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**Report no. 1561**

# The influence of climatic factors on cutworm *(Agrotis segetum)* attack level, investigated by means of linear regression models*

*Klimatiske faktorers indflydelse på angreb af knoporme (Agrotis segetum), undersøgt ved hjælp af lineære regressionsmodeller*

**Søren A. Mikkelsen and Peter Esbjerg**

**Summary**

At irregular intervals cutworms *(Agrotis segetum)* have caused severe damage to various Danish crops. For the years 1906–79 the cutworm attack levels for Denmark as a whole have been estimated on a scale from 1-11 on the basis of local reports from extension officers and scientists to the Plant Pathology Institute.

By means of linear regression methods the estimated attack levels were related to monthly values of ordinary climatic variables. The resulting model of 8 explaining variables was able to account for 64 per cent of the total variation of cutworm attack level during 73 years.

The model showed a negative influence on attack level of the amount of precipitation in late winter and in May. For the months June, July and August there was a stronger negative influence of the numbers of precipitation days than of the amounts of precipitation. The attack level of one year had a positive effect on the attack level the following year.

The negative influence of precipitation in May is possibly due to the harmful effect of soil moisture on pupation and emergence and of rain on early flight of the moths. The negative influence of the number of precipitation days in June and July is partly explained as an effect on flight-mating and flight-oviposition of the moths. Also influence of rain directly and/or via soil moisture on the small larvae is suggested as important particularly for July.

The model's qualification for forecasting was examined by applying it to observations different from the data used for estimation of the parameters in the model.

The model alone can not be used for forecasting in practice, partly because of the late time in the year, forecasting can be issued. However, a combined use of simulation based on the model and results

* The present paper is the result of a co-operation between the research projects »Agricultural meteorology« and »Integrated control of noxious insects«, financially supported by the Joint Committee for Agricultural Research and Experiments and the Council for Agricultural and Veterinary Research, respectively.

from monitoring of the moths' flight may give a valuable guidance about the attack risk the year in question.

**Key words:** *Agrotis segetum,* cutworm attack level, linear regression methods, climatic variables, forecasting.

**Resumé**

Alvorlige knopormeangreb forekommer tilbagevendende på danske afgrøder. Angrebenes styrke i årene 1906–79 for hele Danmark under ét er blevet opgjort på en skala fra 1-11 på basis af indberetninger til Institut for Plantepatologi fra instituttets medarbejdere og lokale planteavlskonsulenter.

Ved hjælp af lineære regressionsmetoder blev angrebsstyrken sammenholdt med månedsværdier for almindelige klima-variable. 64 procent af den totale variation i angrebsgrad kunne forklares ved hjælp af en model med følgende 8 bestemmende variable:

Angrebsniveauet året forud
Middeltemperaturen i juli
Nedbørsmængden i februar-marts-april
Nedbørsmængden i maj
Antallet af nedbørsdage i juni
Antallet af nedbørsdage i juli
Antallet af nedbørsdage i august
Nedbørsmængden i november det foregående år.

Modellen viste, at nedbørsmængden på overgangen mellem vinter og forår (februar-marts-april) samt majnedbøren har en negativ virkning på angrebsgraden. Det vil sige høj nedbørsmængde giver mindre angreb. I månederne juni, juli og august var den negative indflydelse af antallet af regnvejrsdage klarere end den negative indflydelse af nedbørsmængden. Angrebsgraden ét år viste sig at have en positiv indflydelse på angrebsgraden det følgende år. Det vil sige, at ved højt angrebsniveau i det ene år øges risikoen for stærkt angreb også i det følgende år.

Vinternedbørens negative virkning sker formentlig i form af jordfugtighed, der skader de overvintrende larver. På tilsvarende vis må jordfugtighed i maj formodes at indvirke, ikke mindst i forbindelse med forpupning og efterfølgende klækning af agerugler. Noget af virkningen i denne måned kan dog også være en direkte følge af regn på de tidligt flyvende agerugler.

For juni og juli's vedkommende kunne påvises en tydelig indflydelse af nedbørsmængden, men en stærkere virkning af antallet af nedbørsdøgn. Derfor antages en del af den negative virkning at være en direkte følge af regnen på ageruglernes flyvning, parring og æglægning. I juli må der dog også formodes at være direkte virkning af regn og/eller af jordfugtighed på små larver. Den konstaterede fremmende virkning af stigende middeltemperatur på angrebsniveauet formodes især at afspejle de små larvers hurtigere passage af en kritisk livsfase.

Modellens mulighed for at forudsige angrebsgraden af knoporme ud fra klimatiske variable blev undersøgt ved at anvende den på observationer, som var forskellige fra de data, der blev brugt ved estimation af modellens parametre.

I praksis kan varsling ikke baseres på modellen alene, bl.a. på grund af det sene tidspunkt på året, varsling kan udsendes. Kombineret med fældefangst af de voksne sommerfugle kan modellens resultater dog give værdifuld vejledning om risikoen for knopormeangreb det pågældende år. Overvågning ved hjælp af fælder er særdeles vigtig i områder, hvor angrebsniveauet har været højt året før, og hvor vejret har været tørt i februar-marts-april samt maj det pågældende år. Omvendt er angrebsrisikoen generelt lav, hvis angrebsniveauet var lavt året før, og der har været rigelig nedbør i februar-marts-april og maj det pågældende år. Følges denne situation af en så våd juni måned, at allerede nedbørsmængden for maj + juni overstiger normalnedbøren for maj + juni + juli, vil der overhovedet ingen risiko være for større knopormeangreb.

I tvivlsituationer kort før rette behandlingstidspunkt kan modellen anvendes til at simulere, hvad der kan ske ved forskellige temperatur- og nedbørsforhold i løbet af juli. Nytten af denne anvendelsesform vil stige yderligere i takt med udvikling af længere rækkende vejrudsigter.

**Nøgleord:** *Agrotis segetum*, knopormeangreb, klima variable, lineære regressionsmodeller, prognose.

## Introduction

At irregular intervals cutworms have caused severe damage to agricultural and horticultural crops in Denmark. *Stapel* (1977) estimated the attack level for each year 1906–76 on the basis of local reports from extension officers and scientists to the Plant Pathology Institute. In a similar manner the attack levels for the years 1977–79 were estimated by the authors. The resulting estimates are shown in Figure 1a.

Following the severe attack in 1934, *Bovien* and *Stapel* (1935) analysed the attack levels for the preceding 30 years and found a negative influence on the attack level by May-June precipitation. Positive connection between cutworm attack level and the number of moths caught by means of light traps was found by *Thygesen* (1971). His investigations also showed the positive effect on attack level of dry weather in July.

Analysing the above mentioned data from *Stapel* (1977) by simple regression techniques, *Zethner* and *Esbjerg* (1978) found the total May + June + July precipitation to be the most important climatic factor in relation to cutworm attacks with a strong reducing effect.

The present study has been carried out to throw light on more details of the influence of climatic variables on attack level. The obtained knowledge should be used to develop a model by which prognosis of cutworm attack level may be issued. Such prognosis combined with flight monitoring of the moths may lead to improved forecasting of attacks.

## Materials and methods

### *Cutworm data*

The estimated attack levels in Figure la count for Denmark as a whole for the years 1906–79. The attack levels were evaluated on a scale from 1–11, and the evaluations are based on current notes concerning numbers of larvae on, as well as damage to various crops.

Because many people, and often different people from one year to another, were involved in reporting, it is obvious that the grading used is rather rough. The roughness is emphasized by Figure 2, which is a frequency bar chart for the estimated attack levels. A remarkable preference for equal numbers and the top level, 11, is indicated.

Despite the obvious shortcomings of this data material, it was found usable for regression analysis.

### *Climatic data*

The climatic data used are monthly values for the years 1906–1979 for Denmark as a whole, of the following variables: mean temperature (T, °C), precipitation (P, mm), number of precipitation days (PD), number of frost days and number of snow days. The data were published by Department of Statistics (1964) and Department of Statistics (1962–1980).

When dealing with climatic variables in regression analysis, the possibility of inter-correlations must be taken into account. Table 1 shows as an example for each of the year's 12 months the correlation between the month's mean temperature and precipitation and number of precipitation days, respectively.

Table 1 indicates a negative correlation between temperature, and both precipitation and number of precipitation days in summer. In winter the correlations are positive. Except for February, the coefficients are numerically greater for the correlation between temperature and number of precipitation days than for the correlation between temperature and precipitation.

### *Statistical methods*

The estimated cutworm attack levels are typical

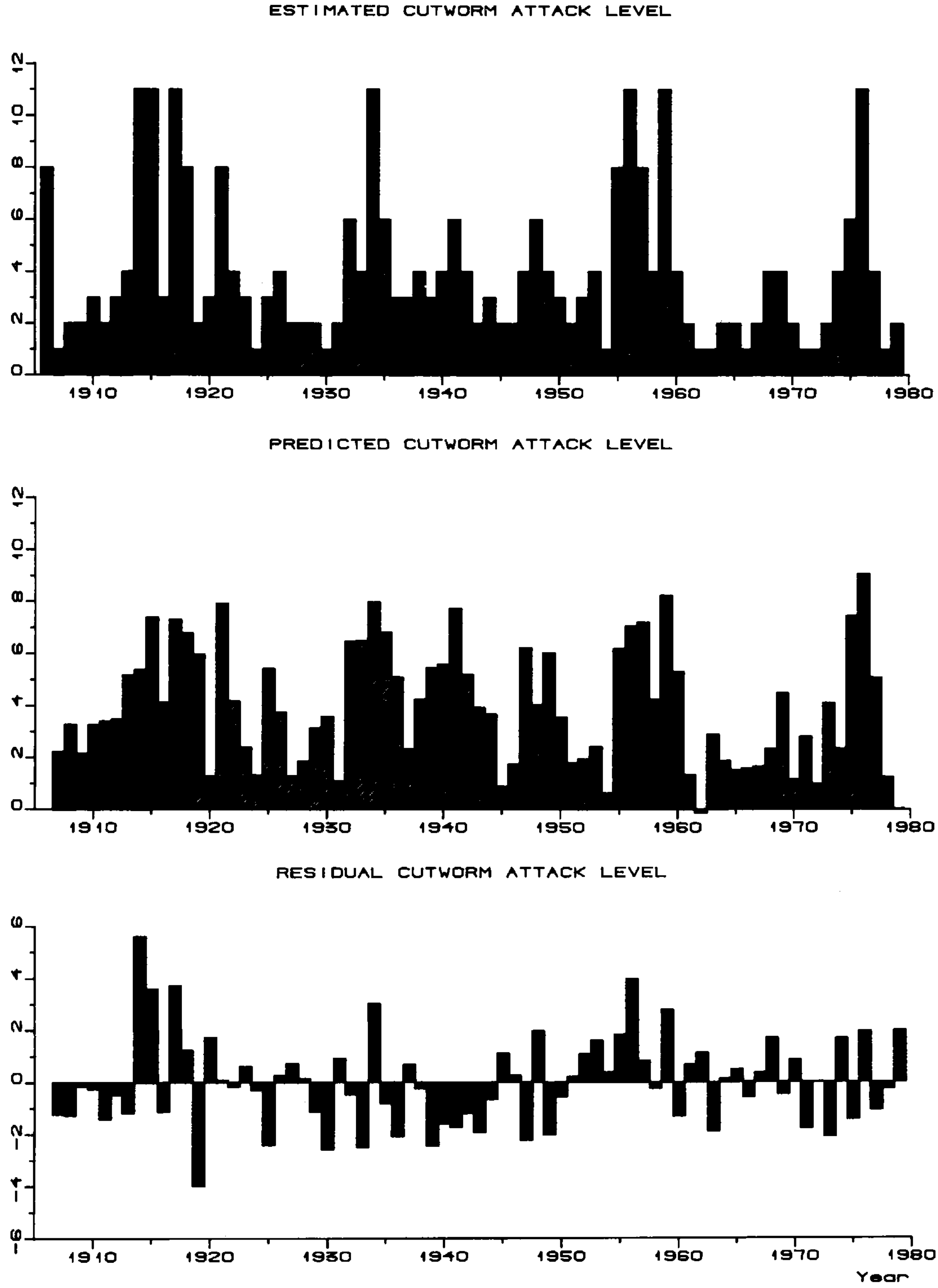


Fig. 1. Cutworm attack levels. 1a (top): estimated levels, 1906–76 estimated by *Stapel* (1977), 1977–79 by the authors. 1b (middle): predicted levels 1907–79, 1c (bottom): residual levels 1907–79.

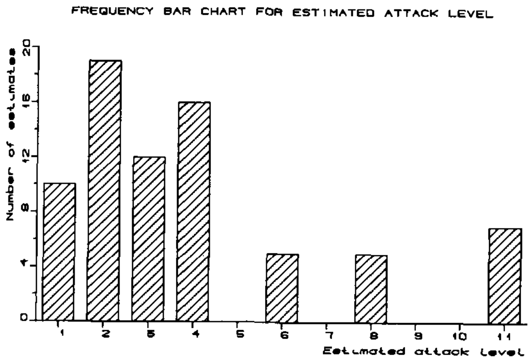


Fig. 2. Frequency bar chart for the estimated cutworm attack levels.

non-experimental data with a level of details which is insufficient for development of causal models.

In this study multiple linear regression was applied where the parameters are estimated by ordinary least square methods. This common technique, and its applications in particular, was described by *Draper* and *Smith* (1966). The computer system for data analysis, *S*tatistical *A*nalysis *S*ystem *(Helwig & Council,* 1979) was used for the calculations. SAS offers various procedures for regression analysis.

The above mentioned climatic variables and some interactions between them were considered as possible explaining variables to account for the variation from one year to another in cutworm attack level (CW). Also the cutworm attack level of the preceding year (CWL) was considered a possible explaining variable.

Selection among all these possible explaining variables was performed by combining knowledge of the cutworms' biology with results from preliminary correlation analyses. Besides, the statistical selection technique »Stepwise« *(Draper & Smith,* 1966; *Helwig & Council,* 1979) was applied. Because of the possible explaining variables' inter-correlation, the results obtained by the stepwise-procedure were not used uncritically but were regarded as valuable guidance.

In addition, the qualification of the »best« models for forecasting was examined by applying the models to observations different from the data used for estimation of the parameters in the models.

When models in practice are used for warning purposes, *genuine* prediction (prognosis) will always be the technique used. Then the model's parameters are estimated from preceding years' registered data and subsequently used to forecast the attack level of the year in question. Here the adjective *»genuine«* is used in order to distinguish between prognosis *(genuine* prediction) and prediction of the same variable values which are used for the parameter estimation.

## Results

### *Coefficients of correlation*

Coefficients of the correlation between the estimated cutworm attack level and mean temperature, precipitation and number of precipitation days in May, June, July and August are shown in Table 2. None of the other monthly climatic variables showed significant (P = 0.05) correlation with estimated cutworm attack level.

**Table 1.** Coefficients of correlation between monthly values of mean temperature and the month's precipitation and number of predipitation days, respectively[1]). N = 74 years.

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Mean temperature, °C* | | | | | | | |
| Precipitation, mm | 0.65*** | 0.43*** | 0.01 | –0.11 | –0.33** | –0.15 | –0.21 | –0.38*** | –0.02 | 0.18 | 0.25* | 0.28* |
| Number of precipitation days | 0.65*** | 0.28* | 0.02 | –0.20 | –0.42*** | –0.47*** | –0.54*** | –0.66*** | –0.18 | 0.18 | 0.38*** | 0.47*** |

[1]) * means P<0.05, ** means 0.05 > P > 0.01, *** means P < 0.001.

**Table 2.** Coefficients of correlation between cutworm attack level and monthly values of mean temperature, precipitation and number of precipitation days for May, June, July and August[1]). N = 74 years.

| | May | June | July | August |
|---|---|---|---|---|
| | | *Mean temperature, °C* | | |
| Cutworm attack level | 0.05 | 0.14 | 0.37** | 0.24* |
| | | *Precipitation, mm* | | |
| Cutworm attack level | –0.28* | –0.38*** | –0.20 | –0.15 |
| | | *Number of precipitation days* | | |
| Cutworm attack level | –0.24* | –0.36** | –0.34** | –0.24* |

[1]) * means P<0.05, ** means 0.05 > P > 0.01, *** means P < 0.001.

The coefficients of correlation shown here indicate that for July and August the number of precipitation days is a »better« explaining variable than the precipitation is.

The correlations shown (Table 2) of cutworm attack level with temperature are positive, and the corresponding correlations with the precipitation variables are negative. This may be due to the negative correlation between temperature and precipitation variables (Table 1).

It must be noted, however, that because of the lack of normality for the estimated cutworm attack levels, the significance levels shown are less reliable.

Simple time-series analysis of CW showed a significant, positive autocorrelation for CW of 0.36.

*Modelling the attack level*

Using the above mentioned statistical methods, the »best« model was found to be:

PrCW = 8.61 + 0.35★CWL + 0.42★T7 – 0.02★P234 – 0.04★P5 – 0.31★PD6 – 0.24★PD7 – 0.06★PD8 – 0.01★P11L

Here PrCW means the predicted cutworm attack level. It should be noticed that the numerical suffices in the variable names refer to the number in the year of the month of the observation (1–12). T7, for example, is the monthly mean temperature (°C) of July, and P234 is the sum of February's, March' and April's precipitation (mm). When the letter »L« is suffix, the variable refers to the preceding year. P11L means »last year's« precipitation in November, and CWL means the cutworm attack level »last year«.

The numerical values of the model's parameter estimates are given to two decimal places, although the standard deviation of the estimates in some cases is rather high.

The levels of significance for the model's parameters, the estimate of variance and the model's multiple linear correlation coefficient, $R^2$, are shown in Table 3. The value 0.64 of $R^2$ means that with the 8 variables listed, it is possible to »explain« 64 per cent of the total variation of the cutworm attack levels.

Prediction with this model is illustrated in Figure 1b, which shows the predicted cutworm attack levels PrCW for the years 1907–1979. The attack level for 1906 can not be predicted, as the variable CWL is part of the model, and there is no estimate of attack level for 1905.

The model's residuals, CW-PrCW, the differences between the estimated and predicted levels, are shown in Figure 1c. The »cutworm years« with large positive residuals and the year 1919 with a large negative residual are remarkable.

The possibilities of forecasting at different times of the growing season (*genuine* prediction) was investigated using three different models A, B and C. Model A was the »best« model, listed in

**Table 3.** The model's explaining variables, the levels of significance of the parameter-estimates, the model's estimate of variance and multiple coefficient of correlation.

| Variable | Level of significance for the parameter-estimate | Estimate of variance, $s^2$ | Multiple coefficient of correlation, $R^2$ |
|---|---|---|---|
| CWL | 0.001 | | |
| T7 | 0.074 | | |
| P234 | 0.001 | | |
| P5 | 0.001 | | |
| PD6 | 0.001 | 3.4 | 0.64 |
| PD7 | 0.001 | | |
| PD8 | 0.263 | | |
| P11L | 0.103 | | |

CW: cutworm attack level
T : mean temperature, suffix refers to the month
P : monthly precipitation, suffix refers to the month
PD : number of precipitation days, suffix refers to the month
L : (as a suffix) refers to the previous year, that is, CWL is »last year's« cutworm attack level, and P11L is the amount of precipitation in November »last year«.

Table 3; Model B was formed by omitting PD8, the number of precipitation days of August, from model A; Model C was formed by omitting T7 and PD7 from Model B. Forecasts on basis of the models A, B and C may then be issued by 1st September, 1st August amd 1st July, respectively.

Estimation of the parameters used in the models revealed a remarkably lower value of $R^2$ for Model C than for Model A and Model B. The two latter models' values of $R^2$ were of the same size.

In Figure 3 the *genuinely* predicted attack levels for the 1970's by the three models are shown, when the models' parameters were developed from the observations 1906–1969. The top of the figure shows the corresponding estimated attack levels, and is merely a part of Figure 1a in an enlarged edition, shown here for comparison. The figure demonstrates that Model C especially undervalues the attack level of the »cutworm year« 1976.

Table 4 gives the sums of squares of the residuals for the three models' *genuine* predictions for the years 1970–79. The sum of squares for Model C is somewhat larger than those for the two other models.

**Table 4.** Sums of squares of the residuals for 1970–79 from *genuine* prediction by the models A–C.

| | Model A | Model B | Model C |
|---|---|---|---|
| Sum of squares of residuals | 27 | 28 | 34 |

Corresponding to Figure 3, Figure 4 shows the results obtained with *genuine* prediction, when the models' parameters for each year are estimated by use of the information from all the preceding years. For the prognosis for 1971 the information from 1906–1970 were used, for 1972 the information 1906–1971, for 1973 the information 1906–1972, etc. The results in Figure 4 are very similar to those in Figure 3.

By updating the models' parameter-estimates every year as has been done for the results shown in Figure 4, all the information available at a given point of time is always utilized.

**Discussion and conclusion**

*Correlations between climatic variables and cutworm attack level.*

The correlations between certain climatic variables and cutworm attack as shown in Table 2 are not surprising. As mentioned in the introduction, negative influence of the precipitation during May and June was found by *Bovien* and *Stapel* (1935) while *Zethner* and *Esbjerg* (1978) found a negative influence of May-June-July precipitation.

The present analysis, however, gives a more detailed background for explaining fluctations of cutworm attack levels (Tables 2 and 3). The influence of the population density in the previous year (CWL) is rather important in this respect as indicated by the positive autocorrelation for CW. This factor is highly significant (Table 3) and the reason for its influence is obvious, Much weaker and possibly speculative is the influence of the precipitation in November the previous year (P11L, Table 3). A possible explanation for such influence may be the larvae entering into diapause eventually causing increased physiological sensitivity to soil moisture. Also soil moisture during late winter and early spring seems harmful to the hibernating cutworms which lay inactive in the soil. This is indicated by the high significance level of the February-March-April precipitation (P234, Table 3). An indirect effect through increased plant growth conditions may not be ruled out but seems rather improbable for this period of time.

The clear influence of May precipitation (Tables 2 and 3) is easier to understand, as pupation takes place mainly during this month and, furthermore, early emergence and flight starts. The fact that the amount of precipitation has a stronger influence than the number of precipitation days may indicate that the direct effect of rain is weak, while soil moisture plays a more important role.

However, it should be pointed out that the influence may be partly indirect through increased plant strength, as the plants are tiny and very sensitive to stress during this period. Such increased strength may have a delayed but important effect in June and July when small cutworms start attacking the plants.

The change from influence of precipitation in May to mostly influence of the number of precipitation days in June and July may be related to flight-mating and flight-oviposition of the moths during the latter period. Both activities may be affected directly by heavy rain especially if it is also cold and windy *(Peersson,* 1971).

The influence of precipitation in May, June and July is particularly strong. This viewpoint is supported by the present results for the single months together with the results of *Zethner* and *Esbjerg* (1978) showing that major outbreaks have never occurred in years with a surplus of more than 10 mm May + June + July precipitation compared to normal (Figure 5). This strong influence of »wet years« is possibly due to the effects on pupation, emergence from pupae and adult flight as already mentioned, together with the effects of rainfall and of soil moisture on small larvae during the last part of June and the whole of July. During this period most larvae are small and move around on the soil surface and the plant leaves. Such influence on small larvae may be decreased if the temperature is so high that the growth rate of the larvae is increased and a dangerous phase of the life cycle is passed quickly. This may be part of the reason for the positive influence of temperature in July (Tables 2 and 3). Of course the soil moisture during June and July may also have a direct influence on the emergence from pupae and an indirect one on larvae via plant vigour.

A general question concerning the probable influence of soil moisture on larvae and pupae of *Agrotis segetum* is whether the influence is due to physiological or behavioral reactions or due to increased activity of microbial pathogens. Eventually a combination of both is also possible.

*Modelling*

The detailed influence of climatic factors on *A. segetum* is unknown. However, 64 per cent of the total variation of cutworm attack level during 73 years can be explained by the influence of the 8 modelling variables for Model A (Table 3).

The prediction quality of Model A is rather high as visualised by the Figures 1a, 1b and 1c. In so-called »cutworm-years«, though, with an estimated attack level of 11, the predicted values are always lower, and so the residuals (Figure 1c) are positive and large. This may partly be due to the regression method. With that technique, it is not possible to predict the extreme values as well as the middle ones.

However, the preference for the top grade 11 (mentioned earlier), which the data indicates, should also be remembered. Maybe some of the »cutworm years'« »true« attack levels were only 9 or 10. Figure 2 demonstrates that no year at all was given one of those grades.

Although the model shows shortcomings in »cutworm years«, these years still are predicted as years with high attack levels.

The remarkably incorrect prediction for 1919 has a particular explanation, as it is known that massive death among cutworms was caused by fungal attack during late summer 1918 *(Rostrup,* 1918). Also Model B has a good forecasting quality, whereas Model C is less good as appears from Figures 3 and 4.

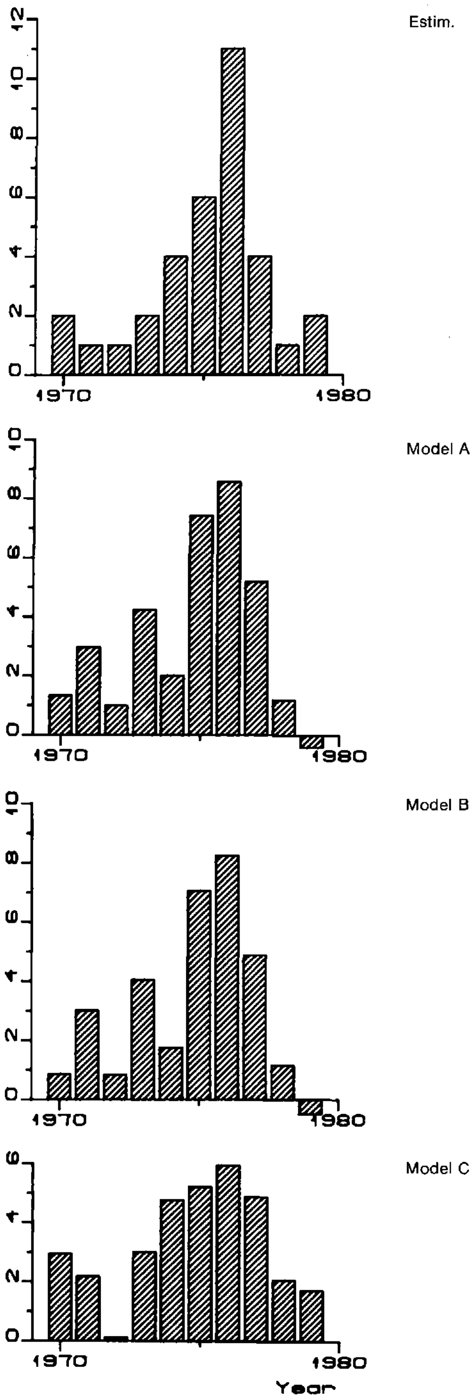


Fig. 3. Estimated (top) and *genuine* predicted cutworm attack levels by the models A, B & C for 1970–79. Parameter estimates from observations 1906–69.

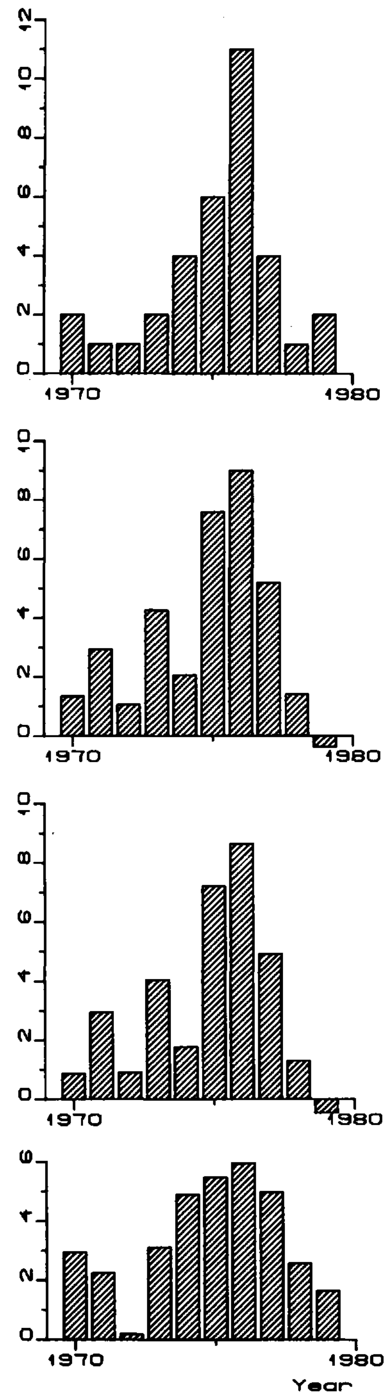


Fig. 4. Estimated (top) and *genuine* predicted cutworm attack levels by the models A, B & C for 1970–79. Parameter estimation performed »runningly«.

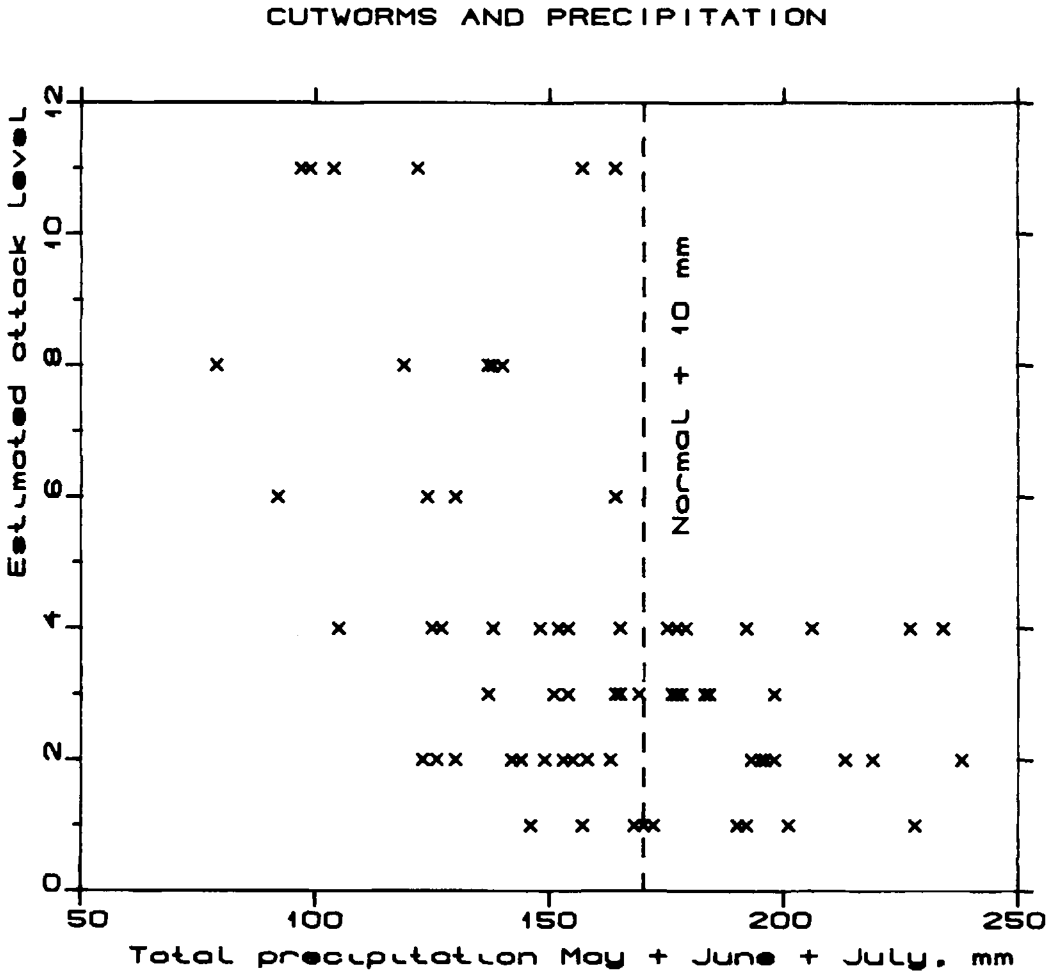


Fig. 5. The relationship between the amounts of precipitation in May + June + Juli (along the abscissa) and the cutworm attack levels (ordinate) as estimated by *Stapel* (1977). The normal amount (= mean of 30 years: 1931–1960) for May + June + July is 160 millimeters. The dotted line showing this amount + 10 millimeters has been drawn to underline the effect of precipitation surplus. (Modified after *Zethner & Esbjerg*, 1978).

*Use for forecasting*

The practical value for warning purposes of model-based prognosis alone is rather low. Prognoses based on both Models A and B come out too late for control measures, while the less accurate prediction based on Model C comes out just in time for the majority of years. Model based forecasts are, however, not intended to be used alone. They should be used together with monitoring results from pheromone traps as described by *Esbjerg et al.* (1980) but with synthetic pheromone *(Arn et al.,* 1980) as lure. In this way a detailed background for forecasting may be obtained not only country-wide but with regional variation taken into account on the basis of trapping catches.

By means of the most important explaining variables in the model (Table 3) and the results of *Zethner* and *Esbjerg* (1978) (Figure 5) some practical guide-lines can be given concerning the attack risk. Monitoring with pheromone traps is very important in regions with high CWL and dry weather during February-March-April (P234) and May (P5). Conversely the risk is low in general if CWL is low and P5 is high. If CWL is low, P234 is high and the precipitation of May-June reaches or exceeds the normal amount of May + June + July (conf. Figure 5) there is no risk at all of a high cutworm attack level for the year in question.

The practical value of the models is particularly high in situations of doubt around 1st July when only 1–2 weeks are left for efficient control time. On such occasions Model B can be used to simulate what will happen depending on different numbers of precipitation days and temperature levels during July. The results together with monitoring results and possible future medium range weather forecast may form a strongly improved background for decision making. The forecasting value of models for cutworm attacks may presumably be improved further in the future if further details of the influence of rainfall and soil moisture on flight, egglaying, larval growth and mortality are unveiled.

*Acknowledgements*

We are grateful to *Jørgen E. Olesen*, the Laboratory for Data Analysis, for doing some of the programming work for this study and to *Ole Zethner*, the Development Cooperation Bureau, Royal Veterinary and Agricultural University, Copenhagen, for critical revision of the manuscript.

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Manuscript received 8th July 1981.