Lucerne or alfalfa (Medicago sativa L.) is a well-known leguminous fodder for livestock and is widely distributed in arid to semi-arid, and temperate to tropical conditions. In India, it is grown as a farm crop in Gujarat, Maharashtra, Rajasthan, Tamil Nadu, Punjab, west Uttar Pradesh and West Bengal, occupying about 1 m ha area and providing about 130 t green fodder per hectare. Its versatility in utilization, adaptation to a wide range of climate and soil conditions makes it a preferable choice in the agricultural production system.

The lucerne weevil, Hypera postica Gyllenhal (Coleoptera: Curculionidae), is the most damaging pest of lucerne, occurring in all the lucerne-growing areas of the country and is particularly severe in northwestern and western Himalayas, Gangetic and central plains. Most of the damage is caused by the larvae which feed within the plant tips, on the young leaves, and under heavy infestation the lower foliage is also consumed. The adult weevil also feeds on the leaves. The weevil-feeding injury can result in shoot-length reduction, forage yield and quality, and stand persistence. In India, it is estimated to reduce yield by 10–15% annually, where reduction in forage quality has not been taken into account.

Development of poikilothermal organisms, which cannot maintain their body temperature on their own, is dependent on the temperature to which they are exposed in the environment. Being a poikilothermal organism, the lucerne weevil also requires a certain amount of heat to develop from one stage to another. Degree-day models can be used to monitor and predict key life stages in lucerne weevil when pest-control tactics need to be implemented. Development of the degree-days concept has been worked out by several workers. Phenology model for growth stages of lucerne weevil has been reported for laboratory and field situations for colder regions. However, this type of information is lacking under Indian conditions. The present study was undertaken to estimate the degree-days requirement for each stage of the weevil development and to develop a degree-days-based prediction model for lucerne weevil incidence in the central Indian region.

A field experiment was conducted for three consecutive (2004–07) ‘rabi’ seasons at the Central Research Farm, Indian Grassland and Fodder Research Institute, Jhansi, central India. Jhansi (25°27’N, 78°35’E, 271 m above sea level) receives an annual rainfall of 906.5 mm with 781 mm during the kharif and 52 mm during the rabi and experiences annual potential evapotranspiration of 1512 mm. The moisture deficit index of the region based on normal data is ~39.5%. Soils of the experimental site were clay loam. It was neutral in reaction (pH 7.56) and non-saline (ECe 0.148 dS/m) in nature. The status of organic carbon (0.29%), available nitrogen (233.1 kg/ha) and available phosphorus (16.1 kg P/ha) in the soil was low, whereas available potassium content of the soil was in the medium range (219.4 kg K/ha). The bulk density, particle density and porosity were 1.20 g/cm3, 2.25 g/cm3 and 0.53% respectively. Water holding capacity (47.6%) indicates that the soil is congenial to crop growth. The crop received 43.6, 25.4 and 45.8 mm of precipitation during the crop growth period of 2004–05, 2005–06 and 2006–07 respectively.

The experiment was conducted with Lucerne (var. RL-58) in plot size of 4 x 3 m and replicated four times. The crop was sown in the first week of November in lines 30 cm apart. A basal recommended fertilizer dose of 20 kg N, 80 kg P2O5 and 40 kg K2O was applied at the time of sowing. Standard agronomic practices were followed, but no pesticides were applied. The larval population was counted at weekly intervals following the sequential method of sampling. The daily temperature data were obtained from IGRFR meteorological observatory. Degree-days (DD) were computed using the equation, DD = [(Tmax + Tmin)/2] – 10, where Tmax is the maximum temperature, Tmin the minimum temperature and 10 the lower developmental threshold for lucerne weevil below which the development stops. In the present calculation, the lower development threshold has been taken as 9°C.

The life cycle of lucerne weevil is characterized by a short period of intensive activity and a long period of inactivity. In India, the aestivating adult weevil makes its appearance in lucerne fields in December and start feeding on the leaves. It is active from December to March only. The larva becomes fully grown in 20–35 days. The pupal stage is completed within 10–15 days. The total life cycle takes 32–50 days. Since each stage has its own heat requirement, the development can be estimated by accumulating degree-days from a starting point.

The degree-days accumulation requirements for different stages of development of lucerne weevil under field conditions are presented in Table 1. The hatching of eggs requires 62 degree-days, which takes about 10 days to complete. The larval period of lucerne weevil includes four instars and it is completed in 28 days, requiring 160 degree-days. In the United States, an average of 148 degree-days is required for larval development and this requirement is completed in Virginia in three weeks. The pupal period took approximately 11 days and required 99 degree-days for development. Therefore, the total degree-days requirement for lucerne weevil development from egg to adult stage is estimated to be 321, and this process takes about 49 days in the central Indian region. The degree-days accumulation required for complete generation time has been reported to be 389 degree-days, with

<table>
<thead>
<tr>
<th>Table 1. Degree-days (DD) accumulation required for each stage of lucerne weevil development</th>
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<tr>
<td>Host: lucerne</td>
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<tr>
<td>DD (°C)</td>
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<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Egg</td>
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<td>Larvae</td>
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<td>Pupae</td>
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<td>Generation time (egg to adult)</td>
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<td>Biofix; Peak of earlier stage.</td>
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developmental threshold of 10°C in Ottawa. It has been observed that the weevil incidence in lucerne crop starts during the last week of December in the field. The first indications of weevil injury are small holes in the leaves near the growing tip. This injury becomes apparent as the weevil larvae grow. The lucerne weevil larva (Figure 1a) is green with a black head and a white stripe down its back (Figure 1b). The larval period includes four instars and the fourth instar is about 1 cm in length. The third and fourth instar causes major damage to the crop. With larval population build-up, the lucerne leaves take on a skeletonized appearance (Figure 1c) since feeding continues and sometimes the entire growing tip can be destroyed. The weevil population with respect to degree-days accumulation during the crop growth period for three years of experimentation is illustrated in Figure 2. The starting date for degree-days accumulation was taken from 1 December onwards. The weevil first instar larval population ranged between 3.2 and 10.2 larvae/ft² plant during different years. Further, as the accumulation of degree-days advances, the larval population starts increasing and attains a peak value ranging from 121.2 to 141.4 larvae/ft² somewhere during the first week of February. It is during this period that significant defoliation (Figure 1d) is observed in the lucerne crop. Further, the larval population starts decreasing gradually as the season advances and by the third week of March, the population touches a low value (~30 larvae/ft²). A second-order polynomial model was fitted to describe the relationship between lucerne weevil population (n = 36) and accumulated degree-days. The equation of the fitted model is:

\[ Y = -110.46** + 0.93049**X - 0.00094**X^2 \quad (R^2 = 0.806; \ P < 0.01), \]

where \( Y \) is the lucerne weevil (larvae/ft²) population and \( X \) the accumulated degree-days from 1 December.

Since the \( P \) value in the ANOVA table is less than 0.01, there exists a highly significant relationship between lucerne weevil population and accumulated degree-days. Moreover, the intercept as well as the highest-order term of the polynomial are also highly significant (\( P < 0.01 \)). The polynomial model fitted (standard error = 19.46) above explains 80.6% of the variability in lucerne weevil population during the crop growth period. Differentiating eq. (1) w.r.t. \( X \), the first (\( dy/dx = 0 \)) and second derivatives (\( d^2y/dx^2 < 0 \)) give the optimum value of \( Y \) at \( X = 495 \). It is worth mentioning here that the fitted model slightly underestimates the peak population observed in the field (Figure 2). The observed higher values of the peak population in the field compared to those predicted by the model may be attributed to the presence of overlapping generations of the lucerne weevil in the field conditions.

The above model was tested with an independent dataset for the current year, i.e. 2007–08. These values indicate that there is a straight-line relationship (Figure 3) between predicted and observed lucerne weevil populations. The predicted and observed values of lucerne weevil

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**Figure 1.** a. Lucerne weevil larva feeding on leaves; b. Weevil larvae; c. Skeletonized leaves, and d. Weevil-damaged lucerne crop.

**Figure 2.** Lucerne weevil population during crop growth period.
population are more or less in good agreement ($R^2 = 0.84$, $P < 0.01$), which shows that the model performs fairly well. The performance of the developed model was also examined using standard error ($SE = 18.91$), mean absolute deviation ($MAD = 16.02$), absolute prediction error ($APE = 0.20$) and coefficient of variation of the residual error ($CVRE = 0.26$). The values of the above indicators are also within the acceptable range. On the basis of all these performance indicators, it can be concluded that the developed degree-day model indicates healthier prediction capabilities and it can be utilized for the prediction of lucerne weevil population in the central region well. This information would be useful in monitoring the weevil activity and evolving an integrated pest management scheme for lucerne management.


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