V.9 Simulation of Near-Surface Soil Temperature on Rangelands

F. B. Pierson, J. R. Wight, G. N. Flerchinger, W. P. Kemp, and J. R. Fisher

To effectively control grasshoppers and the damage they cause requires information about when the potential for grasshopper outbreaks exists, the age structure of grasshopper populations, and how grasshopper population densities will change over time. Central to all these objectives is the ability to predict the timing of hatch and the rate of nymphal (immature) development for different species of grasshoppers. Recent Grasshopper Integrated Pest Management (GHIPM) Project results have shown that the growth and development of grasshoppers can be adequately predicted once the time of hatch has been determined (Dennis et al. 1986, Dennis and Kemp 1988). However, predicting the timing of grasshopper hatch is very difficult.

In late summer and fall, most grasshoppers lay eggs that then hatch the following spring. Several weeks after the eggs are laid, they enter what is called an embryonic diapause until the temperature gets very cold later in the fall or winter. Diapause is a state in which the eggs will not develop beyond a certain stage until the right environmental conditions exist. Diapause prevents the eggs from developing and hatching too early during an unfavorable or inappropriate season of the year. After the eggs experience a period of extreme cold, they begin to develop at a rate governed by the amount of heat they receive. Eggs that receive more heat hatch earlier in the year than eggs in cooler locations. Therefore, to predict grasshopper hatch accurately, scientists must first accurately predict soil temperature conditions that exist in the near-surface soil layers, where grasshopper eggs are laid.

Because continuous monitoring of environmental conditions in the soil is time-consuming and costly, computer simulation of soil temperature is the most practical alternative. However, temperature and moisture conditions near the soil surface change quite rapidly and are strongly influenced by small changes in weather patterns and soil types. Vegetation also strongly influences soil water and temperature conditions by controlling how much sunlight reaches the soil surface and how much heat is lost from the soil at night, when the air is cooler. Soil under a shrub receives much less sunlight than bare soil or soil covered by a grass plant immediately adjacent to the shrub. This causes a great deal of variation in how much heat is accumulated at different locations across a landscape. Pierson and Wight (1991) reported that at 1 cm below the surface, soil temperatures varied by as much as 31 °F between soils under a sagebrush plant canopy and a bare soil in the interspace between the shrubs. Their measurements reflect soil temperature conditions in March, when grasshopper eggs are still in the ground and are just beginning rapid development. Near-surface soil temperatures can be equally influenced by grasses or shrubs. In particular, bunch grasses insulate the soil surface like a shrub canopy does and can cause temperature differences of up to 36 °F between locations only a few centimeters apart.

The SHAW Model

The Simultaneous Heat and Water (SHAW) model was modified to estimate near-surface soil temperatures under varying types of rangeland vegetation (Flerchinger and Pierson 1991). The model simulates the movement of water and heat through the vegetation, snow, soil surface residue, and the soil profile. The model includes the influence of soil freezing and thawing, evaporation, transpiration, infiltration, and surface runoff. SHAW provides hourly predictions of soil temperature and water potential at any specified point throughout the plant canopy or soil profile. The model can simultaneously simulate the influence of several plant species as well as dead plant material on soil water and temperature conditions.

The model looks at the plant–soil system as a series of layers starting from the top of the plant canopy and extending down through the soil to a depth of just over 13 ft (4 m). The model requires weather information to tell it how much water and heat are being received into the top layer of the system. Data requirements include hourly estimates of air temperature, precipitation, solar radiation, windspeed, and relative humidity. The model then predicts how much heat and water will move between layers or will be lost out the bottom of the soil profile or back into the atmosphere.

Model Operation

A great deal of descriptive information about the vegetation and soil is needed before the SHAW model can be used to simulate soil water and temperature conditions at a specific site. Supplying this information in terms the model can use is referred to as the model parameterization process. To facilitate this process, there is a user interface that steps the user through each parameter and allows the user either to enter a value or have it estimated by the model. The interface then formats all the information into the proper computer file formats.

The model interface comprises a series of formatted computer screens that a user can select from a menu. Each screen steps through a variety of related parameters and, where applicable, provides helpful information on estimating a proper value. The menu consists of the following screen options, which allow the user to:

FILE: Recall parameter information from a previous simulation or to save the current parameter values,

CONTROL: Input dates of simulation and location of input and output files,

SITE: Input general information for the site (e.g., latitude, slope, aspect and elevation),

VEGETATION: Input data for plant characteristics,

SOILS: Input data for soil characteristics,

SURFACE: Input data for residue, snow, and surface characteristics,

RUN MODEL: Input data to create model input files using current data values and execute SHAW model simulation, and

EXIT: Exit the model interface.

In addition to parameterizing the model, the user must also supply a computer data file of weather information before a model simulation can be conducted. Values of air temperature, precipitation, solar radiation, windspeed, and relative humidity must be supplied on an hourly or daily basis. If weather data are available only on a daily basis and hourly output is desired, the model will estimate hourly weather values based on the daily values provided. Weather data specific to the site provide the most accurate model simulations, but weather data are not always available for all locations. In such situations, weather data can be computer generated using information from nearby weather stations. A climate generator called CLIGEN (Nicks and Gander 1993 and 1994) has been adapted to provide weather data in the proper format needed to run SHAW for many locations throughout the world.

Model Testing

To test how well the model predicts soil water and temperature conditions under different rangeland vegetation and soil conditions, model-predicted values were compared to measured values taken in the field (Pierson et al. 1992). Measurements of soil water and temperature conditions were taken at several depths in the soil within three different rangeland plant communities. One site was a sagebrush *(Artemisia tridentata tridentata)*–grass plant community, where measurements were taken directly under the shrubs and in the bare-soil interspaces between shrubs. The other two sites were shortgrass prairie plant communities dominated by blue grama grass *(Bouteloua gracilis)*, a sod-forming grass, and a stand of seeded crested wheatgrass *(Agropyron cristatum)*, a bunchgrass. The two sites were close to one another but differed in soil characteristics and elevation. Measurements of soil water and temperature were collected directly under the sodgrass and bunchgrass plants and in the bare-soil interspaces between the grass plants.

At the sagebrush site, SHAW predicted hourly soil temperatures at a depth of 1 cm during the spring growth period with average errors of only 4 °F (2.2 °C) for sagebrush locations and 5.8 °F (3.2 °C) for interspace locations. The model performed well throughout the year except for the hot summer months, when it consistently underestimated soil temperatures near the soil surface. SHAW did not simulate soil moisture conditions as well as it did soil temperature. It predicted soil moisture adequately under the sagebrush canopy but predicted drydown too early in the interspace locations.

On the shortgrass prairie sites, SHAW simulated 1-cm and 2-inch (5-cm) soil temperatures quite well under all conditions. For bare soil conditions, SHAW consistently underestimated soil temperatures during the hot summer months at the 1-cm depth but was much closer at the 5-cm depth. SHAW slightly overestimated soil temperatures during the cooler months, particularly at the 5-cm depth. SHAW predicted periods of wetness very well at both the 1-cm and 5-cm depths but predicted too rapid a dry-down period compared to measured values. Both measured and predicted soil temperature and moisture responses under the sodgrass were similar to those for the bare soil condition.

Under bunchgrass, SHAW simulated 1-cm and 5-cm soil temperatures better than it did under bare-soil conditions. The seasonal problem of underestimating summer soil temperatures exhibited for the bare soil was much less evident. For certain conditions throughout the year, SHAW seemed to overpredict temperatures at both the 1-cm and 5-cm depths, but the errors were generally small. SHAW simulated soil moisture conditions significantly better under the bunchgrass than under bare-soil conditions at both tested depths. Rather than predicting dryness too quickly as SHAW did for the bare soil, the model generally overpredicted the length of the wet periods at both depths.

Testing the SHAW model has shown that it is quite capable of simulating small-scale variations in soil temperature and moisture conditions induced by vegetation. The model performed particularly well under the sagebrush and bunchgrass conditions compared to bare-soil conditions, indicating SHAW's strength at simulating the insulating effect of the plant canopy and the evapotranspiration process.

Model Applications

The ability to simulate the soil water and temperature regimes of the top inch or so of the soil profile will significantly enhance the simulation of grasshopper growth dynamics and the development of management strategies. Simulated soil temperatures can be used to drive other models, such as the grasshopper hatch model developed as part of the GHIPM Project (see IV.2, "Grasshopper Egg Development: the Role of Temperature in Predicting Egg Hatch"). Together these models can be used to develop regional and geographic information systems data bases of the expected time of occurrence of various stages of grasshopper development.

SHAW-simulated soil temperatures were used to drive the grasshopper hatch model and predict grasshopper hatch dynamics at a site near Three Forks, MT. The results were compared against predictions of hatch based on measured soil temperatures and actual field measurements of grasshopper hatch (fig. V.9–1). Early in the season, predictions of grasshopper hatch based on SHAW soil temperatures were very close to those for measured soil temperatures, but both slightly overpredicted the proportion of grasshoppers hatched compared to measured populations. The timing of 50-percent hatch was predicted quite well based on both SHAW-simulated and measured soil temperatures. Later in the season, the hatch model slightly underestimated the proportion of grasshoppers hatched, particularly based on SHAW-simulated soil temperatures. Overall, the grasshopper hatch model performed very well and lost little accuracy when SHAW-simulated soil temperatures were substituted for measured values.

This type of modeling approach can also be used with historical climate information to explore management questions such as how the timing of grasshopper hatch might vary from year to year for different grasshopper species. The SHAW model was used to simulate annual near-surface soil temperatures within a sagebrush–grass plant community for a period of 100 years using simulated climate information. The model output was then used to determine the probability of occurrence of specific temperature conditions that might be associated with the timing of grasshopper hatch. For the purposes of this example, grasshoppers were assumed to hatch when the eggs had accumulated 300 growing degree-days (GDD).

Figure V.9–2 shows the frequency of occurrence of 300 GDD under both sagebrush shrubs and the interspace locations between shrubs. Notice that the distribution of possible hatch times for the entire site covers about 5 weeks (Julian date 124–161) and that there is no overlap of distributions between the two locations. The frequency distribution for the interspace location is only 1 week in length, indicating that there is a very high probability that grasshopper eggs within the interspace locations will hatch every year within 3 days of Julian day 126.

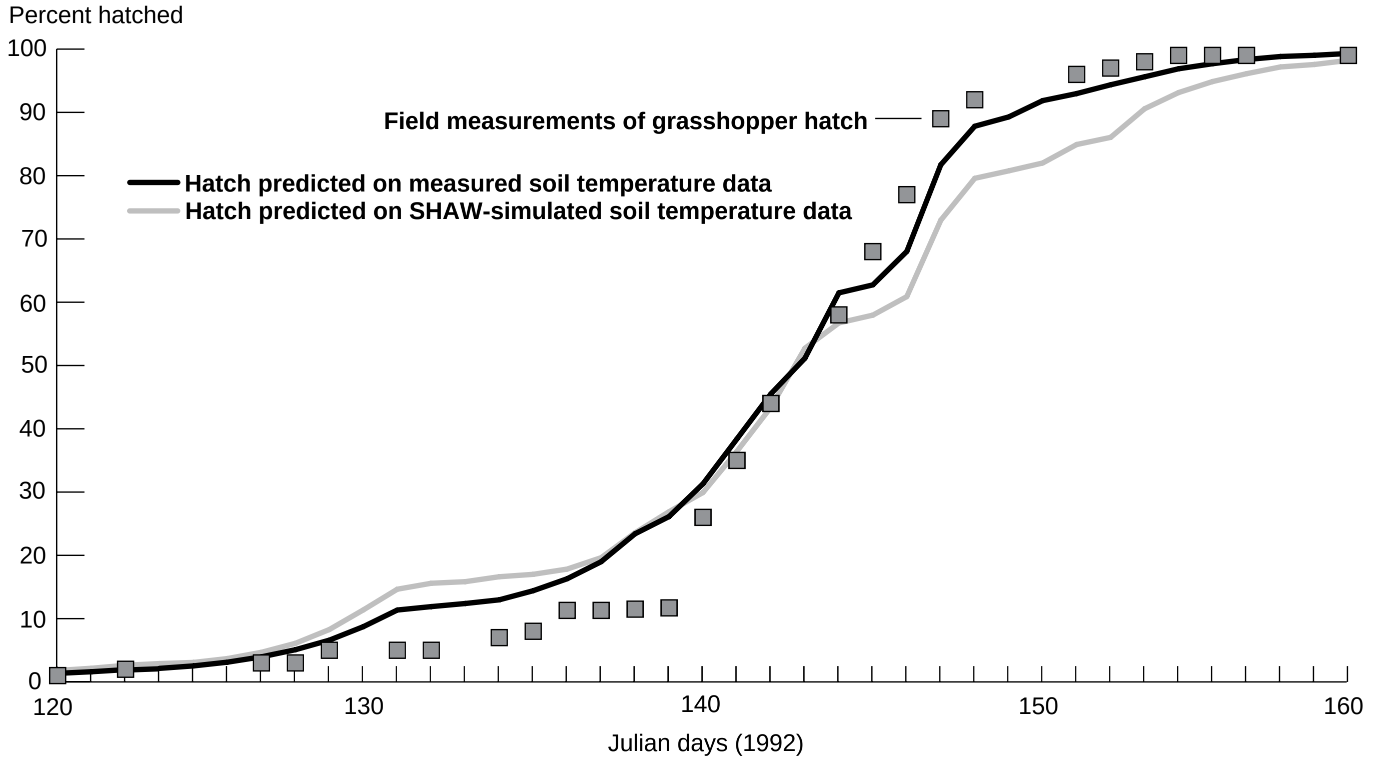

Figure V.9–1—Comparison of measured and predicted proportions of the population of *Aulocara elliotti* grasshoppers hatched for each day during the spring of 1992 near Three Forks, MT.

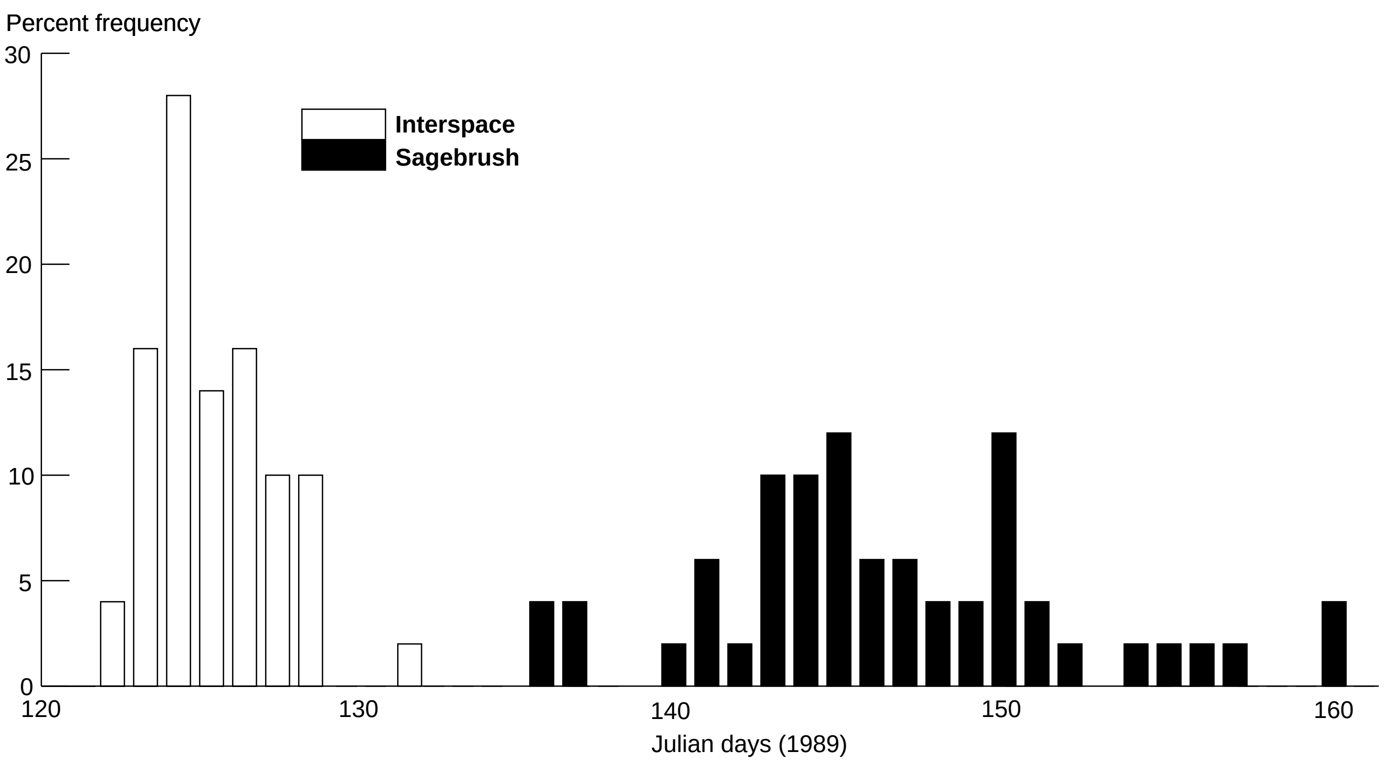

Figure V.9–2—Percent frequency of the timing of the accumulation of 300 degree-days of heat under sagebrush plants and the interspace locations between sagebrush plants at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID (Wight et al. 1992).

So what does this information mean to grasshopper management? If grasshoppers lay their egg pods at random across the landscape, then the variation in hatch time across the site could be as much as 5 weeks. This variation would result in a very mixed-aged population of grasshoppers. However, research has shown that certain species of grasshoppers do not lay their eggs at random across the landscape but selectively choose specific sites (such as directly under a shrub or in full sunlight between shrubs). Thus, the model results can tell managers when to look for hatch to begin for different grasshopper species. For example, if grasshopper species "X" lays its eggs under shrubs and grasshopper species "Y" lays its eggs in the interspaces, then the entire population of grasshopper X will always hatch before grasshopper Y begins to hatch. This kind of information can be useful for improving resource planning and enhancing the efficiency of grasshopper control applications.

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