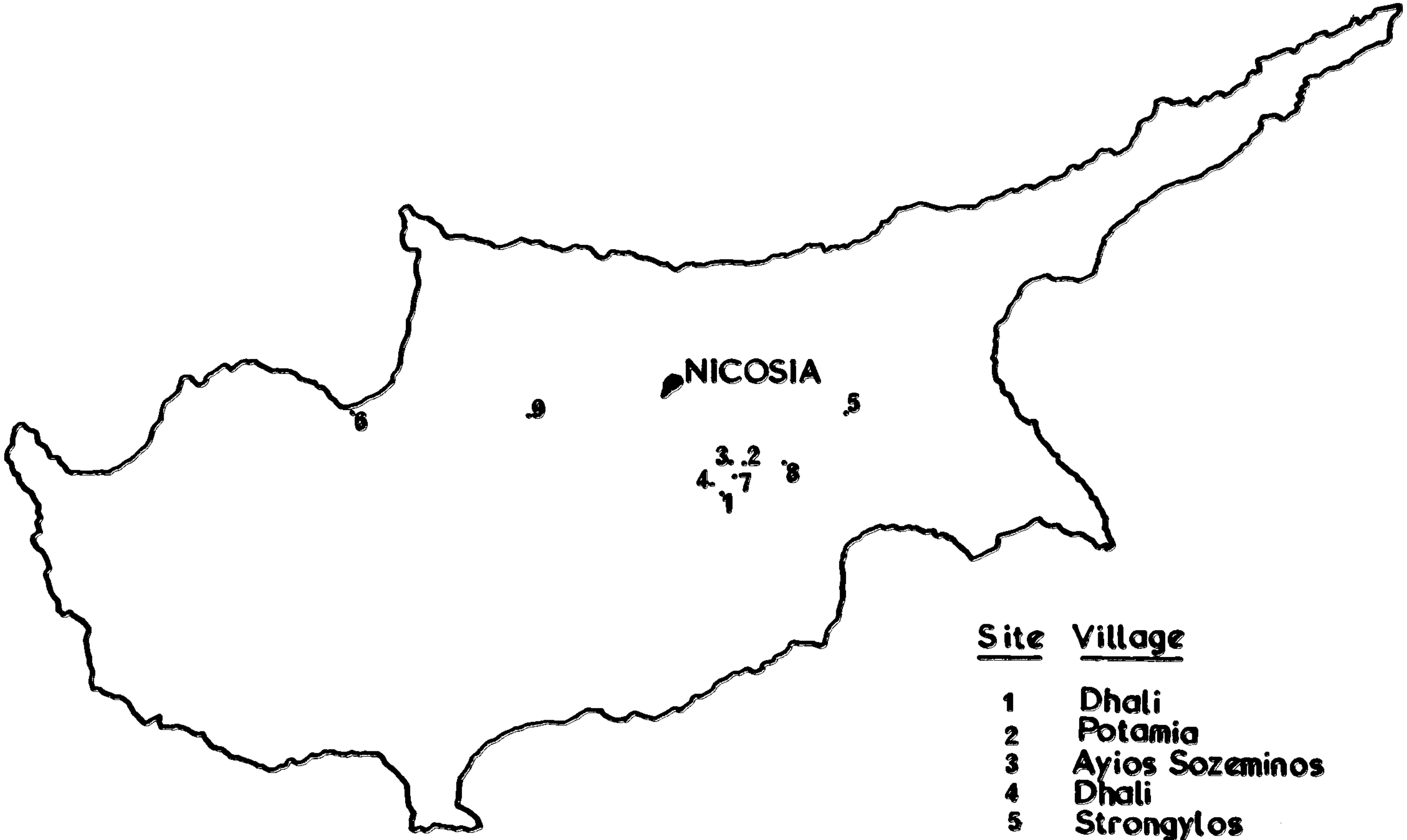
[1] All treated with methamidophos at the recommended rate, see Ch. 7.

Fig. 5:3 Location of the trial inspection sites.



Site	Village
1	Dhali
2	Potamia
3	Ayios Sozeminos
4	Dhali
5	Strongylos
6	Xeros
7	Potamia
8	Athienou
9	Akaki

(i) Methods

The inspection consisted of sweep net sampling and quadrat ground sampling of the pasture for Spodoptera sp. larvae and the adults of their parasitic species, a record of the height of the crop at each visit and an estimate of percentage leaf loss due to pest injury. In addition, a pheromone moth trap was maintained at each site and the catches of male S. littoralis moths were recorded.

The sweep net used for this sampling was of standard construction, consisting of a wire framed muslin bag about 0.3m wide. One sweeping motion with the net covered a length of approximately 1m. of pasture. Hence, three such sweeps were required to sample $1m^2$. of lucerne. $10m^2$. of lucerne were sampled at each site on each occasion by taking three separate 10 stroke sweep samples from different localities in the field. After each sample, the net was inspected and the catches of larvae and parasites were recorded.

A number of authors have pointed out the inadequacy of this method of population estimation when it is used in isolation (e.g. Abul-Nasr and Ali Naguib, 1968; Abul-Nasr et al., 1971). Its limitation is a result of variation in the catching success of sweep nets with such factors as differences in crop height and vertical movement of insects in response to environmental conditions. Therefore, to confirm the sweep counts, quadrat samples were taken. The quadrat used had an area of $0.25m^2$.. It was placed on the ground and the pasture stems contained within the quadrat were shaken into this area. The ground and leaf litter was then thoroughly searched and the total number of larvae were counted. Initially, two quadrat samples were taken, and if there appeared to be a discrepancy between sweep and quadrat estimates, a further eight quadrat samples were made. The quadrat sample larval estimates were considered more reliable than those made from sweeping (Abul-Nasr et al., 1971). Consequently, when these ten samples were taken they were used as a basis for the estimation of the larval population (although of course not of the winged adult parasite population).

The pheromone traps situated at each trial site were of the metal vane type (Turnstall, 1965). They relied on the specific attraction of male S. littoralis moths to caged virgin female moths of the same species, contained within the trap. At each visit, a record was made of the numbers of dead male moths (previous catches), and live male moths (fresh catches), in the trap.

The percentage leaf loss owing to larval injury, was estimated using a field scoring method. Four injury categories were established visually. To give a quantitative expression to these, samples from each of the categories were collected and weighed, and the leaf loss estimated in each (assuming a pre-injury leaf/stem ratio of 1:1, see 3.(2))c). The categories were (a) some injury (estimated at a mean of 20% leaf loss), (b) 'tatty' stems (mean of 30% leaf loss), (c) badly damaged (mean of 65% leaf loss)and (d) stripped (mean of 95% leaf loss).[1] During the pest survey ten stem samples were taken at random from the pasture, and the leaf injury visually

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[1] Consequently, the range of injury varied for each group, this is not an uncommon limitation of visual scoring techniques.

scored for each sample. These ten scores were then converted into an overall mean percentage leaf loss for the plot using the value of the appropriate conversion group (a) - (d). It may be noted that this method was not valid for assessing damage, except in mature pastures, since it did not take into consideration compensating growth by the pasture (see Chapter 6).

(ii) Results

The results of the survey are reproduced in Table A5:1(1)a-c. Statistical examination of the data from those sites with treated and untreated adjacent plots, indicated that no significant differences existed in the incidence and density of any of the pest or parasite species between plots treated with methamidophos and those left untreated. Even when the data from the first month after treatment was analysed independently, no apparent effect on the populations due to insecticide treatments could be detected. In view of this result, all data from both treated and untreated plots, including the single sites (8 and 9) were grouped (Table 5:2).

TABLE 5:2 The mean density of Noctuid larvae and some of their parasites (adults) in nine lucerne pasture sites, and the average monthly *S. littoralis* male moth catches for August - October 1972

Month 1972	Larvae/m^2				Parasites/ m^2	Male Moths Trapped
	S. littoralis	*S. exigua*	Others	Total		
August	0.01	10.58	0.47	11.06	0.87	17.61
September	0.22	1.40	0.18	1.80	1.04	19.16
October	0.17	0.14	0.27	0.58	0.28	66.17

Some larvae of at least one species were detected on 85% of the visits to individual plots. However, on only 5% of the visits were infestations discovered which had more than 10 larvae/m^2. Parasites[1] were recorded in 79% of the samples, but densities were low, as in 70% of these samples populations were estimated at less than one adult parasite/m^2. S. littoralis larvae were poorly represented at all sites surveyed in 1972, indeed throughout the island damage to all crops by this pest was reported to be slight. S. exigua was prevalent in August but declined in importance through the season. Statistical analysis of the monthly variation in larvae and parasite numbers indicated a significantly higher parasite population in August and September and a significant reduction in the numbers of S. exigua larvae in the plots through the season. Approximately 10% of the visits to plots that had a larval population also demonstrated some injury to foliage. However, of the 43 lucerne pasture growth cycles surveyed, only 2 demonstrated sufficient larval damage to have justified control expenditure, indicating an economic infestation rate in August to October of under 5%. Moreover, both these infestations were caused by S. exigua and at no time in the survey did S. littoralis establish a larval population of more than 5 larvae/m^2. This was in spite of large male S. littoralis moth catches at a number of sites (over 400 trapped in four days at site 3).

The majority of these data were therefore from low density, mixed species larval populations that had a small damage potential. Fluctuations in the level of low density populations did not provide much information on the role of environmental variables

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[1] The main parasite represented was Chelonus inanitus (L) (see fig. 5:4), further discussion of parasitism is given in 5.(3)(d) and 7.(4)(c).

in determining the incidence of larger economic infestations, or the relationship between pest population and crop damage. Pest populations may have been low because of a low incidence of egg laying, or because of high field mortality, or a combination of both. To detect any factors predisposing a pasture to attack it is necessary to compare statistically the conditions prevailing in a large number of observed economic infestations with those in uninfested pastures. Similarly, it is invalid to extrapolate to much larger populations any trends in the relationships between endogenous variables and population levels apparent from observations on small populations. For instance, the ubiquitous, but low level of larvae in this survey indicated the possibility of natural controlling factors operating on pest populations which may be entirely absent in dense infestations (5.(3)(d)(iii)).

A number of general conclusions can be drawn from the survey which are useful in framing the control strategy. For example, the presence of parasitic adults in the latter part of August in the plots sprayed with insecticide, indicated that there was either a rapid recolonization by parasites in pastures cleared by insecticide, or parasites emerged from pupae in the cadavers of their host larvae. If the populations were derived from recent emergences, then parasites would appear to enjoy adequate protection from insecticides when in the pupal form. If confirmed, this has clear implications for farmers anxious to foster a rich natural fauna for biological pest control on their pastures, but also wishing to maintain an option on sprayed chemical control.[1] However, this notion is not supported by recent laboratory studies reported by Rechau (1974). This author detected insecticide induced mortality amongst Chelonus inanitus (L) parasites as adults confined with cotton leaves treated up to 22 days earlier with methomyl, or 45 days earlier with parathion. These results suggest that when parasites are located in a larval cadaver at the time of spraying this is not necessarily a sufficient protection to ensure their survival as adults.

The male S. littoralis moth catches in the pheromone traps fluctuated widely between and within sites. At site 3 on 29.9.72 no males were trapped but on 2.10.72 at the same site, 356 were recorded. Assuming that the pheromone traps were functioning with a constant efficiency, it can be concluded that large moth catches are not associated with subsequent high S. littoralis larval populations in the field. Indeed, site 5, with the largest S. littoralis larval population had low moth trap catches prior to the field infestation. However, there are some indications that it might be more usual for large moth catches to occur after a large larval infestation. For instance, at sites 3 and 5 the two sites where S. littoralis larvae were well represented, moth catches were the highest recorded for all sites sometime after these uncontrolled infestations. If these observations are a true reflection of the actual field situation then the implications are that when male moths emerge from the fields they attempt to mate in the locality, however, either the newly emerged females

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[1] This is of course, only one consideration, predators are less specific in their prey preferences and may be well represented in a certain locality before any larvae appear. These may therefore be more effective control agents, and they will certainly be affected by insecticide. This aspect of chemical control is discussed further in Chapter 7 which considers indirect costs and benefits of insecticide spraying.

Fig. 5:4 The egg larval parasite Chelonus inanitus (L.) with a S. littoralis egg mass on a lucerne leaf (x1·4).

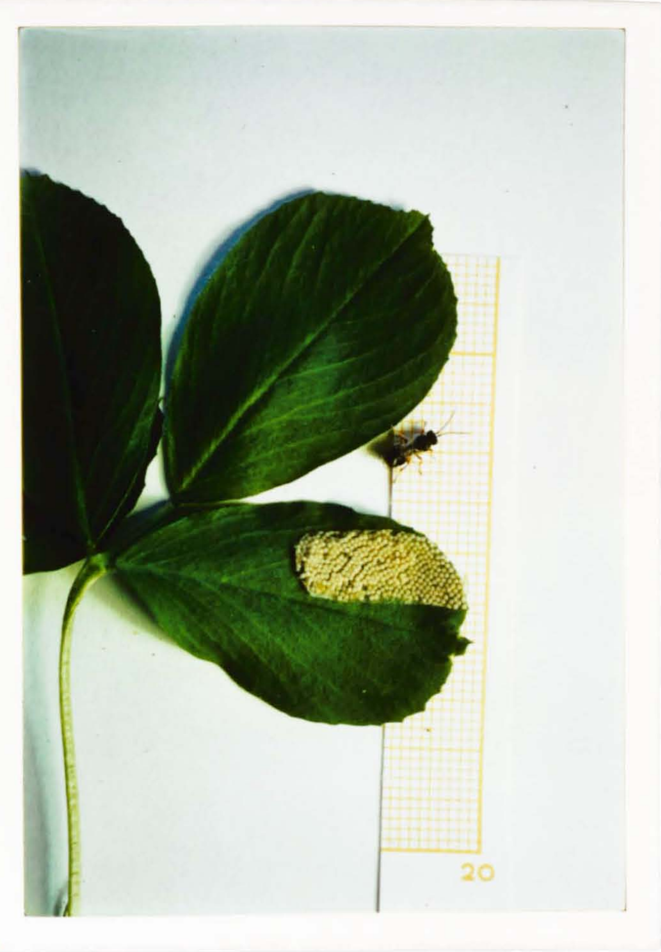

Fig. 5:5 S. littoralis larvae from plot 1 taking cover in the bordering marrow crop after the lucerne harvest.

Two S. littoralis infestations were monitored in the period September to October 1973. One was at the village of Ayios Andronicus (plot 1), and one at Athalassa (plot 2). These infestations were observed so as to provide both qualitative and quantitative data on larval behaviour in an infestation situation, and also to assess the actual crop damage resulting from populations of a known size and duration.

Plot 1 was a small field (approximately 1,000m.^{2}) which had been planted in July 1973. The farmer had sown marrows and tomatoes as border crops to the lucerne field in order that they might take advantage of the pasture irrigations (fig. 5:8 and 5:9). The lucerne had been treated once (on 9.9.73), with 'Folidol', a methyl parathion insecticide, to control an earlier armyworm infestation (species unknown). Fifteen days later (24.9.73), the farmer was preparing to harvest again to salvage his crop from a heavy infestation of early instar S. littoralis larvae.

The results in Table 5:3 show the mean larval counts of S. littoralis as the farmer was harvesting. Three areas were sampled using a quadrat of 0.25m.^{2} area. These were: an area prior to cutting, recently cropped areas (1-2 hours exposure), and those areas beneath piles of lucerne left by the farmer. In recording the larvae, an attempt was made to establish the population age distribution by visually allocating the larvae into instar groups (see 6.(2)).

The plot was revisted on 29.9.73 and more larval counts were made. Half of the lucerne field and some of the bordering vegetables were then sprayed with the insecticide chloropyriphos (the area A, indicated in figs. 5:8(a) and (b); a plan of the experimental field). After this treatment the plot was visited every two days and larval counts were made on the sprayed and unsprayed areas of lucerne. On alternate visits, four 0.25m.^{2} quadrat samples of lucerne foliage were taken to measure regrowth. The results of all these observations are recorded in Table 5:4.

By 2.10.73, nine days after harvest, regrowth had started on all of area A (fig. 5:9), except for a small band of lucerne adjacent to the unsprayed marrow vegetable plot border (Area C, fig. 5:8(b)). Examination of area (C) revealed the presence of S. littoralis larvae of the same size as those existing in the unsprayed sector (area B). Furthermore there was very little injury to the marrow plants, indicating that these had served mainly as a cover for the larvae (fig. 5:5). These larvae then encroached further into the regrowth area (A). This 'invading infestation' continued to extend the width of the defoliated area (C) until 20.10.73 (day 27 after harvest), when further sampling failed to detect larvae. Regrowth in the untreated area (B), was negligible until about the 20th day after harvest (13.10.73), and did not occur vigorously until all the larvae disappeared (16.10.73). Fig. 5:7 shows the extent of area (C) on 20.10.73.

A second infestation occurred on the treated area (A) and was detected at the second instar stage on 20.10.73 (27th day after harvest). This persisted until the lucerne was harvested for the second time. This infestation was presumably derived from

Fig.5:6 S.littoralis larvae found beneath a pile of freshly cut lucerne.

Fig.5:7 Plate of Area C (see figs. 5:8 & 5:9).

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Fig. 5:8(a) Plan showing the main features of Plot 1, including insecticide treated area.

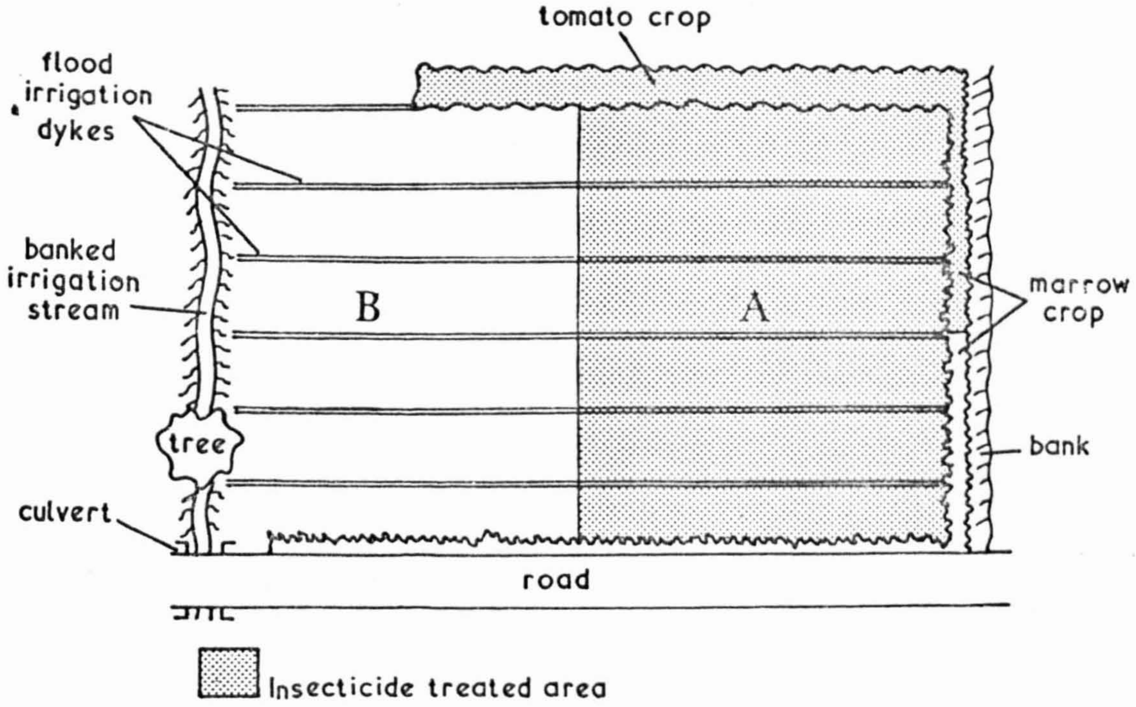


Fig. 5:8(b) Lucerne regrowth nine days after harvest (see fig. 5:9).

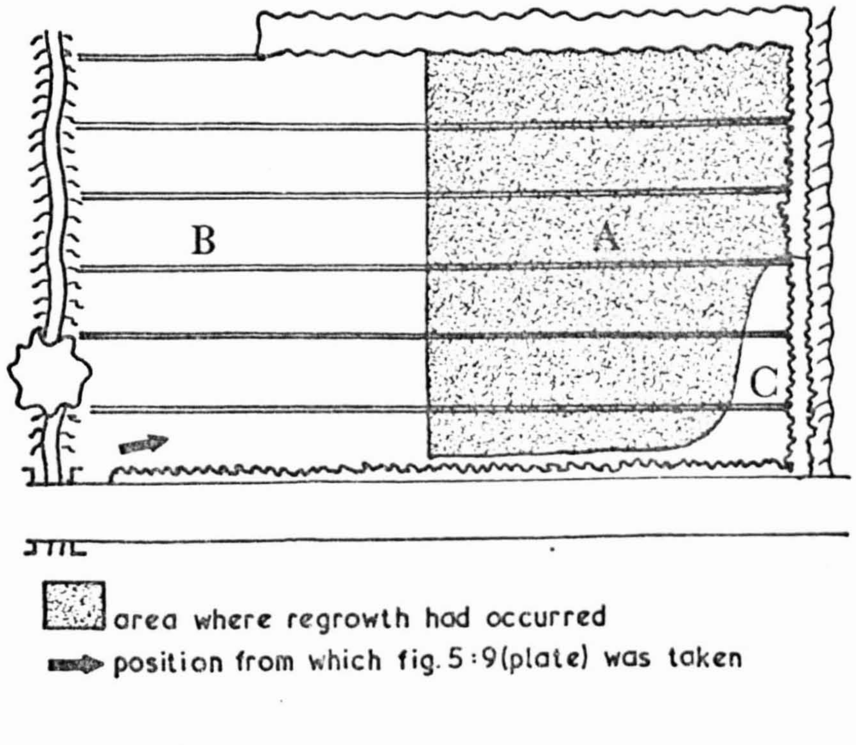
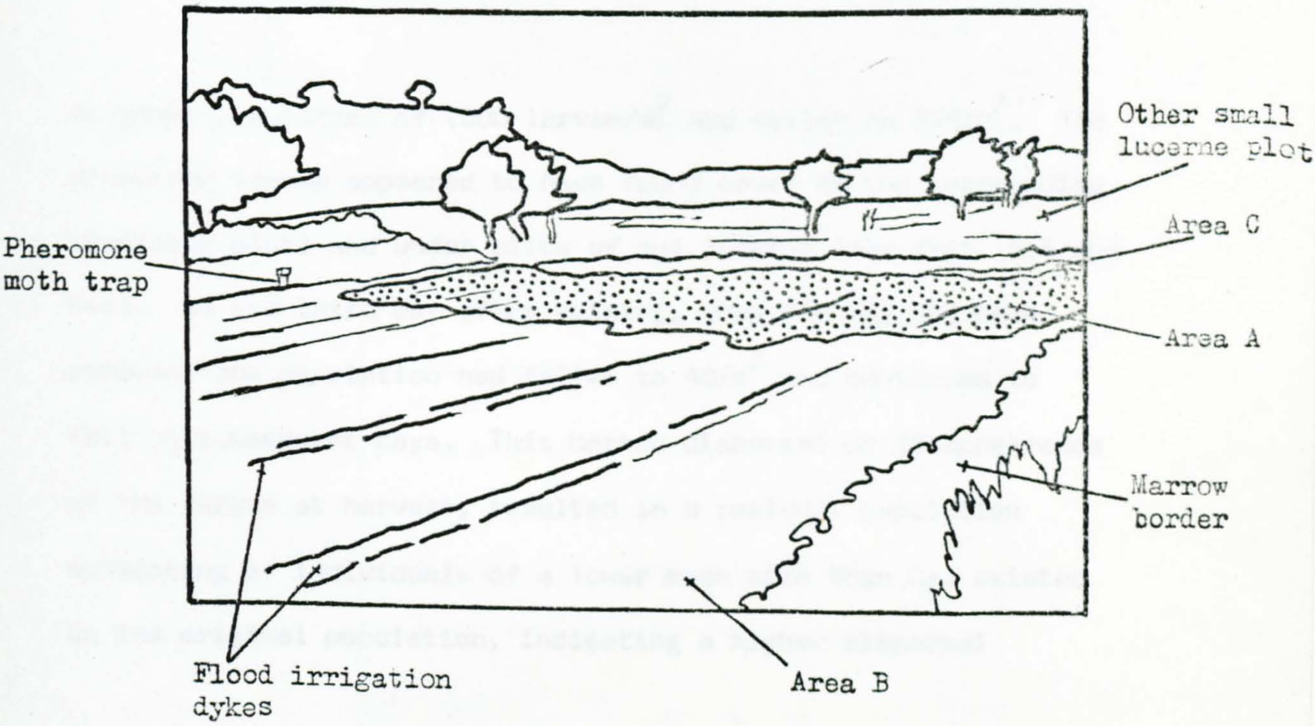


Fig. 5: Plate and plan of plot 1, nine days after harvest and subsequent insecticide treatment.

Plan



egg masses laid on or near the 22nd day after harvest, coinciding with the time of the second pasture irrigation. This is some further support for Bishara's observation (1934) that moths are attracted to oviposit on freshly irrigated and leafy lucerne.

Table 5:3(a) shows the disruptive effect that the crop harvesting had on the larval infestation. Within two hours of cutting, the original population of 1000 larvae/m^2. had fallen to 250/m^2.. The dispersed larvae appeared to have found cover in the surrounding vegetable plots and under piles of cut lucerne (see figs. 5:5 and 5:6). On the third day after cutting, when the hay had been removed, the population had fallen to 40/m^2. and continued to fall on subsequent days. This marked dispersal or disappearance of the larvae at harvest, resulted in a residual population consisting of individuals of a lower mean size than had existed in the original population, indicating a higher dispersal

TABLE 5:3 <u>Plot 1, Larval counts on total plot before insecticide treatment</u>

Time after harvest	Larval instar population*							Estimated leaf loss
	(1)	(2)	(3)	(4)	(5)	(6)	Pupae	
Before	0	502.4	360.4	43.6	24.0	9.2	0	22.30%
2 hrs after	0	149.4	100.8	1.2	0.4	0.4	0	-
3 days after	0	13.6	24.4	0.4	0	0	0	-
Estimated population under hay: 12,000-20,000 larvae/m^2 (mostly large)								

*Expressed as mean nos. larvae/m^2, each estimated from 10 x 0.25m^2. quadrat samples.

TABLE 5:4 Plot 1, Larval counts and lucerne yield in treated area (A)[1] and untreated area (B)[1]

Date	Days after Harvest	Larval instar population[2] Area (A)							Lucerne[3] g./m^2. (dry wt.)	Larval instar population[2] Area (B)							Lucerne[3] g./m^2. (dry wt.)
		(1)	(2)	(3)	(4)	(5)	(6)	Pupae		(1)	(2)	(3)	(4)	(5)	(6)	Pupae	
29. 9.73	5	0	0	0	0	0	0	0		0	13.0	1.0	0.4	0.4	0	0	
30. 9.73	6	0	0	0	0	0	0	0		0	9.2	10.0	1.0	0.4	0	0	
2.10.73	8	0	0	0	0	0	0	0	22.0	0	6.0	6.6	3.2	0	0.4	0	2.0
4.10.73	10	0	0	0	0	0.4	0	0		0	0	8.4	4.8	0.8	1.6	0	
6.10.73	12	0	0	0	0	0	0	0	49.0	0	0	7.4	5.6	1.0	0.4	0	2.5
8.10.73	14	0	0	0	1.2	0	0	0		0	0.4	0	0.8	1.2	0.4	0	
10.10.73	16	0	0	0	0.8	0.4	0	0	96.5	0	0.8	0	0.8	1.2	0.4	0	4.0
12.10.73	18	0	0	0.4	0	0.8	3.2	0		0	0	0	0	0.4	1.2	0	
14.10.73	20	0	0.4	0.4	0.4	0.8	1.2	0	152.0	0	0	0	0	0	1.2	0	13.0
16.10.73	22	0	0.4	0	0.8	0.4	0	0		0	0	0	0	0	0	0	
18.10.73	24	0	0	0	0	0	0	0	161.0	0	0	0	0	0	0	0	43.0
20.10.73	26	0	13.2	1.2	0	0	0	0		0	0	0	0	0	0	0	
22.10.73	28	4.8	54.4	11.6	3.2	0.4	0	0	176.5	0	0	0	0	0	0	0	39.0
25.10.73	31	0.2	74.4	19.2	4.7	0.4	0	0	192.0	0	0	0	0	0	0	0	68.0
27.10.73	33	0	33.6	2.8	1.2	0.8	0.8	0		1.2	0	0	0	0.4	0	0	
29.10.73	35	0.2	26.0	20.0	4.0	0.4	0.4	0	168.0	0.8	0.8	1.2	0.4	0	0	0	104.0

[1] Areas illustrated in fig 5:8(a)

[2] Expressed as mean numbers larvae/m^2., each estimated from ten 0.25m^2. quadrat samples

[3] Mean of four 0.25m^2. quadrat samples

propensity for larger larvae. This might have resulted from a higher mobility of larger larvae, a notion supported by the recorded appearance of late instar larvae (identified by size only), in the treated plot (A) 16 days after harvest (these were presumably migrants from the untreated plot (B) that had grown sufficiently to move effectively in search of a more plentiful food supply). However, Harris, reporting on post cutting larval populations (C.O.P.R., 1974) observed heavy predation of the larger larvae by carabid beetles in areas where they congregate to take cover. There is also the possibility of large scale vertebrate predation at this stage (see: 5.(3)(d)). This may account for the disappearance of larvae at harvest from fields sufficiently large to defeat even the most persistent migrants.

The second observed infestation occurred at the A.R.I. farm at Athalassa, and was an example of an infestation resulting from dispersing larvae. These larvae had presumably originated from a recently cropped adjacent field (field Y, fig. 5:10) and had crossed the farm road to cause a secondary infestation (field X, fig. 5:10). Various areas of damage and infestation were clearly identifiable (areas D, E, F and G, fig. 5:10) and these were sampled for larvae and damage (table 5:5).

The results showed that the dispersed larvae produced a moving band of infestation encroaching into the hitherto undamaged crop (field X). At the forward margin of the infestation (area E) a fairly dense infestation of large larvae were found. Behind this

Fig. 5:10 Plan of infestation occurring on Plot 2

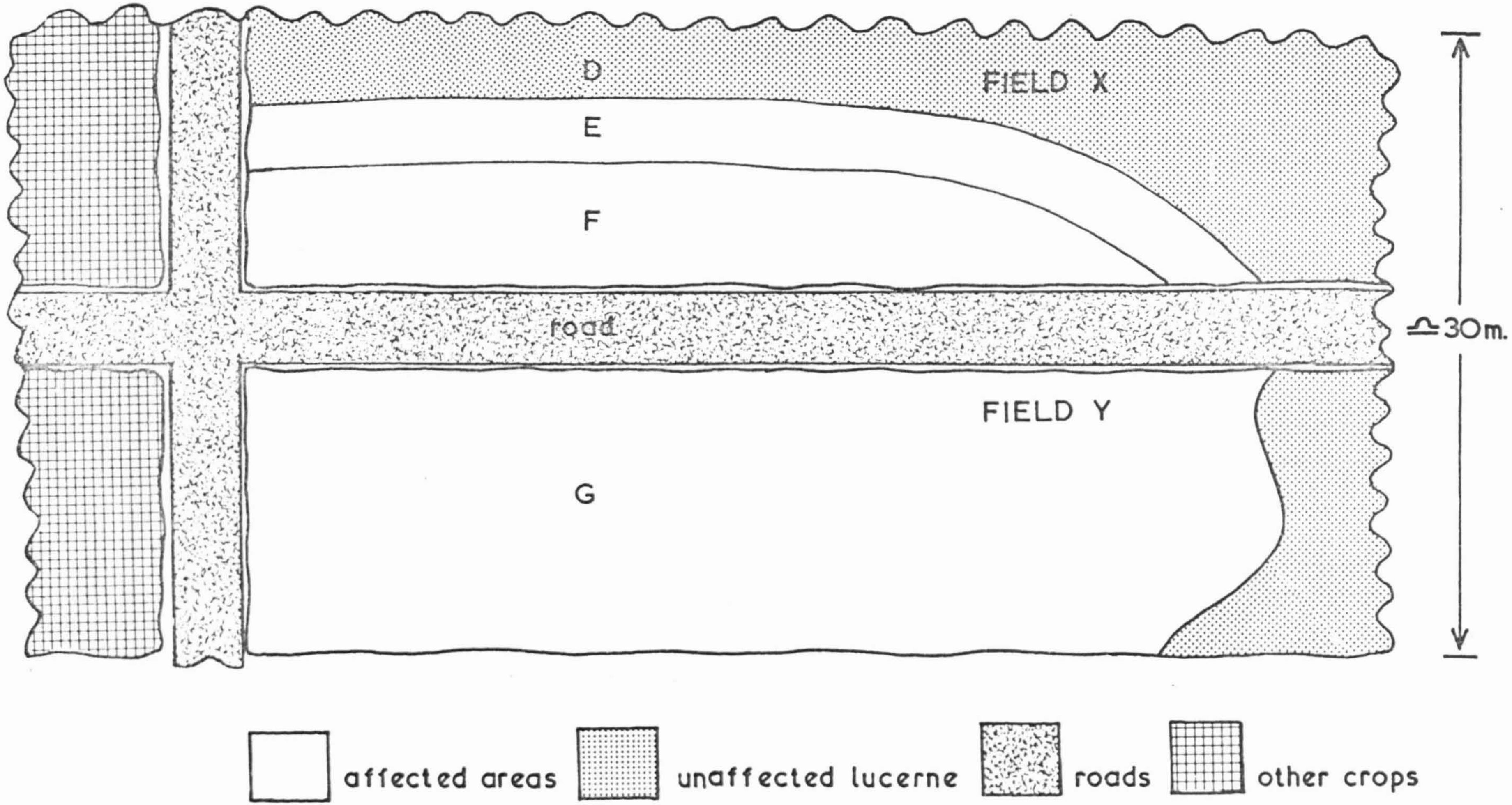


TABLE 5:5 Larval counts and estimated leaf loss in Plot 2

Areas (fig. 5:10)	Larval 'instar' population (larvae/m^2)*							Estimated leaf loss
	(1)	(2)	(3)	(4)	(5)	(6)	(Pupae)	
(D)	0	0	0	0	0	0	0	0
(E)	0	0	0	8.5	7.3	29.8	0	72%
(F)	0	0	0	0	0	0	0	90%
(G)	0	0.5	3.3	2.5	2.5	1.8	0	Just harvested

*Each estimated from 10 x 0.25m^2 quadrat samples.

(i.e. area F) the damage to the crop was almost total leaf loss and no larvae were found. Sampling larvae from the parent infestation (area G) it was found that the remaining larvae were of a smaller size than those represented in the dispersed population. If it is assumed that growth rates in the two populations (G and E) had been the same subsequent to dispersal, then these results are further support to the notion that larger larvae were more active in dispersal.

In conclusion, these infestations indicated the differential dispersal or disappearance propensity of larger larvae, and the role of the residual populations in the suppression of crop regrowth. They also showed that larvae may invade neighbouring plots to cause severe localized crop injury, demonstrating the importance of treating surrounding cover plants when infestations are artificially controlled. This point has been recognized by Abul-Nasr et al. (1972(b)) who recommended a routine insecticide spray treatment of tree trunks, weed banks and wind breaks to control early autumn generations of S. littoralis in Egypt.

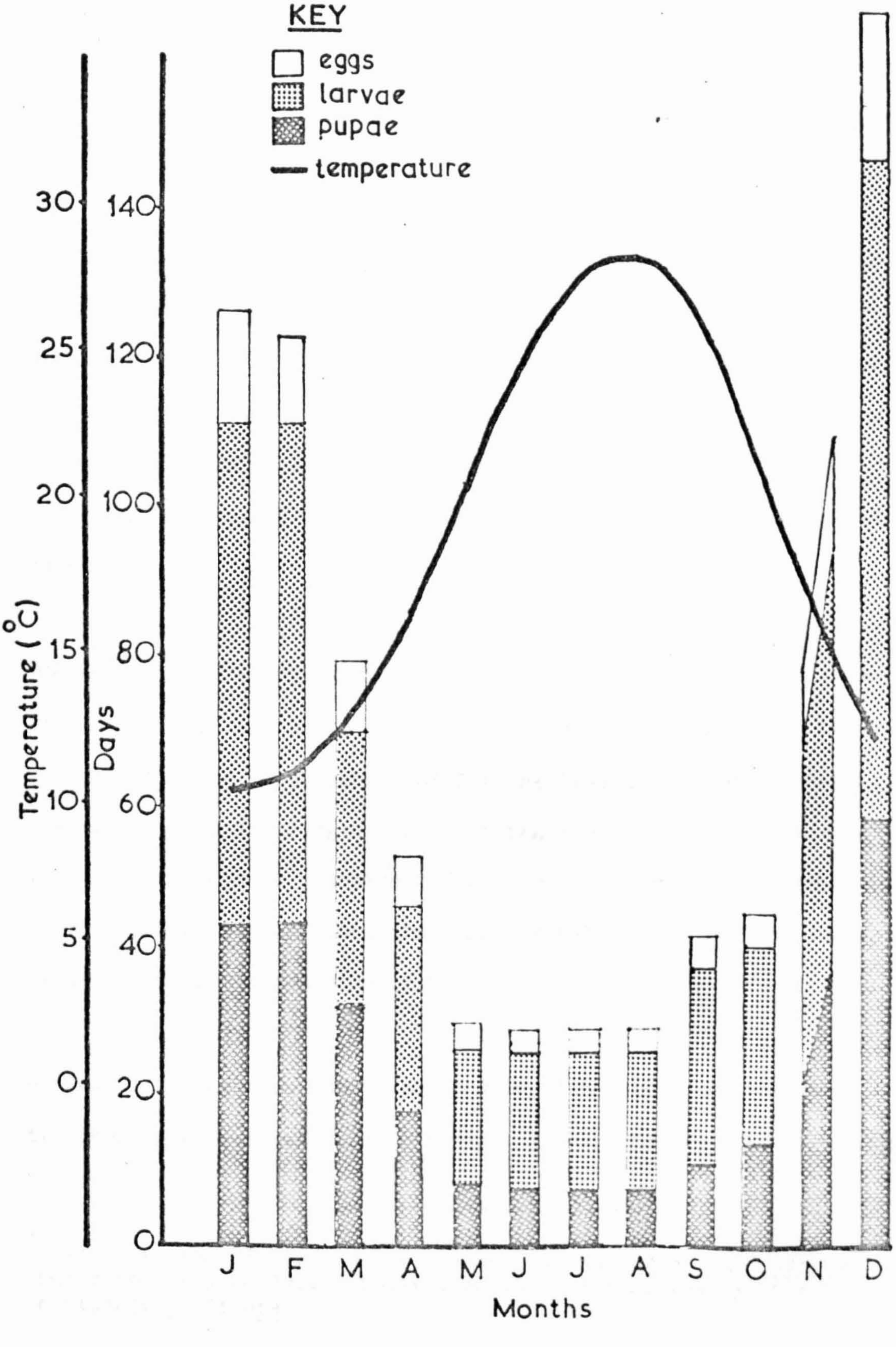
5.(3)(c) Laboratory trials on feeding, growth and development of S. littoralis larvae

The development rate of a pest is an important variable determining its status. It limits the total number of generations achieved in any one season and thus the potential population levels. It also determines the length of time that a pest will spend in any one stage of its life cycle, thus affecting its food consumption and mortality from natural causes. Within the constraints of genetic potential, the variables that could be expected to be of most importance in the determination of development rate are temperature, population density and food source (quality and quantity).

Fig. 5:11 is a plot of development time, and monthly ambient temperature observed with field collected larvae individually reared in the laboratory. These data, collected by W.R. Ingram (unpublished) show a marked decrease in development time with the onset of warmer weather in May. Work by Ingram and other authors has indicated that the optimum temperature for the species is 28-30°C. From 30-50°C growth and development may be quicker, but mortality and infertility are greater, especially above 33°C (Rivnay and Meisner, 1965). Below 10°C development of all stages is arrested, (Bishara, 1934).

Since interest in feeding and development in this study is centred on lucerne as a host plant, the effect of different host

Fig.5:11 *S.littoralis* development time & ambient temperature.



plants was not investigated. However, work with Spodoptera litura[1] by Pandey and Stirvastava (1967) on the feeding responses to 24 types of wild food plants by this closely related species, indicated differences in development rate and mortality with food source. We would expect to find similar differences in S. littoralis and therefore all feeding trials were conducted using lucerne leaves as a food source.

The existing data from growth and feeding trials with S. littoralis using natural food plants, were compiled by Bishara (1934) and Edwards (unpublished). Bishara conducted his experiments at 25°C using cotton leaves as a food source. Edwards monitored feeding and growth in his larvae, fed on a diet of spinach leaves, at 30°C. Both workers noted a rapid increase in weight in consumption in the final two instars, followed by a prepupal decline in weight and cessation of feeding.

As part of this study, the larval growth and food consumption were measured under laboratory conditions for individually reared larvae fed ad lib. on a fresh supply of lucerne leaflets. These trials were conducted with single larvae at the second instar stage and continued through to pupation. Trials were run at two temperatures: 24-26°C and 29-31°C. Since the experimental method was a new one, it is necessary to describe it briefly.

A newly laid egg mass was taken from the laboratory culture and transferred to a fresh lucerne sprig. The incubating eggs were then

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[1] These authors referred to their experimental larvae as Prodenia litura, but since they collected their insects in India, they were almost certainly S. litura.

placed in the constant temperature regime determined for the trial (either 24-26°C or 29-31°C). On hatching, the date was recorded, and the larvae were left to feed gregariously on the sprig until the second instar stage. Twelve larvae from each temperature regime were then individually reared on lucerne leaves in plastic petri dishes, each containing a disc of filter paper, (dampened or dry according to the amount of food presented).

A major problem associated with estimating the consumption of plant material is the variation in plant tissue weight with changes in water content. Estimates were therefore made by a comparative dry weight technique. Lucerne produces a leaf which is divided into three leaflets. Approximately 70% of the paired lateral leaflets appeared to be equal in size. Estimates of the visually assessed matched leaflets showed a low variation: less than 5% between dry weights. It was therefore assumed that the initial dry weight of a leaflet offered as food to the larva could be reasonably estimated from the dry weight of a matched opposite leaflet, thus enabling an estimate of dry weight intake to be made.

Each morning, matched leaflets from freshly picked lucerne were chosen and one of the leaflets was presented to the larva and the other dried. A quantity in excess of the predicted consumption demand was offered to ensure ad lib. feeding. Both the control leaflets and the post-consumption leaf remains were dried for 48 hours at 70°C before weighing.

The estimated food intake per day in g. dry wt. of lucerne leaf, with the corresponding liveweight of larvae for the two controlled temperatures are given for different days since hatching in Appendix 5:2(1). These data were converted to $\log_{10}$ and the geometric means for both food intake and liveweight were calculated for each day after hatching. A plot of this transformation is given in Fig. 5:12.

Fig. 5:12 indicates that both consumption and larval weight increased exponentially from the beginning of the trial until the sixth instar stage (estimated at larval weights > 0.62g, see Table 6:1). Values for the rate of this exponential increase during the period can be found in equation 5:1.

Equation 5:1 Exponential phase of growth (^{W}L) and consumption (Co) of larvae reared at 24-26°C and 29-31°C

$$N_{t_m - t_n} = N_{t_m} . e^{r(t_n - t_m)} \qquad (5:1)$$

where N = ^{W}L or Co for the two trial temperatures

t_n = Upper range of exponential increase in days since hatching

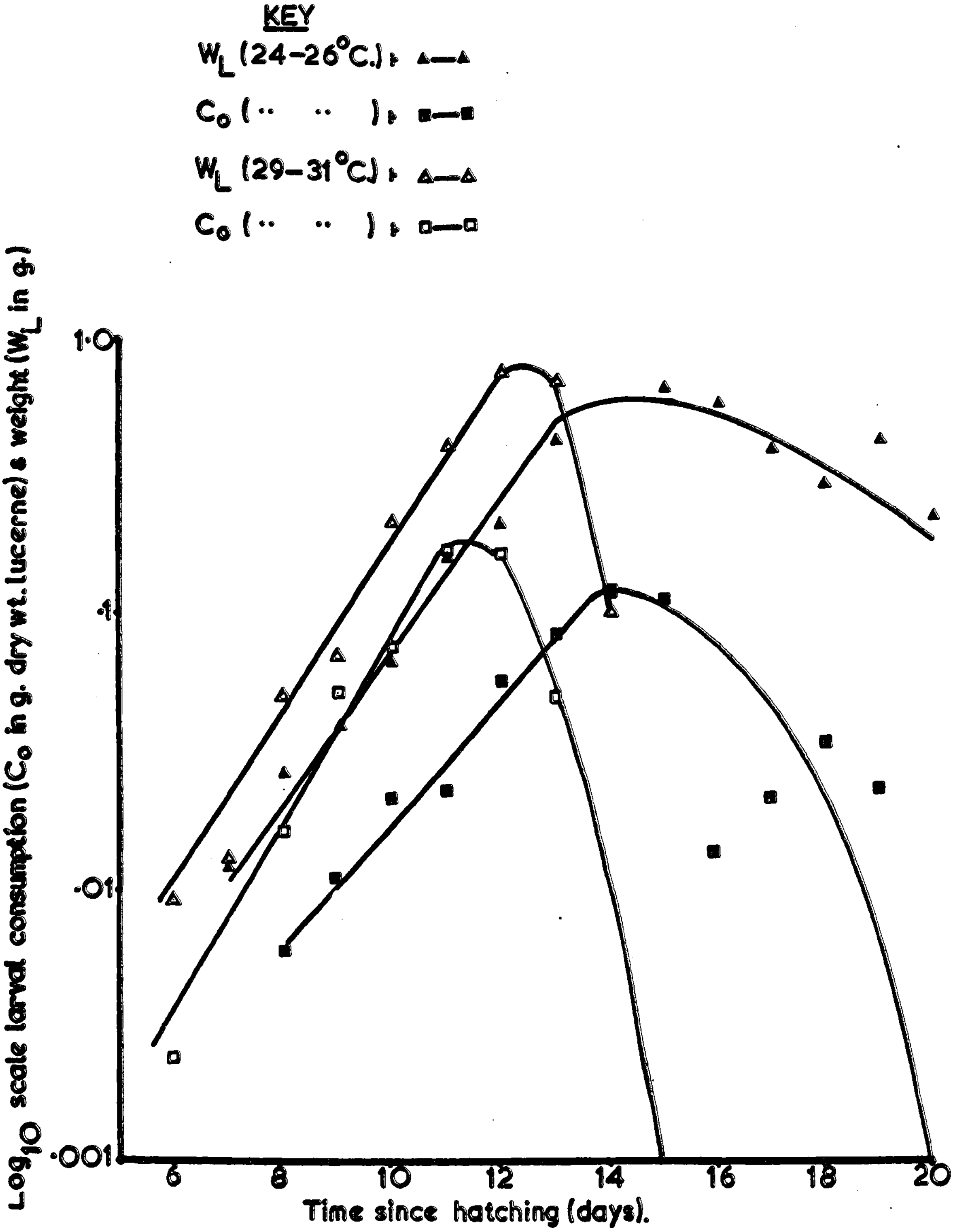
t_m = Lower range of exponential increase in days since hatching

r = rate of exponential increase

e = base of the natural logarithms

The estimated values for the trials were:

Fig. 5:12 S. littoralis larval growth & consumption at 24-26°C, & 29-31°C.



N	t_m	t_n	r
W_L at 24-26°C	8	13	0.5577
Co at 24-26°C	5	13	0.5361
W_L at 29-31°C	6	12	0.8478
Co at 29-31°C	6	11	0.7278

After the fifth instar stage, larvae still grew and consumed lucerne, but at a declining rate. By day 15 after hatching at 29-31°C, and day 20 after hatching at 24-26°C, consumption had ceased and larval weights were falling to their prepupal levels.

These results were consistent with those found by Bishara and Edwards in that a rapid rise in liveweight and consumption (but not rates of growth and consumption), occurred in the last two instars. Comparison of the results obtained for the two temperatures indicated that temperature positively affected growth rate consumption rate and time to maturation, although the mean highest weight attained by mature larvae reared at both temperatures remained constant at about 0.8g.. The higher consumption rate at 29-31°C resulted in a significantly higher total consumption of lucerne from second instar to pupation than was found for larvae reared at 24-26°C.

Since this positive effect by temperature on growth and consumption rates is unlikely to be linear (Krogh, 1916), two temperature trials do not provide enough data to derive a temperature to growth or consumption rate function. It was therefore necessary to choose the results from only one of the trials as a basis for estimating growth and consumption in the damage simulation described in Chapter 6.

The mean daily temperature in Cyprus was approximately 26.0°C in September and 21.5°C in October. Although the clear skies resulted in fairly large diurnal fluctuations in air temperature (over 5°C in November 1971, C.O.P.R., 1974), it is most probable that the larvae maintained a fairly constant temperature environment by retiring to the base of the lucerne during the day; an area which is buffered against temperature change (Geiger, 1965). Consequently, the larval consumption and growth measured at 24-26°C, was considered to be more representative of normal field conditions existing during armyworm infestations, and the results from this temperature trial were used in the subsequent simulation.

Rearing density has been shown to adversely affect a whole range of insect population parameters. Klomp (1966), has shown that the larval stage of the pine looper (Bupalus piniarius) exhibits density dependent mortality (5.(3)(d)(ii)) due to intraspecific competition and parasitism. He also showed that population density was positively correlated with egg mortality, reductions in larval and pupal size, and moth fecundity. Gruys (1963), found that growth in the same larvae may be inhibited by mutual contact, even when food was not limiting. McNeill (1973), has observed density dependent mortality in Lepidopterous larvae during periods of weather stress. McKinley (1970), rearing Spodoptera littoralis larvae on an artificial medium, recorded a lower pupal weight, higher larval mortality, darker colouration and a faster development rate from larvae reared in "crowded conditions".

The author conducted preliminary investigations into the effects of density on S. littoralis larval growth and mortality at 24-26°C.

Ten replicates for larval densities of 1, 2, 4 and 6 larvae/pot were made with plastic pots of 210ml. capacity. Larvae were added at the second instar stage and supplied daily with fresh sprigs of lucerne. Although it cannot be claimed that these rearing conditions faithfully reproduced field conditions, it is useful to express them in terms of field infestation equivalent densities. Assuming larvae feed on the top 20cm.of mature lucerne (Ellis and Veigh, unpublished C.O.P.R. report), then $1m.^2$ contains $0.2m.^3$ of favoured feeding area. The sprigs of lucerne in the pots were introduced at approximately the same density as would be found in a normal pasture, and consequently, 6, 4 and 2 larvae per pot may be considered approximately equivalent to infestations of 5,700, 3,800 and 1,900 larvae/$m.^2$ of pasture, respectively. These represent severe infestation conditions (5.(3)(b)).

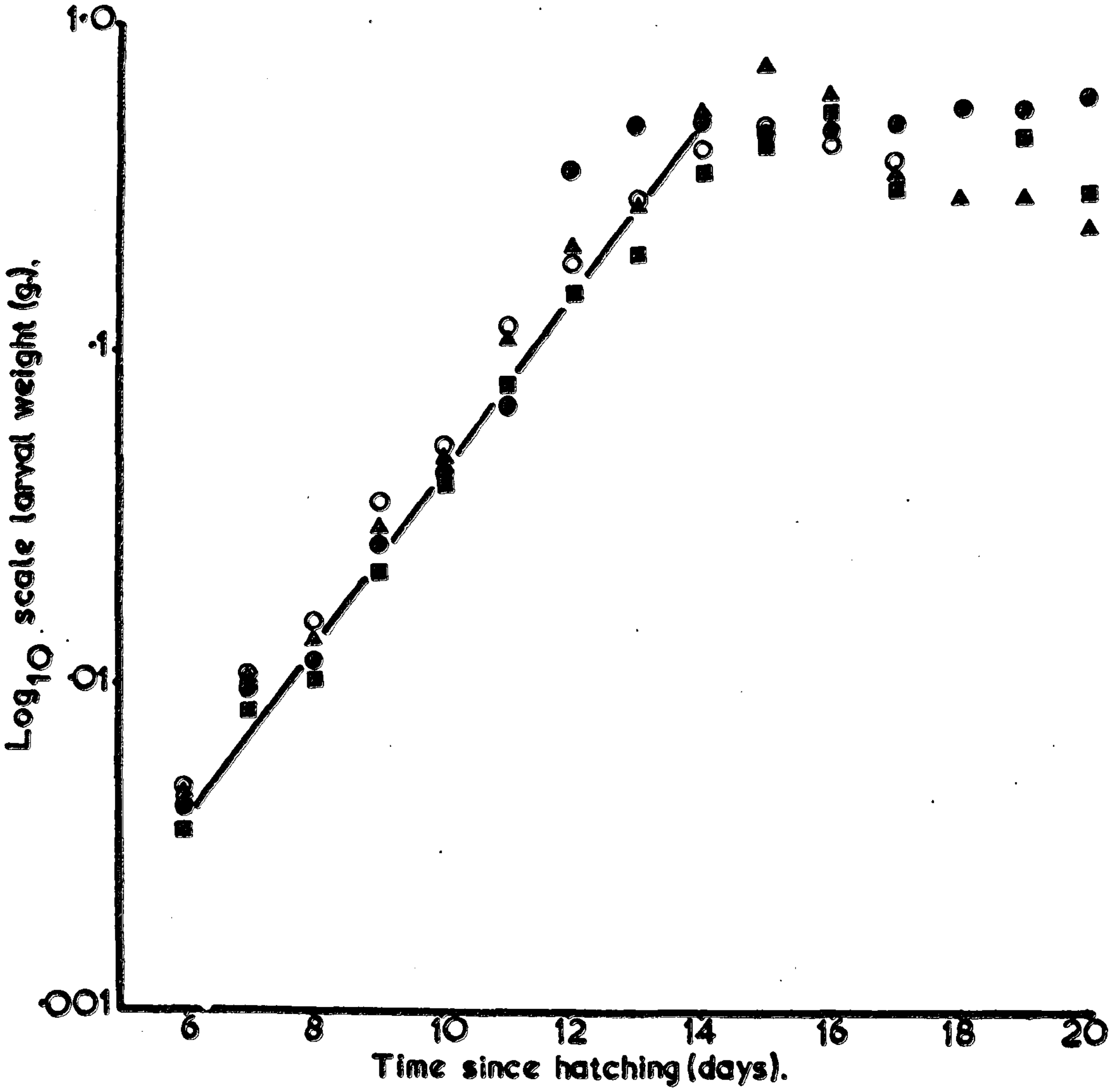
The problem of excess humidity in the pots containing large larvae was dealt with by introducing filter papers and silica gel crystals into the base of the pots. For the purpose of calculating daily weight change at each density, results were taken only from those replicates in which a full complement of larvae survived. The full results of these trials are given in A5:2(2)-(3) and a graph of the means of a $\log_{10}$ transformation of the data given in fig. 5:13.

The results at all density groups reaffirmed the observed exponential increase in growth rate up to the sixth instar, and the subsequent decline in the sixth instar. In the exponential phase, there was no apparent difference in growth rate for any

Fig. 5:13 S.littoralis larval growth reared at four densities at 24–26°C.

KEY

1 larva/pot : ●
2 larvae/pot : ▲
4 ·· ·· : ■
6 ·· ·· : ○



of the density groups. Their growth can be approximately described by the single equation:[1]

$$W_L.t_n = W_L.t_6.e^{0.61018(t_n-6)} \qquad (5:2)$$

(NB. Using the same notation as in equation 5:1, except that n = any value of t > 6 and < 14).

Statistical examination of the liveweight data showed that the mean time taken to the maximum weight achieved by the larvae (and hence their maximum consumption potential) in each group, varied from the 14th day after hatching for larvae reared in groups of six, to the 16th day for larvae reared individually. However, these differences were not statistically significant, indicating that 'maturation' time was not grossly affected by the differences in density. When the mean weights of larvae on the 15th day after hatching (the overall mean 'highest weight day' for all groups for each of the groups were compared, it was found that larvae reared individually resulted in significantly higher maximum weights than those reared in groups of six. However, when those replicates in which some larvae died after the 15th day were excluded, the differences were not significant. Pupae derived from surviving larvae in each density group did not significantly differ in weight (table A5:2(3)). Pupal weight was found to be positively correlated with the maximum weight of the corresponding

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[1] It is noted that the growth rate for the larvae was slightly higher (6.9%), than that found for larvae reared at the same temperature in the feeding trials, this may be due to the differences in the rearing conditions, in particular the form in which the food was presented (sprigs as opposed to leaflets).

larva ($p > 0.01$), this relationship has also been observed for pine looper larvae (Klomp, 1958) and fly larvae (Sarcophaga spp.) (Beaver, 1973). Consequently, imminent mortality amongst some of the grouped larvae may be a reasonable explanation of the rather lower mean weights of the larvae reared in groups of six.

The total number of pupae resulting from these replicates, along with the original numbers of second instar larvae are given in table 5:6. From these figures the percentage mortality from the second instar stage to pupation was calculated for each density group. A positive correlation ($p > 0.001$) was found between the larval rearing density and percentage mortality.

TABLE 5:6 Increase in percentage mortality with increases in rearing density

	Density group (larvae/pot)			
	1	2	4	6
Nos. of second instar larvae at the beginning of the trial	10	18	36	60
Nos. of pupae formed	9	14	19	19
% larval mortality from second instar	10	22	47	68

The results did not demonstrate any unequivocable density effects on larval growth and pupal weight. Consequently, the effects of density on larval growth (or consumption) was not given explicit consideration when designing the simulation program. However, we suggest that an increase in the replicates of the trial, perhaps with larger pots and a greater range of densities, may demonstrate density effects hitherto concealed, particularly if mixed age/sized larvae were reared together.

The mortality response indicated density dependence. In the following discussion on field mortality of S. littoralis larvae, density dependence is not considered, due to the incomplete, and sometimes anecdotical nature of the available evidence. These data therefore highlight the need for more field data on natural mortality of the pest at different levels of infestation.

5.(3)(d) Mortality

(i) Field mortality of S. littoralis larvae

Mortality of S. littoralis in lucerne fields in Cyprus has not been directly measured. However, work in Egypt (Bishara, 1934; Bey, 1951; Abul-Nasr and Ali-Naguib, 1968; Abul-Nasr *et al.*, 1972(c)), suggests that field mortality of eggs, larvae and pupae is extremely high, over 99% in many cases. If larval mortality in Cypriot lucerne fields is significant, then accurate predictions of damage from developing infestations will require some assessment of the population decline due to natural factors.

It is probable that environmental factors, predation, parasitism and viral and bacterial disease account for the majority of larval deaths. Of the environmental factors, temperature and wind are important mortality agents amongst egg masses and newly emerged larvae. Eggs laid on the upper side of leaves and exposed to direct sunlight will be particularly vulnerable, andthe hatching larvae, devoid of the protection of the waxy egg shell and hairy fuzz deposited on the eggs by the moth, will soon perish from dessication if they do not reach less exposed areas. The ability of these larvae to spin gossamer threads may assist in a move downwards in the pasture, but losses of larvae into the air currents are probably quite high. A speculative estimate of the proportion of first instar larvae lost in this way is 20% by dessication and 10% by wind dispersal (Ingram, pers. comm.).

Protracted hot or cold spells may cause significant mortality in larger larvae. However, orientation by the larvae towards more favourable microclimatic areas in the pasture, probably reduces to an unimportant level mortality due to the normal diurnal or short term adverse temperature changes.

Humidity does not seem to be an important environmental mortality factor. Once again there will be behavioural responses by the larvae away from areas of very high or very low relative humidity. However, high humidity probably does have a role in exacerbating disease epidemics.

The results of a preliminary screening for arthropod predators of S. littoralis larvae were reported in C.O.P.R. (1974). This list of potential predators included eleven species to which can be added the larger larvae of other Lepidopterous insects such as Heliothus sp. The main S. littoralis predator species in Egypt, as observed by Bishara (1934), and Bey (1951) were well represented in lucerne fields in Cyprus. Species appearing both in the predator screening list and in Egypt included the adults and larvae of the ladybird Coccinella-11-puncata L and Lacewings (Chrysopida), carabid beetles (Carabidae), ants (Hymenoptera) and spiders (Arachnida). Although this comparison says nothing about the density of predators, the similarity of habitat, cultivation practice and distribution of species, would suggest that mortality due to predators is in the same order of magnitude in Cypriot and Egyptian lucerne fields. Bishara (1934) estimated that 70% of the newly emerged larvae in Egyptian lucerne were destroyed by predators by the end of the first day, and 90% by the end of the second. Data collected by Bey (1951) suggest 92% mortality by the third day. Sampling the predators Bey concluded that irrigation increases their numbers and high winds decrease them. Insecticide dusting and spraying markedly reduced the numbers of all predator species.

One feature of arthropod predation which appeared constant in both laboratory (C.O.P.R., 1974) and field studies (Bishara, 1934) was that many predators were only capable of attacking the smaller larvae, and those that destroyed the larger ones did so at a rate which was inversely related to the size of the larvae. For instance, a number of medium sized spiders (Chiracanthium isiacum) kept alive in the laboratory and supplied with larvae, each destroyed on average 32 first instars, 9-12 second instars and about 6 third instars (Ibid.). Bey (1951) suggested that under the same conditions these spiders may destroy forty newly hatched larvae to every one nine days old.

Conversely, some of the vertebrate predators such as frogs (Ranus sp.), small mammals (Blarina sp. and Sorex sp.), or migrant birds such as warblers (Sylvinae sp.), flycatchers (Muscicopinae sp.), or flocks of wagtails (Motacilla sp.), were mainly predators of larger larvae or pupae of S. littoralis. Of these, the migrant birds were the most effective predators. They were not as intimately a part of the pasture ecosystem as the entomorphagous arthropods and their effectiveness relied on an infestation being sufficiently conspicuous to attract the attention of a passing flock. This frequently occurred when an infested pasture was harvested and the larvae were moving about in the field. The author has observed a flock of wagtails congregating in a newly cropped pasture with a moderate infestation of S. littoralis larvae. Subsequent examination (2-3 hours after harvest) detected only a low density of smaller larvae.

The predation rates we consider appropriate for Cyprus were conservative estimates based on the Egyptian data. It was assumed that arthropod predation was only effective in the first three instars and was negligible for larvae of fourth instar and above. The rates from the first to sixth instars were estimated at 60%, 40%, 10%, 1%, 0% and 0% of the instar population. Vertebrate predation was assessed at 99% of all instars above the fourth if bird flocks discovered the infestation. For the purposes of predicting damage, these flocks could not be relied upon, and consequently the possibilities of vertebrate predation were ignored in the subsequent damage simulation.

Eight named parasite species have been reared from S. littoralis larvae collected from lucerne fields in Cyprus (C.O.P.R., 1974). Two families were represented: the Ichneumonidae and the Braconidae. The most important species, estimated both from the numbers reared from collected larvae (Ingram, see Ibid., p.94), and numbers collected in the larval survey (section 5.(3)(a)), was the Braconid: Chelonus inanitus (fig. 5:4). C. inanitus is an egg/larval parasite, the adults oviposit in the host's eggs and the resulting parasites are reared, and eventually emerge from the host larvae. The host larvae appear to be unaffected by the presence of the parasite and continue to feed and grow apparently normally until the third instar stage when they become torpid and retire to the ground (Gerling, 1969). From the damage viewpoint, it is this time of cessation of feeding that is relevant, not the initial parasitisation.

Ingram's data (unpublished) showed a range of 0% to 65% parasitisation for larvae collected in Cypriot lucerne fields and reared in the laboratory. These figures were associated with a mean (and mode) of approximately 40% parasitism. Since C. inanitus is an egg/larval parasite, all larvae collected would have been either parasitized at the egg stage or have entirely escaped parasitization by this species. Consequently, the incidence of field parasitism by C. inanitus could be assessed with fair accuracy. However, other parasites, notably the Ichneumonids such as Hyposoter didymator Thunb. and Temelucha sp. were also prevalent in the field, and these parasites oviposit into larvae. Since collected larvae reared in the laboratory are isolated from further risk of parasitization, Ingram's figures were probably an underestimate of the total parasitism. With this in mind, the rates of parasitism per instar (at the time of cessation of larval feeding), were approximately estimated for first to sixth instars at 0%, 0%, 40%, 10%, 2% and 1% of the total population.

A mean of 4.3% of the field collected larvae died in culture from either Nuclear Polyhydrous virus (N.P. virus) or bacterial disease. In addition, up to 25% died from unknown causes (Ingram, pers. comm.). The role of N.P. virus as a field mortality factor is obscure. The susceptibility of S. littoralis to the disease has been demonstrated (C.O.P.R., 1974, pp. 27-29), however, there appeared to be no standard response to inoculation. In some cases laboratory inoculation with N.P. virus at the second instar stage resulted in normal larvae giving rise to adults that were either sterile or produced non-viable eggs. Occasionally, eggs from such an adult did hatch to produce larvae that promptly died of a congenital N.P. virus infection. However, the trend for both viral and bacterial disease in the reared larvae, was for late instar mortality.

The deaths from unknown causes may have been a result of the rearing conditions, and so it would be injudicious to anticipate similar mortalities in the field. However, it is almost certain that some were disease induced. In consultation with Ingram, the natural mortality due to disease, including N.P. virus, was estimated for first to sixth instars as 0%, 0%, 2%, 5%, 10%, 10% of the total population.

The estimates of field mortalities given above, along with the total instar rates were converted to daily rates and are given in table 6:3. The total mortality figures for the first instar to the last instar are 71%, 40%, 52%, 16%, 12% and 11%. Assuming the larvae spend two days in each instar, the cumulative mortality from hatching to pupation is approximately 90%. When the activity of parasites and predators is excluded, the cumulative mortality is reduced to 45%. These rates were used as a measure of 'typical' mortality in the infestation model described in Chapter 6.

There has been no consideration of seasonal variation in these rates. Intuitively we would expect a positive numerical response to infestations by parasites and predators, particularly parasites, and hence a general increase in natural mortality through the armyworm season (Holling, 1959). Ingram's data on percentage mortality in collected, laboratory reared larvae, showed a low level of parasitism and disease in larvae collected in July and August. This was followed by a rpaid rise in parasitism to around 40% in September and October, with a coincident rise in death from disease and unknown causes over the same period. The decline in S. exigua (a species also parasitized by C. inanitus), through the months covered by the crop pest inspection survey, was associated with a significant decline in the numbers of adult parasites sampled, suggesting further that parasites respond numerically to their host population. Lower natural mortality rates might therefore be expected for the first infestations in a particular area (assuming no previous S. exigua infestations). However, the mortality estimates offered here are at any rate conservative and are not sufficiently accurate to justify any modification to allow for possible seasonal changes.

(ii) The limitations of the mortality rates: some theoretical considerations

The 'typical' mortality rates for S. littoralis field infestations that are estimated above are deficient in two major respects; firstly, they do not account for the possibility of seasonal effects on mortality, and secondly, they are assumed to be independent of larval density. In order to discuss the implications of using them in a simulation of pest damage, it is necessary to examine them briefly within the context of the current theories of population, particularly arthropod pest population, mortality and regulation. This discussion is also a necessary background to later comments on the possible diseconomies of insecticide treatment (7.(4)(c)).

Seasonal change brings about changes in factors which have been shown to have an impact on pest populations. These include temperature and humidity (Andrewartha, 1970), and also the state of maturity and rate of growth of the host crop (Southwood and Jepson, 1962). It has been stated that S. littoralis larvae occasionally fall prey to migrant birds whose occurrence is markedly seasonal. Seasonal effects may also act indirectly to affect mortality, for instance, weather changes may cause fluctuations in the density of entomorphageous arthropods.

The main limitation of the 'typical' mortality rates, however, lies in the fact that they do not operate in a pest density dependent manner. It is possible that density dependent mortality does not operate on S. littoralis, however, one characteristic of mortality factors, particularly biological mortality factors, that is repeatedly observed is their ability to regulate the numbers of an animal to promote "a steady density" (Nicholson, 1933; Nicholson and Bailey, 1935). Such a regulatory role has been inferred for parasites and predators when, in certain cases, there has been a sudden removal of these fauna, which has resulted in a rapid increase in prey numbers from persistently low densities to the limits of their food supply (De Bach, 1958; 1965).

Holling (1959), has shown that small mammal predation of insect pupae increases with increasing pupal density. This was due to an increase in the numbers of pupae eaten per predator (functional response) and the numbers of predators present (numerical response). These responses have been confirmed for other predators of pest species. For instance, Dixon (1970), has observed a numerical (but not functional) response for Coccinellid predation of sycamore aphids (Drepanosiphum phalanoides), and functional responses have been observed for aphid parasites (Gilbert and Hughes, 1971). Functional responses by predators in the field have been recorded for bird predation on sawfly larvae (Acantholyda nemoralis) (Tinbergen, 1960), and spruce budworm larvae (Choristoneura fumiferana) (Mook, 1963). They have also been observed for predator prey populations in the laboratory. Those reported include spider (Typhlodromus (T) occidentalis) predation on mite protonymphs (Chant, 1961), wolf spider (Pardosa vancouveri) predation on fruit flies (Hardman and Turnball, 1974), mantid (Hierodula crassa) predation on adult houseflies (Holling, 1965) and beetle (Acilius semisulcatus) predation on mosquito larvae (Ibid.).

A numerical response may be caused by an increase in fecundity of predators with increasing prey population density. For instance, Lawton et al. (1975) cite examples of initially linear fecundity responses for a Coccinellid (Coccinella undecimpunctata aegyptiaca), an hemipteran (Podisus maculiventis) and a mite (Typhlodromus occidentalis), and also negatively accelerating fecundity responses for a Coccinellid (Adalia decempuntata), an hemipteran (Notonecta undulata) and a mite (Phytoseuilus persimilis). The numerical response may also be aided by a faster growth response by predators to an increase in prey density (Ibid.), and by the aggregative behaviour of predators to areas of high prey density (Hassell, 1971; Hassell and May, 1974; Smith and Dawkins, 1971). There is therefore, good evidence from a range of taxonomic groups and ecological niches that support the notion that functional and numerical responses are a widespread if not general phenomenon in biological mortality systems.

Due to inter- and intra-specific parasite and predator interference (Watt, 1959; Hassell and Varley, 1969), and the possibility of density effects on the prey which in turn may affect parasites (Podoler, 1974), any numerical response tends eventually to adopt a negatively accelerating form. Similarly, the functional response becomes negatively accelerating as parasites and predators become satiated, or develop time constraints to further predation and parasitism (such as the finite "handling time" of each predator prey encounter (Varley and Edwards, 1957)).

The 'total response' is an imperfect[1] summation of the functional and numerical responses, expressed as a mortality rate with changing pest density. When the two constituent responses are negatively accelerating, the total response curve is peaked (for diagrammatic illustrations see Holling, 1959, p. 317). The implications of such a mortality system are that if the initial ascending phase of the total response produces a mortality which is sufficient at some density of prey to equal the prey birth rate, the system is regulating, and tends to produce a population which oscillates around an equilibrium level. If, however, the prey population can establish itself at a density beyond the peak (by the temporary removal of mortality agents or large prey immigation),to an area on the declining curve which results in a mortality rate below the birth rate, the population will have escaped regulation. This may result in the type of population explosions described by De Bach (1958, 1965).

It is clear that the 'typical' mortality rates estimated for S. littoralis larvae are not regulating in this manner. If they did apply in the field they would result in irruptions of the pest if the mortality rates were below the birth rate, or cause total extinction if the mortality rates were above the birth rate. It might be argued that the moth population dynamics as indicated in fig. 5:2 are consistent with an annual population irruption of S. littoralis from low overwintering levels, and therefore indicate density independent mortality. However, it is necessary

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[1] Imperfect since they are not independent. Due to an increase in interference, any numerical response will affect each predator or parasite's functional response.

to recognize regulation at a number of life history stages and what is of particular interest in this study is the mechanism of larval mortality. Since there are generally more fields uninfested than infested, a larval density dependent mechanism is not inconsistent with a moth irruption as long as fewer moths are ovipositing on fields than emerging from them. A larval density dependent mortality system will only operate as a constraint on the total species population when all available fields are receiving as many gravid females as they are producing; fig. 5:2 indicates that this did not occur in 1973.

The common occurrence, but low density of S. littoralis reported in the survey (5.(3)(a)), coupled with a few instances of extremely dense infestation (5.(3)(b)) is consistent with the Holling (1959) total response model if it is assumed that there is a significant time delay (May et al., 1974) in the numerical response. This is not difficult to envisage for parasites such as C. inanitus (the major parasite species of S. littoralis in 1972) which was not always abundant when S. littoralis eggs were laid. This parasite therefore required one generation (30 days, approximately the length of one lucerne growth cycle, Vermes, 1967) to respond numerically (ignoring the possibility of minor local aggregations). Under these circumstances a total response (in any particular lucerne growth cycle) will consist of a functional response but without a significant numerical response. Consequently, it is possible to interpret a dense infestation as one in which the prey species (S. littoralis larvae) has escaped control by large scale immigration (moth egg laying). Conversely, the frequently observed low prey densities may be a result of moderate infestations being controlled in a density dependent manner by the functional response of the existing parasites and predators.

SUMMARY - CHAPTER 5

The taxonomy, life cycle and behaviour ofthe Noctuid pest S. littoralis is outlined and illustrations of the immature and mature forms given.

The results of a pest survey of commercial lucerne fields are described which indicate a low incidence of S. littoralis larvae in 1972. Some observations of economic infestations occurring in 1973 are reproduced which show that small post-harvest residual populations of larvae may cause serious suppression of lucerne regrowth, and also that economic damage can be caused by larvae invading adjacent plots.

Laboratory feeding trials using lucerne leaflets as a food source showed a positive response in growth and consumption by the larvae with increases in temperature. At both trial temperatures an exponential increase in growth and consumption occurred for developing larvae until the final instar. Some preliminary investigations into the effects of rearing density on larval growth and mortality are described. These did not show a significant growth/density relationship, but did indicate density dependent mortality. Cumulative larval field mortality under normal conditions is estimated provisionally at over 90%. Some discussion is made of these rates and their implications within the context of the current theories of population regulation.

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CHAPTER 6

Crop and pest interaction: the damage function incorporated into a computer simulation

6.(1) Introduction

It was suggested in Chapter 1 that the pest damage function - a necessary input to any economic appraisal of pest loss and control investment - is frequently complicated by the non-linear and interacting nature of its composite variables. It was subsequently shown that armyworm is a case in point, with the growth of the pest host crop lucerne (3.(2)(c)), the growth and consumption patterns of the larvae (5.(3)(c)) and the natural mortality of their populations (5.(3)(d)), all being important interacting factors requiring consideration before any meaningful prediction of damage can be made.

In this chapter, much of the data presented earlier is drawn together and incorporated into a computer program that attempts to simulate a damage function of S. littoralis infestations on lucerne. There were two primary aims in constructing the program. One was to make explicit some implications of the work on the crop and the pest (much of which did not come directly from observations on field infestations, but from laboratory trials and experimental field plots), by testing a wide range in values for the input variables; a method too time consuming and costly by field studies alone. Secondly, the model was to provide a technique for damage prediction, which being based on a few easily measured field variables, would be a practical tool for pest control agencies in Cyprus. Finally, it was hoped that the model would indicate the sensitivity of variables which could be manipulated, or focus attention on areas requiring further study.

6.(2) A description of the simulation and the functions it contains

The infestation simulation is incorporated into a FORTRAN (McCracken, 1965) computer program. This computes the crop yield resulting from two apposing processes: the growth of lucerne leaves in a pasture, and the consumption of those leaves by infesting larvae. No reliable data is available on the normal incidence or severity of infestations (5.(3)(a), therefore the model is designed only to estimate crop damage from an infestation of measured density. Consequently, predictions are confined to the single infestation from which the computer input variables were obtained.

The total amount of lucerne leaf available is derived from a function expressing the lucerne growth data given in Appendix 3.3. Given the number of days since harvest, the amount of lucerne leaf in 1m^2 of pasture can be calculated (equation 6:1).

$$\text{Dry wt. in g. of lucerne leaf } (W_2) = \frac{87}{(1+86.e^{-0.31t_2})} \qquad 6:1$$

where: t_2 = time in days since the last harvest (lucerne equivalent time)

e = the base of the natural logarithms

The simulation establishes both the amount of lucerne leaf and the maturity (in days since harvest) of the stand at the beginning of the infestation. During a simulated infestation, the larval consumption reduces the leaf available to below that expected after a given number of post-harvest days regrowth. Injury compensating growth by the pasture is assumed to occur at the same rate as post-harvest regrowth. Consequently, two separate time variables are used: the absolute time t_1, andthe lucerne equivalent time t_2 which is generated from the amount of lucerne remaining after consumption. t_2 is derived from equation 6:2 which is substituted from equation 6:1.

$$\text{Lucerne equivalent time } (t_2) = \frac{\log_e \left(\frac{86.0W_2}{87.0-W_2}\right)}{0.31} \qquad 6{:}2$$

The numbers of larvae in the simulated infestation is a function of the original larval density, less the numbers maturing out of the system to pupate, the mortality from all causes and also the numbers that have dispersed due to food shortage.

The original larval population is entered into the program as the mean number of larvae in each of the 'instar' groups present in $1m^2$. of lucerne pasture. The classification of instar groups for real larvae during field sampling was not accurate, since instars can only be identified with any true precision by the measurement of nondistensible parts such as the head capsule (table 5:1), and only approximately by general body size, markings and behaviour. In order to standardize the estimation of instars, laboratory cultured larvae were visually allocated to an 'instar'[1] group and then weighed. The results of the weighings formed the basis of the six 'instars' used in the simulation. In drawing the weight boundaries between 'instars' due regard was given to the range of the original weighings by establishing an equal number of standard deviation units between any two adjacent 'instar' groups. The results of the weighings, and the 'instar' weight boundaries are given in Table 6:1.

The infestation density for the simulation input is determined by field sampling, and is entered as the mean number of larvae in each 'instar' found within $1m^2$ of pasture. In the program, each larva is assigned a random weight within the limits of its 'instar' group. It then grows at the rate determined as the mean growth for larvae reared at 24-26°C under laboratory conditions (5.(3)(c). This function in the program is an expression of the relationship between the number of days since hatching, and the liveweight in grams of the larvae. Initially, larval maturity in days since hatching plus one day's simulated growth (t_o), is determined for each of the larvae from their random weights (W_N):

$$\text{Age of larva in days since hatching } (t_0) = 1+3.4091+1.1095x+0.4461x^2$$
$$\text{where: } x = \log_{10} 10{,}000\ W_N \qquad 6:3$$

Once the age of each larva is established on infestation day + 1 their corresponding weight on infestation day + 1 is estimated from the growth equation (6:4) substituted from (6:3).

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[1] When these approximate instar groups are referred to, use of inverted commas ('instars') indicates that they are the allocated rather than the actual groups.

TABLE 6:1 Weight boundaries of 'instar' groups

'Instar'	Sample size	Mean ($\bar{x}$) wt. of 'instar'	Standard Deviation(s)	Lower Limit	s. units below $\bar{x}$	Upper Limit	s. units above $\bar{x}$
1	-	-	-	0.0001	-	0.0021	1.50
2	18	0.0091	0.0047	0.0021	-	0.0159	1.45
3	67	0.0540	0.0264	0.0159	1.45	0.1014	1.81
4	63	0.2223	0.0670	0.1014	1.81	0.2991	1.14
5	54	0.4681	0.1479	0.2991	1.14	0.6199	1.02
6	42	0.8340	0.2100	0.6199	1.02	1.2000	To zero consumption

$$\text{Liveweight of larva in g.}(W_N) = \frac{e^{2.581(\sqrt{(1.7842t_0-4.8516)} - 1.1095}}{10,000} \qquad 6{:}4$$

By the use of these two equations[1] the 'age' and 'weight' of the simulated larvae is estimated on infestation day + n.

Simulated larval mortality is a random event, the probability of which is set by the mortality rates specified for any particular 'instar'. A facility for increasing mortality to 100% for a specified absolute time is included so that fast acting control treatments such as insecticide spraying can be simulated.

The amount of lucerne leaf that a simulated larva requires is estimated from a function relating larval weight in grams, to grams dry weight of lucerne leaf consumed per day. This function is derived from data on lucerne consumption by larvae reared in the laboratory at 24-26°C (5.(3)(c)).

Both the growth and consumption rates of the larvae showed an increase and subsequent decline through the larval period. A function directly combining the two would therefore be ambiguous since for some of the larval weights there would be two possible equivalent consumptions: one before the maximum weight achieved and one after the maximum. To avoid this confusion, the data on

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Equation 5:1 in the text of Chapter 5 is not used for two reasons. Firstly, the $\log_{10}$ growth phase is not continuous for the full range of larval weights, and secondly, the growth data had to be transformed so that the consumption function could be more easily incorporated into the program.

growth is transformed. Any reductions in larval weight were recorded as positive additions to the highest actual larval weight. This resulted in a continuously ascending larval weight/time function. When the liveweights thus transformed are plotted against the corresponding consumption data a parabolic relationship results (fig. 6:1). From this the consumption function was calculated.

In order to describe the whole of fig. 6:1 four separate expressions are used. A polynomial regression equation was fitted for the first curvilinear phase (larvae < 0.4g. liveweight) using consumption data transformed to $\log_{10}$. Larvae falling beyond this point are divided into three groups and their consumption demands estimated from two linear regressions using linear consumption and liveweight data, and a third linear function derived from a line drawn by eye (the points were so scattered in this area that a least squares fit would not have been useful). The full equations as they are used in the program are given in Table 6:2.

TABLE 6:2 <u>The consumption function</u>

Area of Curve in fig. 6:1	W_N	Co (Consumption in g. dry weight lucerne leaf consumed/day)	
(1)	0.0001-0.4g	$x = \log_{10} 10{,}000\, W_N$	6:5
		$y = -87.8373+125.441x-65.2327x^2 +14.9246x^3-1.2608x^4$	6:6
		where:	
		$Co = \dfrac{e^{(2.3026y)}}{10{,}000}$	6:7

TABLE 6:2 (Continued)

(2)	0.4-0.7g	$Co = 0.29\ W_N - 0.038$	6:8
(3)	0.7-0.95g	$Co = -0.3\ W_N + 0.375$	6:9
(4)	0.95g	$Co = -0.360\ W_N + 0.432$	6:10

Equation 6:10 and fig. 6:1 show that there is zero consumption for larvae weighing 1.2g. When larvae develop to this stage, they exit from the system and are recorded as 'pupae'.

In a situation where the total consumption demanded by the simulated infestation is in excess of the amount of leaf available (a consumption demand deficit), some larvae disperse to reduce consumption demand to a level commensurate with the supply. It has been indicated (5.(3)(b)), that larvae in different instar groups will vary in their propensity to disperse. In the program, the probability of a larva dispersing in a situation of consumption demand deficit is determined by the size of that deficit and the intrinsic dispersal propensity of the 'instar' group to which it belongs.

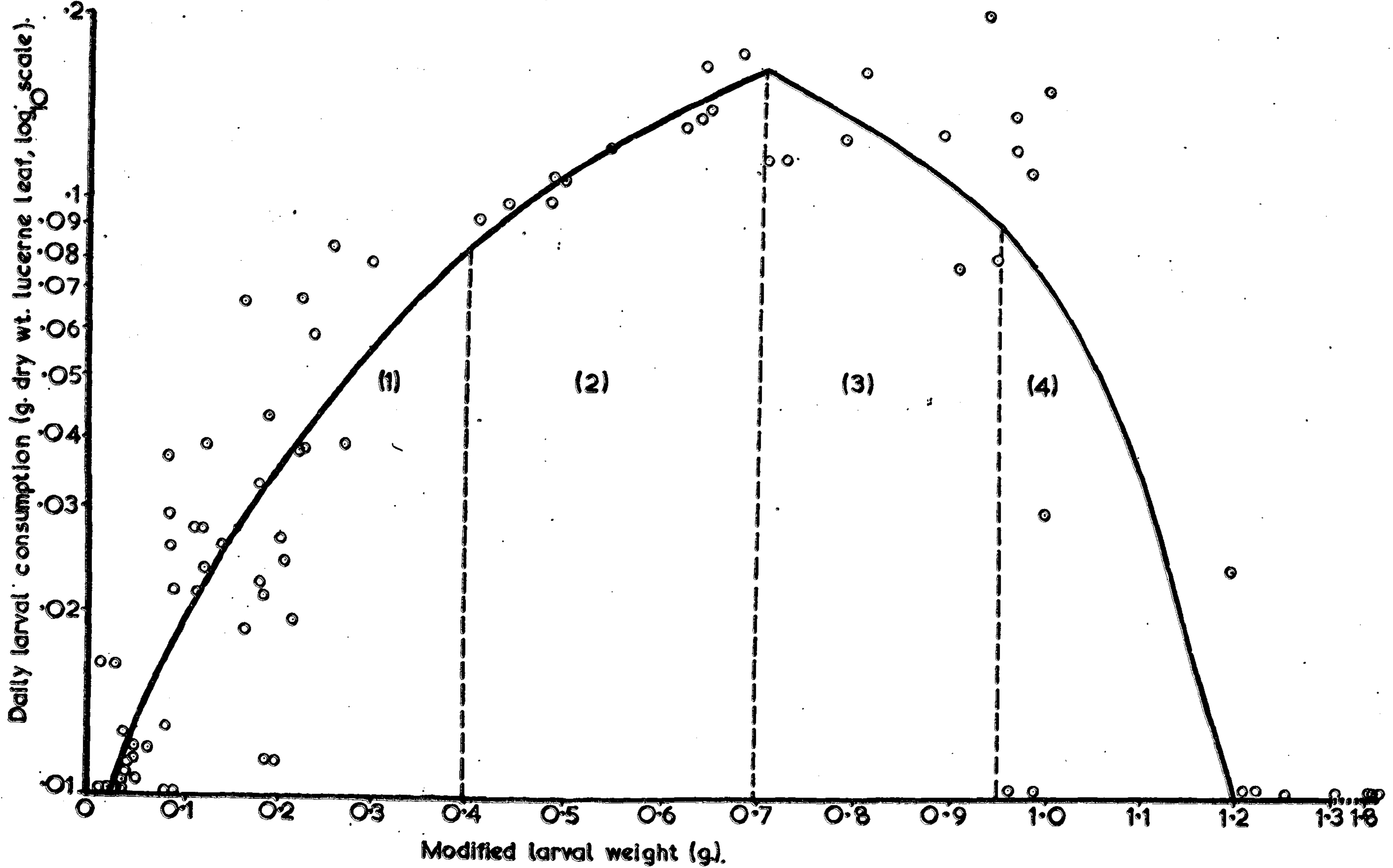
The program calculates the numbers dispersing from each 'instar' group by applying the following scheme:

Let:

Ni = Numbers of larvae in each 'instar'

Ni(o) = Numbers of larvae in each 'instar' before dispersal

Fig.6:1 Larval consumption and modified liveweight data, measured at 24-26°C.



$Ni(1)$ = Numbers of larvae in each 'instar' after dispersal

$D'(i)$ = Propensity for 'instar' (i) individuals to disperse

$W(1)$ = Leaf remaining after consumption

$W(o)$ = Consumption demanded by $\Sigma Ni(o)$

$C(i)$ = Consumption/larva in 'instar' (i)

Di = Proportion of $Ni(o)$ that disperse to leave $Ni(1)$

D_6 = Total proportion of $\Sigma Ni(o)$ that disperse

If:

$$Di = \frac{Ni(o)-(Ni(1)}{Ni(o)} \tag{6:11}$$

$$Di = D'(i).D_6 \tag{6:12}$$

$$Ni(1) = Ni(o)-D_6D'(i).Ni(o) \tag{6:13}$$

$$W(o) = C(i).Ni(o) \tag{6:14}$$

$$W(1) = C(i).Ni(o)-D_6\Sigma C(i).Ni(o).D'(i) \tag{6:15}$$

then

$$D_6 = \frac{W(o)-W(1)}{\Sigma C(i).D'(i).Ni(o)} \tag{6:16}$$

D' (i) is given in the program and from 6:11 the proportion of any 'instar' that is required to disperse (Di) is calculated.

The timing of the infestation is set by a specification of the 'infestation day' (t) in terms of absolute time t_1. When $t = t_1$ the infestation larval density, as specified by the data input begins to consume an undamaged crop. Hence, the simulation ignores any damage prior to the time when the actual population was sampled.

On day $t_1=28$ the lucerne leaf is reduced to that amount existing on $t_1=0$, thus simulating a crop harvest. The program then continues until the crop yield is at its maturation level $W_2 \geqslant 86.0 g/m^2$ and then stops. It is necessary to monitor two growth cycles of the lucerne so that the effects of an infestation occurring late in a crop growth cycle can be properly assessed by the inclusion of damage caused by an after cropping residual population of larvae.

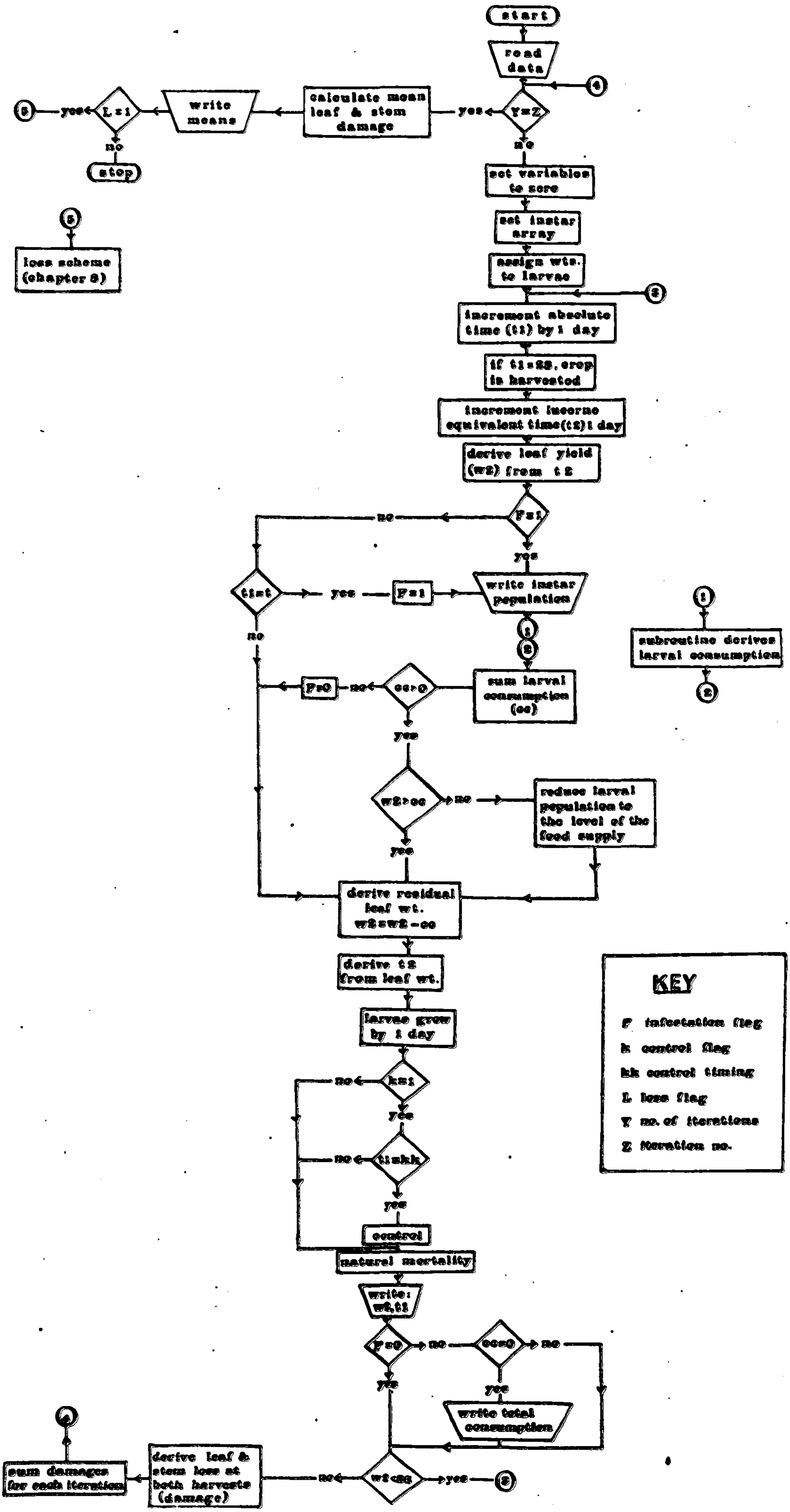
The program is rerun with the same data according to the number of iterations (Y) specified in the data input. A number of output samples are required since some of the events in the simulation are determined randomly, such as the initial allocation of larval weights, or are probabilistic events such as mortality.

A simplified flow-diagram of the program is given in fig. 6:2.

6.(3) The inputs and output of the simulation program

The field data required for the simulation are the numbers of larvae/m^2 in each of the 'instar' groups, and the maturity of the lucerne stand in days since last harvest. In addition, the program requires the specification of the number of reruns (iterations) with the same data, and whether pest control is to be simulated and if so on which day. For flexibility, the mortality rates per'instar' and the dispersal propensity ratios are also entered as data, although reasonable 'standard input' values for these are given below.

Fig.6:2 Simplified flow-diagram



The program output prints the input variables and then a list of daily events including the absolute time, the corresponding amount of lucerne leaf in g. dry wt./m^2., the total larval consumption, the larval population by 'instar' and the numbers of larvae either pupated, dead or dispersed. A sample of output is given in Appendix 6:2.

Two damage components can be recognized from the output: the loss of stem yield and the loss of leaf yield. It has been shown (3.(2)(c)) that leaves and stems have different nutritional qualities. Consequently, for a given level of total damage (i.e. leaf + stem damage) there are a range of loss values corresponding to the range of possible proportions of total damage that may be attributed to leaf loss. Hence, important differences in losses may be concealed, such as when the total damage resulting from infestations occurring early and late in a pasture growth cycle are compared. In instances following a late infestation, a moderate total damage figure may result from an abundance of mature, but defoliated stems. It would be misleading to equate such a yield with a rapidly growing leafy and semi-mature pasture emerging from early injury and giving the same yield on the scheduled harvest date. Since there is no single leaf: stem value ratio that may be determined as being an appropriate reflection of farmers' preferences for leaves rather than stems as a fodder source (3.(2)(e)), it is not possible unequivocably to express total loss in terms of total damage. Consequently, leaf and stem damage are given separately.

From the program output, the total larval consumption is taken to represent injury due to larvae, the difference between expected and actual leaf yield at harvest (both harvests - days 27 and 55 - if there is a carry-over population) is taken as leaf damage, and the difference between the expected leaf yield at harvest and the highest leaf yield simulated during the growth cycle is taken to represent stem damage. Stem damage is calculated on this basis because of the assumed 1:1 ratio between leaves and stems during the growth cycle (3.(2)(c)). Also on the further assumption that stem growth is equal to leaf growth until injury reduces leaf weight to below stem weight, in the event of which stem growth is halted until the leaves are restored to a level equal to the stems. The mean values for leaf and stem damage calculated from the results of each program rerun are printed in the output.

6.(4) Input values tested

Infestations have been reported occurring during most stages in the growth cycle of lucerne, and with a wide range of larval densities. Similarly, fields in different localities on the island, or those subject to different cultivation regimes, may vary in their natural faunal wealth resulting in a range of larval mortality rates. There is therefore no standard infestation. However, from the field data it is possible to indicate 'typical' values for the inputs. By testing a range around these values and by keeping all the other inputs constant, an assessment was made of the importance of variations in the input factors in terms of their overall impact on simulated injury and damage.

As many as 1,000 larvae/m.^{2} have been observed in armyworm infestations of lucerne. A range of larval densities from 30-1,350 larvae/m^2. in the proportion of 1:2 first to second 'instar' was tested.

The timing of the infestation is specified in terms of crop maturity. Hence, the infestation day is the lucerne equivalent time (t_2) on which the larvae were sampled. There is evidence that S. littoralis moths are attracted to oviposit on freshly irrigated lucerne (5.(2)). If the first irrigation occurs 2-3 days after harvest, and the second 10 days later, there would appear to be two periods of high susceptibility: days 3-6 and 13-16. Egg laying on these dates would result in populations of second instar larvae on days 8-11 and 18-21 respectively. If the farmer harvests his lucerne on day 27 any infestations following the second irrigation will be disrupted. However, the early infestations have sufficient time to develop to maturity before the scheduled harvest. Consequently, day 9 was taken as the typical day for the appearance of first and second instars. However, other possible timings from the earliest (t_2=1) to the latest (t_2=27) were also tested.

It is stated in 5.(3)(d) that the overall mortality from the eggs to the adults of S. littoralis in lucerne fields is probably very high and to exclude this factor from the simulation would result in over-pessimistic estimates of crop injury and damage.

Table 6:3 is a summary of the conservative estimates of field mortality for *S. littoralis* larvae made in the previous chapter. These have been converted to give daily mortality rates (assuming two days/'instar') and are offered as 'typical' values for field mortality amongst armyworm in Cypriot lucerne fields.

A cumulative mortality for the total larval period is calculated from the daily rates.

TABLE 6:3 Some estimates of the 'typical' daily mortality rates in field infestations of *S. littoralis* larvae

Mortality Factor	Rates expressed as fractions of each 'instar' group/day						Cumulative Mortality (2 days in each 'instar')
	1	2	3	4	5	6	
Wind Dispersal[1]	0.05	0	0	0	0	0	
Dessication[1]	0.10	0	0	0	0	0	
Parasitism	0	0	0.20	0.05	0.01	0	
Predation							
(a) Arthropods	0.30	0.20	0.05	0	0	0	
(b) Birds					0.99 or 0		
Disease	0	0	0.01	0.02	0.05	0.05	
TOTAL FOR EACH INSTAR[2]	0.35	0.20	0.26	0.08	0.06	0.05	0.90

In addition to these values, the effect of changes in the mortality rates on simulated injury and damage was estimated using the rates given in table A6:1(3).

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[1] These mortality factors will probably operate soon after hatching, consequently, predation is 0.3 of the surviving first 'instars'.

[2] Bird predation counted at zero since it is of intermittent occurrence.

Field observations show that armyworm larvae disperse or disappear from recently defoliated or cropped pasture to leave a small residual population composed mainly of the smaller larvae. from the original population (Chapter 5). Population counts before and after dispersal (table 5:3),were used to calculate factors expressing the change in the proportions of each 'instar' through a dispersal situation.

Since it is likely that the dispersal effect is independent of field size (5.(3)(b)), it is not necessary to define the field boundaries of a particular infestation under consideration. The assumption that the infestation can be modelled in the form of $1m^2$ samples wastherefore retained.

There is no data for first instar larvae, but it is assumed that they are of extremely low mobility and further, that none would have dispersed if they had been present in the population recorded in table 5:3. Using the data from that table, a measure of the relative dispersal propensity of each 'instar' is derived from reciprocals of their proportionate survival through a dispersal situation (Table 6:4).

TABLE 6:4 <u>Changes in 'instar' populations through dispersal and the relative dispersal propensities for each 'instar'</u>

	'Instar' Groups					
	(1)	(2)	(3)	(4)	(5)	(6)
Larvae/m^2 before dispersal	-	502.4	360.4	43.6	24.0	9.2
Larvae/m^2 after dispersal	-	149.4	100.8	1.2	0.4	0.4
Proportion remaining (A)	1	0.2974	0.2797	0.0275	0.0167	0.0435
Relative dispersal propensity $\left(\frac{1}{A}\right)$	1	3	4	36	60	23

These ratios are the best proxy values, given the paucity of data, however, the sensitivity of damage estimates to changes in these values was tested. This was done by applying a range of values from those favouring early 'instar' dispersal, through equal 'instar' dispersal propensity, to ratios causing a preferential dispersal of the later 'instars'.

It has been stated that the program will reduce the larval population to zero on a specified day, thus simulating pest control treatment. The simulated injury and damage from an infestation controlled at progressively later intervals of infestation is given in table A6:1(5). The specification for no control is 0,0, and for control it is 1,n, where n is the number of days after the infestation day when the control treatment is to be applied (n can be 0).

The program is rerun a specified number of times with the same data. For the purposes of estimating the trends in the sensitivity analysis, 3 iterations were specified, however, for a reliable mean value of simulated injury and damage from a single set of input data, 5 or more iterations are recommended.[1]

Having discussed the data inputs, Table 6:5 is presented which shows the form and order of a set of typical data input cards. Each set of variables is printed on a separate card beginning

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[1] This source of variability in the program output cannot be used in a wider context for field prediction unless some estimate of the extent of the infested area is given. Clearly, the smaller the area the more susceptible it is to a 'random drift' in damage.

in column one. The purpose of the two indicator flags on card 2 is described in Chapter 8. For the moment, it is only necessary to state that for the routine under consideration they need to be set to zero.

TABLE 6:5 Set of sample data input for damage simulation[1]

Card number	Type of data	Program variables	Real* or integer	Representative values
(1)	Instruction to start reading data			& RUN
(2)	Indicators for schemes described in Chapter 8	L Flag, ET Flag	integers	0,0,
(3)	Larval density by 'instar' in larvae/ m^2	N	integers	100,200,100, 0,0,0,
(4)	Infestation day	T	integer	9,
(5)	Iterations	Y	integer	5,
(6)	Dispersal ratios by 'instar'	D	integers	1,3,4,36,60,23
(7)	Daily mortality rate by 'instar'	M	real	0.35,0.20,0.26, 0.08,0.06,0.05
(8)	Control: specification (yes or no) and timing	K,KK	integers	0,0,
(9)	Instruction to end or read in a different set of data			& RUN or & END

*Real numbers contain decimal points, see McCracken, 1965.

6.(5) Results

In the following subsections, the simulated response of injury and

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[1] Program control and data and input will be different when using other computers. Format shown here was compatible with Stirling University's ICL 1430 computer.

leaf damage to a range of different values in single input variables are shown separately, in graphical form, for each of the input variables. It must be emphasized that these two dimensional representations are likely to be misleading if seen in isolation, and that the main value of the simulation lies in its ability to express the total effect of a number of changing inputs. However, it is useful to establish the characteristic effects of the various inputs so that their contribution to damage or possible control can be assessed. Leaf and stem damage were not combined to give a total damage plot in these figures for reasons given above (6.(3)). A further reason was that such combined representations would have served to obscure the direct effects of the variables on leaf damage. Since leaf damage was, from the loss point of view, the most significant damage component, and since simulated stem damage was directly derived from leaf damage, only the latter are shown in the results. However, mention is made of the stem damage response to each of the variables.

6.(5)(a) The simulated effect of larval density on injury and damage

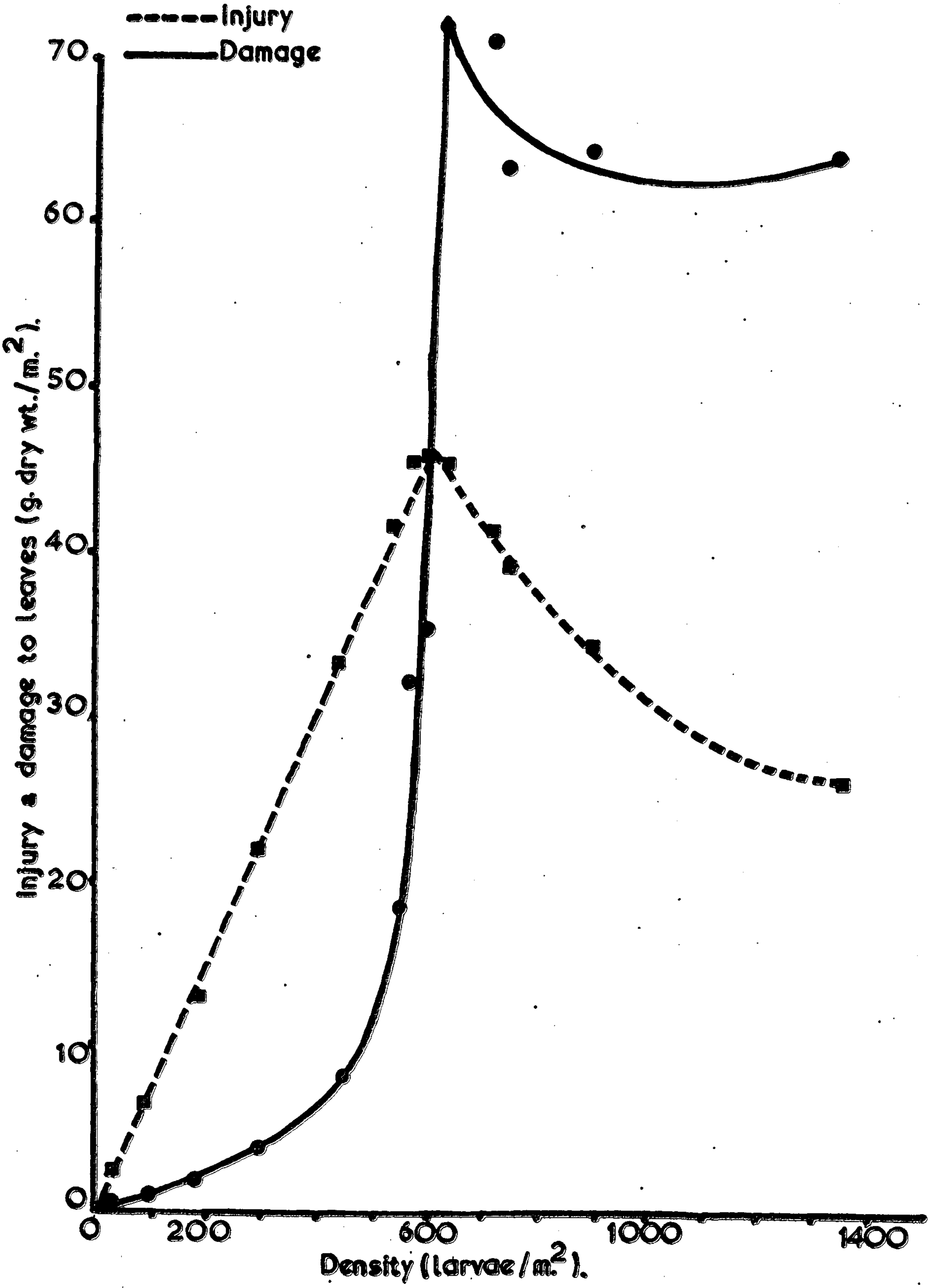
Fig. 6:3 shows the simulated relationship between injury and leaf damage with changes in larval density. Table A6:1(1) gives the values of the other input variables and records the mean injury and damage estimates from the output.

Injury is a linear function of larval density until a leaf consumption demand deficit situation occurs. In this event, some of the larvae disperse according to the scheme described above. At those larval densities where the demand deficit first appears (600-650 larvae/m^2.) there is a fairly rapid decline in injury, this trend diminishes with further larval density increases.

The initial linear increase in injury with larval density is explicable by the constant 'instar' proportions and growth and mortality rates within the population at each density. The decline in injury after a larval dispersal situation is due to the interaction of larval consumption with the regenerative properties of the lucerne.

In a consumption demand deficit situation, all the existing leaf has been consumed. The simulated crop then produces an estimated 1g. dry wt. leaf/m^2./day from crown buds. The total consumption of a population undergoing dispersal will thus be equal to that quantity of lucerne that was consumed prior to the demand deficit situation, plus approximately 1g./day for as long as the residual population survives in the pasture. The denser an infestation in a demand deficit situation, the smaller will be the figure for injury since dispersal occurs sooner, leaving the residual larvae to survive on the small amount of regeneration from a totally defoliated stand. Hence, the minimum value that injury will reach in this declining phase is attained when the population disperses on the first day of effective infestation. In this situation, the total injury will be the amount available on the infestation day plus the daily regeneration of leaf consumed by the residual

Fig. 6:3 Simulated effect of changes in larval density on injury & leaf damage.



population. In fig. 6:3 the infestation occurs on day 9 when 13.0g./m^2. of leaf is available. It lasts for approximately 12 days. Assuming 0.0-1.0g./m^2. daily consumption after dispersal on day 9, the total consumption will be 24.0g./m^2.. This injury occurs for a larval density of approximately 1,400 larvae/m^2..

The other plot in fig. 6:3 indicates the simulated relationship between leaf damage and the larval density. This is curvilinear in form sharply ascending at the point where larval densities exceed 500/m^2.. Damage reaches a peak of 84% leaf loss just prior to those densities causing dispersal.

The leaf damage relationship is a result of the balance between the timing and size of larval consumption demands, and the leaf growth of the lucerne. With low larval densities the leaf loss is negligible by harvest time since the small total consumption demands are occurring in the rapid growth phase of the lucerne (days 10-20 normally), and compensation by the crop is sufficient to overcome this early injury. However, as consumption increases the damage increases disproportionately, since the amount of leaf taken relegates the lucerne compensation rate further towards the slower growth area. At that particular larval density where consumption demands equal the total leaf available on the last day of the infestation, leaf damage will be at its maximum.[1] Greater larval densities than this cause

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[1] At this density, the leaf will be reduced to zero on day 21 (infestation day 9 plus 12 infestation days), and has only 7 days recovery growth resulting in a yield of 8g./m^2. leaf at harvest.

dispersion before the last day of infestation, and there is likely to be a small amount of leaf on day 21 giving rise to a higher yield at harvest. A second rise in leaf damage occurs when there are sufficient early 'instar' larvae maturing to cause a double dispersion during one infestation.

Stem damage rises with increases in larval density until there are sufficient larvae present to reduce the quantity of leaf to a level below that existing on the day of infestation for the duration of the infestation. When this occurs stem damage remains constant for all further increases in larval density. However, stem damage is ultimately controlled by infestation timing (6.(5)(b)).

6.(5)(b) The simulated effect of infestation timing on damage and injury

Table A6:1(2) records the simulated effect that a change in the time of infestation has on injury and leaf damage. Fig. 6:4 is a graphical illustration of these results.

With very early infestations, a situation of consumption demand deficit occurs. The earlier in the lucerne growth cycle that this occurs, the smaller the amount of leaf available and the greater the dispersal.

When the total consumption demands are met by the lucerne, crop injury maintains a constant value for all subsequent timings until day 19. The decline in injury after day 19 is due to the disruption and dispersal of the population caused by the first cropping of the lucerne on day 28.[1]

Leaf damage relates less obviously with infestation timing. In fig. 6:4 there is an initial ascending phase of increased damage with later infestations, and then a rapid decline until around day 4-5. There is then a slow increase in leaf damage with subsequently later infestations, until a further decline and following rise is indicated.

The initial increasing phase of damage shown in fig. 6:4 continues until day 3 and is a result of the suppression of lucerne regrowth by the larval population. The later the suppression continues, the greater will be the damage. The peak is achieved at the margin where sufficient larvae exist to reduce the available leaf to zero at the latest infestation timing. Beyond this point the balance moves in favour of the lucerne.

In the descending damage phase (day 3 to day 7), there is a reduction in leaf damage, since the leaf remaining after consumption is contributing to production. The very sharp decline in damage in this phase is due to the rapid increase

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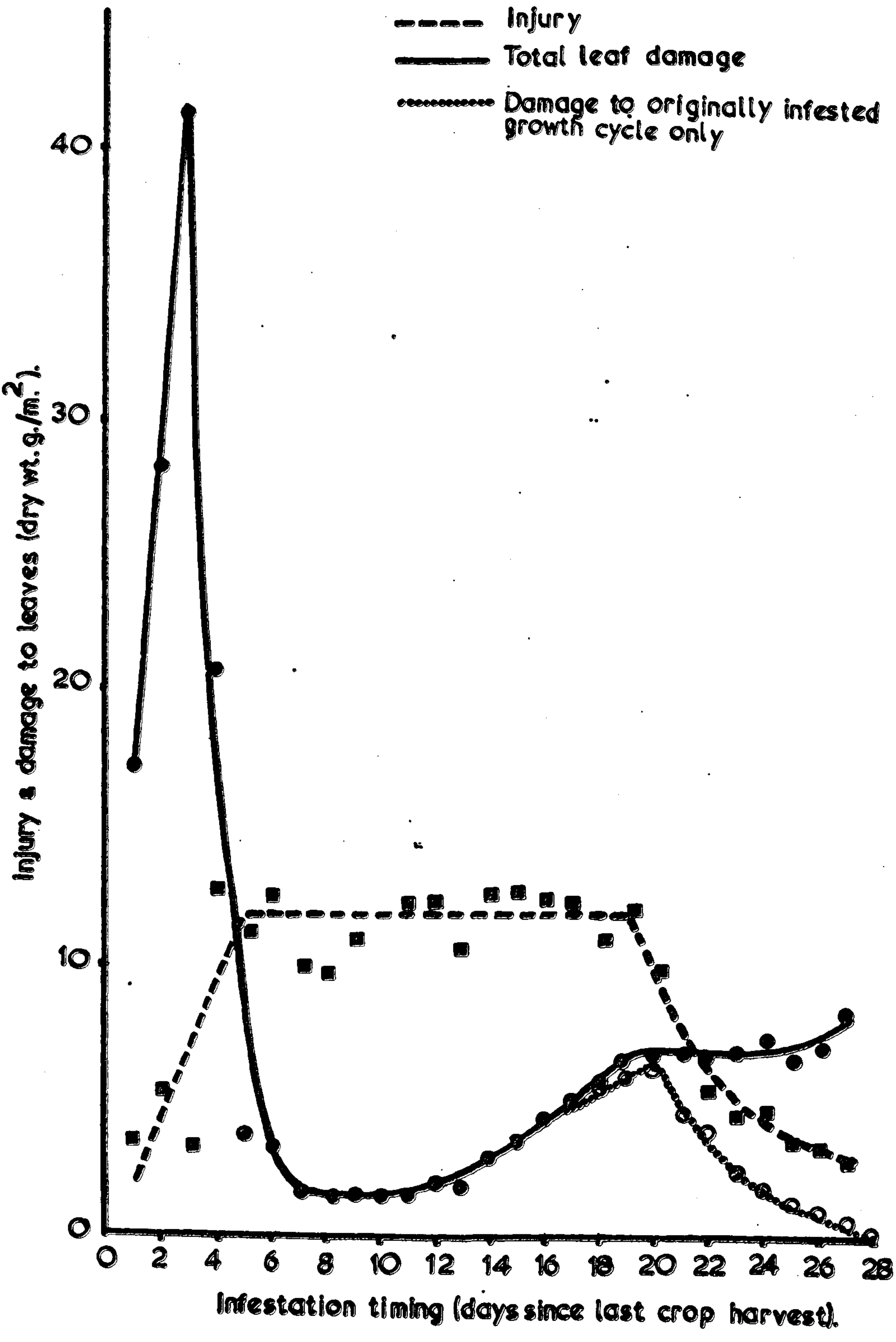
[1] Given the definition of injury as total larval consumption, there is no inconsistency about future events affecting injury.

Fig. 6:4 Simulated effect of changes in infestation timing on injury & leaf damage.



in lucerne leaf surplus with later infestation timings. Even a small surplus is sufficient to by-pass the slow growth stage in regeneration which is incurred by dispersal capacity infestations.

This trend is complete in the middle phase (days 8-18), where there is sufficient leaf surplus for compensation to occur at the rapid rate. In this phase, there is a gradual rise in losses with later infestations, this is because the lucerne although growing at the rapid rate is given less time for compensation before harvest.

At infestation timings later than day 18 there is a residual population of larvae left after the first cropping and this affects the second lucerne growth cycle. The total damage due to infestations occurring subsequent to this time therefore includes damage to both the first and the second lucerne cropping. The separate, and total leaf damage figures are given in the tables and shown in fig. 6:4.

The decline in the leaf damage estimates for the first cropping during this stage, is non-linear. This is the result of two effects: firstly, there is the non-linear compensatory growth by the lucerne, and secondly, infestations are disrupted at progressively earlier stages, when their consumption capacity is not fully developed.

The increases in the total leaf damage estimates in this area are largely a result of the suppression of regrowth of the second lucerne growth cycle. This follows the same pattern as an early infestation in the first growth cycle, but the relationship is somewhat masked by the declining first cropping damage.

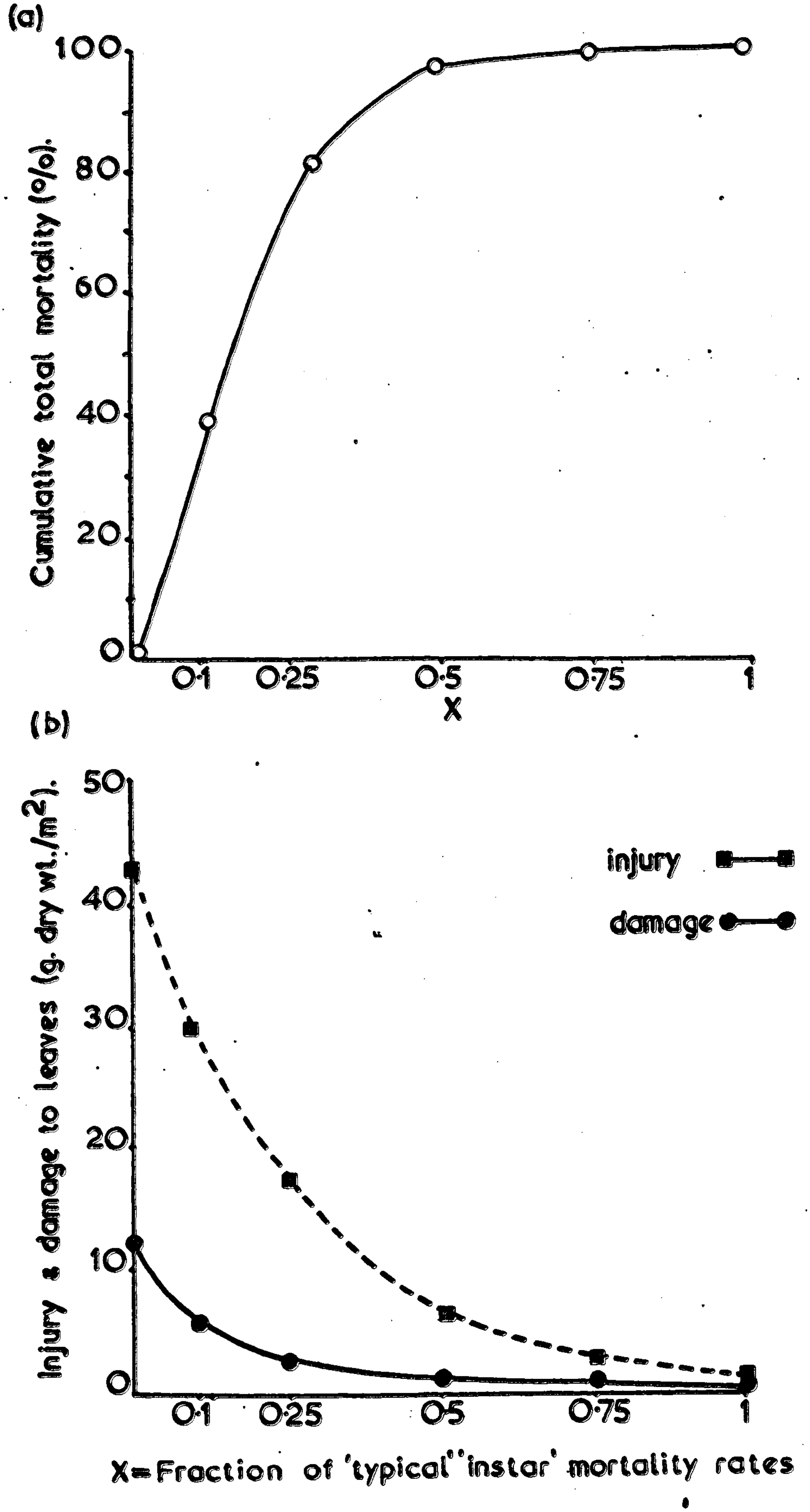
Simulated stem damage under circumstances of changing infestation timing is never more than the difference between the existing amount of stem on the first infestation day and the expected yield at harvest. It may be less than this due to compensation by the leaves, in which case leaf and stem damage are equal, but since stems are not attacked they must be as well represented after an infestation as before it.

6.(5)(c) The simulated effect of changing mortality rate on injury and damage

Increases in the severity of an endemic disease, or the numbers of mortality agents such as parasites or predators, result in a disproportionate increase in total overall mortality. This is because a unit increase in mortality affects each 'instar'. This relationship is shown in fig. 6.5(a) (data: table A6:1(3)). The limitations of these rates as approximations of the field conditions have been discussed (5.(3)(d)).

Since, for a given age distribution in the larval population the total consumption demand is a direct function of numbers, a similar relationship is manifested in fig. 6:5(b): the simulated

Figs. 6:5(a) & (b) Effect on cumulative total mortality & simulated effect on injury & leaf damage caused by changing instar mortality rates.



effect of changes in mortality rate on injury.

The simulated relationship between leaf damage and changes in larval mortality is also of this form (fig. 6:5(b)). However, leaf loss at harvest is sensitive to other factors such as infestation timing, and the curve may take a variety of forms depending on the values of the other inputs.

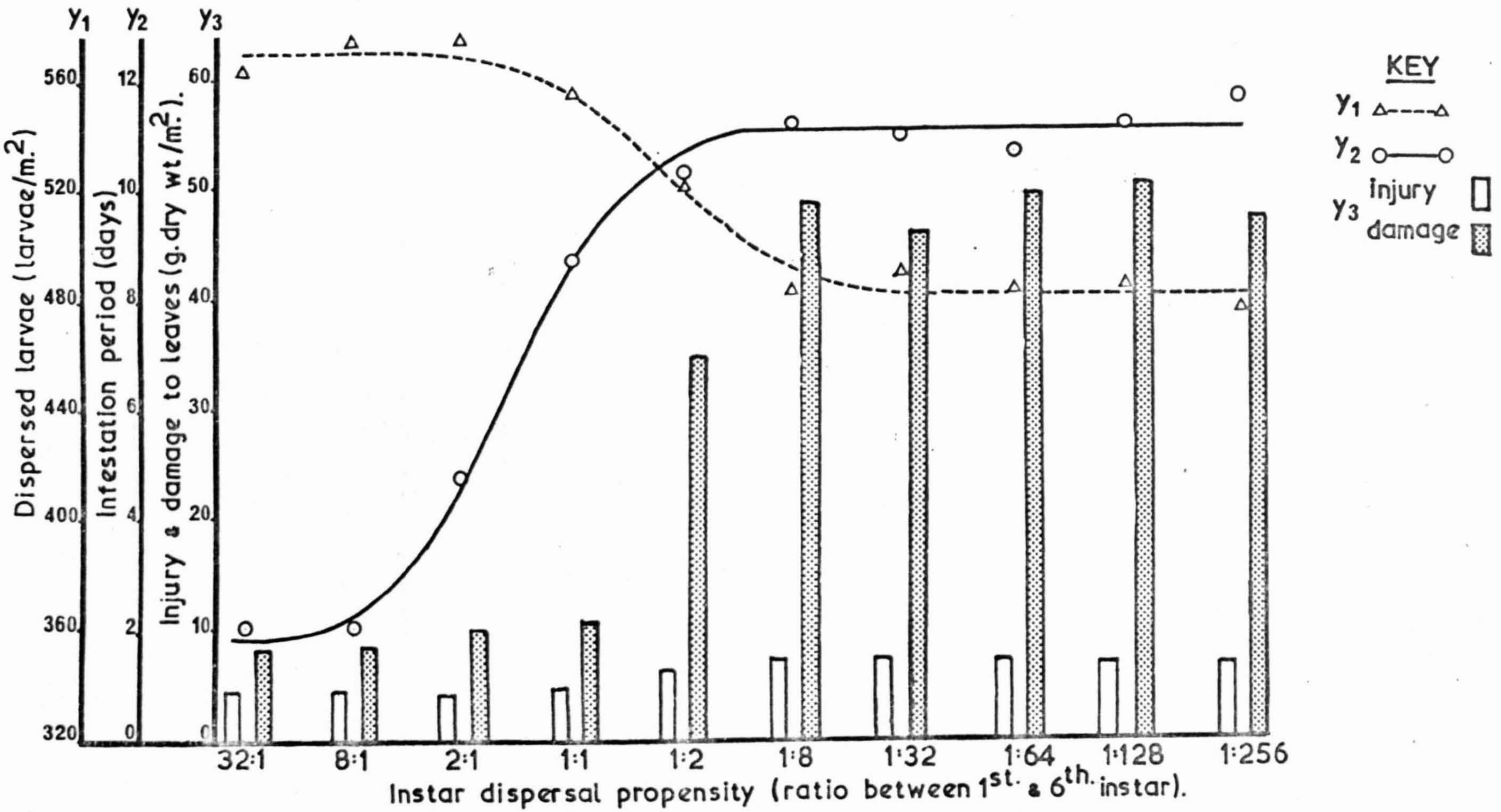
The response of stem damage to changes in larval mortality rates is as in the case of leaf damage, similar to the response to larval density changes.

6.(5)(d) The simulated effect of changing the larval instar dispersal ratios on injury and damage

The simulated effect of a change in dispersal ratios is shown in fig. 6:6 (data: table A6:1(4)). Also shown in this figure is the mean infestation time period and the mean number of larvae dispersing from infestations identical except for different dispersal properties.

A residual population of late 'instar' larvae will pupate out of the system sooner than an equivalent population of early 'instar' larvae. Therefore, the effect of changing the dispersal ratios from favouring early 'instar' dispersal to later 'instar' dispersal is to extend the infestation period. An increase in the infestation period in a situation of consumption demand

Fig. 6:6 Simulated effect of changes in instar dispersal propensity on injury, damage, infestation period & total number of dispersed larvae.



deficit has only a slight effect on injury since the amount of lucerne generated for the extra days is small (1.0g./m.^{2}/day). However, the extra days suppression of regrowth has a marked effect on the leaf damage which rises rapidly when dispersion ratios move in favour of later 'instars'.

The extension of the infestation period is limited to the length of a normal period during which no dispersal occurs, this is approximately 12 days. The introduction of a small bias in the dispersal ratios, favouring late 'instar' dispersal, causes the infestation period to increase rapidly towards this limiting value. Thus, a change from a small bias towards early 'instar' dispersal (ratio 2:1 between first and last 'instar' dispersal), to a small bias favouring late 'instar' dispersal (1:2 ratio), is sufficient to raise the infestation period from a mean of 4.8 days to a mean of 10.8 days, with resulting large increases in leaf damage estimates. However, increasing this bias over one hundred times (ratio 1:256), increases the period by only a further mean of 1 day, with correspondingly small increases in damage.

As in previous examples, the response of stem damage to changes in dispersal ratios is governed by infestation timing. In early infestations when very little stem is present the response is as of leaf damage.

Since in a consumption demand deficit situation more smaller larvae are required to disperse than larger ones, a tendency towards later 'instar' dispersal results in a reduced total number of larvae dispersing.

The implication of these results is that once a marked bias favouring later 'instar' dispersal has been demonstrated for larvae in the field, further observations to establish an accurate quantitative expression for this, will not greatly increase the accuracy of prediction. This illustrates one important role of modelling techniques when dealing with complex ecological problems. They may, as in this case, justify excluding a considerable amount of field work from the research programme.

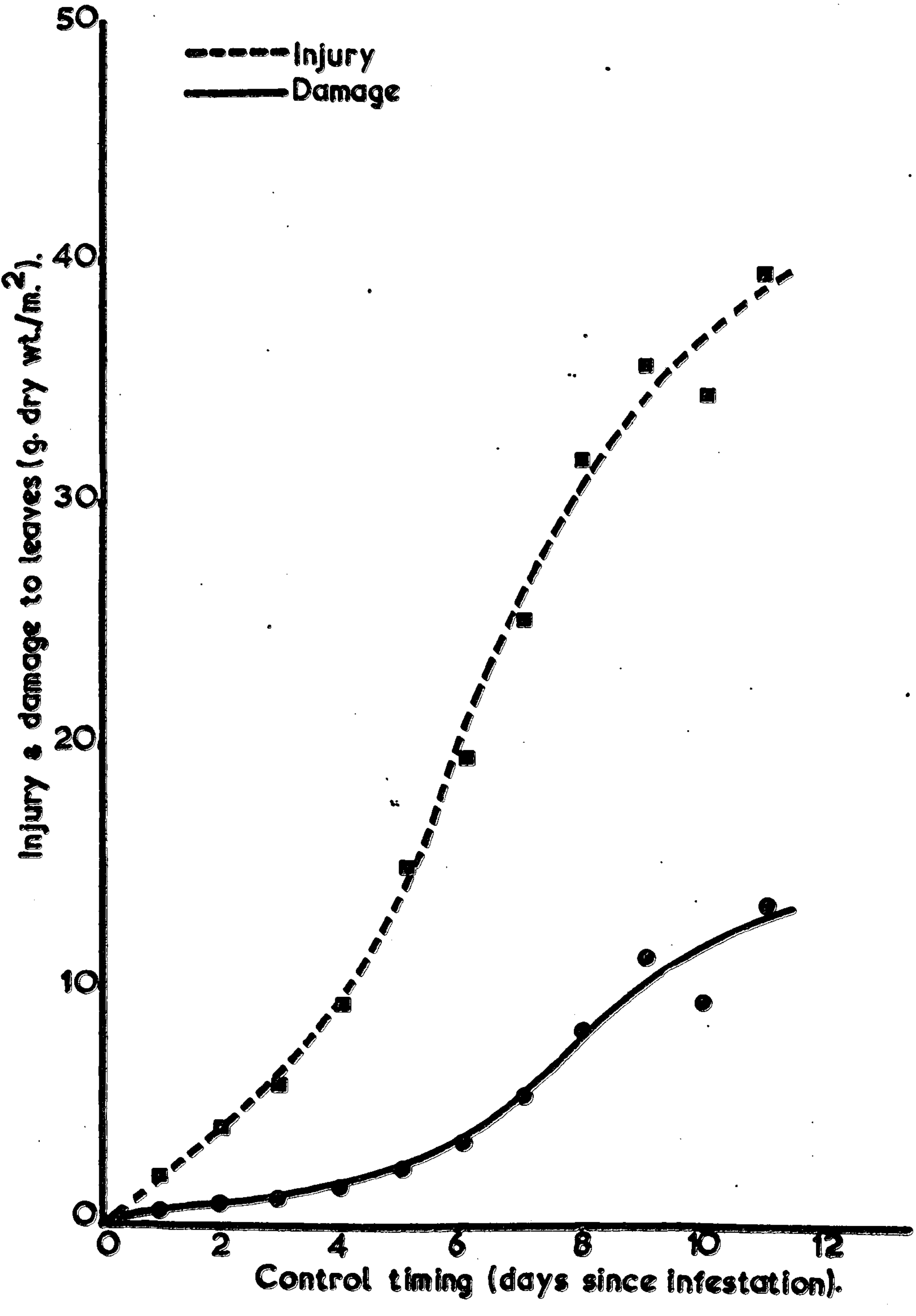
6.(5)(e) The simulated effect of timing of control application on injury and damage

Table A6:1(5) and fig. 6:7 show the simulated injury and damage caused by larval populations of 450 larvae/m^2. controlled at increasing time after infestation.

The injury response illustrates the rising consumption demand of a growing infestation. This rise does not follow the consumption pattern of an individual larva since the total population is constantly being reduced by mortality.

The simulated leaf damage shows a much less marked response, but damage is affected grossly by other factors and a characteristic curve for relationship cannot be drawn without specification of some other variables.

Fig.6:7 Simulated effect of changes in control timing on injury & leaf damage.



6.(6) Simulation of observed infestations

An advantage of using simulation techniques is that they can be operated with actual field data as inputs, and the simulated results compared with the observed ones. If repeated for a sufficient variety of field conditions, these comparisons can form a basis for estimating the confidence limits of any action based on predictions by the simulation.[1]

In this study, the low incidence of armyworm infestations in the two seasons field observations (1972-3) prevented any extensive collection of data from developing infestations. Only two sets of observations were at all useful for this purpose.

The first infestation plot (plot 1, Chapter 5) was detected during harvesting and observations were made to determine the density of the residual population and the regeneration of the pasture. The observed population at harvest was entered into the simulation with an infestation timing of day 28[2] and the inputs for dispersal and mortality as in table 6:5. The observed and simulated infestations are compared in fig. 6:8.

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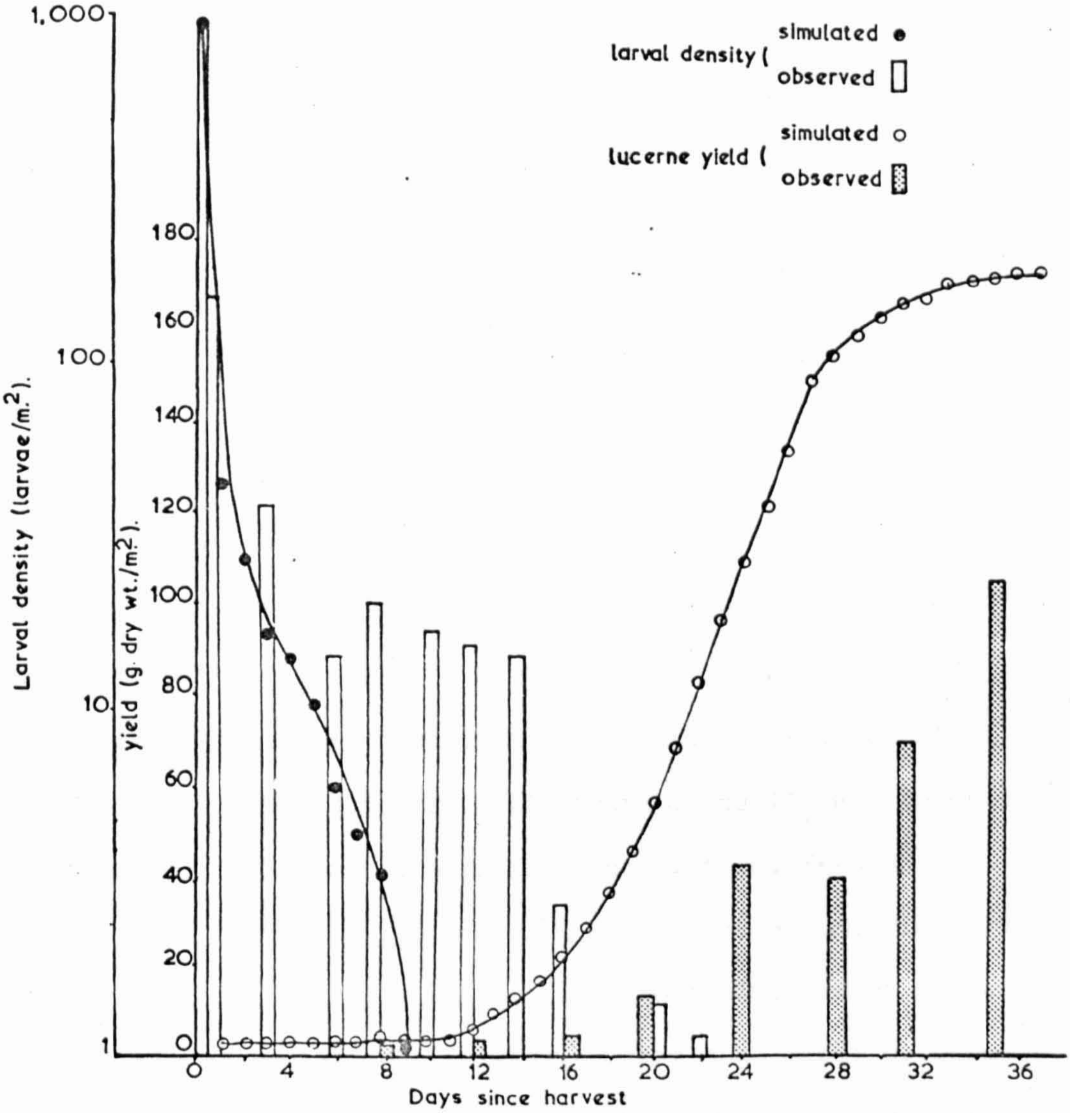
[1] Bearing in mind that errors may arise from a failure to include in the simulation one or more critical factors of irregular occurrence in the field.

[2] This is equivalent to day 1 in the second growth cycle. The second growth cycle was used in order that the program would compute yield estimates until pasture maturity, and not be disrupted by a programmed harvest date.

Fig. 6:8 The observed & simulated effect on crop regrowth of 1,000 larvae/m.^{2} on a newly harvested lucerne field.



The results show a rapid decline in larval density in both the observed and simulated infestations from approximately 1,000 larvae/m^2. to 20-40 larvae/m^2., over the first five days. The residual population in the simulated infestation continue to fall until day 10 when no more larvae are recorded. In the observed infestation, the residual population stabilizes at about 15 larvae/m^2. until day 14, then the population undergoes a decline to zero by day 22.

The shorter infestation period of the simulated infestation gives rise to an earlier simulated lucerne regrowth than is actually observed. Observed regrowth in the infested lucerne appears to be slower than might normally be expected, but this may be partly due to the lateness of the season (late October).

Those data shown in Fig. 6:8 involve the dispersal scheme. This scheme is something of an abstraction requiring a number of assumptions not necessary for the simulation of non-dispersing infestations. These are that in a consumption demand deficit situation, the larvae disperse until there is sufficient lucerne being produced to support the residual population, feeding and growing at the normal <u>ad lib</u>. feeding rate. The actual field data indicates that although the larvae disperse rapidly after harvest, they maintain a population of higher numbers than might be expected from the simulation results, and demonstrate a slower growth and maturation rate.

This higher residual population may be due to a greater daily production of lucerne from the cropped pasture than was estimated for the simulation. However, the higher numbers and slower growth and maturation rate exhibited by the larvae, are also consistent with a reduced intake per larva. The author considers this a more reasonable explanation under the circumstances.

Data collected from a fairly heavy infestation of S. littoralis and other species of noctuid larvae on a nearly mature lucerne pasture growing in September 1971 (C.O.P.R., 1974), were converted to provide an additional set of simulation inputs for comparison of an observed and simulated infestation. The other noctuid larvae (mainly Spodoptera exigua, Heliothus sp. and Plusia sp.), were not a large proportion of the total larval population and are input in the program as third instar S. littoralis. This is consistent with their approximate age as given by the data (Ibid., p.44), although it is expected that their consumption would have been somewhat different. The actual damage to the lucerne in the field was estimated by a visual scoring method of leaf injury, and by measuring dry weights of leaf and stem from standard (1 ft.^{2}) samples of damaged pasture. Both methods similar to those described in Chapter 5.

Fig. 6:9 is a comparison of the observed and simulated results. For the observed infestation, a single damage figure is given which represents the estimated leaf loss at harvest (day 35). For the simulated infestation a single total damage[1] (leaf +

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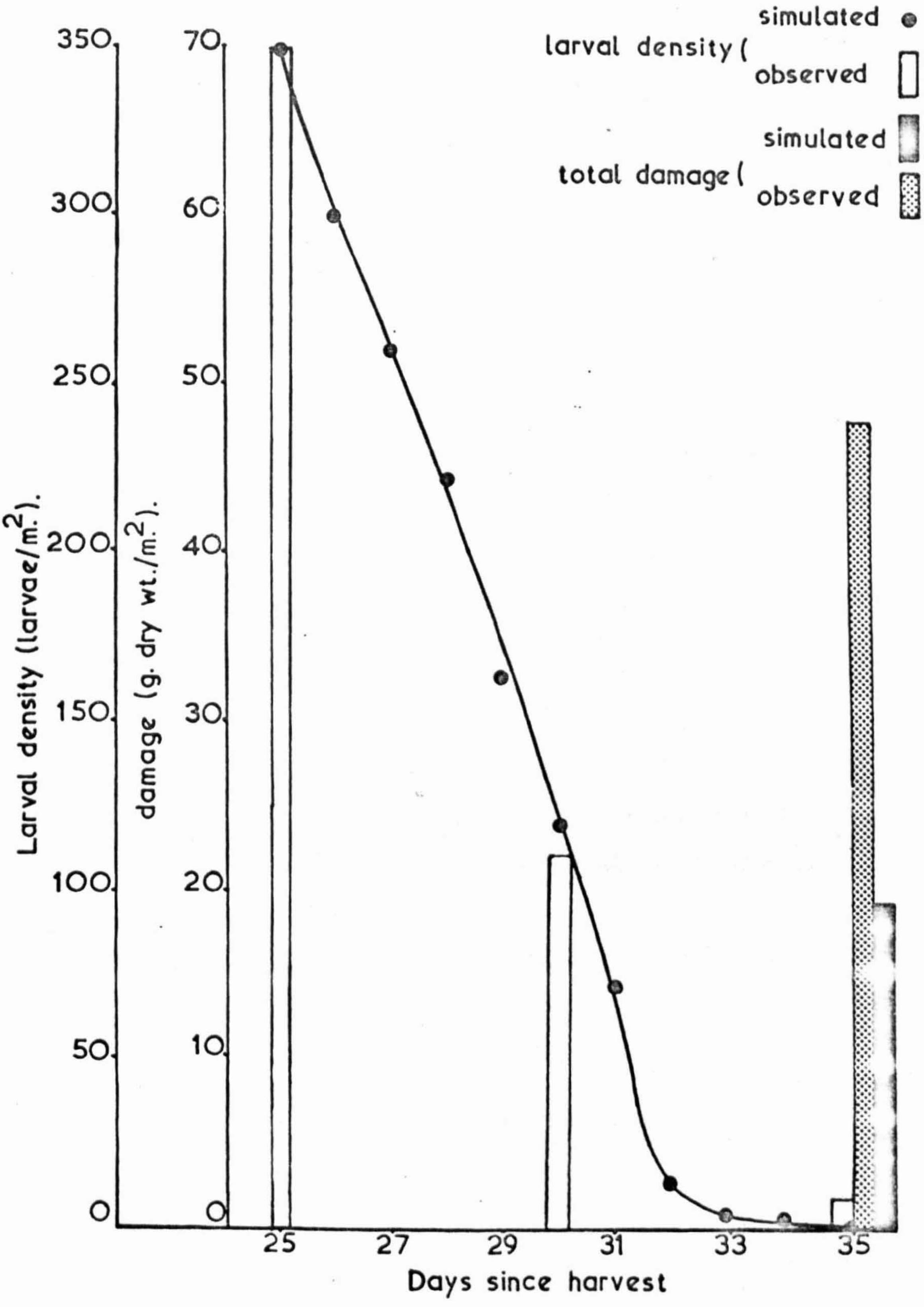
[1] Since the infestation was late in the growth cycle and the stems were near maturity, only 4g./m^2 of the total damage was attributable to stem damage.

Fig. 6:9 The observed & simulated effect on damage of ≏ 350 larvae/m.^{2} occurring on a mature lucerne pasture



stem damage) figure is given for the same day. Fig. 6:9 shows that the simulated larval population declines in a way which closely coincides with the observed population. However, the single damage estimates are not similar.

Apart from any inaccuracies of the simulation, two possible reasons are postulated for this difference in the damage results. Firstly, a "largish number" (Ibid., p.44) of S. exigua and Heliothus sp. were present six days before systematic larval counts were made. These will have contributed to damage which cannot be assessed in the simulation.

A second possible source of error lies in the method of damage estimation in the field (Ibid., pp.47-50). Estimates of the amount of holed or lost leaves indicate the level of injury and not damage. This is because such estimates do not fully take into consideration any compensation by the plant in the form of extra tillers and emergent buds. Consequently, damage can only be plausibly estimated by comparing the yields of a number of destructive sample harvests with similar samples from undamaged control plots from the same field. In this case, estimates of leaf and stem yields were made but only from the damaged plot.

From the data given on stem yield it can be deduced that the total lucerne yield, in the absence of the pest and assuming a 1:1 leaf to stem ratio (see Chapter 3), would have been 204g./m^2. This is 41g./m^2 more than the mean yield of commercial lucerne plots harvested at maturity (Table 3:1) and represents a level six standard error units above that mean yield. However, the total actual yield, because of leaf injury, was below the mean yield for commercial plots and was estimated at $149g./m.^2$, a figure $14g./m.^2$ below the mean of untreated plots. The high 'inferred undamaged yield' would suggest that either the plot under consideration was an exceptionally high yielding plot[1], or that some injury compensation had occurred in the form of extra tiller growth (i.e. resulting in more stem yield). If compensation had occurred, then any estimates of apparent damage based on the amount of leaf missing would overstate the actual damage since some of the damaged tillers would have existed only as a result of the plant's response to a reduced leaf area index due to previous leaf injury.

6.(7) Discussion

A major assumption in the simulation is that the rate of pasture compensation after grazing injury is equal to the observed rate of regrowth after cropping. The whole question of injury compensation is exceedingly complex and can only be resolved by more empirical data derived from the sort of direct yield comparisons outlined in the previous section. The two observed infestations are not sufficient to confirm or discredit thesingle lucerne growth function used in the program,and they certainly do not present opportunities for deriving a separate function for compensation to be used in conjunction with the original post-harvest regrowth function. Consequently, some discussion is appropriate on the implications and limitations of using the single growth function.

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[1] One plot in Table 3:1 did yield over $204g./m.^2$.

Two basic differences exist between pasture regeneration and injury compensation. First of these is that in a pasture grazed by larvae, all the stem stubble remains whereas during a normal harvest this is taken. Secondly, since harvest cropping occurs at the optimal vegetative maturity of the pasture (3.(2)(c)), the root reserves after grazing may frequently be in a less well developed state in comparison to the roots of a cropped pasture. It might be expected that the state of these reserves is an important determinant of the plant's ability to restore its photosynthetic area.

Experiments by Leach (1967) using the Australian Hunter river variety of lucerne, indicate that the level of reserves is only important for a very short interval after defoliation, provided that the environment is condusive to the re-establishment of an adequate leaf area. It is possible that any shortage of reserves during this critical time in grazed pasture is compensated by photosynthesis in the remaining green stem stubble.

Herbaceous stems of plants such as the annual sunflower (Helianthus annuus) contribute up to one fifth of the leafy plant's total photosynthetic area (Evans, 1972). However, the productive role of stem chlorophyll is difficult to assess. It is clear from the physical and biochemical structure of leaves that they are the principal, and presumably most efficient, photosynthetic organs in most plants. Yet in the typical green stem, not only is stomatal[1] frequency different from the leaf, but stomatal aperture is also.

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[1] Stomata are pores in the epidermis of plant leaves and stems, and are of fundamental importance in regulating photosynthesis.

Furthermore, the photosynthetic tissue itself has a different structure (Ibid.). Such differences indicate a lower efficiency or specialist role of stem photosynthesis, suggesting that the green stem contributes rather less to general production than might be expected from its proportionate share of the plant's total photosynthetic area. In spite of this, it is difficult to conceive that stem photosynthesis in defoliated stubble plays no role in leaf regeneration. We therefore suggest that all things being equal, defoliated pastures with stubble will enjoy an advantage in this respect, and further, that stubble may compensate for some depletion of root reserves.

Another role of the grazed stem appears to be in bud and shoot development. In a cropped pasture shoots develop from the crown. The system of apical dominance[1] in lucerne maintains a fairly constant shoot number per crown (Leach, 1967). However, to quote Leach: "Where stubble is left on the plant many more shoots extend than where the crown alone is the source of new shoots. Also a greater proportion of the final population of shoots extend earlier and will therefore be photosynthesising over a longer time interval. The effect of stage of defoliation on the size of the population of shoots is also large, especially where there are only crown shoots. The size of shoots at harvest is markedly influenced by the time when they begin extension, and any not extending within seven days of defoliation will grow to less than one quarter the size of those extending at the time of defoliation". It is important to note that these experiments were

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[1] Apical dominance is the term given to the mechanism of hormonal suppression of development exerted by a plant's top buds on its auxiliary buds.

carried out with individually potted plants. In the highly competitive conditions existing in commercial pastures, the rate of growth of a few shoots will probably be more important than the number of shoots emerging. Consequently, it is possible that there is not a large overall difference in the rate of leaf production from stubble and crown regrowth in commercial fields.

The assumption that stem regrowth occurs so as to maintain a constant 1:1 ratio between leaves and stems, both after cropping and injury, is no doubt an oversimplification. This is suggested by the extra tiller growth indicated in the second observed infestation in 6.(b). However, no data on the stem and leaf composition of pastures regenerated after injury was collected, and since defoliation was associated with the temporary arresting of pasture growth (personnel observation), we consider the assumptions on stem growth to be acceptable approximations.

It might be suggested that a further method of injury compensation not accounted for by the lucerne growth equation is the possibility of repair in partially grazed leaves. However, this requires the production of new tissue, which cannot be accomplished without cell division.[1] This activity is confined to the meristematic areas of the plant (i.e. buds, young leaves and root tips).

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[1] A clear distinction has to be drawn between regeneration by the production of new tissue and growth. Growth can occur in many places on a plant and is defined as: "an irreversible increase in volume which may or may not be accompanied by cell division" (Evans, 1972). Mature leaves cannot repair damage by further cell enlargement, new tissue and thus meristematic activity is necessary.

Another implicit assumption made in the estimation of the injury compensation rate, is that injured leaves contribute as much to production as intact leaves of the same weight. To the first approximation this is not unreasonable since injury caused by late second instar and older larvae, is in the form of discrete holes in the leaflets which generally avoid the ribs of vascular tissue.[1] Early instar damage is of a different form, the larvae strip the leaf epidermis causing dessication and death to the underlying tissues. These larvae therefore cause more injury than can be accounted for by their food intake. However, except for extremely heavy infestations this factor is not important, since the early instars are gregarious, and only one or two leaflets per egg mass are affected in this way.

The observed change in growth rate of lucerne through the season (3.(2)(c)) might have been due to photoperiod, light intensity or temperature variations, all of which have been shown to affect dry matter yields of lucerne pastures (Langer, 1967; Gist and Mott, 1967; Bula et al., 1959). Consequently, the data used for the growth equation in the simulation was derived from lucerne grown in Cyprus during September and October; the two months when armyworms are most prevalent. However, it is conceded that pastures growing during early or late infestations, or those experiencing a period of unusually high or low seasonal temperatures, will not be particularly well described by the single equation.

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[1] This tissue transports the products of photosynthesis from active areas and supplies water and minerals to them.

We conclude, that the use of the single function for crop growth is a plausible approximation for both post-cropping regrowth and injury compensating growth by the crop. However, until more data on compensation becomes available the single function must be viewed as a possible source of significant error in damage prediction when using the program.

The positive effects of temperature increases of up to 30°C on larval maturation and consumption have been discussed (5.(3)(c)). Diurnal and seasonal fluctuations in temperature will therefore affect the damage potential of an infestation. In the program, the functions for the growth and consumption of the larvae are derived from laboratory trials on single larvae reared at 24-26°C. Although this temperature was probably a reasonable estimate of the mean temperature experienced by larvae infesting late summer lucerne pastures (fig. 5:2), fluctuations in temperature render the single consumption function in the program an oversimplificiation. However, a modification to include an environmental temperature input to the program would result in only a limited increase in the accuracy of the simulation since it would necessarily be a projected estimate from the day the infestation was first monitored. It would also reduce the present convenience of having only two infestation variables to measure in the field: namely the timing and the larval density.

Another source of discrepancy between real and simulated damage estimates is the mortality scheme. Some mention of the difficulties of arriving at realistic rates for mortality, and discussion of the theoretical implications of the scheme used has already been made (5.(3)(d)). However, the coincidence of the observed and simulated larval densities in fig. 6:9 is some indication of the value of these mortality rates as first approximations of field conditions.

A further limitation of the simulation is that it does not take account of previous consumption by an infestation discovered some time after larval hatching. This may not be particularly important for populations below the fourth 'instar' stage, but may cause inaccuracies when estimating damage from a more mature population. However, damage from these populations can be estimated with fair accuracy without recourse to a simulation. We therefore considered it unnecessary to include the reverse larval development and mortality scheme that would be required to simulate previous consumption.

6.(8) Conclusion

In conclusion, the simulation described produces some useful indications of the possible magnitude of damage given variations in pest density and timing. The model has been insufficiently tested to ascertain the confidence that may be attached to any results, however, it was shown to be deficient in accounting fully for the suppression of regrowth caused by a residual post-cropping population of larvae (plot 1, 5.(3)(b)). Consequently, it is offered as a preliminary tool to pest control agencies in Cyprus who may more thoroughly test it, modify it and employ it as a damage forecasting aid. For the purposes of this study the simulation is adopted as the best available expression of the armyworm damage function on lucerne. It is used in conjunction with the costs of control estimates in the following chapter, as a basis for estimating the economic threshold of treatment (Chapter 8).

SUMMARY - CHAPTER 6

A computer program is described, which by incorporating empirically derived functions, calculates the expected quantity of lucerne leaf in a pasture at given times after recropping and with various densities and timings of armyworm infestation. This is used as a pest damage function.

CHAPTER 6 - REFERENCES

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CHAPTER 7

S. littoralis control methods and their estimated cost

7.(1) Introduction

In this chapter the current (1972) control methods used by Cypriot farmers for the control of armyworm infestations on their crops are described. The recommended control practice, which arose from insecticide trials conducted by the C.O.P.R. (C.O.P.R., 1974), is also stated. In the text and the appendix to this chapter, estimates of the cost of control using the recommended techniques are given for both types 1 and 2 lucerne growers (see (3.(2)(b)) for the definition of types 1 and 2 growers). Finally, the potential for baited insecticides in armyworm control is briefly discussed.

7.(2) Current control practice

Communication with pest control agencies and individual growers on the island suggested that most farmers used some form of insecticide preparation against armyworm infestations on their lucerne and vegetable crops. In an attempt to identify the compounds and the method of application adopted by the farmers for this purpose, a pest control section was incorporated into the growers' questionnaire reproduced in Appendix 3:2.

It was found that 98% of the farmers who returned the questionnaire and used insecticides for armyworm control on vegetables and lucerne,

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[1] As stated in Chapter 3 the returns from lucerne growers were probably all from type 2 farmers.

used some form of sprayed application and only 2% used baits or dusts. Of those using sprays, 90% used a knapsack sprayer and 10% used a tractor mounted with boom and nozzle-spraying equipment. In 80% of the reported cases, farmers used insecticides when armyworm injury became apparent and only 20% of the farmers reported routine treatment.

A total of 22 brands of insecticides were reported used for Spodoptera sp. control on lucerne or vegetables, although only 6 were common (Tables 7:1 and 7:2 and Appendix 7:2). All of these commonly used compounds were organophosphorous insecticides. The insecticides

TABLE 7:1 Use of insecticides for Spodoptera sp. control on lucerne

Insecticide	Number of applications/month[1]					
	June	July	August	September	October	November
Chloropyriphos*	0	0	0	3	3	3
Methomyl*	0	0	0	0	0	0
Methamidophos*	0	0	5	0	0	0
Parathion Preparations	31	35	41	32	18	8
Monocrotophos	0	0	2	9	3	2
Cyolane	0	3	2	2	2	0
Baits	0	1	0	0	0	0
Others	3	5	12	11	10	2
Total applications	34	44	62	57	36	15
Total applications using * insecticides	0	0	5	3	3	3
Total applications using any others	34	44	57	54	33	12
PERCENTAGE USE OF * INSECTICIDES	0	0	8.7	5.2	8.4	19.0

(N.B. *Insecticides are those recommended by the C.O.P.R.).

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[1] Data from 74 questionnaire returns.

considered to be most effective in the control of armyworms (C.O.P.R., 1974), were not extensively used by lucerne growers. These farmers appeared to favour methyl parathion preparations, notably 'Folidol'.

TABLE 7:2 Use of insecticides for *Spodoptera sp.* control on late potatoes, beans, tomatoes and artichokes

Insecticide	Number of applications/month[1]					
	June	July	August	September	October	November
Chloropyriphos*	13	14	3	23	9	2
Methomyl*	0	0	29	42	40	21
Methamidophos*	7	17	9	11	13	0
Parathion Preparations	27	12	15	34	13	1
Monocrotophos	18	13	12	26	16	2
Cyolane	4	7	9	14	20	1
Baits	0	0	0	5	2	0
Others	26	32	30	27	51	6
Total applications	95	95	107	182	164	33
Total applications using * insecticides	20	31	42	76	62	23
Total applications using any others	75	64	65	106	102	10
PERCENTAGE USE OF * INSECTICIDES	21.0	32.6	39.3	41.8	37.8	69.0

(N.B. *Insecticides are those recommended by the C.O.P.R.).

This was also true for vegetable growers, but to a lesser extent. Vegetable growers frequently used monotrotophos (sold as 'Nuvacron') and showed a higher percentage adoption of the recommended insecticides

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[1] Data from 158 questionnaire returns.

than did lucerne growers. For all growers there appeared to be a trend towards the use of these more efficient compounds through the year. There is no reason to postulate a change in the supply of these insecticides during that year, and therefore the change in insecticides used was unlikely to have been a seasonal effect.

The peak treatment months for lucerne were August and September and for vegetables September and October. This later peak for vegetables was largely due to the emergence of leaves on the potato crop in late August. The relative incidence of control applications (and since control was generally applied after some crop injury, the relative incidence of infestation) was therefore more clearly indicated by the insecticide applications on the perennial lucerne crop. The peak in August and September was probably due to the high levels of *S. exigua* and low levels of *S. littoralis* in 1972 (5.(3)(a)). We expect, that in years when *S. littoralis* is prevalent, a high level of control activity would continue until the end of October.

7.(3) Recommended control practice

Two potential methods of armyworm crop protection arose from work by the C.O.P.R. in Cyprus. One, the use of artificial sex pheromones to disrupt the mating behaviour of *S. littoralis* (C.O.P.R., 1974; Campion *et al.*, 1974a and 1974b), was suspended by the events of July 1974, and to date no workable shcme has been formulated. However, laboratory and field trials on insecticides currently in widespread use on the island and a number of recently introduced compounds led to an extension exercise in 1973 aimed at persuading farmers to discontinue using some insecticides, to which larvae had developed resistance, and to adopt the use of some of the newer compounds.

The insecticide trials were made using locally available equipment and on commercial lucerne and potato plots. It was concluded (C.O.P.R., 1974) that S. littoralis larvae had a high degree of toxicity resistance to methyl parathion and to a lesser extent to monocrotophos, the two insecticides most frequently used for S. littoralis control. Tests on seven other compounds indicated that chloropyriphos ('Dursban'), methomyl ('Lannate'), methamidophos ('Tamaron') and phospholane ('Cyolane') were the most effective insecticides for controlling S. littoralis on the island. It was also found that spraying insecticides after sunset when the larvae were feeding on the stem apices, gave a higher rate of mortality than daytime treatments. Residue tests on treated crops formed the basis for estimating the safety period between treatment and the time when the pasture could be fed to the animals without risk of insecticide toxicity. The dosage rates and safety periods recommended by the C.O.P.R. for S. littoralis control on lucerne and vegetables are given in Table 7:3. Phospholane was not recommended since it was the least effective of the four 'better' compounds and had a higher operator hazard.

7.(4) Direct and other insecticide treatment costs

7.(4)(a) Direct costs

The direct costs of applying the three recommended insecticides

Table 7:3 Application rates and safety period of the three recommended insecticides

Insecticide	Recommended dosage in kg/ha		Water required for diluting the insecticide in l/ha		Type of action	Safety period (days)
	Daytime	Nightime	Tractor Sprayer	Knapsack Sprayer		
Chloropyriphos ('Dursban')	0.750	0.450	750	225	Contact	7-10
Methomyl ('Lannate')	0.600	0.450	750	225	Contact and Stomach	7-10
Methamidophos ('Tamaron')	0.700	0.525	750	225	Contact and Stomach	15-18

(Data from C.O.P.R., 1974).

at their established dosage rates are itemized for both types 1 and 2 lucerne farmers in Appendix 7:1 and summarized in Table 7:4.

7.(4)(b) Pest resistance

It was suggested in (1.(2)) that the costs and benefits of treatment extend beyond the cost of the chemical and its direct application costs, and that the benefits may be more than the value of the crop saved. There may be significant additional effects which complicate the assessment of the return on a treatment. For instance, where a farming community uses insecticides extensively or intensively, pest resistance may develop. When this occurs the farmers will incur extra costs, either by the need to increase dosage rates, or by changing to other more costly compounds. If the rate at which resistance develops is determined in part by the frequency and extent of the insecticide applications, a farmer is faced with an

TABLE 7:4 Estimated direct cost of applying the recommended insecticides to lucerne

Insecticide	Type 1 Farmers		Type 2 Farmers	
	Daytime C£/ha.	Nightime C£/ha.	Daytime C£/ha.	Nightime C£/ha.
Chloropyriphos ('Dursban')	6.365	4.065	7.005	5.165
Methomyl ('Lannate')	6.890	5.340	7.530	6.440
Methamidophos ('Tamaron')	4.640	3.765	5.280	4.865

additional cost at each application, which reflects the finite effective life of these compounds.

It has been stated that S. littoralis resistance to parathion and monocrotophos in Cyprus resulted in a search for new effective insecticides, which are now being adopted by farmers in spite of a higher cost of application. However, in this instance, three effective compounds are offered with similar direct costs of application, and by changing from one insecticide to another a long period of effective use can be maintained. In addition, a resistance monitoring laboratory has been established on the island. This will enable the Government more fully to rationalize the rotational use of the insecticides in response to any developing resistance detected in the island's armyworm population. Hence, those costs attributable to insecticide resistance are largely the cost of this service which will be trivial when estimated on a cost per application basis.

7.(4)(c) The diseconomies of insecticide treatment associated with reducing the activity of beneficial arthropods

7.(4)(c)(i) Introduction

It has been frequently asserted, that applying broad spectrum toxicity insecticides to crops reduces their ability to resist subsequent infestations. This is apparently due to a large proportion of 'non-target' beneficial arthropods (such as parasites and predators of the pest) being adversely affected by the treatment. Such effects have been predicted theoretically (Nicholson, 1940) and demonstrated (Woglum, 1947).

Since the insecticides recommended by the C.O.P.R. for armyworm control in Cyprus are broad spectrum toxicity compounds sprayed onto crops it might be expected that spraying lucerne fields will result in such adverse effects. A fully rational spray programme would take account of any such effects by quantifying them as short and long-run diseconomies. At present, it is not possible to produce an accurate quantification since data on the 'normal' natural mortality rates in untreated Cypriot lucerne fields are provisional (5.(3)(d)), and detailed observations on the effects of a sprayed insecticide treatment on a Cypriot lucerne pasture fauna and the subsequent recolonization by arthropods, are entirely lacking. Consequently, the significance of this aspect of insecticide spraying remains a subject of some conjecture. The survey results reported in 5.(3)(a)(iii) indicate that recolonization, or emergence of parasites, rapidly occurred in pastures after insecticide treatment, and that no differences in pest incidence occurred as a result of previous treatment. In addition, those farmers identified through the questionnaire returns as having used insecticidal sprays early in the year (May-June) for the control of aphids, did not suffer significantly more infestations than those that had not used them. However, these surveys were deficient in a number of respects (5.(3)(a)(i)). Furthermore, laboratory studies by Rechav (1974) produced evidence suggesting that parasites may be adversely affected by insecticides for some considerable period after treatment. Observations by Bey (1951) on S. littoralis predators in Egyptian cotton fields (species also found in Cyprus), showed a reduction in these beneficial arthropods by up to 50% after dusting with arsenicals and nearly 100% after spraying with nicotine.[1]

In this section, the nature of the possible adverse effects due to spraying are explored, and a method of calculating any associated costs is offered, given a number of simplifying assumptions about the form of predator and prey interaction.

Table 6:3 indicates that the mortality action of the beneficial arthropods on S. littoralis occurs mainly in the early instar groups, and that this form of mortality is insignificant after the fourth instar stage. Fig. 5:12 shows that the consumption demands of the larvae (and hence their crop injury potential) only develops to a high level after the fourth instar stage (day eight after hatching). Consequently, the injury caused by an infestation of S. littoralis larvae is, to the first approximation, proportional to the numbers of larvae developing to the fourth instar stage (Fig. 7:1).

If the initial density of S. littoralis eggs is (De) then let (D_L) be the surviving larval population at the fourth instar stage. Let it also be assumed that crop loss is directly proportional to the abundance of these larvae :

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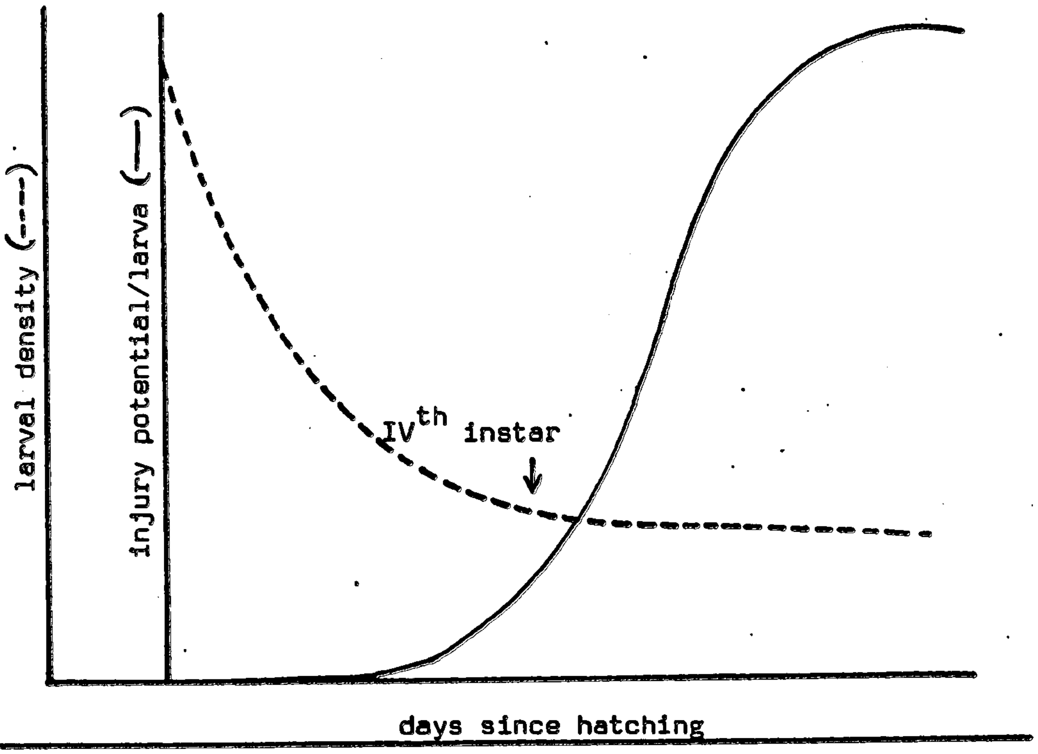
[1] Although nicotine is a more persistent chemical than the organophosphorous compounds recommended for use on S. littoralis infestations.

Fig. 7:1 Larval mortality and individual larva injury potential



$$\text{i.e. Economic loss (E)} = a.D_L \qquad 7:1$$

where a is a constant

As has been shown in 6.(5) this may not always be true, but generally more injury results in more damage which is reflected directly as economic loss.

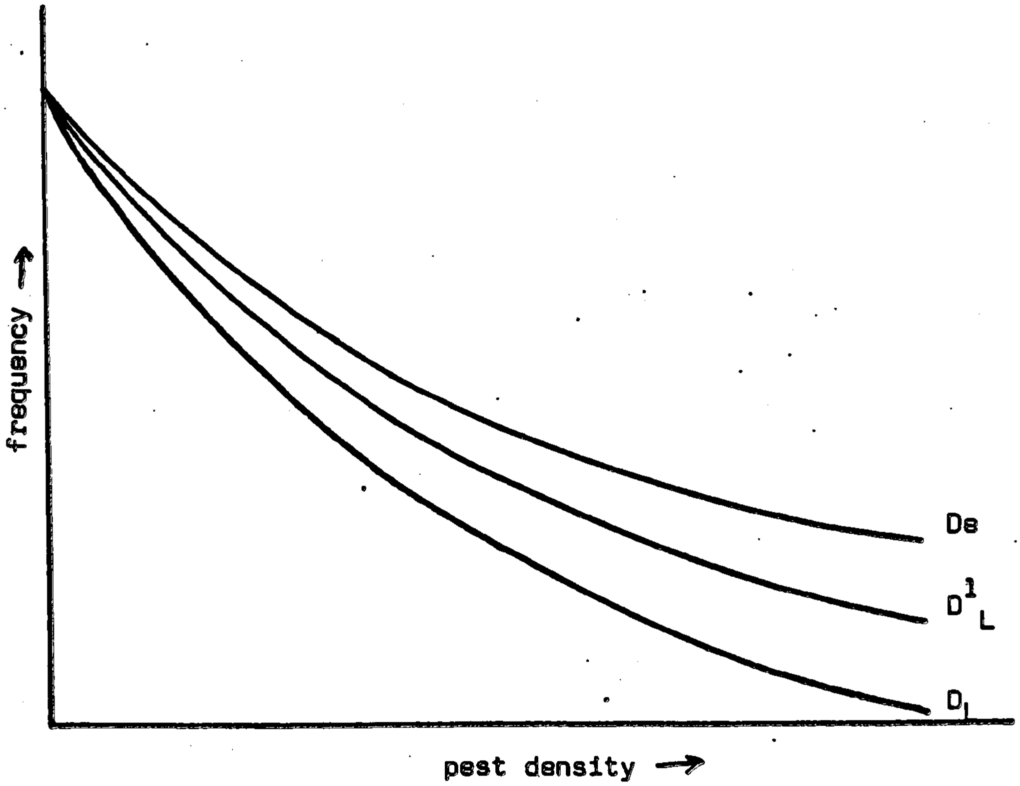
The initial egg-laying density (De) gives rise to the early instar population and is assumed to be a stochastic variable independent of the state of the field with respect to predators, parasites or whether the crop was sprayed in the previous growth cycle. This is not unreasonable since a lucerne growth cycle subsequent to treatment will have only small amounts of insecticide residues in the crop, all of which will have grown after the harvest of the treated crop. Similarly, in view of the inappropriate oviposition sites sometimes chosen by moths (5.(2)) it seems unlikely that they assess the faunal density of the pasture before depositing their eggs.

Mortality of larvae due to parasites and predators has been described (5.(3)(d)) as a constant rate of larvae being removed per day for all larval densities. If an insecticide spraying eliminates these parasites and predators this will result in a greater value of (D_L) for any given level of egg-laying (De) in a subsequent lucerne growth cycle.

The normal frequency of S. littoralis infestations in Cypriot lucerne fields has not been satisfactorily established. There appear to be large annual fluctuations in pest incidence and a changing level in the total S. littoralis moth population within any one year (fig. 5:2). However, the pest survey (5.(3)(a)) and other observations (5.(3)(b)) did suggest that larvae were common at low levels with occasional instances of heavy infestation. A plausible shape for the frequency of infestations of egg density (De) might therefore be a declining exponential (fig. 7:2). Fig. 7:2 shows the two frequency curves of fourth instar larval densities derived from given levels of egg-laying and corresponding to previously treated (no parasites and predators $(D_L'))$ and untreated (with parasites and predators $(D_L))$.

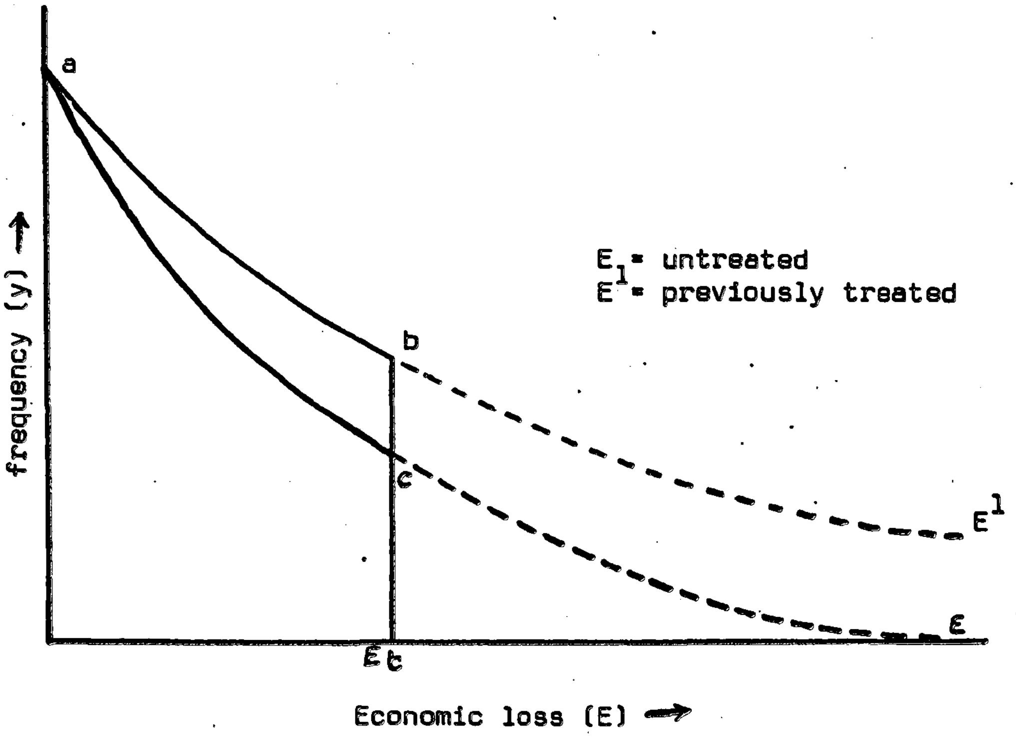
From equation 7:1, the frequency curves D_L^1 and D_L each have a corresponding economic loss frequency curve (E and E^1 respectively).

Fig. 7:2 A hypothetical representation of the frequency of *S. littoralis* infestations and resulting larval densities with and without parasites and predators



For the rational farmer, these will only extend to the economic threshold of treatment (E_t), since all larger infestations will be controlled (1.(2)). Consequently, the diseconomy of insecticide treatment associated with reducing the activity of parasites and predators in the subsequent lucerne growth cycle, is the increased cost resulting from operating on the frequency loss curve ab instead of ac (fig. 7:3) plus the increased frequency of incurring spray costs.

Fig. 7:3 The economic loss frequency curves for previously treated and untreated pastures



A general equation for the curve of (E) in unsprayed fields may be:

$$y = y_o . e^{-kE} \qquad 7:2$$

The probability that an infestation is above the economic threshold in previously unsprayed fields is:

$$1 - \frac{y_o \int_0^{E_t} e^{-kE} . dE}{y_o \int_0^{\infty} e^{-kE} . dE} \qquad 7:3$$

On integrating, the $0 \to \infty$ lower term reduces to $\frac{1}{k}$ and the constant y_o is cancelled, and the probability simplifies to: $\frac{1}{e^{k(E_t)}}$

The expected loss from previously unsprayed fields can be expressed as:

(ΣAll possible losses up to (E_t) x their probability of occurrence) + (Probability of economic infestations x (E_t))

$$= \frac{y_0\int_0^{E_t} E.e^{-kE}.dE}{y_0\int_0^{\infty} e^{-kE}.dE} + E_t \cdot \frac{1}{e^{k(E_t)}} \qquad 7{:}4$$

which simplifies to: $\frac{1}{k}\left(1-e^{-k(E_t)}\right) = Z$ 7:5

Let the equation for (E^1) be:

$$y = y_0 e^{-k_1 E} \qquad 7{:}6$$

then spraying increases the probability that spraying will be necessary in subsequent growth cycles by:

$$\frac{1}{e^{k_1(E_t)}} - \frac{1}{e^{k(E_t)}} = S \qquad 7{:}7$$

and the overall expected loss from Z to:

$$\frac{1}{k_1}\left(1-e^{-k_1(E_t)}\right) = Z_1 \qquad 7{:}8$$

Hence Z_1-Z is a measure of this particular diseconomy, expressed in terms of an increased vulnerability to damage in the subsequent crop growth cycle. These may be termed the indirect costs of treatment.

The indirect costs of insecticide treatment are probably not a simple calculation unless the crop growth cycle to which the insecticide is to be applied is the penultimate one in the S. littoralis season (clearly the indirect costs of treating the last crop growth cycle in the season will be zero since there is a zero probability of subsequent infestations). This is because there may be complex and cumulative faunal disturbances resulting from a series of sprayings which will affect the pasture ecosystem, particularly with respect of the re-establishment of parasites and predators. Such effects would give rise to a range of possible indirect costs derived from the different combinations of spray and non-spray sequences. Since the estimated indirect costs are a legitimate component of the economic threshold, the threshold itself would have a probabilistic range of values. Consequently, the indirect costs (which are calculated on the basis of the economic threshold value) would need to be estimated with respect to the integration of all possible values of the economic threshold and the probability of occurrence of these threshold values, except in the penultimate growth cycle when the insecticide treatment history is known.[1]

Any attempt to incorporate such an elaborated scheme would be unjustified in the absence of reliable data on the parasite and predator population dynamics in Cypriot lucerne. However, the possible importance of the position of the lucerne growth cycle with respect to others in the armyworm season in

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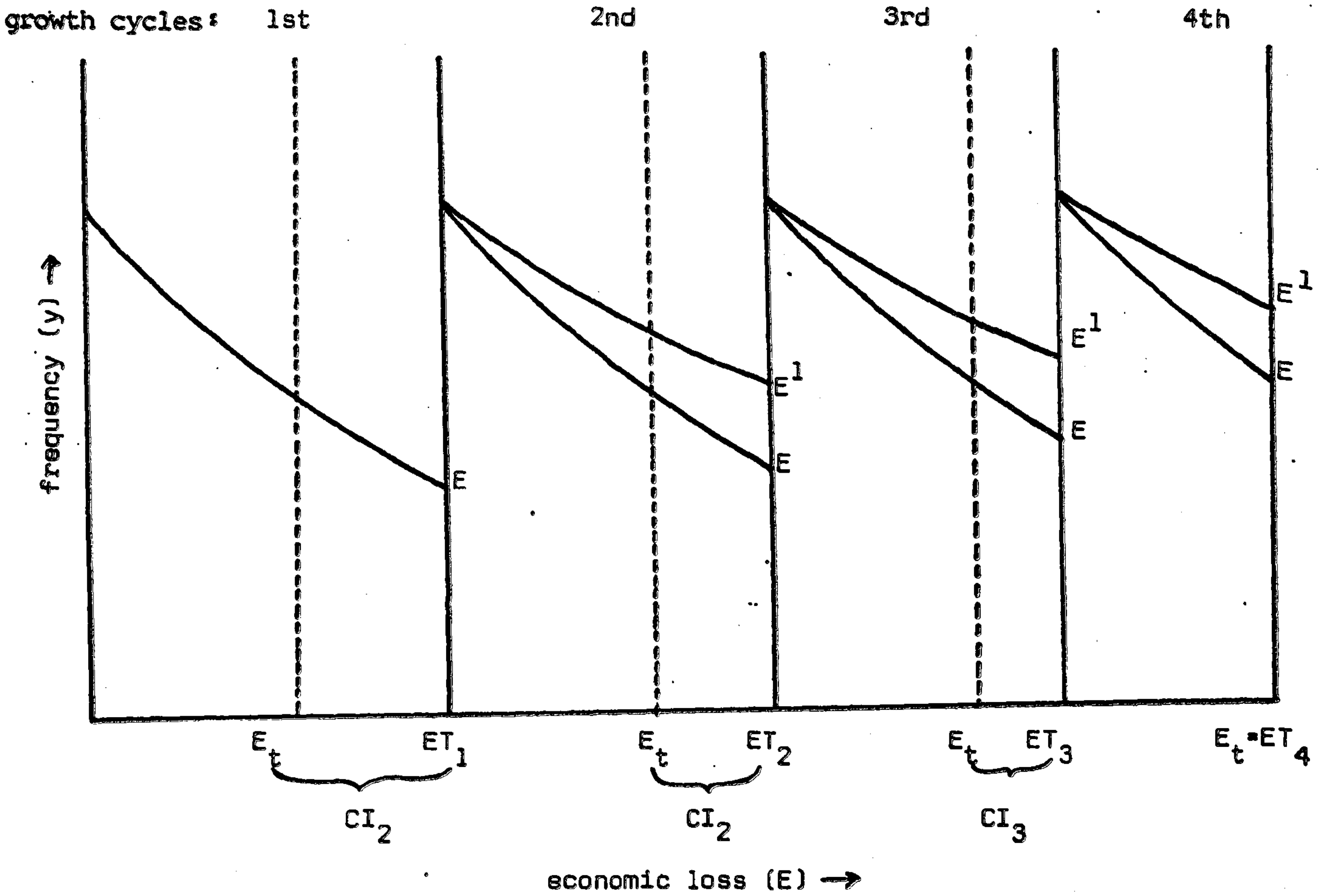
[1] Assuming that the consequences of each combination of spray/non-spray sequence can be quantified.

determining the degree of 'carry-over' of the indirect costs of treatment from one growth cycle to those remaining, is illustrated below. In this scheme, the indirect cost equations are given for each growth cycle after a number of grossly simplifying assumptions about parasite and predator activity and pest incidence have been made. These assumptions are that: there are four lucerne growth cycles occurring in the armyworm season, that the frequency of pest egg-laying (De) is constant for each cycle, that spraying insecticide in any growth cycle reduces the parasites and predators to a constant level in the subsequent growth cycle, that one growth cycle left unsprayed is a sufficient period for the parasites and predators to re-establish themselves to their pre-sprayed levels, that the cost of treatment (E_t) is a constant throughout the season and that the farmer has an unsprayed crop with a full complement of parasites and predators at the beginning of the armyworm season. Although these assumptions render the following scheme implausible in detail, the carry-over effect demonstrated might be expected to appear in a rigorous model, albeit in a modified form.

Fig. 7:4 is an illustration of the four relevent lucerne growth cycles with the frequency of economic losses up to the economic threshold indicated.

Fig. 7:4 Illustration of the relevant treatment costs in the four lucerne growth cycles growing in the armyworm season



N.B. ET_i^1 = Economic threshold of growth cycle (i)

$C_{I_i}^1$ = Indirect costs of treatments in growth cycle (i)

other variables as defined above.

In the 4th growth cycle the probability of losses in the next = 0

$$C_{I_4} = 0 \qquad 7:9$$

and $$ET_4 = E_t \qquad 7:10$$

In the 3rd growth cycle the indirect costs of spraying are given as:

$$C_{I_3} = Z^1 - Z \qquad 7{:}11$$

and $$ET_3 = E_t + C_{I_3} \qquad 7{:}12$$

In the 2nd growth cycle the indirect cost of spraying is given as:

$$C_{I_2} = \left(Z_1{}^1 - Z_1\right) + S.C_{I_3} \qquad 7{:}13$$

and $$ET_2 = E_t + C_{I_2} \qquad 7{:}14$$

where $Z_1{}^1$ and Z_1 correspond to the values of Z^1 and Z estimated with the economic threshold level adjusted from $E_t \rightarrow ET_3$.

In the 1st growth cycle the indirect cost of spraying is given as:

$$C_I = \left(Z_2{}^1 - Z_2\right) + S_1 C_{I_2} + S_1 S.C_{I_3} \qquad 7{:}15$$

and $$ET_1 = E_t + C_{I_1}$$

where $Z_2{}^1$ and Z_2 correspond to the values of Z^1 and Z estimated with the economic threshold level adjusted from $E_t \rightarrow ET_2$.

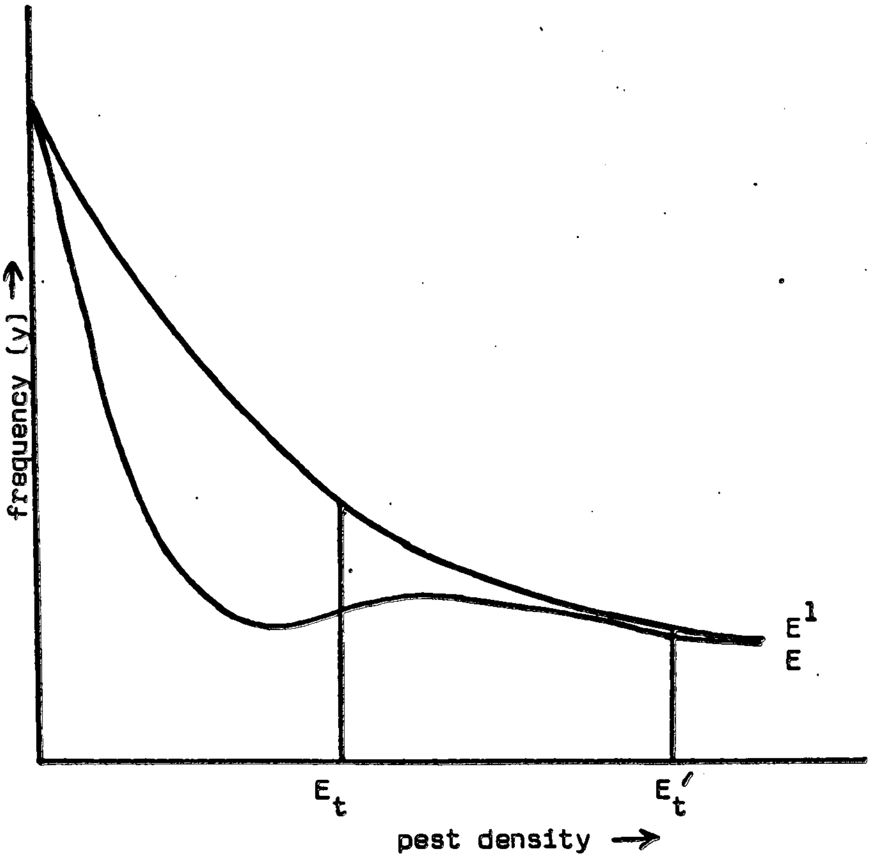
and $$S_1 = \frac{1}{e^{k_1(ET_3)}} - \frac{1}{e^{k(ET_3)}}$$

The larger indirect costs in the earlier growth cycles are due to the inclusion of terms expressing the increased likelihood of future treatments being necessary because of current treatment $(S_i C_{I_i})$. Clearly, the greater number of growth cycles outstanding, the greater the expected losses due to this factor. However, it is noted that since probabilities are multiplied by each other the actual expected loss for growth cycles two or three cycles subsequent to treatment will be small.

As stated previously, it was not possible to substitute values into these functions due to lack of data. Consequently, the importance of these indirect costs remain conjectural. However, fig. 6:5 suggests the relationship between larval mortality and economic loss is of the inverse form shown in equation 7:8. Furthermore, table 6:3 shows that parasites and predators, the mortality agents that are affected by spraying, are estimated as the main cause of larval deaths. The implications of the functions relating frequency of damage to expected loss are that during those years when *S. littoralis* infestations are infrequent, indirect costs will be low since the overall probability of infestation will be low. Also, in years of extremely heavy infestation the indirect costs will be low, since there is a high probability that even 'non-vulnerable' unsprayed crops will require protection. Indirect costs will be highest in years when infestations are frequent but when the chances of escaping from economic infestation are also good.

Although the model is consistent with the way parasite and predator induced mortality has been described for *S. littoralis* (5.(3)(d)(i)), theoretical considerations (5.(3)(d)(ii)) suggest that a constant mortality rate due to these agents is not a particularly realistic situation. Fig. 7:5 shows the modification that would occur if the peaked total response (5.(3)(d)(ii)) were found to be an appropriate description of parasite and predator mortality of *S. littoralis* larvae. By indicating two possible economic threshold levels (E_t) and (E_t') it is possible to show

Fig. 7:5 Theoretical effect on frequency loss curve of a peaked total response mortality curve



that such a response may result in there being significant indirect costs of spraying associated with an increase in frequency of future sprayings (E_t) or a negligible indirect cost of spraying associated with this factor (E_t'). However, the indirect costs associated with an increase in crop losses due to sub-economic damage will always be an appreciable factor.

7.(4)(d) The effect of the insecticide on the pasture

An insecticide may have the effect of stimulating growth and increasing yield, suppressing growth and decreasing yield, or it may be directly phytotoxic to the existing plant tissue. All of these effects may be exhibited by the same insecticide when applied at a range of concentrations. However, the effects of the insecticide are more frequently adverse. During the trials with the insecticides eventually recommended for S. littoralis control, no inimical effects were noticed except for a tendency for local phytotoxicity when conducting ultra-low volume spraying; a technique that ultimately was not recommended. However, we saw individual instances of insecticide induced phytotoxicity in commercial lucerne pastures on the island. In each case excessive concentrations of insecticide had been used. We conclude, that at the concentrations recommended, the inimical effects of insecticide treatment on crop performance are negligible.

7.(4)(e) The effect of the application process on the pasture

Mechanical damage may occur during spraying operations. Although no systematic data is available to confirm this notion, it was evident that farmers were reluctant to use tractor mounted spraying equipment on pastures approaching maturity.

7.(5) Insecticide treatment benefits

The essential benefit derived from insecticide treatment is the prevention of further crop injury by an infestation. This is discussed further in Chapter 8 where crop losses are estimated and compared with treatment costs. However, an additional benefit is recognized which may have its largest component external to the farmer's calculations. This is the possibility of a reduction in the total pest population on the island with the control of individual infestations. Since S. littoralis in Cyprus is a pest of broad leaved herbaceous plants, its summer and autumn populations must be mainly sustained by irrigated crops, the majority of which are sufficiently valuable to justify pest control expenditure. More effective control may therefore reduce the island's adult pest population, resulting in a lower incidence of egg-laying. However, at present this statement cannot be supported by empiricalevidence and so these benefits of improved pest control have not been assessed.

A more tangible external benefit of insecticide treatment is the prevention of larvae invading neighbouring plots. In type 2 farmers' plots particularly, total defoliation of a pasture by larvae, or the harvesting of an infested plot, has been shown to result in an exodus of larger larvae that may infest adjacent fields (5.(3)(b)), gardens and houses. Earlier control, or post-harvest spraying, clearly would prevent this. The external benefit accruing to neighbouring farmers from an individual's control treatments will depend on the proximity and topographical characteristics of the plot as well as the crops grown. Consequently, a single monetary figure for all cases is not appropriate. However, such an empirical assessment of this benefit would only be necessary if invididual incentives to farmers (by tax, subsidy, or direct legislation) were required to realize this external benefit for the total community. In this study, total defoliation of lucerne at any stage in its growth, and post-harvest residual larval populations sufficient to cause dispersal, are shown to be beyond the economic damage threshold (Chapter 8) and hence provide the necessary and sufficient internal incentives for farmers to invest in control.

7.(6) The use of insecticidal baits for S. littoralis control in Cyprus

Pests may develop resistance to chemicals or demonstrate behavioural responses peculiar to quite localized area. Consequently, caution must be exercised in interpreting pest control research results from areas other than where the work was actually done. For this reason,much of the artificial control work on S. littoralis in other countries has not been considered. However, some work outside Cyprus appears to hold considerable promise for controlling S. littoralis on the island, in particular, the recommendation by the Division of Plant Protection in Israel for the adoption of the granular baited insecticide 'Prodan'[1] for S. littoralis control on lucerne.

This recommendation arose from trials by Teich et al. (1968) and Rechav (1973). In the course of this work these authors found that the granules of poisonous bait were attractive at very small distances,and werefound, largely at random, by the larvae crawling on the ground. Control was therefore only effective for third instars and larger larvae that spent some of their time on the ground (5.(2)). In heavy infestations, most of the granules were consumed before individual intakes reach a lethal level, because of this, it was suggested that 'Prodan' was not useful for controlling larvae at densities above 100/m^2 (Ibid., p. 108).

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[1] See Appendix 7:2

The most effective control was found using 'Prodan 1,000' (containing 1,000,000 round granules/kg.)at a rate of 30 kg./ha.

Cypriot farmers were familiar with the use of poisonous baits for armyworm control, many farmers prepared their own from bran, sugar, water and an insecticide such as parathion. 'Prodan 500' (containing 100,000 granules/kg) was available in Cyprus although it was not extensively used. Preliminary trials by the author, using the equivalent of45 kg./ha.of 'Prodan' on a recently cropped pasture infested with a residual population of larvae, showed a normal regrowth pattern for the lucerne on the treated section, and a suppression of growth on the controls, however no systematic larval counts were taken. 'Prodan' was also tested as a barrier to larval dispersal by treating a border approximately 1 metre in width with a double dose of 'Prodan' (equivalent to 80kg./ha. at the edge of a plot from which larvae were dispersing. Subsequent inspection revealed large numbers of larvae dead on the treated border. It seems clear that Cypriot S. littoralis larvae were susceptible to 'Prodan' although the most effective formulation ('Prodan 1,000') was not available, and the dosage appropriate for infestations of lucerne pastures on the island was not ascertained. A provisional costing of the use of 'Prodan' bait basedon the dosages used in these preliminary trials is given in Appendix 7:1.

7.(4) Conclusions

With the present state of S. littoralis pest control research findings in Cyprus, the best option farmers have of improving cost efficiency in control is by adopting a rotational use of the three insecticides: chloropyriphos, methomyl and methamidophos. Certain disadvantages of using sprayed insecticides exist, possibly the most important being the destruction of beneficial arthropods in the pasture and the safety period required before the crop is safe for livestock feeding. These problems, and the need for an investment in spray equipment, would render these compounds less attractive, especially to type 2 farmers, if the bait 'Prodan' was fully tested and found to be economically competitive.

SUMMARY - CHAPTER 7

Cypriot lucerne farmers use insecticides for controlling armyworms on their lucerne crop. However, the majority use compounds that are not very effective for this purpose. The results of insecticide trials on the island suggest that sprayed chemicals - chloropyriphos, methomyl and methamidophos offer the best protection against armyworms.

Certain indirect costs and benefits of insecticide treatment are recognised such as the development of resistance by the pest and the resultant need to transfer to more expensive chemicals. The indirect costs of destroying 'beneficial' non-target organisms are discussed and a scheme for estimating them is given.

The potential use of baited insecticide granules for armyworm control on lucerne is considered good, especially for the control of post-cropping residual larval populations and those occurring prior to harvest (when it is unsafe to spray the crop).

CHAPTER 7 - REFERENCES

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CHAPTER 8

Predicted crop loss and the economic threshold of treatment

8.(1) Introduction

In this chapter, a scheme is described which has been incorporated into the larval infestation simulation discussed in Chapter 6. The extended computer program calculates the predicted loss and the economic threshold of treatment, with infestation timing, crop value and cost of control entered as variables.

8.(2) Predicted crop loss

For the conversion of total damage into total loss the specification of three additional variables is required. These are the unit value of the crop, the weighting factor expressing a farmer's preferences for lucerne leaves rather than stems in their lucerne harvests, and the elasticity of demand for the crop or the products derived from it.

Let the value of crop lost at harvest be E C£/tonne (fresh wt.), the quantity of leaf damage be D_L tonnes (fresh wt.)/ha. and the quantity of stem damage be D_S tonnes (fresh wt.)/ha. Also, let the proportion of the value of an undamaged crop (i.e. 1:1 leaf to stem weight ratio) that may be attributed to the leaves be X, where X may take any value from 0 to 1. Then assuming perfect elasticity of demand:

$$\text{Total loss } (\phi) = 2X(E.D_L) + 2(1-X)(E.Ds) \qquad 8:1$$

In a situation where farmers are faced with a falling demand curve:

$$\text{Total loss } (\phi_1) = \phi(\frac{e-1}{1}) \qquad 8:2$$

where e = an expression for the elasticity of demand.

This scheme was adopted to transform the damage predictions made by the simulation into expected loss.

Tucker and Hodson (C.O.P.R. unpublished report) presented data on the fresh and dry weights of Cypriot grown lucerne leaf and stem samples. The fresh to dry weight ratios derived from these data are:

leaves 5.07:1

stems 4.82:1

The predicted leaf and stem damage estimates are therefore converted from dry wt.g./m^2.(d) to fresh wt.tonnes/ha.(D) by:

$$D_L = 0.0507.d_l$$

$$D_s = 0.0482.d_s$$

Farmers may exhibit differences in preference for leaves and stems as a fodder crop for their livestock. For instance, the similar total energy available in the leaves and stems may cause farmers whose livestock are kept for work purposes (i.e. donkeys, mules or horse etc.) to be indifferent between leaf and stem damage; again they may favour stemmy lucerne if they are also feeding animals concentrated energy foods, since stems provide more roughage. On the other hand, those farmers mainly interested in production from their animals (either as dairy products or flesh from growing animals), due to the higher protein content of the leaves, may prefer leafy lucerne to an equal quantity of defoliated lucerne. Consequently, this factor is left as a variable, and a range of values for X tested in the scheme.

It seems unlikely that individual lucerne farmers in Cyprus are in anything but a perfectly elastic demand situation. Consequently, damage is valued on a pro-rata basis with unit crop value. However, in the event of an increase in type 1 cultivated pastures, perhaps for seed production or as a basis of a lucerne meal industry as in Israel (4.(3)), then a factor such as that shown in equation 8:2 may be necessary to more accurately predict loss for a farmer in large scale production.

Predicted loss is calculated by the program when the indicator flag (L Flag) is set to 1 (resulting in change in the data card 2 shown in table 6:5 from 0,0, to 1,0,) and also when two additional variables are specified. These variables are X (represented in the program as XL), and E (represented in the program as EL). These are entered as real numbers on the same data card (separated by a comma). This card is positioned after the seventh data card shown in table 6:5 (i.e. M).

Crop value (variable E) is not derived directly from the expected profit of growing lucerne (table 3:4). This is because profit is a residual revenue figure which is net of a number of cost items that will have been already incurred by the time the farmer is considering pest control. To maximize future income a farmer will only take into consideration his anticipated future receipts and expenditures. Consequently, E is the gross revenue that would accrue from the sale or use of the predicted damage quota if saved, minus any costs (excluding for the moment any pest control treatment costs) that are incurred by realizing this revenue. Of those items listed in table 3:4 only harvesting, conservation and possibly irrigation costs will be uncommitted by the time the farmer is considering pest control investment.[1] Farmers wishing to maintain a viable lucerne pasture for the remainder of the season will irrigate irrespective of the presence of the pest, consequently, the costs of any irrigations still outstanding when larvae are detected can be considered as committed expenditure.[2] However, a damaged crop may result in reduced harvesting and conservation costs.

The reduction in harvesting costs with increasing damage can be expressed as:

$$h(D_L + D_s)$$

where h = the cost in C£/tonne fresh wt. of lucerne of harvesting and conservation as estimated in Appendix 3:5.

In the program, the constant (h) is entered as C£0.350/tonne. This is a reasonable approximation of the costs encountered by type 1 farmers,

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[1] This refers to the consideration of developing infestations as described in Chapter 6. Farmers will have considered crop protection before committing themselves to the cultivation of a particular crop.

[2] Unless the lucerne pasture growth cycle under consideration is the last one in the four year life of the crop (the probability of which is $\frac{1}{4\times9}$ = 0.027).

and type 2 farmers who value their permanent labour at C£0.050/hr. (3.(2)(f)(ii)). The variable E is therefore entered into the program with a value equal to the opportunity cost of lucerne in C£/tonne fresh wt. (3.(2)(f)(i)), and the program automatically adjusts for any changes in the expected harvesting and conservation costs.

8.(3) The economic threshold of treatment

If in addition to the L Flag indicator being set to 1, the ET Flag indicator is also set to 1 (resulting in a change in the data card 2 shown in table 6:5 from 0,0, to 1,1,) the program calculates the economic threshold of treatment. This is defined generally in 1.(2), but is defined here as the lowest density of first instar larvae occurring on a specified day in the lucerne growth cycle, that if uncontrolled may be expected to cause crop losses equal to the value of a control treatment. This scheme requires the specification of an additional variable: (E_c) the cost of control. However, other variables do not require specification, consequently, table 8:1 has been given to show the form and order of a set of data input for the economic threshold scheme. In Appendix 8:1 the simulated economic threshold of treatment for a range in values of X, E and E_c have been given for larvae occurring from day 1 to day 27 in the lucerne pasture growth cycle.

TABLE 8:1 Data input for the economic threshold scheme

Card number	Type of data	Program variables	Real or integer	Representative Values
(1)	Instruction to read data	-	-	& RUN
(2)	Indicators for scheme	L Flag, ET Flag	integers	1,1,
(3)	Cost of control in C£/ha	E_c	real	5.5
(4)	Dispersal ratios by 'instar'	D	integers	1,3,4,36,60,23
(5)	Daily mortality rate by 'instar'	M	real	0.35,0.20,0.26, 0.08,0.06,0.05
(6)	Proportionate value of leaf (X) and total value of crop (E)	XL, EL,	real	0.7,5.6,
(7)	Instruction to end or read in a following set of data	-	-	& RUN or & END

8.(4) Conclusion

Apart from the wet-dry wt. ratios and the estimated cost/tonne of harvesting and conservation, the two schemes described in this chapter do not incorporate any additional empirical data. Consequently, the limits to the accuracy of the threshold values given in A8:1 are essentially those of the simulation described in Chapter 6.

CHAPTER 9

General conclusions and recommendations

Currently, the most cost effective and proven method of dealing with S. littoralis infestations on lucerne is by applying one of the three sprayed insecticides discussed in Chapter 7. It has been stated (1.(2)) that the main problem facing potential users of insecticides is that of predicting crop loss from given levels of infestation. Consequently, the economic threshold values offered in Appendix 8:1 provide an immediate policy aid to growers. However, some important limitations of the empirical data used to derive the threshold values have been indicated (Chapter 6). Therefore, we recommend that the tables be used with the caution appropriate for first estimates. In particular, it appears probable that the suppression of regrowth by residual populations of larvae result in economic infestations at larval density levels lower than those estimated in Appendix 8:1 (fig. 6:8 indicates that suppression of regrowth occurs until the residual larval population falls below 5 large larvae/m^2).

Table 7:3 gives the safety periods between insecticide spraying and the time when the crop may be fed to livestock. If economic infestations are predicted in the latter part of the lucerne growth cycle when there is not sufficient time before harvest for the crop to be rendered safe for feeding in the fresh state, one of two courses of action may be adopted. A farmer may either use an insecticide such as 'Prodan', which is in a formulation that does not contaminate the crop, or he may harvest his lucerne prematurely, and then treat the cropped pasture for any residual infestation. It has been stated (7.(6)) that the insecticide 'Prodan' was found to be most effective after cropping, however, it may be least reliable in nearly mature pastures where larvae are feeding at the top of the lucerne stems on an abundant supply of foliage. Consequently, we suggest that late infestations are controlled by premature cutting, a practice that probably does not adversely affect crop vigour if adopted in moderation (3.(2)(d)). To minimize direct and indirect costs (7.(4)) of treating any residual population with insecticide, 'Prodan' bait should be used. However, this insecticide was not fully tested in Cyprus and cannot be given an unreserved recommendation as an effective technique.

The preliminary recommendations arising from this study are that lucerne farmers should treat their pastures with one of the three insecticides: chloropyriphos, methomyl or methamidophos (and with periodic changes in the compound used), at the dosages shown in table 7:3, whenever the density of new hatched S. littoralis larvae exceeds the density indicated in the appropriate economic threshold table in Appendix 8:1. However, when an economic infestation is expected to occur within 7-10 days of harvest and a farmer wishes to use his crop in a fresh state, then the crop should be cut before the larvae develop to cause significant damage.[1] Any residual larval population occurring in the subsequent

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[1] This can be tested by using the control scheme in the program where the timing of control is set to the anticipated timing of the premature harvest. A simpler general guide might be that infestations do not cause significant damage until they have reached the fourth instar stage (day 6-8 after hatching).

growth cycle, that is in excess of 5 larvae/m^2., should be treated with 'Prodan' bait applied at a dosage of 45 kg/ha..

We hope that these preliminary recommendations may go some way to improving control of S. littoralis, however, they are largely untried and consequently require further trials before they can be established as effective. The main aim of this work was to attempt to identify the major technological and economic problems associated with the pest, and to formulate a framework to deal with some of those. A consequence of this broad approach has been fewer solid data on which to base all of the conclusions offered. This is regrettable. However, the search for such data in similar problems has sometimes resulted in the germination of numerous sub-projects which develop away from the original objectives. In this study, the relevance of future work in such fields as pest mortality and crop injury compensation can be seen, and the potential value of reliable data for these parameters in terms of increased accuracy of crop loss prediction, can be estimated. We hope therefore, that the integration of a number of facets of the Cyprus armyworm problem will prove, in itself, to be a useful contribution to their economic control on the island. In addition, we suggest that the simulation described in Chapter 6 and the additional schemes in Chapter 8 combine enough characteristics common to a variety of pest problems that they may provide a useful primary structure for modelling other crop pest systems.

APPENDIX 2:1

The estimated costs of flood and sprinkler irrigation in Cyprus

The cost of each unit of water from government-sponsored irrigation schemes such as dams, are estimated for each project and water is sold to the farmers at a price commensurate with these costs. However, the major quantity of irrigation water used on the island is supplied from groundwater sources under private ownership and exploitation. The costs associated with exploiting these privately owned wells have not been satisfactorily estimated. In this appendix, an attempt is made to identify the cost components of the two most prevalent irrigation systems using pumped water. These are field flooding, and the use of pipe and sprinkler equipment. In addition, provisional estimates are made of the likely cost incurred by using each system to irrigate lucerne pastures ranging in scale from 0.1 ha.- 10 ha..

It is assumed that a farmer has full control over the groundwater required for his crops, and that the rate of pumping is not limited by the characteristics of the well.

A2:1(1) Costs of sprinkler irrigation

Three major cost components are recognized:

(1) Capital investment: pipes, sprinklers and pumps
(2) Running costs: pumping etc.
(3) Labour: moving pipes

Capital costs of sprinklers

Let: A = Total area in ha. irrigated at any one time by existing investment in sprinklers

Csf = Annual fixed costs/ha. of sprinklers due to depreciation (including interest charges), in C£

Variable costs are effectively zero.

$\therefore$ Total annual costs = $A.Csf$

Cost of gathering and laying pipes

These are labour costs.

Let: T = Total area to be irrigated in ha.

n_1 = Number of times T area is irrigated/yr.

r = Cost in C£/ha. of laying pipes

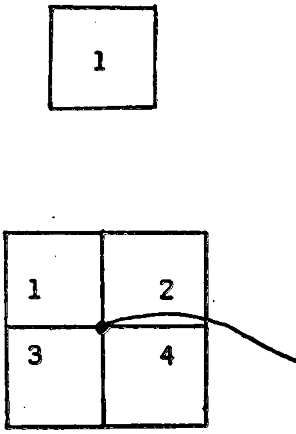
Cost of gathering and laying pipes = $T.r.n_1$

Transfer piping

To economize on the number of pumps and bore-holes required, transfer piping is used to carry water from the bore-hole and pump to an area some distance from it. This method can be also adopted for economizing on the amount of sprinkler pipe used. It is clear, that if no transfer piping was used the area of sprinkler equipment available to the farmer could only serve at the most four adjacent areas to the bore-hole

(Fig. 1). By using a transfer pipe equal to the length of the square A (Fig. 2), it is possible to irrigate a further 8.A without

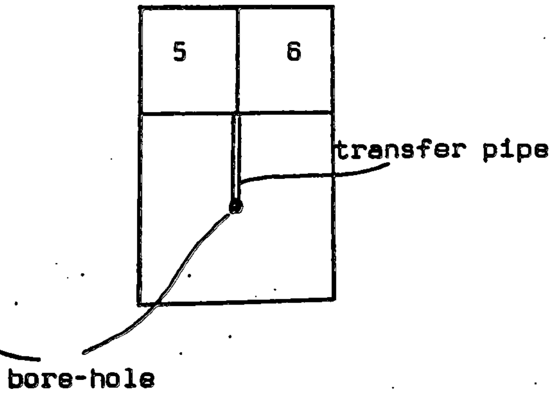
Fig. 1



Area of sprinkler equipment = A.ha. =

Area served by one bore-hole with no transfer piping =

Fig. 2



further investment in either sprinklers or pumps. The total area covered by one pump and bore-hole with a transfer pipe length lp and lateral extent of sprinkler equipment A, is a circle with a radius $lp + \sqrt{A}$ (this assumes the bore-hole is situated in the centre of the field).

$$\text{Total Area} = \pi\,(lp + \sqrt{A})^2$$

The length of lp will be equal to twice the length of area A from the total area to be irrigated: $lp = \sqrt{T} - 2\sqrt{A}$

If Csf is the total annual cost of 1 ha. of sprinkler pipes which are laid in 5 rows across a 1 ha. field, then the use of one pipe as a transfer pipe costs $\frac{Csf}{5}$

$$\text{Total cost 1 yr. of lp transfer piping} = \frac{Csf}{5}(\sqrt{T} - 2\sqrt{A})$$

Movement of sprinkler pipes

Let n = number of times sprinkler pipes are moved to cover the field once

$$n = \frac{T}{A}$$

Pumping

Let: Ch = Annual fixed costs of bore-holes in C£

Cpf = Annual fixed costs of pump and turbine due to depreciation (including interest charges) in C£

Cpv = Variable costs/hr. of operating pump (fuel, maintenance etc.) in C£

t = hrs. used/yr..

If: w = water requirements of 1 ha. of crop for each irrigation

n_1 = number of times T is irrigated/yr.

r_1 = pumping rate is m^3/hr.

then $t = n_1 \left(\frac{T.W}{r_1}\right)$

Total cost of operating 1 pump/yr. = Ch + Cpf + Cpv.t

and total cost of operating np pumps = np (Ch + Cpf) + Cpv.t

Labour 'dead' time associated with each pipe moving

Each time the farmer wishes to irrigate A area he has to arrange to transport his sprinklers and transfer piping and start his pumps.

These activities may not take a long time, but if the farmer has a high T:A ratio (ratio of total area to be irrigated and total sprinkler area available) this 'dead' labour time is an additional factor that might influence his decision to buy more sprinkler equipment.

(1) Labour required to arrange for the transport of sprinklers will be directly proportional to the number of times they are moved (i.e. n and n_1 using the above notation).

Let C_{sup} = Cost of this factor for each move of sprinklers (in C£)

Then total set up costs/yr. = $n_1 \; (n.C_{sup})$

(2) The same costs are associated with moving the transfer piping. It is assumed that transfer piping is used whenever T > 4A, and is moved once for every additional A area required to cover total T. If a second pump is added then additional 4A areas are irrigated free of transfer piping.

Let C_{sut} = Cost of this factor (C£) for every move of a transfer pipe.

Total transfer piping labour 'dead' time costs = $n_1 \; (n.C_{sut} - C_{sut}(n-4np)$

Combining (1) and (2)

Total labour 'dead' time of moving sprinklers and pipes =

$n_1(n.C_{sup} + n.C_{sut} - C_{sut}(n-4np))$

The total cost equation for sprinkler irrigation

$$T.C. = \left[\overset{\boxed{A}}{A.Csf}\right] + \left[np(Ch + Cpf) + \overset{\boxed{B}}{\frac{Csf}{5}}(\sqrt{T} - 2\sqrt{A})\right] +$$

$$\left[\overset{\boxed{C}}{n_1(n.C_{sup} + n.C_{sut} - C_{sut}(n-4np))}\right] + \left[\overset{\boxed{D}}{T.r.n_1}\right] + \left[\overset{\boxed{E}}{Cpv.t}\right]$$

Equation terms

$\boxed{A}$ Varies with T and A (size of field and available sprinkler area).

$\boxed{B}$ Varies with the number of pumps.

$\boxed{C}$ and $\boxed{D}$ Vary with the number of irrigation moves.

$\boxed{E}$ Varies with T, the size of field.

A2:1(2) Costs of flood irrigation

With this method of irrigation farmers merely allow pumped water to flow onto their fields. The water is directed in 1.5m. channels by small dykes. By breaching and rebuilding these dykes a farmer can direct the flow into each of the channels and thus flood the field. This method requires supervision by the farmer to maintain an even flooding of the field, but requires no equipment other than a pump. Water is transported from field to field by dug ditches and culverts (see fig. 5:9).

There appear to be only two major cost components:

(1) Capital investment in pumping equipment.

(2) Supervision of flooding (labour costs).

Pumping Costs

Using the same notation as in A2:1(1) the pumping costs are:

$$np(Ch + Cpf) + Cpv.t^{*}$$

*t will be higher with flood irrigation as this method requires more water/unit area irrigated (i.e. w is larger).

Labour costs

It will be assumed that a farmer can supervise more than one pump if the need arises.

(1) Let Cl = labour costs associated with supervising pumps and flooding in C£/hr.

Using the same notation, total labour costs = $\frac{Cl.t}{np}$

Total cost equation for flood irrigation

$$T.C. = \frac{Cl.t}{np} + np\ (Ch + Cpf) + Cpv.t$$

A2:1(3) Substitution of values in the component costs of sprinkler and flood irrigation for lucerne pastures

Wherever possible cost estimates of items are taken from the most recent Cyprus Government publication (Papachristodoulou, 1970) on agricultural machinery costs. When no guidance from published sources exists, reasonable estimates are made by the author, based on observations and personnel communications.

A : Area of sprinkler investment in ha.

T : Total area of lucerne plot in ha.

r : Cost of pipe laying expressed as a rate in C£/ha. The farm manager at the A.R.I. farm estimated C£1.50/ha. (based on two women and a tractor driver working for approximately 2.5 hrs/ha.)

n_1 : Number of irrigations of the field (area T) in one year = 16

w : Water requirements/ha. of lucerne/irrigation

(1) sprinkler irrigation w = 700 $m.^3$) (source: Hadjichristodoulou,
(2) flood irrigation w = 1200 $m.^3$) pers. comm.)

r_1 : Pumping rate estimated at 120 $m.^3$/hr

Ch : Fixed costs of bore-hole/yr. As there is effectively a zero rate of depreciation, fixed costs will be equal to the annual rate of interest on the original bore-hole drilling cost expenditure. Assuming a cost of £100 and a 6% interest rate Ch = C£6.000

Cpf : Fixed costs of pump and turbine = C£65.000/yr.

Cl : Labour costs C£.200/hr.

Cpv : Variable costs of pumping = C£0.217/hr.

C_{sup} : C£0.075

C_{sut} : C£0.075

np : Number of pumps. The addition of another pump to a sprinkler system is justified when term $\boxed{B}$ in the total cost equation exceeds term $\boxed{C}$ plus some of the labour dead time of term $\boxed{D}$. In other words pumps are traded off against transfer piping. A more fundamental constraint necessitating extra pumps occurs when the total number of hours pumping (t) required by one pump to complete the years irrigation, exceeds the time available.

By substitution it is found that a field of 100 ha. with a large amount of transfer piping still requires only one pump to minimize total cost, but 1 ha. requires 94 hrs pumping/yr. If a pump is used throughout the summer (allowing for maintenance stops) the maximum area it could service would be approximately 25.5 ha. Therefore fields larger than 25.5 ha. require at least two pumps.

The addition of another pump to the flood irrigation system is only justified when there is not sufficient time available for the completion of the years irrigation. 1 ha. requires 133 hrs/yr. One pump can therefore service approximately 18.0 ha. of lucerne. In practice, flood irrigated lucerne fields of this size do not exist in Cyprus, it is therefore assumed that each farmer who uses flood irrigation uses only one pump.

Substitution for sprinkler irrigation

The cost equation for sprinkler irrigation presents a potential trade-off situation between labour costs, transfer piping, sprinkler piping and pumping costs. The optimum least cost solution to the equation will change according to T the total area to be irrigated. Table A2:1(1) gives 4 solutions with T ranging from 0.1-10 ha. and with varying values of(A) (expressed as a fraction of T). Fig. A2:1(1) is a graphical plot of T =5.0 ha. with changing values of A.

The trends that emerge from these solutions are that (1) the larger T the larger is A for a least cost operation and (2) the larger T the smaller is A as a proportion of T for a least cost operation.

Substitution for flood irrigation

For a given number of pumps there is only one solution to the equation

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for each value of T. These costs are given in Table A2:1(1).

A2:1(4) A comparison of sprinkler and flood irrigation

Fig. 3:3 in text gives the minimum cost in total C£/yr. for both systems from 0.1-10 hectare fields. The general conclusions are that below 0.2-0.3 ha. flood irrigation is cheaper than the least cost sprinkler system, above this value flood irrigation becomes progressively more costly. Owing to the fixed cost component of the pump (C£71.000 per year) both types of irrigation show a marked increase in costs/ha. below 1 ha. This is a possible further reason for the sharing of pumping facilities by numerous small producers.

0.1 ha - 10 ha in size, and the Corresponding Flood Irrigation Costs

Size of the Lucerne Field (T)	Area of Sprinklers as a proportion of total $\frac{A}{T}$	n	Solution of Equation Terms in C£/yr					Total Cost C£/yr 16 irrigations by sprinklers	Total cost C£/yr 16 irrigations by flooding
			$\boxed{A}$	$\boxed{B}$	$\boxed{C}$	$\boxed{D}$	$\boxed{E}$		
T = 0.1 ha	A = 0.01T	100	0.030	71.000	2.324	235.200	4.400	312.954	77.672
	A = 0.05T	20	0.170	71.000	1.631	43.200	4.400	120.401	
	A = 0.20T	5	0.690	71.000	0.931	7.200	4.400	84.220	
	A = 0.50T	2	1.730	71.000	0	2.400	4.400	79.530	
	A = 1.00T	1	3.460	71.000	0	1.200	4.400	80.060	
T = 1.0 ha	A = 0.01T	100	0.346	71.000	5.600	235.200	44.000	356.140	137.720
	A = 0.05T	20	1.730	71.000	4.660	43.200	44.000	164.590	
	A = 0.20T	5	6.920	71.000	3.490	7.200	44.000	132.610	
	A = 0.50T	2	17.300	71.000	0	2.400	44.000	134.700	
	A = 1.00T	1	34.600	71.000	0	1.200	44.000	150.800	
T = 5.0 ha	A = 0.01T	100	1.730	71.000	12.43	235.200	220.000	540.360	404.600
	A = 0.05T	20	8.650	71.000	8.56	43.200	220.000	351.410	
	A = 0.20T	5	34.600	71.000	1.56	7.200	220.000	334.360	
	A = 0.50T	2	86.500	71.000	0	2.400	220.000	379.900	
	A = 1.00T	1	173.000	71.000	0	1.200	220.000	465.200	
T = 10 ha	A = 0.01T	100	3.460	71.000	20.500	235.200	440.000	770.160	738.200
	A = 0.05T	20	17.300	71.000	18.900	43.200	440.000	537.250	
	A = 0.20T	5	69.200	71.000	1.750	7.200	440.000	589.150	
	A = 0.50T	2	173.000	71.000	0	2.400	440.000	686.400	
	A = 1.00T	1	346.000	71.000	0	1.200	440.000	858.200	

APPENDIX 3:1

Growers' questionnaire and damage survey (1972)

A3:1(1) Introduction

During September 1972, letters in Greek were sent to the top official of each of those villages in Cyprus with any appreciable quantity of irrigation water. These letters requested the return of a list of all the farmers in the village who grew either: lucerne, late potatoes, tomatoes, beans or artichokes.

Within two weeks, approximately 35 lists had been returned from the total of 64 villages to which letters had been sent. Subsequently, visits were made to the more important farming villages from which no lists had been received. In this way a list of 1,064 farmers growing at least one of the five crops was accumulated. These farmers were distributed amongst 49 villages.

A five part questionnaire was constructed to send to the farmers listed. The objective of the questionnaire was firstly to establish the cultivation practice by Cypriot farmers of the five main Spodoptera sp. host crops: lucerne, late potatoes, tomatoes, beans and artichokes. Secondly, to assess the overall level of pest damage by Spodoptera sp. in 1972. Finally, it was hoped that the questionnaire would establish the normal control practices adopted by the farmers in combating Spodoptera sp. infestations.

Only those parts of the questionnaire which were relevant to the particular farmer were sent. Hence, those growing only lucerne and artichokes were sent, on introduction, a questionnaire on lucerne and artichoke cultivation and damage, and the concluding tabulated questions on insecticide applications. In addition to the questions on their crops, farmers were supplied with a photocopy of a map of their village with field boundaries marked on it. They were requested to identify their fields and indicate which of the five crops they were cultivating. It was hoped that a pattern of damage would emerge from these individual records.

The questionnaires were translated into Greek and Turkish and distributed according to nationality to the 1,064 farmers on the list. During the following weeks visits were made to the coffee shops of the main villages sampled and farmers were persuaded to complete and return their questionnaire.

A3:1(2) <u>The questionnaire</u>

It is very important that you complete and return this questionnaire even if you had no damage from larvae this year, or the area of land you own is very small. Would you please mark the position of your fields on the map of your village provided, using the notation below.

π	for potatoes
Tp	for lucerne
ϕ	for beans
T	for tomatoes
A	for artichokes

Write here:

(1) Your Name ....

(2) Your Village ....

(3) How many donums of land do you rent, own, or belongs to your wife ....

To make this form easier to complete some examples will be given on how to answer the types of questions asked. If you are asked the amount of anything or the number of times you did something write the number in the box alongside the question. For instance if you are asked how many donums of lucerne you cultivated in 1969 and the amount was three donums fill in a 3 in the box. So :

(1) How many donums of lucerne did you cultivate in 1969? [3]

Where you are asked to choose between two, three or four or more answers put a (+) in the square opposite the number most correct. For instance if the question appears as below :

(2) How many times a month in the summer do you water your tomatoes?

Once	
Twice	+
Four times	
More than four times	

and you had watered them twice you would put a (+) in the box as in the example above.

If the question is in the "yes" or "no" form you will put a (+) in the box alongside the "yes", if you agree or the "no" if you don't. For instance in the question below:

Did you have any damage from larvae in 1972? YES [+] NO ☐

and you had had damage you would put a (+) in the box alongside the "yes" as shown in the example.

These are the questions to be answered by you.

(1) In the table below fill in which crops you grew this year and how many donums, and also the number of animals you have.

Crops	Number of Donums	Livestock	
		Type	Numbers
		Sheep	
		Goats	
		Cattle	
		Others (name them)	

LUCERNE

(1) How many donums of lucerne did you cultivate:

— in 1969 ☐ in 1970 ☐ in 1971 ☐ in 1972 ☐

(2) If the amount of lucerne you have grown has fallen in the last few years is it because

(1) Water shortage ☐

(2) Other reasons ☐

If other reasons please state them ....

....

(3) How often do you irrigate your lucerne.

(1) Once every cut ☐
(2) Twice every cut ☐
(3) Three times every cut ☐
(4) More than three times ☐

(4) Which method do you use

Flood ☐
Pipes and Sprinklers ☐

(5) How many days between harvests?

In the months April - June ☐
July - September ☐
October - December ☐

(6) What do you use lucerne for?

Feed it fresh to livestock	☐	If yes, how many donums	☐
Sell it fresh	☐		☐
Sell it as hay	☐		☐
Sell it as meal	☐		☐

(7) If you sell your lucerne where do you sell it?

To neighbours ☐
In the market ☐
To the Government Co-operative ☐

(8) Have you had any damage from larvae?

Yes ☐ No ☐

If yes then read these instructions and fill in the table below.

The damage to the leaves may be all the leaves gone, half the leaves gone or just some. Put a (+) in the box appropriate to the amount of damage you had in your lucerne during the months of June - December.

Please indicate also whether the damage was due to small green larvae (Laphygma) or large grey ones (Prodenia).

Month	Damage to Leaves			Larval Type		How many donums	How old is the pasture?			
	All	Half	Some	Grey	Green		1 yr	2 yr	3 yr	4 yr
June										
July										
August										
September										
October										
November										
December										

(9) Have you used insecticides on lucerne this year?

(1) For aphids Yes ☐ No ☐

(2) For larvae Yes ☐ No ☐

If you did use insecticides when did you apply them?

(1) When you saw damage ☐

(2) Before you saw damage ☐

If you used insecticides

Month	How many times did you use them	How many donums each time	Which equipment*		How high was the lucerne (centimetres)	Name of insecticide
			Knapsack	Tractor		
June						
July						
Aug.						
Sept.						
Oct.						
Nov.						

*If you used baits or dusts indicate here

LATE POTATOES

(1) How many donums of late potatoes did you plant

in 1969 ☐ in 1970 ☐ in 1971 ☐ in 1972 ☐

(2) If the area of potatoes you have grown has fallen in the last few years is it because

(1) Water shortage ☐

(2) Other reason ☐

If other reasons please state them ....

....

(3) How many days between each watering ☐

(4) Which varieties of potato did you cultivate

Varieties	Date Planted	Date Harvested
1		
2		
3		
4		
5		

(5) How many days between each irrigation. ☐

(6) Have you had any damage from larvae this year.

YES ☐ NO ☐

If you have had any damage this year read the instructions and complete the tables below.

The damage to the leaves may be all the leaves gone, half the leaves or only some of them. Put a (+) in the box appropriate to the amount of damage you had on your potato plot during the months of August - November. Please indicate whether the larva causing this damage were small and green (Laphygma) or large and grey (Prodenia).

Months	Donums affected	Type of larvae		Damage to leaves		
		Green	Grey	All	Half	None
August						
September						
October						
November						

(7) Did you use an insecticide on your potatoes

YES ☐ NO ☐

If yes, please complete the table below:

Months	How many times did you treat	How many donums did you treat	Which equipment		Name of the insecticide
			Knapsack	Tractor	
August					
September					
October					
November					

A questionnaire for Tomatoes, Beans and Artichokes was also prepared. These were identical to the questions on potato cultivation except for the table asking for varieties grown; this was omitted.

A final table on the questionnaire was aimed at establishing the types of insecticide used by farmers.

Table Instructions

Write in the table below the names of the insecticides you have bought, the amount of each and whether you used them for larval control.

Month	Name of insecticide	Amount bought in wt. or volume	Was it for larvae or other pests		Name of Agent from which you purchased it
			Larvae	Other	
April					
May					
June					
July					
August					
September					
October					
November					

A3:1(3) Questionnaire results

In spite of the persuasion to farmers to complete and return the questionnaire, only 158 correctly completed returns were received, constituting a 15% total response rate. These returns represented an ownership of 6,500 donums (871 ha.) of farmland, of which 2,347 donums (314.5 ha.), were irrigated.

The data was translated onto computer cards and analysed. It was found that greater than 80% of the farmers recorded damage at some time during the 1972 season. This figure was much higher than that estimated from the pest survey (Appendix 5:1), and it was thought that the farmers returning the questionnaire were motivated towards improved Spodoptera sp. control due to recent damage. The returns were therefore considered too biased to be of use in the estimation of total damage on the island, or the estimation of any regional trends indicated by the photocopy maps. However, the assumption was made that they were a representative sample for the purposes of establishing the normal cultivation and pest control practices adopted by farmers. This implicitly discounted the possibility of liability to damage being dependent on such factors.

The tables below are the data from assumed 'neutral' questions the results of which are used in the text. In situations where the full data is given in text the results are not reproduced in this appendix.

TABLE A3:1(1) Frequency of lucerne plot ownerships reported

Number of Farmers	Area of Lucerne Field Ownership	Number of Farmers	Area of Lucerne Field Ownership
11	0.13 ha.	2	1.56 ha.
9	0.26 ha.	2	1.69 ha.
7	0.39 ha.	1	2.43 ha.
6	0.52 ha.	3	2.50 ha.
3	0.65 ha.	1	2.76 ha.
2	0.78 ha.	1	3.02 ha.
3	0.91 ha.	2	3.41 ha.
8	1.04 ha.	1	4.32 ha.
2	1.17 ha.	1	4.58 ha.
4	1.30 ha.	1	8.55 ha.
1	1.43 ha.		

TABLE A3:1(2) Interval between summer lucerne irrigations

Number of Farmers	Interval in days	Number of Farmers	Interval in days
1	3	4	11
1	4	3	12
5	5	2	14
6	6	1	15
2	7	1	17
18	8	2	20
5	9	2	24
3	10		

TABLE A3:1(3) Reasons for decline in area of irrigated crop cultivation

	Lucerne	Late Potatoes	Tomatoes	Beans	Artichokes	All Crops
No decline	64	45	34	28	10	181
Water Shortage	3	14	2	11	1	31
Other Reasons	4	7	1	2	0	14

APPENDIX 3:2

Results of lucerne growth assessment trial

Table A3:2(1) gives the results of the sample harvests taken at different intervals after the harvest of a pasture on 29.9.73.

TABLE A3:2(1) Dry wt. yields of a series of destructive harvests during a lucerne pasture regrowth cycle in September-October 1973

Sampling time in days after last harvest	Dry wt. in g. of leaf and stem of four 0.5m.x 0.5m.(0.25m^2.) quadrat samples				Mean Yield in g./m^2.
Harvest 29.9.73	1	2	3	4	
8	5	3.5	4	3.5	16.0
12	17	20	23	15	75.0
16	22	23.5	20.5	23	89.0
20	37	50	42	44	173.0
24	38	43	43	44	168.0
28	28	40	35.5	51	154.0
31	34	48	40	53	175.0
35	41	47	32	49	169.0

The lucerne was harvested by hand, picking each of the fresh green shoots growing within the area of the 0.25m^2. quadrat. This method was favoured instead of using shears to crop the pasture as it ensured that only the newly emergent shoots were collected. This was considered to be a possible source of discrepancy between these results and the data collected by Hodson and Tucker (see text 3.(2)(c)). These workers used shears, and therefore collected some older stubbly material which was dense, and could cause an upward bias in dry weight estimates of very early regrowth.

APPENDIX 3:3

Results of lucerne cutting regime trials

Plots were $1m^2$. and adjacent to each other, the yield sample harvests were taken from the centre of each plot using a $0.25m^2$ quadrat. Table A3:3(1) gives the yields of the individual harvests and the mean estimates in g/m^2.

Table A3:3(2) gives the results of the chemical analysis of the final harvests from the plots after an equal 42 days growth period for all of the cutting regimes.

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TABLE A3: 3(1) Yields from Trial Plots

Cropping Regime	Harvest date	Cropping Interval (days)	Dry Wt. Lucerne in g./m^2 for each replicate					Means
			(1)	(2)	(3)	(4)	(5)	
1	8.11.73	125	264.0	240.0	224.0	288.0	190.0	241.2
TOTAL		125	264.0	240.0	224.0	288.0	190.0	241.2
	20.12.73	42	305.8	311.4	307.0	333.9	315.2	314.7
2	1. 8.73	26	144.0	142.0	116.0	136.0	116.0	144.8
	25. 8.73	24	190.0	198.0	170.0	154.0	170.0	206.4
	19. 9.73	25	88.0	138.0	124.0	106.0	58.0	88.4
	18.10.73	29	126.0	142.0	132.0	136.0	132.0	133.6
	8.11.73	21	98.0	84.0	116.0	93.0	66.0	93.6
TOTAL		125	648.0	704.0	658.0	625.0	542.0	666.8
	20.12.73	42	321.0	326.1	320.3	327.4	348.6	328.7
3	24. 7.73	18	84.0	87.2	92.0	108.0	64.0	87.0
	11. 8.73	18	108.0	98.0	116.0	88.0	102.5	102.5
	29. 8.73	18	112.0	114.0	94.0	107.2	84.4	102.3
	16. 9.73	18	80.0	44.0	52.0	48.0	30.0	50.8
	14.10.73	28	106.0	80.0	100.0	76.0	60.0	84.4
	8.11.73	25	104.0	72.0	80.0	72.0	60.0	77.6
TOTAL		125	594.0	495.2	534.0	499.2	400.9	504.6
	20.12.73	42	347.5	337.9	339.7	383.4	385.4	358.7
4 —	16. 7.73	10	48.0	60.0	70.0	72.8	60.0	62.2
	26. 7.73	10	54.0	36.0	40.0	26.0	24.0	36.0
	7. 8.73	12	72.0	68.0	74.0	70.0	68.0	70.0
	15. 8.73	8	13.2	12.0	16.0	24.8	20.0	17.2
	25. 8.73	10	25.6	30.0	20.4	38.0	44.4	31.7
	4. 9.73	10	4.8	10.4	8.4	10.0	10.4	8.8
	14. 9.73	10	12.0	1.0	4.0	0.8	3.0	4.2
	26. 9.73	12	0	0	0	0	0	0
	8.10.73	12	4	8	4	0	0	3.2
	23.10.73	15	4	8	2	0	0	2.8
	8.11.73	16	0	0	0	0	0	0
TOTAL		125	237.6	233.4	238.8	242.4	229.8	236.1
	20.12.73	42	0	0	0	0	0	0

An analysis of variance on the total yields for the initial 125 day period indicated a highly significant difference between yields of the different treatment regimes (>> 1%). However there was no significant differences between the total yields for regimes 1 and 4 and between regimes 2 and 3.

TABLE A3:3(2) General chemical analysis of lucerne from the final harvest of plots in table A3:4(1)

Cropping regime	Days Growth	Yield in dry wt. g/m2	%age moisture (at 65°C) of fresh plant	Concentration of substance on a %age dry wt. basis (65°C)					
				Moisture at 100°C	Dry Matter	Protein (N x 6.25)	Crude Fibre	Crude Fat	Ash
1(1)	42	152.9	78.8	10.44	19.11	26.50	18.54	4.14	11.19
1(2)	42	155.7	78.2	10.72	19.46	24.06	19.94	3.69	11.59
1(3)	42	153.5	78.6	10.35	19.19	24.00	21.11	3.91	11.58
1(4)	42	166.8	76.8	10.03	20.87	24.87	19.02	3.70	10.44
1(5)	42	157.6	78.0	9.86	19.70	25.56	19.57	4.15	11.08
MEANS	42	157.3	78.1	10.28	19.68	24.99	19.71	3.92	11.18
2(1)	42	160.5	77.6	10.62	20.06	26.19	19.50	4.19	11.47
2(2)	42	163.0	77.2	10.46	20.38	24.75	19.97	4.06	11.31
2(3)	42	160.1	77.5	11.04	20.02	26.06	18.64	3.98	11.98
2(4)	42	163.7	77.1	10.65	20.46	25.25	19.16	4.25	10.29
2(5)	42	174.3	75.8	9.95	21.79	26.06	18.26	4.37	10.94
MEANS	42	164.3	77.0	10.54	20.54	25.66	19.12	4.17	11.20
3(1)	42	173.7	76.0	9.48	21.72	23.75	20.34	3.88	11.36
3(2)	42	168.9	77.6	9.76	21.12	25.56	18.70	4.11	11.31
3(3)	42	168.3	76.5	9.67	21.23	26.94	18.18	4.07	11.56
3(4)	42	191.7	73.2	10.59	23.96	27.07	15.92	4.33	12.23
3(5)	42	192.7	73.3	9.76	24.09	26.94	16.75	4.11	11.50
MEANS	42	179.3	75.3	9.85	22.42	26.05	17.98	4.10	11.59

Chemical analysis by courtesy of A.R.I. Chemistry Dept.

TABLE A3:3(3) Statistical analysis of yield differences

	Regimes between which differences were detected	Level of significance
Yield differences in first 125 day growth period	1 and 2	> 1%
	1 and 3	> 1%
	2 and 3	> 5%
	2 and 4	> 1%
	3 and 4	> 1%
Yield differences between final harvests on 42nd day of regrowth	1 and 3	> 2%
	2 and 3	>10%

TABLE A3:3(4) Statistical analysis of nutrient composition differences

Plant Substance	Regimes between which differences were found	Level of significance
Moisture at 100°C, and resulting dry matter	1 and 3	> 2%
	2 and 3	> 10%
Protein	None	
Crude Fibre	None	
Crude Fat	None	
Ash	None	

APPENDIX 3:4

Milk yields of Friesian cow fed with S. littoralis larvae in the ration

A Friesian cow was established on a lucerne hay diet (30 kg. per day for 21 days). Then S. littoralis larvae were introduced along with the daily ration at a rate of 25 larvae/kg. of lucerne (equivalent to ingesting approximately 60 larvae per $m.^2$ whilst grazing). This regime was continued for 9 days then no more larvae were fed to the cow. Table A3:4(1) gives the milk yields prior, during and immediately after the larval feeding. An analysis of variance indicated that the introduction of larvae into the ration had no significant effect on milk yields.

The larvae were mostly fourth to sixth instars (1.5-2.5 cm). Some larvae were lost into the bottom of the feeder or onto the ground. It is estimated that 20-40 larvae/feed were lost in this manner.

TABLE A3:4(1) Milk yield of Friesian cow fed with *S. littoralis* larvae in lucerne ration

Date	Milk Yield in kg.			Date	Milk Yield in kg.			Date	Milk Yield in kg.		
	Morning	Afternoon	Weekly Total		Morning	Afternoon	Weekly Total		Morning	Afternoon	Weekly Total
1.8.71	5	3		23.8.71	5	3		14. 9.71	5.5	2.5	
2.8.71	5	3		24.8.71	6	3		15. 9.71	5	3	
3.8.71	6	3		25.8.71	5	4		*16. 9.71	6	3.5	
4.8.71	5	3		26.8.71	5	3.5		*17. 9.71	6	2.5	
5.8.71	5	3		27.8.71	5	3.5		*18. 9.71	6	3	
6.8.71	5.5	3		28.8.71	5.5	2.5	60.0	*19. 9.71	6	3	57.0
7.8.71	6	3	58.5	29.8.71	6	4		*20. 9.71	5.5	3.5	
8.8.71	6	3		30.8.71	5.5	3		*21. 9.71	6	3	
9.8.71	6	3		31.8.71	5.5	3		*22. 9.71	5.5	3	
10.8.71	6	3		1.9.71	5	3		*23. 9.71	5.5	2.5	
11.8.71	6	3		2.9.71	5.5	3.5		*24. 9.71	5	3	
12.8.71	5	3		3.9.71	5	3.5		25. 9.71	5.5	3	60.0
13.8.71	5.5	3		4.9.71	5.5	3	61.0	26. 9.71	5	4	
14.8.71	6	3.5	62.0	5.9.71	5	3		27. 9.71	5.5	2.5	
15.8.71	5	3		6.9.71	5	3.5		28. 9.71	5	3	
16.8.71	5	2.5		7.9.71	5	2.5		29. 9.71	5.5	2.5	
17.8.71	5	3		8.9.71	4	3		30. 9.71	5	3	
18.8.71	5.5	3		9.9.71	5	3		1.10.71	6	3	
19.8.71	5	3		10.9.71	4	2.5		2.10.71	5.5	2.5	58.0
20.8.71	5	3		11.9.71	5	2	52.5	3.10.71	5	3.5	
21.8.71	5	4	57.0	12.9.71	5	2		4.10.71	5	2	
22.8.71	6	3		13.9.71	5	2		5.10.71			
								6.10.71			

*Days when larvae were included with ration

APPENDIX 3:5

Costs associated with cultivating lucerne by type 1 and type 2 farming methods

Costs taken largely from A.R.I. publication on norm input-output data for the main crops of Cyprus (Papachristodoulou, 1970).

A3:5(1) Land preparation costs

For any crop there are two forms of land preparation required. Firstly, basic improvements on virgin ground, such as levelling, terracing, or any measure required before the ground is rendered suitable for cultivation. Secondly, there are specific establishment costs andtillage required at each rotation. Since an imputed rent is charged at the rate of 4% per annum on the total value of the land it is assumed that preliminary improvements have been made and these costs will not be included. Land preparation for lucerne occurs once every four years and costs are estimated in Table A3:5(1). The hrs/yr. for machinery is an estimate of total usage for all purposes on the farm.

TABLE A3:5(1) Land preparation costs - Type 1 farmers

VARIABLE COSTS	hrs/yr.	C£/hr.	hrs/ha.	C£/ha.
(i) Disc Plough	400	0.062	4	0.248
(ii) Harrow	400	0.048	1.5	0.072
(iii) 35 h.p. Tractor	1,200	0.202	9.5	1.919
(iv) Seed Drill	400	0.149	4	0.596
(v) Seed				37.500
TOTAL VARIABLE COSTS				40.335
TOTAL VARIABLE COSTS/YR.				10.083
FIXED COSTS				
(1) Permanent Labour		0.200	9.5	1.900
TOTAL FIXED COSTS				1.900
TOTAL FIXED COSTS/YR.				0.475

Type 2 farmers

VARIABLE COSTS				
(i) 5 h.p. Rotary Cultivator	200	0.223	8	1.784
(ii) Seed				37.500
TOTAL VARIABLE COSTS				39.284
TOTAL VARIABLE COSTS/YR.				9.821
FIXED COSTS				
(i) Permanent Labour				
(a) Using cultivator		0.200	8	1.600
(b) Raking		0.200	40	8.000
(c) Seeding		0.200	5	1.000
TOTAL FIXED COSTS				10.600
TOTAL FIXED COSTS/YR.				2.650

A3:5(2) Fertilizer costs

Type 1 farmers use a tractor and disc fertilizer pellet spreader and can complete the fertilizing of a one hectare field in two hours. Type 2 farmers walk through their fields and broadcast fertilizer pellets from a bag. The costs of both systems are estimated in Table A3:5(2).

TABLE A3:5(2) The estimated costs of lucerne pasture fertilizer applications

Type 1 farmers

VARIABLE COSTS

		hrs/yr.	C£/hr.	hrs/ha.	C£/ha.
(i)	Tractor and Spreader	200 (spreader)	0.300	2	0.600
(ii)	Fertilizer				88.600
TOTAL VARIABLE COSTS/YR.					89.200

FIXED COSTS

		hrs/yr.	C£/hr.	hrs/ha.	C£/ha.
(i)	Permanent Labour		0.200	2	0.400
TOTAL FIXED COSTS/YR.					0.400

Type 2 farmers

VARIABLE COSTS

		hrs/yr.	C£/hr.	hrs/ha.	C£/ha.
(i)	Fertilizer				88.600
TOTAL VARIABLE COSTS/YR.					88.600

FIXED COSTS

		hrs/yr.	C£/hr.	hrs/ha.	C£/ha.
(i)	Permanent Labour		0.200	8	1.600
TOTAL FIXED COSTS/YR.					1.600

A3:5(3) Cutting, harvesting and conservation costs

Type 1 farmers typically harvest with mowers and bale their lucerne as hay. Type 2 farmers cut their lucerne by hand and use it fresh, or conserve it as meal. Cutting and conservation costs are incurred nine times per year and are estimated in Table A3:5(3).

TABLE A3:5(3) Cutting and harvesting costs

Type 1 farmers

VARIABLE COSTS

	hrs/yr.	C£/hr.	hrs/ha.	C£/ha.
(i) Machine Cutter and Tractor	200	0.342	2	0.684
TOTAL VARIABLE COSTS				0.684
TOTAL VARIABLE COSTS/YR.				6.156
FIXED COSTS				
(i) Permanent Labour		0.200	2	0.400
TOTAL FIXED COSTS				0.400
TOTAL FIXED COSTS/YR.				3.600
CONSERVATION - Hay				
VARIABLE COSTS				
(i) Tractor & Baler		0.402	4	1.608
TOTAL VARIABLE COSTS				1.608
TOTAL VARIABLE COSTS/YR.				14.472
FIXED COSTS				
(i) Permanent Labour		0.200	4	0.800
TOTAL FIXED COSTS				0.800
TOTAL FIXED COSTS/YR.				7.200

Type 2 farmers

VARIABLE COST - NONE .

FIXED COST	C£/ha.			hrs/ha.	C£/ha.		
	(a)	(b)	(c)		(a)	(b)	(c)
(i) Permanent Labour	0.100	0.050	0	6	6.000	3.00	0
TOTAL FIXED COSTS					6.00	3.00	0
TOTAL FIXED COSTS/YR.					54.000	27.000	0

Conservation as meal (not included in table 3:4)

VARIABLE COSTS

	C£/ha.	hrs/ha.	C£/ha.
(i) Transportation	0.202	0.25	0.050
(ii) Drier Charge (C£5.000 tonne)			9.000
TOTAL VARIABLE COSTS			9.050
TOTAL VARIABLE COSTS/YR.			81.450

FIXED COSTS

(i) Permanent Labour	0.200	0.50	0.100
TOTAL FIXED COSTS			0.100
TOTAL FIXED COSTS/YR.			0.900

All the figures given for types 1 and 2 harvesting and conservation costs are calculated on the basis of average production (table 3:4). It is stated in the text that harvesting and conservation costs were assumed to vary in direct proportion to yield. Consequently, the mean figures are converted into total cost/tonne in order that estimates can be made of harvesting and conservation costs at low and high production.

Type 1 farmers

	C£/tonne fresh wt.
(i) Total harvesting costs	0.121
(ii) Total conservation costs	0.270
(i) + (ii)	0.391

Type 2 farmers

	C£/tonne fresh wt.
Total harvesting costs	
(a)	0.672
(b)	0.336
(c)	0

A3:5(4) Rent

It is assumed that the value of agricultural land suitable for lucerne cultivation is C£.500/ha. for small fragmented plots and C£560/ha. for larger areas suitable for extensive cultivation. With an imputed rent of 4% of the value per year, the rent fixed costs for the two types of farming are:

Imputed rent for type 1 farmers	C£22.400/ha./yr.
Imputed rent for type 2 farmers	C£20.000/ha./yr.

A3:5(5) Irrigation

Using the scheme in Appendix 2:1 it is assumed that the type 1 farmer cultivates 10 ha. of lucerne and irrigates using the optimal investment in sprinklers appropriate for the size of his pastures. It will be further assumed that the type 2 farmer shares the fixed costs of pumping between five other farmers and employs flood irrigation on his 0.1 ha. plot.

Cost/yr in C£/ha. of irrigation for type 1 farmer = 53.000

Cost/yr in C£/ha. of irrigation for type 2 farmer = 73.830

APPENDIX 5:1

TABLE A5:1(I)a) RESULTS OF THE PEST SURVEY FOR ADJACENT TREATED AND UNTREATED PLOTS

SITE	Sample date	PLOTS TREATED WITH INSECTICIDE JUST PRIOR TO SURVEY							ADJACENT UNTREATED PLOTS							Nos. Mot Trap at sit
		Larvae/m^2			Parasites/m^2		Lucerne		Larvae/m^2			Parasites/m^2		Lucerne		
		S.litt.	S.ex.	Others	Ch.in	Others	Height cm.	% Leaf loss	S.litt.	S.ex.	Others	Ch.in.	Others	Height cm	% Leaf loss	
1	24.8	0	1.1	.5	n.r	n.r	50	0	0	2.0	0	n.r	n.r	45	0	0
	31.8	0	1.0	0.2	0.5	0	50	0	0.1	1.9	0.3	0.7	0	45	1	0
2	24.8	0	4.2	0.5	n.r	n.r	60	3	0	4.4	0.5	n.r	n.r	60	0	7
	31.8	0	8.2	0.7	0.5	0	60	0								1
3	24.8	0	17.0	0.8	n.r	n.r	40	0	0	24.7	0.7	n.r	n.r	40	10	n.r
4	24.8	0	2.7	1.6	n.r	n.r	60	0	0	0	0.1	n.r	n.r	65	0	136
	31.8	0	21.2	0.3	0.7	1.0	50	7	0	3.4	0.1	0.5	0	40	0	0
	25.8	0	0	0	n.r	n.r	30	0	0	3.1	0	n.r	n.r	30	0	0
6	28.8	0	1.7	0.3	0.5	0	40	0	0	1.5	0.4	0.6	0	45	0	11
	31.8	0	5.3	0.4	3.3	0	60	0	0	4.4	0	1.2	0	40	0	5
1	4.9	0	0.4	0.2	0.3	0	50	16	0	0.5	0.1	0.6	0.5	10	0	0
	7.9								0	1.2	0.1	4.2	1.2	15	0	6
	12.9	0	0.3	0	0.7	0.1	15	0	0	0.9	0.3	2.1	2.1	25	0	2
	14.9	0	0.5	0.3	0.5	0.2	30	0	0	0	0	1.1	0.2	30	0	6
	20.9	0	0	0	0.8	0	50	0	0	0.2	0.1	0.8	0.1	40	0	9
	23.9	0.1	0.5	0	0.7	0	40	0	0.1	0	0.2	1.7	0	40	0	2
	25.9	0.1	0.8	0.1	1.2	0.1	45	0	0	0	0	0.8	0	45	0	11
	28.9	0	0.1	0.4	0.5	0.1	55	0	0.1	0.1	0.2	0.6	0.1	45	0	20
2	4.9	0	6.6	0	1.0	0	65	0	0	1.9	0	0.4	0.1	30	0	1
	7.9	0	2.0	0	0	0.1	65	0	0	0.9	0	1.1	0.1	40	0	0
	12.9	0	0.2	0.2	1.0	2.0	65	0	0	0.2	0	1.7	0.9	50	0	1
	14.9	0	0	0.3	1.2	0	65	0	0	0	0	0.3	0.4	50	0	6
	20.9	0	0	0.1	0	0	30	0	0	0	0	0.3	0.3	60	0	34
	23.9	0	0.1	0.1	0.1	0.3	40	0	0.1	0.5	0.4	0.5	0.1	50	0	12
	28.9	0	0.2	0	0.8	0.2	60	0	0	0	0.2	0	0	25	0	18

TABLE A5:1(1)a RESULTS OF THE PEST SURVEY FOR ADJACENT TREATED AND UNTREATED PLOTS (continued)(1)

SITE	Sample date	PLOTS TREATED WITH INSECTICIDE JUST PRIOR TO SURVEY							ADJACENT UNTREATED PLOTS							Nos. Moths Trapped at site
		Larvae/m^2			Parasites/m^2		Lucerne		Larvae/m^2			Parasites/m^2		Lucerne		
		S.litt.	S.ex.	Others	Ch.in	Others	Height cm.	% Leaf loss	S.litt.	S.ex.	Others	Ch.in	Others	Height cm	% Leaf loss	
3	2.9	0	0	0	0.4	0.1	40	0	0	5.4	0	0.1	0.2	10	53	78
	11.9								0	0	0	0	0	20	53	0
	22.9	0	3.5	0	0.5	0.3	15	0	0.8	5.6	1.0	0.4	0.1	20	20	145
	25.9	0.1	0.7	0.2	0	0	30	0	1.4	9.0	0	0.6	0	30	0	9
	29.9	0	0.6	0	0	0	40	0	0	0.7	0	0	0.1	40	0	0
4	4.9	0	25.6	0.4	0.2	0.1	60	12	0	1.9	0.1	0.1	0	50	0	11
	7.9	0.3	12.6	2.3	0.1	0	60	6	0	2.4	0.4	1.2	0.5	50	0	6
	12.9	0.2	2.1	0.5	0.3	0.1	65	9	0	0	0	0	0	10	0	0
	14.9	0	0.5	0.2	0.6	0.3	60	0	0	0	0.1	0	0	20	0	11
	20.9	0	0	0.1	2.5	0.1	25	0	0	0	0.1	0.4	0.1	40	0	0
	23.9	0.1	0.2	0	7.5	0.6	35	0	0	0.4	0.4	0.5	0.1	45	0	19
	28.9	0	0.2	0	0.8	0	45	0	0.3	0.5	0.4	1.0	0.2	55	0	24
5	16.9	0	1.3	0.7	1.2	0	55	0	0	0.6	0.4	0.1	0.1	55	0	24
	25.9	1.6	1.0	0.4	0.1	0	25	0	0.4	0.6	0.3	0.4	0	20	0	2
	30.9	4.2	0.1	0	0	0	30	0	3.1	0	0.7	0	0	30	0	27

n.r = no record

TABLE A5:1(1)a Continued (2)

SITE	Sample date	TREATED PLOTS							UNTREATED PLOTS							Nos Moths Trapped at site
		Larvae			Parasites		Lucerne		Larvae			Parasites		Lucerne		
		S.litt.	S.ex.	Oth	Ch.in.	Oth	Ht.	% L.L.	S.litt.	S.ex.	Oth	Ch.in.	Oth	Ht.	% L.L.	
6	6.9	0	0.8	0.2	0.6	0	50	0	0	0.6	0.3	1.4	0	50	0	46
	22.9	0	0.1	0.1	0.2	0	30	0	0.2	0	0.2	0.1	0	n.r	0	n.r
	27.9	0	0	0	0.2	0.8	45	0	0	0.1	0.1	0.4	0	45	0	5
7	4.9	0	3.3	0	3.3	0.3	60	0	0	2.9	0	1.2	1.5	50	0	5
	2.9	0	0	0	0	0.3	20	0								46
	12.9	0	0.9	0.1	0.7	0.4	25	0	0	0	0	0	0	25	0	2
	14.9	0	0	0	0.6	0.2	30	0	0	0	0	0	0	30	0	7
	20.9	0	0	0	0.9	0.3	40	0	0	0	0	0.2	0.2	30	0	20
	23.9	0	0.5	0.1	2.0	0.1	45	0	0	0.1	0.1	0.6	0.1	35	0	11
	25.9	0	0.2	0.4	0.6	0	50	0	0	0	0.1	0.5	0.5	40	0	22
1	6.10	0	0	0.2	0	0.1	15	0	0.3	0	0	0	0.4	20	0	24
	9.10	0.2	0.2	0	0.2	0.5	25	0	0.4	0	0	0	0	25	0	33
	16.10	0	0	0	0	0	40	0	0	0	0.1	0	0	35	0	0
	23.10	0	0	0	0.1	0.1	45	0	0	0	0	0	0	35	0	22
	27.10	0	0	0	0	1.1	50	0	0.3	0.2	0	0	0.3	30	0	0
2	2.10	0.1	0.1	0.5	0	0	65	0	0.1	0.3	0.2	0.1	0.1	40	0	25
	6.10	0	0.2	0.3	0.2	0.3	65	0	0	0	0.2	0	0	40	0	47
	9.10	0	0	0.2	0.1	0.4	60	0	0	0	0	0	0	50	0	5
	16.10	0	0	0.1	0	0.2	30	0	0	0	0.2	0	0	50	0	0
	23.10	0.1	0	0.1	0	0.2	40	0	0	0	0.2	0.3	0.2	50	0	24
	27.10	0	0	0.1	0	0.6	50	0	0	0	0.2	0	0.8	55	0	0
3	2.10	0	1.3	0.4	0.5	0.2	40	0	0.1	0.1	0.5	0	0	40	0	356
	6.10	0.1	1.0	2.2	0.3	0	40	0	0	0	0.8	0.4	0	35	0	403
	16.10	0.5	0.9	0.9	0.4	0.3	20	0	0	0	0	0	0	20	0	215
	23.10	0	0	0.3	0	0.1	30	0	0.4	0.2	2.9	0	0.1	35	0	306

TABLE A5:1(1)a Continued (3)

SITE	Sample date	TREATED PLOTS							UNTREATED PLOTS							Nos Moths Trapped at site
		Larvae			Parasites		Lucerne		Larvae			Parasites		Lucerne		
		S.litt.	S.ex.	Oth	Ch.in.	Oth	Ht.	% L.L	S.litt.	S.ex.	Oth	Ch.in.	Oth	Ht.	% L.L	
4	2.10	0.1	0.5	0.2	0	0	60	0	0	0	0.2	0.3	0	60	0	109
	6.10	0.2	0.4	0.2	0	0	60	0	0	0.3	0.7	0.1	0	65	0	126
	9.10	1.0	0.4	0.2	0	0	60	0								0
	16.10	0.1	0	0	0	0	20	0	0	0.1	0.2	0	0	35	0	29
	23.10	0.4	0.2	0	0.1	0.4	30	0	0.2	0.1	0	0	0.3	45	0	71
	27.10	0	0	0	0.2	0	40	0	0	0	0	0.5	0	40	0	0
	30.10								0	0	0.1	0.1	0	50	0	87
5	2.10	1.9	0	0	0.1	0	40	0	0.6	0	0.5	0	0	40	0	45
	16.10	0	0.2	0.6	0.5	0	30	0	0.5	0.6	0.3	0.3	0.2	30	0	7
	23.10	0	0	0.4	0	0.2	45	0	0.4	0	0.1	0.1	0.2	45	0	260
7	2.10	0	0	0	0	0	10	0	0.1	0	0	0.7	0.1	50	0	74
	6.10	0	0	0	0	0.1	10	0	0	0.1	0	0.2	0	60	0	73
	16.10	0	0	0.4	0	0	40	0	0	0	0	0	0	35	0	0
	23.10	0.1	0	0.2	0.2	0.1	50	0	0.2	0	0.2	0	0.3	40	0	0
	27.10	0.1	0	0.1	0	0.2	50	0	0	0	0	0	0.5	50	0	0

TABLE A5:1(1)b <u>SINGLE PLOT SITE 8 TREATED</u>

Sample Date	Larvae per m^2			Parasites per m^2		lucerne		Nos. Moths Trapped
	S.litt.	S.ex.	Oth.	Ch.in.	Oth.	Height cm.	% Leaf loss	
24. 8	0	38.0	0	0	0	60	29	32
25. 8	0.1	57.7	1.9	0	0	60	21	30
30. 8	0	39.5	1.1	0	0	60	53	0
2. 9	0	2.1	0	0	0	0	-	8
9. 9	0	0.2	0	0	0	10	-	0
16. 9	0	0.6	0	2.2	0	35	0	0
20. 9	0	2.4	0.2	0	0	45	0	114
22. 9	0	8.3	1.2	0	0.7	50	0	26
25. 9	0	4.9	0.5	0.1	0.4	60	0	87
29. 9	0	0.2	2.2	0	0	60	0	52
6.10	0.3	0.7		0	0.1	60	0	0
9.10	0.7	0.3	1.7	0.2	0.8	10	0	0
16.10	1.1	0.6	0.3	0.4	0.8	35	0	34
23.10	0.4	0	0.3	0	0.7	45	0	0

TABLE A5:1(1)c <u>SINGLE PLOT SITE 9 UNTREATED</u>

Sample Date	Larvae per m^2			Parasites per m^2		Lucerne		Nos. Moths Trapped
	S.litt.	S.ex.	Oth.	Ch.in.	Oth.	Height cm.	% Leaf loss	
28. 8	0	0.3	0.4	0	0	60	0	7
13. 9	0	0.3	0.2	0	0	50	0	1
22. 9	0.2	0.1	0.2	0.6	0.2	65	0	0
27. 9	0	0	0	0	0.1	10	0	3
7.10	0	0	0	0	0	30	0	7
21.10	0	0	0	0	0	40	0	0

TABLE A5:2(1) DAILY CONSUMPTION OF LUCERNE LEAF IN g DRY WEIGHT/LARVA AND CORRESPONDING LIVEWEIGHT OF LARVA in g FOR LARVAE REARED INDIVIDUALLY AT 24-26°C

Days since hatching	LARVAE REPLICATES (C = consumption, L = larval weight)																						Means		Geometr means	
	1		2		3		4		5		6		7		8		9		10		11					
	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L
4	0.0017	–	0.0012	–	0	–	0	–	0.0002	–	0	–	0	–	0	–	0	–	0	–	0	–	0.0003	–		
5	0.0004	–	0.0022	–	0.0013	–	0.0005	–	0.0014	–	0.0019	–	0.0008	–	0.0036	–	0.0035	–	0.0013	–	0.0029	–	0.0018	–		
6	0.0050	–	0.0083	–	0.0060	–	–	–	0.0054	–	0.0077	–	0.0019	–	0.0026	–	0.0039	–	0.0035	–	0.0053	–	0.0045	–		
7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		
8	0.0111	0.0250	0.0090	0.0300	0.0106	0.0322	0.0093	0.0160	0.0099	0.0234	0.0047	0.0152	0.0022	0.0098	0.0072	0.0250	0.0073	0.0228	0.0011	0.0120	0.0080	0.0214	0.0073	0.0212	$\bar{3}.7880$	$\bar{2}.438$
9	0.0114	0.0588	0.0131	0.0472	0.0112	0.0621	0.0061	0.0399	0.0093	0.0480	0.0058	0.0442	0.0164	0.0124	0.0126	0.0464	0.0119	0.0461	0.0121	0.0223	0.0162	0.0296	0.0115	0.0415	$\bar{2}.0385$	$\bar{2}.582$
10	0.0366	0.0860	0.0388	0.1272	0.0279	0.1127	0.0296	0.0680	0.0301	0.0855	0.0155	0.0543	0.0058	0.0277	0.0278	0.1057	0.0290	0.0870	0.0093	0.0893	0.0234	0.0125	0.0248	0.0880	$\bar{2}.3405$	$\bar{2}.822$
11	0.0246	0.2134	0.0381	0.2772	0.0168	0.2774	0.0148	0.1809	0.0135	0.1939	0.0245	0.1346		0.0409	0.0263	0.2032	0.0195	0.2109	0.0214	0.0893	0.0425	0.1929	0.0242	0.1831	$\bar{2}.3556$	$\bar{1}.215$
12	0.0968	0.3542	0.0928	0.4352	0.0627	0.2827	0.0471	0.2520	0.0360	0.2344	0.0823	0.1855	0.0175	0.0434	0.0814	0.2600	0.0664	0.2269	0.0427	0.1289	0.0775	0.3050	0.0582	0.2462	$\bar{2}.7634$	$\bar{1}.334$
13	0.1256	0.7138	0.1164	0.7350	0.1201	0.5490	0.1251	0.4816	0.0567	0.4582	0.0546	0.3894	0.0215	0.1158	0.1383	0.6437	0.0972	0.4409	0.0636	0.1637	0.1400	0.6504	0.0963	0.4856	$\bar{2}.9310$	$\bar{1}.630$

TABLE A5:2(1) Continued

Days since hatching	LARVAE REPLICATES (C = consumption, L = larval weight)																						Means		Geom	
	1		2		3		4		5		6		7		8		9		10		11					
	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	
14	0.2066	0.9467	0.1245	1.0509	0.1119	0.9907	0.1297	0.8920	0.1749	0.6781	0.1610	0.6224	0.0187	0.1696	0.1208	0.9727	0.1149	0.8344	0.1069	0.4823	0.1051	1.0473	0.1250	0.7902	$\bar{1}.0431$	$\bar{1}.26$
15	0	1.3537	0.0928	0.5828	0.1290	1.2963	0.1154	1.1635	0.1749	1.1387	0.1531	1.0744	0.0379	0.2312	0	0.8048	0	0.6972	0.1641	0.8147	PP	0.8780	0.0867	0.9124	$\bar{1}.0453$	$\bar{1}.829$
16	PP	0.6300	PP	0.3571	0	1.2696	PP	0.5759	0.1668	L.6496	0.0180	1.2372	0.0469	0.3339	PP	0.3560	PP	0.2934	0.0291	1.0045			0.0237	0.6434	$\bar{2}.1535$	$\bar{1}.766$
17					PP	0.4183			PP	0.3606	PP	0.4335	0.0505	0.4060					0	0.3705			0.0252	0.3715	$\bar{2}.3516$	$\bar{1}.596$
18													0.0349	0.4206					PP	0.3011			0.0349	0.3518	$\bar{2}.5428$	$\bar{1}.478$
19													0.0247	0.4262									0.0247	0.4262	2.3927	$\bar{1}.629$
20													PP	0.2248									0	0.2248		1.352

PP = Prepupal stage (ceases feeding)

TABLE A5:2(1) DAILY CONSUMPTION OF LUCERNE LEAF IN g. DRY WEIGHT/LARVA AND CORRESPONDING LIVEWEIGHT OF LARVA IN g. FOR LARVAE REARED INDIVIDUALLY AT 29-31°C

Days since hatching	LARVAE REPLICATES (C = consumption, L = larval weight)																						Means		Geometr means	
	1		2		3		4		5		6		7		8		9		10		11					
	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L
6	0.0029	0.0150	0.0058	0.0122	0.0036	0.0103	0.0063	0.0097	0.0040	0.0100	0.0024	0.0082	0.0001	0.0091	0.0053	0.0085	0.0025	0.0075	0.0018	0.0094	0.0025	0.0062	0.0034	0.0096	$\bar{3}.3945$Δ	$\bar{3}.973$
7	0.0102	0.0156	0.0055	0.0156	0.0150	0.0133	0.0087	0.0146	0.0107	0.0157	0.0173	0.0119	0.0227	0.0113	0.0162	0.0131	0.0200	0.0103	0.0125	0.0169	0.0107	0.0080	0.0126	0.0133	$\bar{2}.1023$	$\bar{2}.114$
8	0.0119	0.0487	0.0243	0.0656	0.0273	0.0596	0.0270	0.0485	0.0321	0.0564	0.0071	0.0581	0.0125	0.0495	0.0163	0.0529	0.0068	0.0567	0.0079	0.0250	0.0122	0.0350	0.0169	0.0505	$\bar{2}.2279$	$\bar{2}.703$
9	0.0447	0.0892	0.0553	0.1064	0.0637	0.0970	0.0441	0.1049	0.0402	0.1103	0.0575	0.0513	0.0655	0.0500	0.0566	0.0724	0.0540	0.0428	0.0433	0.0332	0.0518	0.0656	0.0524	0.0748	$\bar{2}.7142$	$\bar{2}.841$
10	0.1559	0.2332	0.1616	0.3118	0.0722	0.2393	0.1019	0.2325	0.2155	0.2622	0.0408	0.2387	0.0554	0.2011	0.0851	0.2140	0.0382	0.2027	0.0351	0.1576	0.0326	0.1998	0.0904	0.2266	$\bar{2}.8661$	$\bar{1}.349$
11	0.2588	0.6580	0.2665	0.8118	0.1963	0.4620	0.1781	0.5064	0.2717	0.8992	0.1431	0.2996	0.1503	0.3180	0.1820	0.4238	0.1065	0.2371	0.0883	0.2030	0.1254	0.2669	0.1788	0.4623	$\bar{1}.2281$	$\bar{1}.615$
12	0.1522	1.0714	0.1220	1.1965	0.2067	0.8140	0.1853	0.8820	0.1205	1.2320	0.1840	0.6822	0.2089	0.6556	0.2165	0.7600	0.1998	0.5869	0.1276	0.4629	0.1713	0.5913	0.1723	0.8123	$\bar{1}.2265$	$\bar{1}.890$
13	0.0010	0.6206	0.0024	0.1928	0.1039	1.0087	0.0652	0.9779	PP		0.1003	0.9495	0.1098	0.8369	0.0894	0.9089	0.2626	0.9012	0.1799	0.6885	0.1325	0.7892	0.1047	0.7874	$\bar{2}.7000$	$\bar{1}.862$
14	PP		PP		PP		PP				PP		PP		PP		0.1408	1.1158	0.0888	0.9169	PP		0.1148	1.0164	$\bar{1}.0488$	$\bar{1}.005$
15																	PP		PP							

PP = Prepupal stage (ceases feeding)

TABLE A5:2(2) DAILY LIVEWEIGHT OF LARVA IN g. REARED INDIVIDUALLY ON LUCERNE AT 24-26°C

Days since hatching	LARVAE REPLICATES:LIVEWEIGHT IN g										Means	Geomet[illegible] means
	1	2	3	4	5	6	7	8	9	10		
6	0.0038	0.0042	0.0082	0.0026	0.0044	0.0037	0.0037	0.0061	0.0044	0.0032	0.0041	$\bar{3}.6246$
7	0.0066	0.0117	0.0158	0.0054	0.0122	0.0094	0.0094	0.0119	0.0.119	0.0086	0.0102	$\bar{3}.9918$
8	0.0060	0.0124	0.0235	0.0100	0.0122	0.0106	0.0090	0.0168	0.0136	0.0090	0.0123	$\bar{2}.0622$
9	0.0143	0.0364	0.0385	0.0094	0.0275	0.0268	0.0238	0.0440	0.0314	0.0252	0.0277	$\bar{2}.4061$
10	0.0219	0.0582	0.0555	0.0187	0.0542	0.0571	0.0480	0.0449	0.0575	0.0474	0.0463	$\bar{2}.6381$
11	0.0245	0.1404	0.0723	0.0301	0.0612	0.1067	0.0531	0.1431	0.0994	0.0759	0.0807	$\bar{2}.8451$
12	0.0963	0.7969	0.2645	0.1016	0.2967	0.7056	0.2675	0.8196	0.6932	0.4993	0.4541	$\bar{1}.5516$
13	0.1929	0.9894	0.2767	0.1177	0.3113	1.1550	0.4690	0.9781	1.0510	0.8944	0.6435	$\bar{1}.6694$
14	0.2670	0.6767	0.3070	0.1720	0.4637	1.4596	0.7351	0.6009	0.6732	1.2813	0.6636	$\bar{1}.7391$
15	0.2013	0.3699	0.3852	0.2545	0.6389	0.7682	0.8143	0.3992	0.4093	0.8371	0.5078	$\bar{1}.6595$
16	0.3179	P	0.5231	0.2942	0.7516	0.4950	0.8213	P	P	0.3920	0.5143	1.6813
17	0.4509		0.6657	0.2872	0.6988	P	0.6164			0.3687	0.5160	$\bar{1}.6895$
18	0.6797		0.8325	0.4488	0.6307		0.3339			P	0.5851	$\bar{1}.7457$
19	0.7956		0.8296	0.5693	0.2706		P				0.6178	$\bar{1}.7544$
20	0.3921		0.6595	0.7974							0.6163	$\bar{1}.7712$
	P			D								

P = Larva pupated (trial discontinued)

D = Larva dead (trial discontinued)

TABLE A5:2(2) MEAN DAILY LIVEWEIGHT IN g. /LARVA FOR LARVAE, REARED IN PAIRS, ON LUCERNE AT 24-26°C

Days since hatching	LARVAE REPLICATES: MEAN LIVEWEIGHT IN g.									Means	Ge[illegible] means
	1	2	3	4	5	6	7	8	9		
6	0.0052	0.0033	0.0083	0.0040	0.0059	0.0061	0.0037	0.0038	0.0036	0.0048	$\bar{3}.6685$
7	0.0086	0.0083	0.0127	0.0098	0.0117	0.0111	0.0093	0.0086	0.0097	0.0100	$\bar{3}.9942$
8	0.0174	0.0106	0.0244	0.0107	0.0180	0.0179	0.0095	0.0102	0.0107	0.0144	$\bar{2}.1341$
9	0.0343	0.0236	0.0534	0.0242	0.0416	0.0342	0.0243	0.0241	0.0243	0.0315	$\bar{2}.4806$
10	0.0572	0.0480	0.0398	0.0440	0.0552	0.0499	0.0437	0.0498	0.0578	0.0494	$\bar{2}.6911$
11	0.1045	0.0736	0.2045	0.0906	0.1504	0.1213	0.0774	0.0905	0.0909	0.1115	$\bar{1}.0237$
12	0.1890	0.1533	0.2531	0.2066	0.2716	0.2159	0.1289	0.2093	0.2108	0.2042	$\bar{1}.3005$
13	0.2084	0.2236	0.5509	0.2301	0.3982	0.2780	0.2347	0.3087	0.2561	0.2987	$\bar{1}.4528$
14	0.4237	0.3711	0.8697	0.4776	0.7411	0.5580	0.4802	0.6229	0.5816	0.5695	$\bar{1}.7414$
15	0.5440	0.6426	0.8444	0.7140	0.9759	0.7708	0.7831	0.7763	0.8364	0.7653	$\bar{1}.8785$
16	0.4406	0.8282	0.4878	0.6580	0.5866	0.4659	0.8185	0.5767	0.8623	0.6361	$\bar{1}.7906$
17	0.3634	0.6646	0.3792	0.4642	0.3658	0.3162	0.4868	0.5929	0.4980	0.4516	$\bar{1}.6441$
18	0.4368	0.3139	P	0.1364	P	P	0.2856	0.3436	P	0.3033	$\bar{1}.4528$
19	0.3519	P		P			P	0.2322		0.2921	$\bar{1}.4560$
20	0.2979							0.2034		0.2507	$\bar{1}.3909$
21	P							P			

P = Time when first larvae pupated

TABLE A5:2(2) MEAN DAILY LIVEWEIGHT IN g./LARVA FOR LARVAE REARED IN GROUPS OF FOUR ON LUCERNE AT 24-26°C

Days since hatching	LARVAE REPLICATES:MEAN LIVEWEIGHT IN g									Means	Ge
	1	2	3	4	5	6	7	8	9		
6	0.0034	0.0032	0.0028	0.0031	0.0022	0.0043	0.0042	0.0048	0.0041	0.0036	$\bar{3}.540$
7	0.0082	0.0075	0.0076	0.0075	0.0063	0.0103	0.0079	0.0103	0.0104	0.0084	$\bar{3}.920$
8	0.0116	0.0107	0.0090	0.0106	0.0089	0.0119	0.0101	0.0143	0.0120	0.0110	$\bar{2}.054$
9	0.0245	0.0226	0.0200	0.0185	0.0159	0.0287	0.0181	0.0288	0.0337	0.0234	$\bar{2}.357$
10	0.0420	0.0468	0.0433	0.0384	0.0336	0.0498	0.0354	0.0333	0.0512	0.0415	$\bar{2}.613$
11	0.0806	0.0876	0.0762	0.0741	0.0610	0.0951	0.0585	0.0786	0.1149	0.0807	$\bar{2}.898$
12	0.1751	0.2058	0.1201	0.1457	0.1335	0.1912	0.1065	0.1210	0.2142	0.1570	$\bar{1}.182$
13	0.2366	0.2426	0.2490	0.1944	0.1696	0.2753	0.1262	0.1202	0.3053	0.2132	$\bar{1}.297$
14	0.4510	0.5292	0.4718	0.3092	0.3237	0.4792	0.1879	0.1526	0.5854	0.3878	$\bar{1}.550$
15	0.6454	0.7461	0.7155	D	0.5746	0.6101	0.2603	0.2223	0.6651	0.5548	$\bar{1}.629$
16	0.6272	0.6108	0.8221		0.4845	D	0.4501	D	0.4868	0.5803	$\bar{1}.754$
17	0.4490	0.3783	0.5757		0.4079		0.3826		0.3972	0.4318	$\bar{1}.630$
18	P	P	P		D		0.3222		0.5879	0.2940	$\bar{1}.638$
19							0.3013		P	0.3013	$\bar{1}.478$

P = first larva pupated (trial discontinued) D = larval death (trial discontinued)

TABLE A5:2(2) MEAN DAILY LIVEWEIGHT IN g/LARVA FOR LARVAE REARED IN GROUPS OF SIX ON LUCERNE AT 24-26°C

Days since hatching	LARVAE REPLICATES: MEAN LIVEWEIGHT IN g										Means	Ge[illegible] mea[illegible]
	1	2	3	4	5	6	7	8	9	10		
6	0.0045	0.0050	0.0046	0.0040	0.0045	0.0053	0.0064	0.0040	0.0060	0.0035	0.0047	$\bar{3}.672$
7	0.0108	0.0097	0.0103	0.0101	0.0102	0.0111	0.0104	0.0108	0.0133	0.0092	0.0105	$\bar{2}.0129$
8	0.0164	0.0163	0.0156	0.0127	0.0140	0.0175	0.0201	0.0137	0.0212	0.0122	0.0160	$\bar{2}.1966$
9	0.0414	0.0357	0.0377	0.0294	0.0325	0.0393	0.0398	0.0310	0.0504	0.0275	0.0365	$\bar{2}.5536$
10	0.0459	0.0559	0.0551	0.0502	0.0477	0.0528	0.0562	0.0486	0.0639	0.0471	0.0523	$\bar{2}.7167$
11	0.1271	0.1278	0.1310	0.1024	0.0948	0.1273	0.1290	0.1008	0.1606	0.0946	0.1195	$\bar{1}.0715$
12	0.1903	0.2225	0.1946	0.1757	0.1659	0.2060	0.1897	0.1657	0.2238	0.1762	0.1910	$\bar{1}.2798$
13	0.2715	0.3014	0.3172	0.2576	0.2357	0.3401	0.3006	0.2224	0.3600	0.2759	0.2888	$\bar{1}.4559$
14	0.4370	0.4955	0.4096	0.3922	0.3475	0.4584	D	D	D	D	0.4234	$\bar{1}.6237$
15	0.5315	0.5434	0.4926	0.4595	0.4190	0.5193					0.4942	$\bar{1}.6920$
16	D	D	0.4954	0.4458	P	0.4770					0.4727	$\bar{1}.6741$
17			0.3855	D		0.3949					0.3902	$\bar{1}.5911$
18			P			P						

P = first larva pupated (trial discontinued)

D = larval death (trial discontinued)

TABLE A5:2(3) WEIGHT OF PUPAE DERIVED FROM EACH DENSITY GROUP

Weight of pupae in g.			
1*	2*	4*	6*
0.1799	0.2961	0.3297	0.2541
0.3288	0.2240	0.3369	0.2816
0.1800	0.3620	0.3432	0.3140
0.2053	0.3468	0.3196	0.2927
0.4397	0.3547	0.2947	0.2875
0.2340	0.3233	0.3196	0.2620
0.3593	0.3204	0.2870	0.1802
0.3674	0.2919	0.2981	0.2464
0.3232	0.2980	0.3590	0.2328
	0.3547	0.3093	0.3409
	0.2608	0.2993	0.1727
	0.1800	0.3062	0.2250
	0.3569	0.2224	0.2821
	0.3241	0.1683	0.2647
		0.1022	0.2662
		0.1817	0.2567
		0.2878	0.2974
		0.3320	0.3215
		0.1796	0.3333
$\bar{X}$=0.2908	$\bar{X}$=0.3066	$\bar{X}$=0.2777	$\bar{X}$=0.2682

*Density groups (larvae/pot)

APPENDIX 6:1

Tables of simulation output

TABLE A6:1(1) Simulated effect of changing larval density on the total consumption and damage

Larval density/instar/m²						Total	g/m² dry wt. of lucerne leaf	
(1)	(2)	(3)	(4)	(5)	(6)	larvae/m²	Total Consumption	Total damage
10	20	0	0	0	0	30	2.34	0.42
30	60	0	0	0	0	90	6.84	0.90
60	120	0	0	0	0	180	14.80	2.03
100	200	0	0	0	0	300	25.03	3.74
150	300	0	0	0	0	450	33.11	8.13
180	360	0	0	0	0	540	41.72	18.87
190	380	0	0	0	0	570	45.94	32.55
200	400	0	0	0	0	600	47.10	35.37
210	420	0	0	0	0	630	45.71	72.31
240	480	0	0	0	0	720	41.28	71.22
250	500	0	0	0	0	750	39.26	63.15
300	600	0	0	0	0	900	34.32	64.17
450	900	0	0	0	0	1,350	26.17	63.85

Other inputs: Infestation day : 9,
Iterations : 3,
Dispersal ratios : 1,3,4,36,60,23
Mortality rates : 0.35,0.20,0.26,0.08,0.06,0.05
Control : 0,0,

TABLE A6:1(2) Simulated effect of infestation timing on total consumption and damage

Infestation day	g/m² of dry wt. lucerne leaf				Population dispersal?
	Total Consumption	leaf loss on day 27	leaf loss on day 55	Total damage	
1	3.23	17.41	0	17.41	✓
2	5.11	28.21	0	28.21	✓
3	10.08	41.16	0	41.16	✓
4	12.96	20.80	0	20.80	
5	11.39	3.67	0	3.67	
6	12.66	3.11	0	3.11	
7	9.94	1.60	0	1.60	
8	9.81	1.37	0	1.37	
9	10.92	1.43	0	1.43	
10	11.78	1.56	0	1.56	
11	12.02	1.45	0	1.45	
12	12.24	1.91	0	1.91	
13	10.55	1.83	0	1.83	
14	12.48	2.72	0	2.72	
15	12.51	3.36	0	3.36	
16	12.35	4.28	0	4.28	
17	12.19	4.91	0	4.91	
18	10.94	5.42	0.11	5.53	✓
19	11.92	6.80	0.08	6.88	✓
20	9.71	6.14	0.28	6.42	✓
21	6.63	4.21	0.63	4.84	✓
22	6.38	3.85	1.39	5.24	✓
23	4.39	2.12	3.01	5.13	✓
24	4.34	1.82	5.27	7.09	✓
25	3.35	1.20	5.13	6.33	✓
26	3.02	0.85	6.04	6.89	✓
27	2.78	0.43	7.75	8.18	✓

Other inputs:
Larval density : 50,100,0,0,0,0,
Iterations : 3,
Dispersal ratios : 1,3,4,36,60,23
Mortality rates : 0.35,0.20,0.26,0.08,0.06,0.05
Control : 0,0,

TABLE A6:1(3) Simulated effect of changing mortality rates on percentage overall mortality, total consumption and damage

Mortality rates/instar/day							g/m² dry wt. lucerne leaf		
	(1)	(2)	(3)	(4)	(5)	(6)	Overall mortality	Total consumption	Total damage
x1.0	(0.90	0.80	0.60	0.40	0.20	0.10)	.99	1.16	0.32
x0.75	("	"	"	"	"	")	.99	2.33	0.44
x0.50	("	"	"	"	"	")	.97	6.52	0.88
x0.25	("	"	"	"	"	")	.81	17.20	2.40
x0.10	("	"	"	"	"	")	.39	29.96	5.55
x0	("	"	"	"	"	")	0	42.79	12.73

Other inputs: Larval density : 50,100,0,0,0,0,
Infestation day : 9,
Iterations : 3,
Dispersal ratios : 1,3,4,36,60,23
Control : 0,0,

TABLE A6:1(4) Simulated effect of changing dispersal ratios on total consumption, damage, nos. of larvae dispersing and infestation period

Dispersal ratio/instar						g/m² dry wt.lucerne leaf			Infestation period
(1)	(2)	(3)	(4)	(5)	(6)	Total consumption	Total damage	Number of larvae dispersing	(days)
32	16	8	4	2	1	3.87	8.07	563	2
8	8	4	2	1	1	3.94	8.50	575	2
2	2	2	1	1	1	4.17	10.08	576	4.7
1	1	1	1	1	1	4.50	10.66	557	8.7
1	1	1	2	2	2	6.12	34.72	520	10.7
1	1	2	4	8	8	6.84	47.66	486	11.2
1	2	4	8	16	32	6.85	46.18	492	11
1	2	8	16	32	64	7.25	49.69	487	10.7
1	4	16	32	64	128	7.01	51.18	489	11.2
1	8	32	64	128	256	6.87	47.89	476	11.7

Other inputs: Larval density : 100,100,100,100,100,100
Infestation day : 9,
Iterations : 3,
Mortality : 0.35,0.21,0.28,0.08,0.0[illegible]

TABLE A6:1(5) Simulated effect of changing control timing on the total consumption and damage

Days after infestation on which control was applied	g/m^2 dry wt. of lucerne leaf Total consumption	Total damage
0	0	0
1	2.12	0.51
2	3.98	0.77
4	5.72	1.00
4	9.52	1.60
5	15.03	2.68
6	19.87	3.77
7	25.49	5.44
8	31.92	8.14
9	35.83	11.37
10	34.79	9.55
11	39.30	13.70

Other inputs:
Larval density : 150,300,0,0,0,0,
Infestation day : 9,
Iterations : 3,
Dispersal ratios : 1,3,4,36,60,23
Mortality rates : 0.35,0.20,0.26,0.08,0.06,0.05

APPENDIX 7:1

Itemization of the direct costs of insecticide treatment for types 1 and 2 farmers and a provisional estimate of the cost of control using 'Prodan' bait

Type 1 farmers used a tractor mounted boom and nozzle sprayer for insecticide applications. The most common type had a 400 l. polyethylene tank and a 10m. boom fitted with striker plate spray nozzles.[1] The speed of tractor driving during spraying varied, but was usually approximately 1m/sec. Since the recommended application rate was 750 l./ha. (Table 7:3) the tank required two fillings/ha. The time taken to fill the tank twice, add the insecticide, and also wash the equipment after use, was approximately 0.5 hrs. Spraying after sunset reduced effective dosage rates (see text) but involved the farmer in marking out his fields with white posts of every boom width. The labour costs are therefore increased by 0.5 hrs. The total cost of insecticide and application for type 1 farmers for both day and night treatments is given in table A7:1(1).

TABLE A7:1(1) Type 1 farmer's direct costs of insecticide treatment

	C£/hr.	hrs/ha.	Application costs C£/ha.	
			Day	Night
Labour				
Day spraying	0.200	0.8	0.160	
Night spraying	0.200	1.3		0.260
Tractor & Sprayer	0.432	0.3	0.130	0.130
			0.290	0.390
Insecticides	Dosage costs C£/ha.		Total direct costs in C£/ha.	
	Day	Night	Day	Night
Chloropyriphos	6.075	3.675	6.365	4.065
Methomyl	6.600	4.950	6.890	5.340
Methamidophos	4.350	3.375	4.640	3.765

---

[1] Manufactured by Carl Platz Co., W. Germany.

Type 2 farmers generally used knapsack sprayers (see text). The type most commonly adopted by the farmers were of 15 l. capacity and operated by a left hand piston pump. The correct height for the hand held nozzle was 1m. (King, pers. comm.), giving a treatment width of 1m. of crop. An operator refilled his knapsack tank 15 times in the course of treating 1 ha. and walked at the rate of approximately 1m/sec. For night spraying a knapsack spray operator required guidance to prevent double treatments or gaps in spray cover. This was most easily accomplished by a second operator guiding the first with a torch light (this method was tried with success by Watts and King in 1972). The total direct costs of insecticide treatment for both day and night applications are given in table A7:1(2).

TABLE A7:1(2) <u>Type 2 farmer's direct costs of insecticide treatment</u>

	C£/hr.	hrs/ha.	Application costs C£/ha. Day	 Night
<u>Labour</u>				
Refilling and washing	0.200	1.5	0.300	0.300
Actual spray time	0.200	2.8	0.560	0.560
Night marker	0.200	2.8		0.560
<u>Knapsack sprayer</u>	0.025	2.8	0.070	0.070
			0.930	1.490

<u>Insecticides</u>	Dosage costs C£/ha. Day	 Night	Total direct costs in C£/ha. Day	 Night
Chloropyriphos	6.075	3.675	7.005	5.165
Methomyl	6.600	4.950	7.530	6.440
Methamidophos	4.350	3.375	5.280	4.865

'Prodan' bait can be broadcast by hand or distributed by pellet spreader. A provisional costing of application at the dosage of 45 kg/ha. is given in Table A7:1(3), assuming type 1 farmers mechanize their applications and type 2 farmers broadcast the bait.

TABLE A7:1(3) Provisional estimates of the cost of control using 'Prodan' bait

			Application costs C£/ha.	
	C£/hr.	hrs/ha.	Type 1 farmers	Type 2 farmers
Labour				
Type 1 farmers	0.200	1		0.200
Type 2 farmers	0.200	0.3	0.060	
Tractor and spreader	0.400	0.3	0.120	
Cost of bait			4.500	4.500
			4.680	4.700

APPENDIX 7:2

Proprietary and chemical names, and the formulation of some of the insecticides currently used against *S. littoralis* in Cyprus

Proprietary name	Chemical name	Formulation*
Dursban	diethyl 3,5,6-trichloropyridil phosphorothioate	40% w/v a.i. E.C.
Lannate	methomyl	90% w/w a.i. W.S.P.
Tamaron	OS - dimethyl phosphoroamidothioate	50% w/v a.i. E.C.
Folidol	parathion-methyl	50% w/v a.i. E.C.
Nuvacron	monocrotophos	40% w/v a.i. E.C.
Azodrin	monocrotophos	60% w/v a.i. E.C.
Cyolane	diethyl 1,3-dithiolan-2-ylidenophosphoramidate	25% w/v a.i. E.C.
Prodan	sodium flurosilicate and attractants	w/w 90% attractants 100,000 grains/kg

*Abbreviations key

w/v = weight to volume

w/w = weight to weight

a.i. = active ingredient

E.C. = Emulsifiable concentrate

W.S.P. = Water soluble powder

APPENDIX 8:1

TABLE A8:1

Economic threshold estimates for a range in cost of control, crop value and leaf versus stem value.

Cost of control = C£5·00/ha.

Value of crop (C£/tonne) =	(a) 4·48		(b) 5·60		(c) 6·72	
Leaf: stem value =	0·5	0·66	0·5	0·66	0·5	0·66
	Economic threshold larval density (1st instars/m^2)					
Infestation day						
1	150	250	150	250	180	180
2	205	301	200	301	202	190
3	355	301	350	301	247	258
4	355	369	346	329	327	323
5	419	409	390	434	395	403
6	531	659	590	489	440	468
7	603	639	596	575	551	518
8	716	688	644	654	611	590
9	756	779	714	696	646	640
10	822	828	722	727	660	682
11	849	837	722	735	667	661
12	858	776	674	674	603	626
13	703	728	603	632	501	495
14	625	667	568	526	466	445
15	618	572	453	451	355	359
16	576	536	438	406	343	331
17	621	590	493	421	375	355
18	846	716	612	546	488	440
19	1206	1074	859	768	678	596
20	>1500*	1490	1211	998	754	672
21	>1500	>1500	1316	1281	1044	891
22	>1500	>1500	1400	1335	1055	828
23	>1500	>1500	>1500*	>1500	1146	950
24	>1500	>1500	>1500	>1500	1182	950
25	>1500	>1500	1488	1491	78	121
26	1388	1385	151	95	93	121
27	204	215	121	145	143	131

*Economic threshold is in excess of 1500 larvae/m^2

TABLE A8:1 continued

Cost of control = C£6·00/ha.

Value of crop (C£/tonne) =	(a) 4·48		(b) 5·60		(c) 6·72	
Leaf: stem value =	0·5	0·66	0·5	0·66	0·5	0·66
	Economic threshold larval density (1st instars/m^2)					
Infestation day						
1	350	350	150	250	150	150
2	301	301	205	301	208	208
3	301	301	355	301	358	358
4	501	501	355	501	338	338
5	501	501	555	501	538	538
6	561	561	550	521	538	538
7	628	628	610	821	598	598
8	781	781	731	717	628	628
9	789	789	731	765	663	663
10	896	910	755	765	726	726
11	905	940	803	781	709	709
12	915	899	766	749	668	668
13	814	908	692	672	562	562
14	745	751	615	609	538	538
15	737	695	560	519	443	423
16	713	625	560	499	448	394
17	769	718	572	546	468	427
18	998	878	764	684	637	550
19	>1500	1336	1064	936	875	724
20	>1500	>1500	>1500	1288	1131	952
21	>1500	>1500	>1500	>1500	1464	1280
22	>1500	>1500	>1500	>1500	1479	1293
23	>1500	>1500	>1500	>1500	>1500	>1500
24	>1500	>1500	>1500	>1500	>1500	>1500
25	>1500	>1500	>1500	>1500	1374	>1500
26	>1500	>1500	949	820	109	102
27	815	296	129	205	109	200

TABLE A8:1 continued

Cost of control = C£7·00/ha

Economic threshold larval density (1st instars/m^2)

Value of crop (C£/tonne) =	(a) 4·48		(b) 5·60		(c) 6·72	
Leaf: stem value =	0·5	0·66	0·5	0·66	0·5	0·66
Infestation day						
1	320	150	150	350	150	150
2	301	250	270	301	352	352
3	301	295	273	301	301	301
4	701	595	573	501	501	501
5	701	701	701	701	701	701
6	701	701	701	701	701	701
7	725	689	656	701	701	701
8	813	724	790	741	711	709
9	913	1124	833	853	751	797
10	927	1124	842	898	759	789
11	997	984	860	871	799	797
12	957	934	860	821	711	805
13	927	894	786	783	678	649
14	870	858	684	635	576	569
15	870	779	642	621	522	502
16	852	739	635	586	492	472
17	876	812	691	625	534	492
18	1312	1033	954	786	741	663
19	>1500	>1500	1396	1199	1089	953
20	>1500	>1500	>1500	>1500	>1500	1300
21	>1500	>1500	>1500	>1500	>1500	>1500
22	>1500	>1500	>1500	>1500	>1500	>1500
23	>1500	>1500	>1500	>1500	>1500	>1500
24	>1500	>1500	>1500	>1500	>1500	>1500
25	>1500	>1500	>1500	>1500	>1500	>1500
26	>1500	>1500	>1500	>1500	116	176
27	1476	155	155	233	206	301

CONTAINS
PULLOUTS

```
C INPUT ARRAY DIMENSIONS AND HEADINGS
      DIMENSION W(4480),R(7),N(6),C(6),L(6)
      COMMON W
      REAL M(6)
      INTEGER Y,Z,D(6),T,P(6),PP,V(4480),F,T1,P7
      INTEGER ETFLAG
      XX=G05AAF(-1)
      WRITE(2,120)
  120 FORMAT(1H1,20HLUCERNE GROWTH MODEL)
      DATA R/0.0001,0.0021,0.0159,0.1014,0.2991,0.6199,1.4000/
      READ(7,277)LFLAG,ETFLAG
      WRITE(2,200)LFLAG,ETFLAG
  200 FORMAT(1H ,8HLFLAG = ,I2,10X,9HETFLAG = ,I2)
      IF(ETFLAG.EQ.1)GOTO 245
      READ(7,230)N
  230 FORMAT(6I4)
      WRITE(2,220)N
  220 FORMAT(1H ,24HINPUT INSTAR POPULATIONS,6I8)
      GOTO 252
  245 READ(7,262)EC
      WRITE(2,255)EC
  255 FORMAT(28HOCOST OF CONTROL IN C£/HA = ,F8.3)
      IF(ETFLAG.EQ.1)GOTO 261
  252 READ(7,230)T
      WRITE(2,240)T
  240 FORMAT(1H ,21HINPUT INFESTATION DAY,I11)
      READ(7,230)Y
      WRITE(2,260)Y
  260 FORMAT(1H ,29HINPUT NO. OF MODEL ITERATIONS,I3)
  261 READ(7,230)D
      READ(7,262)M
  262 FORMAT(6F4.0)
      WRITE(2,264)D
  264 FORMAT(1H ,16HDISPERSAL RATIOS,6I8)
      WRITE(2,266)M
  266 FORMAT(1H ,15HMORTALITY RATES,6F5.2)
      IF(LFLAG.NE.1)GOTO 270
      READ(7,262)XL,EL
      WRITE(2,1290)EL
 1290 FORMAT(26HOVALUE OF CROP (C£/TONNE) ,F8.3)
      WRITE(2,1295)XL
 1295 FORMAT(55H PROPORTIONATE VALUE OF LEAVES OF TOTAL UNDAMAGED CROP ,
     1       F8.3)
      IF(ETFLAG.EQ.1)GOTO 210
  270 READ(7,277)K,KK
  277 FORMAT(2I4)
      IF(K.NE.1)GOTO 218
      KK=T+KK
      WRITE(2,278)KK
  278 FORMAT(1H ,11HCONTROL DAY,10X,I11)
      GOTO 218
  210 WRITE(2,215)
  215 FORMAT(1H0,15HINFESTATION DAY,4X,
     1          33HECONOMIC THRESHOLD LARVAL DENSITY)
      NPREV=N(1)
      NTRIAL=1
      N(1)=1
      T=1
```

```
      Y=2
      K=0
      KK=0
  218 TWF1=0.0
      TWS1=0.0
      TWF2=0.0
      TWS2=0.0
      DO 1250 Z=1,Y
      IF(ETFLAG.EQ.1)GOTO 310
      WRITE(2,300)Z
  300 FORMAT(1H0,13HITERATION NO.,I19)
      WRITE(2,304)(I,I=1,6)
  304 FORMAT(1H0,10HDAYS SINCE,5X,13HDRY WT. YIELD,5X,12HTOTAL LARVAL,
     1       5X,11HCONSUMPTION,9X,37HNUMBER OF LARVAE IN EACH INSTAR RAN
     2GE,5X,4HDEAD,5X,9HDISPERSED/12HLAST HARVEST,3X,7HOF LEAF,11X,11HCO
     3NSUMPTION,6X,14HDEMAND DEFICIT,8X,6(I1,4X),5HPUPAE)
  310 C1=0
      C2=0
      MM=0
      NN=0
      PP=0
      P7=0
      LL=0
      WS=0.0
C INPUT LARVAL POPULATION AND ASSIGN RANDOM WEIGHTS
      DO 390 I=1,6
      P(I)=N(I)
      PP=PP+P(I)
      NLOW=NN+1
      NHIGH=NN+P(I)
      DO 380 NN=NLOW,NHIGH
      V(NN)=I
      XX=G05AAF(1)
      W(NN)=R(I)+(R(I+1)-R(I))*XX
  380 CONTINUE
      NN=NHIGH
  390 CONTINUE
      T1=0
      T2=0.0
      F=0
      CC=0.0
C ADD ONE DAY AND DERIVE LUCERNE YIELD
  420 T1=T1+1
      IF(T1.EQ.28)T2=0.0
      T2=T2+1
      W2=87/(1+86*EXP(-0.31*T2))
      CALL DAMAGE(T1,TWF1,TWS1,TWF2,TWS2,W2,WS)
C CHECK INFESTATION FLAG
      IF(F.EQ.1)GOTO 520
      IF(T1.EQ.T)GOTO 480
      GOTO 1100
  480 F=1
      IF(ETFLAG.EQ.1)GOTO 520
      WRITE(2,510)P
  510 FORMAT(1H ,68X,6I5)
  520 CC=0
      DO 521 I=1,6
      C(I)=0.0
```

```
  521 CONTINUE
      DO 590 NN=1,PP
      IF(ABS(W(NN)).LE.1.0E-62)GOTO 590
C DERIVE CONSUMPTION
      CALL CONSUM(NN,CO)
      CC=CC+CO
      I=V(NN)
      C(I)=C(I)+CO
  590 CONTINUE
      IF(CC.GT.0)GOTO 660
      IF(ETFLAG.EQ.1)GOTO 640
      WRITE(2,630)C1
  630 FORMAT(1H ,36X,F8.4)
  640 F=0
      GOTO 1100
  660 IF(C2.GT.0)GOTO 680
      C3=-1*CC
  680 C2=0
C REGULATE POPULATION TO LUCERNE AVAILABLE
      IF(W2-1.0.GT.CC)GOTO 920
      DO 720 I=1,6
      C2=C2+D(I)*C(I)
  720 CONTINUE
      C2=(CC-W2+1.0)/C2
      DO 820 I=1,6
      L(I)=1+INT(P(I)*D(I)*C2)
      IF(L(I).LT.P(I))GOTO 790
      L(I)=P(I)
  790 P(I)=P(I)-L(I)
      LL=LL+L(I)
  820 CONTINUE
      DO 870 NN=1,PP
      IF(ABS(W(NN)).LE.1.0E-62)GOTO 870
      I=V(NN)
      IF(L(I).EQ.0)GOTO 870
      W(NN)=0.0
      L(I)=L(I)-1
  870 CONTINUE
      GOTO 520
  920 DO 921 I=1,6
      P(I)=0
  921 CONTINUE
      DO 1090 NN=1,PP
      IF(ABS(W(NN)).LE.1.0E-62)GOTO 1090
      X=ALOG(10000*W(NN))/2.3026
      T0=1+(3.4091+1.1095*X+0.4461*X*X)
      W(NN)=EXP(2.581*(SQRT(1.7842*T0-4.8516)-1.1095))/10000
      DO 1000 I=1,6
      IF(W(NN).LT.R(I+1))GOTO 1030
 1000 CONTINUE
      P7=P7+1
      GOTO 1050
 1030 XX=G05AAF(1)
      ZZ=M(I)
      IF(K.EQ.1.AND.T1.EQ.KK)ZZ=1.0
      IF(XX.GT.ZZ)GOTO 1070
      MM=MM+1
 1050 W(NN)=0.0
```

```
  0164                GOTO 1090
  0165           1070 P(I)=P(I)+1
  0166                V(NN)=I
  0167           1090 CONTINUE
                C DERIVE GROWTH EQUIVALENT TIME
  0168           1100 W2=W2-CC
  0169                T2=ALOG(86.0*W2/(87.0-W2))/0.31
  0170                IF(ETFLAG.EQ.1)GOTO 1160
  0171                IF(K.EQ.1.AND.T1.EQ.KK)WRITE(2,1101)
  0172           1101 FORMAT(1H0,22HCONTROL METHOD APPLIED)
  0173                WRITE(2,1140)T1,W2
  0174           1140 FORMAT(1H ,4X,I3,10X,F9.4)
  0175           1160 IF(F.EQ.0)GOTO 1230
  0176                IF(ETFLAG.EQ.1)GOTO 1220
  0177                IF(ABS(C3+CC).LE.1.0E-62)GOTO 1200
                C PRINT OUTPUT
  0178                WRITE(2,1180)CC,C3,P,P7,MM,LL
  0179           1180 FORMAT(1H+,35X,F8.4,8X,F9.4,9X,1H-,6(I3,2X),1H-,I4,2(8X,I4))
  0180                GOTO 1220
  0181           1200 WRITE(2,1210)CC,P,P7,MM,LL
  0182           1210 FORMAT(1H+,35X,F8.4,27X,6(I3,2X),1H-,I4,2(8X,I4))
  0183           1220 C1=C1+CC
  0184           1230 IF(W2.LT.86.0)GOTO 420
  0185                IF(ETFLAG.EQ.1)GOTO 1250
  0186                WRITE(2,1240)
  0187           1240 FORMAT(1H )
  0188           1250 CONTINUE
  0189                CALL MEANS(ETFLAG,TWF1,TWS1,TWF2,TWS2,WF1,WS1,WF2,WS2,Y)
  0190                IF(LFLAG.NE.1)STOP
  0191                CALL LOSS(ETFLAG,WF1,WS1,WF2,WS2,XL,EL,TL3,EC)
  0192                IF(ETFLAG.NE.1)STOP
  0193           2002 INCR=1
  0194                IF(ABS(TL3-EC).GT.1.0)INCR=5
  0195                IF(ABS(TL3-EC).GT.2.0)INCR=10
  0196                IF(ABS(TL3-EC).GT.3.0)INCR=50
  0197                IF(ABS(TL3-EC).GT.4.0)INCR=100
  0198                INCR=INCR*(PP/100+1)
  0199                IF(TL3.LE.EC)GOTO 1410
  0200                IF(N(1).GT.NPREV)GOTO 1400
  0201                N(1)=N(1)-INCR
  0202                NPREV=N(1)
  0203                GOTO 218
  0204           1410 IF(TP.GT.1500)GOTO 1400
  0205                N(1)=N(1)+INCR
  0206                GOTO 218
  0207           1400 WRITE(2,1405)T,PP
  0208           1405 FORMAT(1H ,8X,I2,29X,I4)
  0209                IF(T.GE.27)STOP
  0210           1500 NPREV=N(1)
  0211                NTRIAL=1
  0212                T=T+1
  0213                GOTO 218
  0214                END
```

```
FORTRAN IV G LEVEL  21                 MAIN                DATE = 75239          08/54/34                PAGE 0005

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   *OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =        60
   *STATISTICS*    SOURCE STATEMENTS =       214,PROGRAM SIZE =    23706
   *STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL  21                 CONSUM              DATE = 75239          08/54/34                PAGE 0001

  0001                SUBROUTINE CONSUM(NN,CO)
                C CALCULATES THE LAVA CONSUPTION
  0002                DIMENSION W(4480)
  0003                COMMON W
  0004                IF(W(NN).GT.0.4)GOTO 1330
  0005                X=ALOG(10000.0*W(NN))/2.3026
  0006                CO=-87.8373+125.441*X-65.2327*X**2+14.9246*X**3-1.2608*X**4
  0007                CO=EXP(CO*2.3026)/10000.0
  0008                RETURN
  0009           1330 IF(W(NN).GT.0.70)GOTO 1360
  0010                CO=0.29*W(NN)-0.038
  0011                RETURN
  0012           1360 IF(W(NN).GT.0.95)GOTO 1390
  0013                CO=-0.3*W(NN)+0.375
  0014                RETURN
  0015           1390 CO=-0.360*W(NN)+0.432
  0016                RETURN
  0017                END
```

```
 *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = CONSUM   , LINECNT =       60
 *STATISTICS*    SOURCE STATEMENTS =       17,PROGRAM SIZE =       732
 *STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL  21                  DAMAGE               DATE = 75239           08/54/34              PAGE 0001

      0001            SUBROUTINE DAMAGE(T1,TWF1,TWS1,TWF2,TWS2,W2,WS)
      0002            INTEGER T1
      0003            WS1=0.0
      0004            WS2=0.0
      0005            WF1=0.0
      0006            WF2=0.0
      0007            IF(W2.GT.WS)WS=W2
      0008            IF(T1.NE.27)GOTO 1
      0009            WS1=85.3002-WS
      0010            WS=0.0
      0011            WF1=85.3002-W2
      0012          1 IF(T1.NE.55)GOTO 4
      0013            WS2=85.7468-WS
      0014            WS=0.0
      0015            WF2=85.7468-W2
      0016          4 TWF1=TWF1+WF1
      0017            TWS1=TWS1+WS1
      0018            TWF2=TWF2+WF2
      0019            TWS2=TWS2+WS2
      0020            RETURN
      0021            END
```

```
FORTRAN IV G LEVEL  21                  DAMAGE               DATE = 75239           08/54/34              PAGE 0002

 *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = DAMAGE   , LINECNT =       60
 *STATISTICS*    SOURCE STATEMENTS =       21,PROGRAM SIZE =       670
 *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
      SUBROUTINE MEANS(ETFLAG,TWF1,TWS1,TWF2,TWS2,WF1,WS1,WF2,WS2,Y)
      INTEGER ETFLAG,Y
      WF1=TWF1/Y
      WS1=TWS1/Y
      WF2=TWF2/Y
      WS2=TWS2/Y
      IF(ETFLAG.EQ.1)RETURN
      WRITE(2,1260)
 1260 FORMAT(50HOMEAN SIMULATED DAMAGE ESTIMATES IN G/M**2 DRY WT.,/
     1      49(1H-))
      WRITE(2,1265)WF1
 1265 FORMAT(36H LEAF DAMAGE - FIRST GROWTH CYCLE = ,F8.3)
      WRITE(2,1270)WS1
 1270 FORMAT(36H STEM DAMAGE - FIRST GROWTH CYCLE = ,F8.3)
      WRITE(2,1275)WF2
 1275 FORMAT(37H LEAF DAMAGE - SECOND GROWTH CYCLE = ,F8.3)
      WRITE(2,1280)WS2
 1280 FORMAT(37H STEM DAMAGE - SECOND GROWTH CYCLE = ,F8.3)
      RETURN
      END
```

```
FORTRAN IV G LEVEL  21                  MEANS               DATE = 75239          08/54/34            PAGE 0002


   *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
   *OPTIONS IN EFFECT*  NAME = MEANS    , LINECNT =       60
   *STATISTICS*    SOURCE STATEMENTS =        19,PROGRAM SIZE =      1044
   *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G LEVEL  21                  LOSS                DATE = 75239          08/54/34            PAGE 0001

      SUBROUTINE LOSS(ETFLAG,WF1,WS1,WF2,WS2,XL,EL,TL3,EC)
      INTEGER ETFLAG
      DF1=0.0507*WF1
      DF2=0.0507*WF2
      DS1=0.0482*WS1
      DS2=0.0482*WS2
      DL=EL-0.35*(DF1+DF2+DS1+DS2)
      WF1=       DF1*2.0*XL*DL
      WF2=       DF2*2.0*XL*DL
      WS1=       DS1*2.0*(1.0-XL)*DL
      WS2=       DS2*2.0*(1.0-XL)*DL
      TL1=WF1+WS1
      TL2=WF2+WS2
      TL3=TL1+TL2
      IF(ETFLAG.EQ.1)RETURN
      WRITE(2,1300)
 1300 FORMAT(28HOMEAN EXPECTED LOSS IN C£/HA,/27(1H-))
      WRITE(2,1305)TL1
 1305 FORMAT(1H ,10X,19HFIRST GROWTH CYCLE ,F8.3)
      WRITE(2,1310)TL2
 1310 FORMAT(1H ,10X,20HSECOND GROWTH CYCLE ,F8.3)
      WRITE(2,1315)TL3
 1315 FORMAT(1H ,10X,11HTOTAL LOSS ,F8.3)
      RETURN
      END
```

```
*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = LOSS     , LINECNT =        60
*STATISTICS*    SOURCE STATEMENTS =         25,PROGRAM SIZE =       984
*STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G LEVEL  21                  G05AAF               DATE = 75239          08/54/34             PAGE 0001

    0001                FUNCTION G05AAF(X)
    0002                INTEGER X
    0003                DATA IY/153/
    0004                IY=IY*65539
    0005                IF(IY) 5,6,6
    0006              5 IY=IY+2147483647+1
    0007              6 G05AAF=IY*.4656613E-9
    0008                IF(X) 7,8,8
    0009              7 G05AAF=-G05AAF
    0010              8 RETURN
    0011                END
```

```
INPUT INSTAR POPULATIONS      250      500      250       0       0       0
INPUT INFESTATION DAY         21
INPUT NO. OF MODEL ITERATIONS  2
DISPERSAL RATIOS       1       3       4      36      60      23
MORTALITY RATES 0.35 0.20 0.26 0.08 0.06 0.05

VALUE OF CROP (C£/TONNE)    4.480
PROPORTIONATE VALUE OF LEAVES OF TOTAL UNDAMAGED CROP     0.660

ITERATION NO.                  1

DAYS SINCE      DRY WT. YIELD      TOTAL LARVAL      CONSUMPTION          NUMBER OF LARVAE IN EACH INSTAR RANGE        DEAD       DISPERSED
AST HARVEST    OF LEAF            CONSUMPTION       DEMAND DEFICIT          1     2     3     4     5     6    PUPAE
      1             1.3578
      2             1.8408
      3             2.4906
      4             3.3608
      5             4.5187
      6             6.0468
      7             8.0412
      8            10.6072
      9            13.8485
     10            17.8488
     11            22.6470
     12            28.2088
     13            34.4063
     14            41.0154
     15            47.7417
     16            54.2692
     17            60.3178
     18            65.6877
     19            70.2765
     20            74.0718
                                                                       250   500   250     0     0     0
     21            73.0454           4.0814                             38   304   326   121     0     0  -    0         211            0
     22            69.5954           6.7124                              2   169   291   163    12     0  -    0         363            0
     23            63.2198          10.2958                              0    46   248   110   115     0  -    0         481            0
     24            55.1861          13.0017                              0     7   126   160    76    77  -    0         554            0
     25            45.4721          15.6740                              0     0    63   116    82   125  -    9         605            0
     26            34.4471          17.6540                              0     0    17    72   135    50  -  103         623            0
     27            26.1966          14.8614                              0     0     1    48    63   109  -  143         636            0
     28             1.0366           0.3212        -13.7661          -   0     0     0     0     0     0  -  151         636          213
                                    82.6018
     29             1.4072
     30             1.9074
     31             2.5801
     32             3.4802
     33             4.6771
     34             6.2546
     35             8.3105
     36            10.9506
     37            14.2773
     38            18.3703
     39            23.2615
     40            28.9064
     41            35.1655
     42            41.8046
     43            48.5237
     44            55.0082
     45            60.9858
     46            66.2675
     47            70.7623
     48            74.4670
     49            77.4407
     50            79.7772
     51            81.5826
     52            82.9595
     53            83.9994
     54            84.7788
     55            85.3598
     56            85.7909
     57            86.1100


ITERATION NO.                  2

DAYS SINCE      DRY WT. YIELD      TOTAL LARVAL      CONSUMPTION          NUMBER OF LARVAE IN EACH INSTAR RANGE        DEAD       DISPERSED
AST HARVEST    OF LEAF            CONSUMPTION       DEMAND DEFICIT          1     2     3     4     5     6    PUPAE
      1             1.3578
      2             1.8408
      3             2.4906
      4             3.3608
      5             4.5187
      6             6.0468
      7             8.0412
      8            10.6072
      9            13.8485
     10            17.8488
     11            22.6470
     12            28.2088
     13            34.4063
     14            41.0154
     15            47.7417
     16            54.2692
     17            60.3178
     18            65.6877
     19            70.2765
     20            74.0718
                                                                       250   500   250     0     0     0
     21            73.0553           4.0715                             51   308   314   126     0     0  -    0         201            0
     22            69.6431           6.6726                              3   182   290   162    19     0  -    0         344            0
     23            62.8591          10.6955                              0    55   260    99   122     0  -    0         464            0
     24            54.1940          13.6857                              0     9   133   157    79    76  -    0         546            0
     25            44.5160          15.7338                              0     0    71   124    76   124  -   12         593            0
     26            31.4142          19.7632                              0     0    16    74   132    55  -  101         622            0
     27            22.5884          15.2740                              0     0     3    50    57   116  -  144         630            0
     28             1.0241           0.3336        -13.4283          -   0     0     0     1     0     4  -  159         632          204
     29             1.2555           0.1349                              0     0     0     1     0     0  -  163         632          204
     30             1.6487           0.0541                              0     0     0     0     1     0  -  163         632          204
     31             2.1784           0.0541                              0     0     0     0     0     1  -  163         632          204
     32             2.8892           0.0541                              0     0     0     0     0     1  -  163         632          204
     33             3.8381           0.0541                              0     0     0     0     0     0  -  164         632          204
                                    86.5811
     34             5.1504
     35             6.8742
     36             9.1109
     37            11.9666
     38            15.5388
     39            19.8945
     40            25.0435
     41            30.9111
     42            37.3253
     43            44.0258
     44            50.7014
     45            57.0455
     46            62.8099
     47            67.8375
     48            72.0687
     49            75.5236
     50            78.2760
     51            80.4257
     52            82.0790
     53            83.3355
     54            84.2818
     55            84.9897
     56            85.5164
     57            85.9069
     58            86.1956


MEAN SIMULATED DAMAGE ESTIMATES IN G/M**2 DRY WT.


-----------------------------------------------------
LEAF DAMAGE - FIRST GROWTH CYCLE =    45.840
STEM DAMAGE - FIRST GROWTH CYCLE =     8.173
LEAF DAMAGE - SECOND GROWTH CYCLE =     0.572
STEM DAMAGE - SECOND GROWTH CYCLE =     0.572

MEAN EXPECTED LOSS IN C£/HA


------------------------------
          FIRST GROWTH CYCLE    11.705
          SECOND GROWTH CYCLE     0.200
          TOTAL LOSS    11.905
```