DYMEX v2

Plant Modeling Tutorial

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An Overview of DYMEX

DYMEX Uses

DYMEX is a computer package which enables interactive modelling of fluctuating populations of organisms in changing environments. The program provides the user with almost unlimited flexibility when building a model because the choice of the model's variables, functions and parameters, as well as its applications are made by the user who determines the level of complexity required. Similar flexibility is available when running the model applications because parameter values of the model can be altered within user-set boundaries in order to manipulate the model behaviour. Model refinement is therefore an iterative procedure.

It should be understood at the outset that DYMEX's applications are not limited to plants. DYMEX can be used to model the population dynamics of any species, and can be used to describe the environments in which organisms exist.

DYMEX works by creating files which describe the processes that determine population change, using icons and dialogue boxes under Windows, to enable the users to by pass the need to create the computer code themselves.

The DYMEX Package

Two separate programs are contained within the DYMEX package but the operation of each is complementary to the other. The DYMEX 'Model Builder' is used to build the model, while the 'Simulator' is used to run the model over a series of time steps. The actual population model is a file which always has the ending 'gmd'. A gmd-file is an ASCII text file which can be opened and read by any suitable text-editor. A user can by-pass the Model Builder and produce a 'gmd' file using a text-editor, however this requires considerable pre-knowledge of model building in the Model Builder (together with the file format for the Simulator), and it would be an extremely cumbersome and difficult process for most users. The Model Builder was designed to allow the user to build and alter a model's gmd-file with far less effort. Model gmd-files are rarely (if ever) edited by most users.

The Model Builder and its Modules

When DYMEX's Model Builder is used to build a model file to describe a population's behaviour, it uses a procedure which employs predetermined units called modules. The modules may be thought of as 'building blocks' where each block has a set shape which can be joined with other blocks to build a structure. Some building blocks can be used in a number of ways, while others have a single purpose. The module concept differs from the building block concept in that the DYMEX modules can not only be joined in different ways, they can also pass information about the structure between each other. Like the building blocks, some DYMEX modules can be used for a number of purposes, while others have a single operation. ‘Timer, Lifecycle, QueryUser, Evaporation, Meteorological Database and Event’ are some of the available modules in DYMEX.

The name of each DYMEX module suggests its purpose. For example, Timer runs the time counts for the model; Lifecycle models the organism’s life cycle; QueryUser allows the user to set outside parameters, functions or other data; Evaporation calculates the rate of evaporation from a surface when given inputs from climatic data and time; Meteorological Database reads and processes information from a meteorological file; and finally, Event allows the user to introduce an important incident into the model such as spraying or fire.

Building a Model

Before starting to build a model all aspects of the species to be modelled should be considered together with the desired information outputs from the model. Some information about the organism’s lifecycle may be unknown and estimates will then have to be used when choosing values for parameters which determine how the organism reproduces, matures or reacts to events. Familiarity with the module concept in DYMEX is of critical importance. If the user has limited understanding of the species’ ecology, models may be expected to be equally limited in how well they simulate the actual changes in a species’ abundance.

It is also important to know that a DYMEX model need not contain an organism. Although of limited use, models can be built which process only climatic or other similar variables. When these are run over a time period with access to a meteorological database, a variety of outputs can be produced including values for soil moisture, humidity, etc. which can be graphed or tabulated to provide information about the climatic conditions under which the organism’s population is existing.

When building a model using DYMEX, it is recommended that initially the model contain only two modules, the Timer and the Lifecycle. Lifecycle modules can simulate almost any aspect of species life by setting up units within the Lifecycle module called ‘Lifestages’. Each Lifestage represents one part of the life cycle. For example, a tree-fern might have 6 lifestages of sporangium, spores, prothallus, juvenile sporophyte, mature sporophyte and sori, if such a level of realism was required. However if the user was interested in a pathogen which attacked only the mature sporophyte, a Lifecycle module might contain fewer lifestages which combined some of the total number of stages: spores, prothallus and mature sporophyte; the number (and types) of lifestages depends purely on user requirements.

Once the number of lifestages in the Lifecycle module is decided, several aspects must be considered: when and under what circumstances does the species develop; what are the conditions under which the species passes from one lifestage to the next; how is mortality to be modelled for each lifestage; what are the effects of climate; how and when does the species reproduce; what information is required from each lifestage ? The list is bounded only by the degree of realism desired by the user and the time that can be allocated to the model's construction.

The complexity of information required by the Lifecycle module frequently requires additional modules to be selected in order adequately to form reliable inputs to the Lifecycle module. For example, in order to model the effects of dryness on mortality of a species, DYMEX modules which refer to latitude (which in turn determines solar radiation intensity), rainfall and evaporation have to be linked to the function within the lifecycle which determines the final mortality rate. In many ways, the Lifecycle module can be thought of as the core of the model with peripheral modules acting as driving variables. The Timer module keeps the whole system in step with annual climatic data input.

The Simulator

The Simulator is the vehicle which takes the model created using the Model Builder and implements it. The RUN command starts the simulation, using default parameter values established while building the model, unless new values are set prior to the run. The Simulator controls the nature of the presentation of the results.

Depending upon how a model has been built, the Simulator can provide graphical and tabular outputs of the model variables over a period of time. A particularly useful aspect of the DYMEX model is that it can provide predictions for total populations in any lifestage of the organism being studied. With these, the user has additional information to assist in determining the best strategies to control a pest population. Provided the user has built this aspect into the model, the Simulator is able to adjust model parameters within pre-set limits and the user is thereby able to run the model for different settings of its parameter values.

If an Event module (such as spraying/burning/ploughing etc.) has been built into the model, DYMEX offers another option in the form of a 'Run Sequence'. Here, the Simulator can be instructed to run the model successively over a single time period and step the event at a pre-set regular interval through that period. For example, suppose the period was a year and the regular interval was a week. The Simulator would then process 52 runs over the year's time period and in each the event would be placed one week further into the year. Using such a sequence the user can determine from graphical or tabular outputs where the event caused most destruction to the weed population.

1.0 An Introduction to Plant Modelling with DYMEX

Important

This tutorial set assumes that the user has no previous knowledge of the DYMEX package. It is designed to be followed sequentially. Do not skip any section as vital information will be missed. The assumption is also made that the user's computer platform is 'Windows95'.

1.1 The DYMEX Programs

DYMEX comes in two parts: the **Model Builder** and the **Simulator**. The Model Builder is used to build a model, while the Simulator applies the model's set of functions and parameters and simulates possible outcomes. This introduction will discuss the procedures involved in assembling such a model. DYMEX models can be extremely complex, however this introductory tutorial uses a greatly simplified hypothetical species so that the resulting model is reduced to the absolute minimum. This illustrates the basic procedures involved in operating DYMEX, and also shows how additional functionality can be added to this simple model in order to increase its realism. The complexity of any model created using the DYMEX Model Builder is determined by the user within the bounds of the Model Builder. The model's accuracy and reliability are measured by how well the model represents the real system. *Always remember that DYMEX is modelling a population, not an individual organism.*

1.2 Modelling A Hypothetical Annual Plant

1.2.1 'Gen-weed'

The characteristics of the hypothetical species used in this tutorial were suggested by a flowering annual herb and for convenience, the species is referred to as 'Gen-weed' (generic weed) in all subsequent tutorials. At first, Gen-weed will be described as a very simple organism, however as the tutorial set progresses, its characteristics will be made more complex.

> Gen-weed exists as either seeds or adult plants. All seeds germinate to become adult plants after a dormancy interval of 40 weeks following their dispersal by the parent plant. The adults flower once per year and produce a single batch of 15 seeds at the start of the twelfth week. Adult plants have a life-span of 14 weeks. For this initial tutorial, no lifestage of Gen-weed is affected by temperature. It is assumed that soil nutrients and water are always sufficient for growth of the plant and that there are no predators/pathogens on either lifestage.

1.2.2 Model Attributes

Even with such a ‘simple’ life cycle, there are a number of attributes which need to be described in DYMEX. From the description of the life cycle, a DYMEX model will have to include the following:

The number of life cycle stages;
The type of each life cycle stage (eg. seed, adult);
The length of time an average individual spends in each life cycle stage;
Conditions which affect the organism's transformation from one stage to another;
The timing of reproduction;
The number of potential offspring;
The pattern of production of offspring (eg batches, continuous, etc.);
Mortality and when and how it occurs; and finally
Output of results from the model.

Throughout the following tutorial, the user should refer to this list as the model is developed.

1.3 Using DYMEX to Build the Model

1.3.1 Starting

Either open the ‘Start’ menu and select ‘Model Builder’ or if it is on the desktop, select the Model Builder icon (as shown here) in order to open the Model Builder program. From this point, keystrokes will be given as complete sequences after either explanations or discussions. (If the computer platform is ‘Windows 3.1’, a DYMEX folder will be present on the desktop which can be opened; the icon as illustrated here will be found in the folder and can be selected in the usual way.)

The main DYMEX window contains a blank screen and a menu bar containing various options. The following procedure allows the user to produce a new model.

1. From the menu bar, select **‘File’** to produce a drop-down menu;
2. Select **‘New Model’** from the drop down menu.

Once this selection is made, the **‘Model Details’** window appears (figure 1.1). This window allows the user to insert details about the model and it should always be at least partially completed at this stage. The name of the new model, the name of the builder and the version number should be inserted; details on the model's construction can be added immediately or added later as the model is developed. The **'Model Details'** window appears automatically when a new file is created or a previously saved file is opened, however the user can always open the **'Model Details'** window by selecting '**Model'** from the main menu bar and then **'Details'** from the drop-down menu. If the user decides not to enter any details at this stage, then the **'OK'** button is selected from the window and the Model Window appears. The only difference will be that no information is provided to any future users of the model.

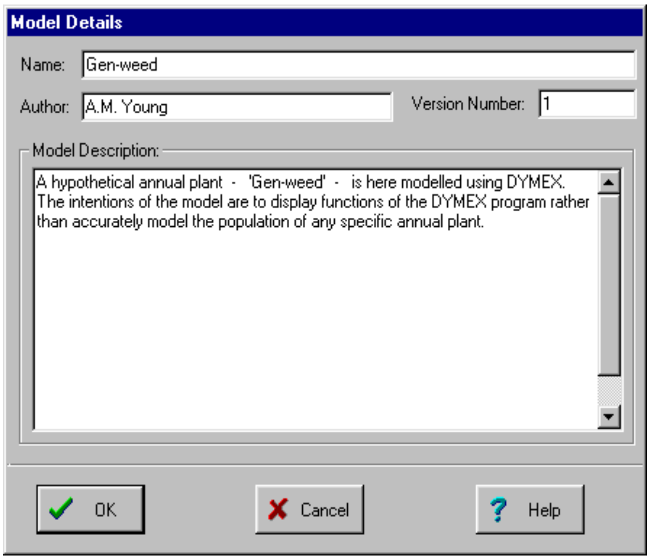


Figure 1.1 Model Details Window

3. Enter model details in the **'Model Details'** window and select **'OK'** on completion.

Once the above selection is made, the **'Model'** window appears (figure 1.2). Currently, it will have no name other than the default 'Document1' because it has not yet been saved under any specific model name. The **'Model'** window lists the modules used in the model currently under construction. Since all models *must* have a **'Timer'** module, this module is already present by default.

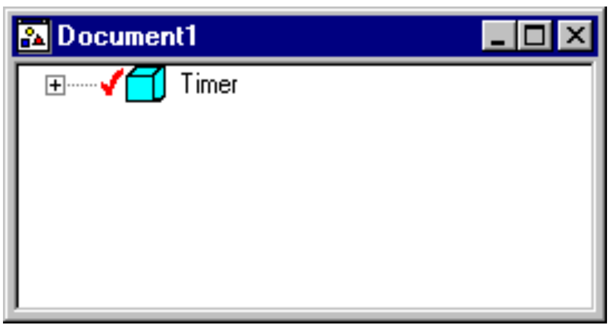


Figure 1.2 The DYMEX Model Window

The blue cube icon indicates that the line of information represents a module in the model while the red tick shows that the module already contains sufficient information to allow a model to be run, although it may be altered by the user if variations on time step or start date are required. At the start of the line is a small 'plus' button. If this is selected, the module can be opened as a tree diagram to display its components (figure 1.3). If the final text components of the tree diagram are "double clicked', their relevant windows can be opened for data insertion. The **'Timer'** module can also be opened if the module name is 'double clicked' with the mouse and the module's functions, variables and parameters are then available for editing.

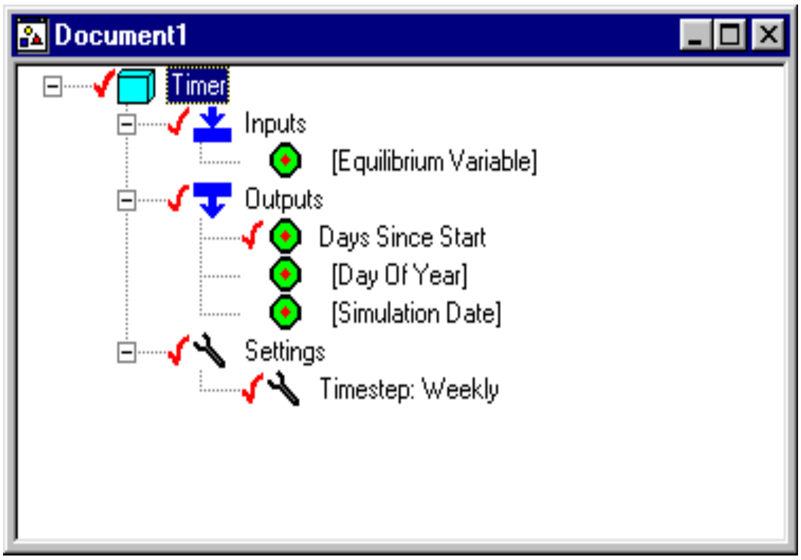


Figure 1.3 Timer module with 'Component Tree' opened

1.3.2 Building the Model

The Timer module is already in place, however it must be instructed to operate in weekly steps. A weekly interval step is essential for Gen-weed: as an annual as it will flower only once per year and therefore 52 steps are required for each generation to complete. DYMEX will operate using either daily or weekly time steps as required: if a daily step was used for Gen-weed, the program would still run but would require longer times to process the model.

1. 'Double click' on the **'Timer'** text in the **'Model'** window to open the **'Timer'** dialogue box;

The 'Timer' module cannot be given any user defined name and this is indicated by the fact that its module name is 'greyed out' .

2. Select the **'Settings'** button to obtain the **'Timer'** selection box and then examine the **'Model Timestep'** panel;
3. Change the timestep from **'1 day'** to **'7 days'**;
4. Select **OK'** and return to the **'Timer'** dialogue box;

5. Select the **'Outputs'** button to open the **'Outputs Timer'** selection box;
6. In a list box, **'Days Since Start'** should be highlighted in blue - if it isn't, place the cursor on this choice and click once - it should then appear highlighted;
7. Click once on the **'Select'** button - the symbol **' +> '** will appear in front of the text of **'Days Since Start'**;
8. Select **'OK'** and return to the **'Timer'** window;
9. Select **'OK'** and return to the **'Model'** window.

Users may query the use of 'Days Since Start' rather than a choice such as 'Weeks Since Start'. DYMEX automatically increments the 'Days Since Start' choice in 7 day steps when it processes a simulation run or produces an output.

Once back in the **'Model'** window, open the **'Timer'** module tree. If all steps have been completed correctly, there should be red ticks now present in front of **'Days Since Start'** and **'Timestep: Weekly'** and the tree should be identical to the diagram of figure 1.3 . Small icons denote the function of each of the parts of a module.

The next requirement is a Lifecycle module.

1. From the menu bar, select '**Model**';
2. From the drop-down menu, select **'Add Module'**;
3. From the **'Create Module of Type ?'** dialogue box, select **'Lifecycle'**;
4. Select **'OK'**;

The **'Lifecycle'** window will now be opened automatically with a **'Lifestage'** panel displayed (figure 1.4). If the **'Model'** and **'Lifestage'** windows are kept open but minimised, the user can move back and forth between them using the standard Windows95 method of clicking on the exposed part of the window required. If the two windows are set to maximised, the required window can be obtained by using the menu bar command of **'Window'** followed by selection of the required window from the drop down menu.

Important: When a model is loaded in the Model Builder, the **'Model'** window is always loaded by default. To obtain the **'Lifecycle'** window from this situation, double click on the **'Lifecycle'** text. Once it is opened, the windows can be opened or changed as noted above. Any module in the **'Model'** window can be opened by double clicking on its text.

NOTE: ***To delete a module that has been accidentally created***, return to the 'Model' window and the unwanted module will be shown in the list of modules present. Click on the unwanted module so that it is highlighted. Next, select 'Model' from the main menu bar and obtain the drop-down menu; select 'Delete Module' and follow any required steps. When completed, the unwanted module will disappear from the listing. You can swap between the 'Lifecycle' and 'Model' windows by selecting 'Window' on the main menu bar and the selecting the required window from the drop-down menu.

1.3.3 Constructing the Lifecycle

The window now represents a life cycle and contains a **'Lifestage'** panel (Figure 1.4).

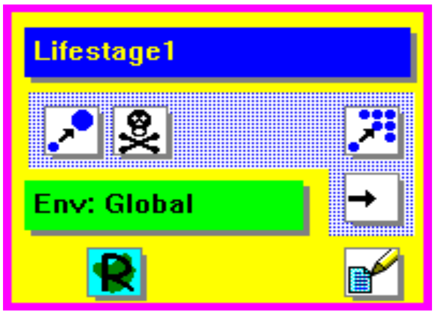


Figure 1.4 The Lifestage Panel

This panel represents one lifestage of the plant species being investigated. A number of environmental factors, (eg. temperature, moisture, predators, nutrient availability, diseases, etc.) influence the species' rate of development, survival and reproduction. DYMEX can be set to simulate these processes by using the button icons in the Lifestage panel, each of which controls some aspect of the lifestage. (The function of each button icon is described below.) When an organism's life cycle is being developed, the Model Builder always shows which lifestage is currently selected by outlining it in magenta.

Each lifestage panel defines a particular stage (eg. seed, juvenile, adult, etc.) together with its environment and attributes. The number of stages is set by the user. For Gen-weed, two stages are required (seed and adult plant), however several stages could be used depending upon the detail required by the model or the life cycle of the organism. Many plants may require a number of lifestages: for example, a model of an apple tree might include stages corresponding to seed, seedling, adult plant and fruit; however it is conceivable that a user may wish to condense two of these three stages into one for a particular model and might end up with the three stages of seed, adult plant and fruit. Exactly how the model is constructed depends completely on the requirements and applications of the user.

The lifestage can now be given a name. (The lifestage button marked 'Global' is only required for more complex simulations and can be ignored for this tutorial.)

1. Select the **'Lifestage1'** button on the **'Lifestage'** panel to open the **'Lifestage Name'** edit box;
2. Type **'Seed'** into the **'Name'** text entry box;
3. Exit from the edit box by selecting **'OK'**.

1.3.4 Lifestage Attribute Buttons

These buttons (located in the Lifestage panel) permit the user to open dialogue boxes in order to select variables or functions , name parameters and enter values for constants or variables. When entering variable names into edit boxes, always choose descriptive names that allow easy recognition of the variable's application in the model. The functions of each of the buttons are now described.

1.3.4.1 *Lifestage Outputs*

When opened with this button, the 'Lifestage Outputs' dialogue box allows the user to select which variables will be used as outputs from that lifestage when the model is simulated in the 'Simulator'. Outputs may be tabular, graphical or written to a file.

1.3.4.2 *Development*

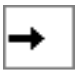
The 'Development' dialogue box is opened with this button. The user is allowed to select the functions and parameters controlling lifestage development and aging (i.e., the rate of accumulation of 'Chronological or Physiological Age').

1.3.4.3 *Mortality*

The 'Mortality' dialogue box is opened with this button. The user is allowed to select the functions and parameters controlling the lifestage mortality rate.

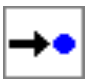
1.3.4.4 *User-defined Cohort Properties*

Within a model, certain cohort properties (such as chronological age, physiological age, fecundity, etc.) are pre-set. Situations can arise where the user needs to set new cohort properties for the particular organism being modelled: stress, plant size, sex ratio, etc. This button allows the user to define a set of functions which will control these properties. It **only** appears on the lifecyle icon after at least one new cohort property has been correctly defined.



1.3.4.5 *Next Stage*

The **'Next Stage'** button adds a further lifestage. Once it has completed this operation, it changes and becomes a **'Stage Transfer'** button (see below) and consequently, only the last lifestage in a lifecycle will still have an operational **'Next Stage'** button. To remove an unwanted lifestage, selecting its panel, followed by **'Lifestage'** from the Main Menu bar of the window, and finally select **'Delete Stage'** from the drop-down menu.



1.3.4.6 *Stage Transfer*

This button opens the 'Transfer Function' dialogue box in order to define/create or modify the transfer process which governs how an organism moves from one lifestage to the next. It is derived from the **'Next Stage'** button (see above).

1.3.4.7 *Reproduction*

The 'Reproduction' dialogue box is opened with this button. Two processes, 'fecundity' and 'progeny production' (as well as their associated parameters) can be selected by the user.

1.3.4.8 *Resource Variable Selection*

This button opens the 'Resource Variable Selection' list box which then allows the user to choose which variable will be used as the divisor by the program when it is calculating density.

1.3.5 Completing the Lifecycle

Since Gen-weed only occurs as seeds or adult plants, two life cycle stages are needed in the model.

1. Select the **'Next Stage'** button;
2. Name the new lifestage **'Adult Plant'**.

Reproduction for the Adult Plant is modelled next.

1. Select the **'Reproduction'** button;
2. In the **'Adult Plant Reproduction'** window use the **'Destination Stage'** panel's scroll button to find and select **'Seed'**;
3. Select **'OK'**.

A line ending in an arrow is now present which links the Adult Plant stage back to the Seed stage, and the whole structure should now resemble Figure 1.5. The arrows on the diagram define the direction of the flow of individuals within the life cycle.

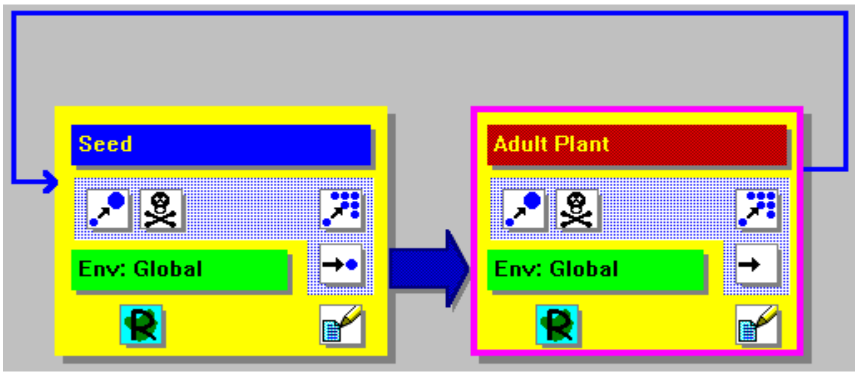


Figure 1.5 The completed life cycle structure for Gen-weed

Notice that the **'Next Stage'** button for the Seed lifestage has altered slightly so that it has an extra blue dot. This indicates that it is now a **'Stage Transfer'** button and is able to set the functional processes by which the Seeds reach the Adult Plant lifestage.

1.3.6 Setting Lifestage Processes, Functions and Parameters

Once the structure of the life cycle has been defined, the physiological and ecological processes that define conditions under which individuals develop, die, and reproduce need to be specified. The lifestage buttons are used to select and define these relationships. Because Gen-weed has such a simple life cycle, not all of the buttons and their operations are needed in this first tutorial.

1.3.7 Completing the Seed Stage

In this initial form of the Gen-weed model, seeds germinate after 40 weeks to become adult plants. Because of this simplicity, there are no requirements for development, reproduction or death, so the **'Development'**, **'Reproduction'** and **'Mortality'** buttons are ignored for this stage. The **'Lifestage Outputs'** button is required to produce output from the stage and the **'Stage Transfer'** button is used to set the conditions under which the seeds become adult plants. The extreme simplicity of the model means there are very few output variables to consider.

1. Select the **Lifestage Outputs'** button to obtain the **'Seed Outputs'** list box;
2. In the **'Seed Outputs'** list box, highlight **'Total Number'** then click on the **'Select'** button - once this is done, **'+>'** will appear beside the variable to indicate it is correctly selected;
3. Select **'Rename'** button and type in a suitable name (eg. 'Total Number of Seeds';
4. Select **'OK'** until back at the **'Lifecycle'** window.

The red tick that now appears on the 'Lifestage Outputs' button indicates that an output variable has been successfully selected for use by the model. **Always** give each variable a name that is easily recognisable and distinct from all others. Since each lifestage has the same default names for its output variables, they will be rejected by the Simulator unless the user inserts new names for each variable used in the model.

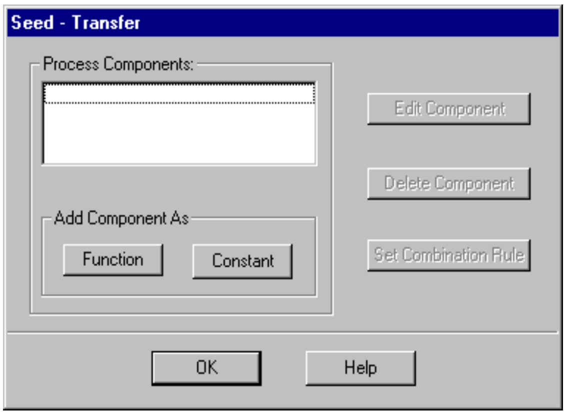


Figure 1.6 Seed - Transfer Selection Window

The **'Stage Transfer'** button is used to modify the process under which Gen-weed changes from seeds into the adult plant. When variables and functions for any 'rates of change' lifestage process are required , DYMEX uses a standard selection window (Figure 1.6) with five buttons: 'Function, Constant, Delete Component, Edit Component' and 'Combination Rule'. The last is used only when two or more Process Components are selected.

1. Select the **'Stage Transfer'** button.

The **'Seed - Transfer'** window (figure 1.6) is now used to select the functions and variables that define stage transfer. All seeds germinate to become adult plants 40 weeks after dispersal which implies the stage transfer variable is chronological age; since all seeds become adults simultaneously, a step function is indicated.

2. Select the **'Function'** button in the **'Add Component As'** panel to obtain the **'Function'** selection window (figure 1.7).

The **'Function'** selection window (figure 1.7) is used to set the stage transfer function and its associated variables. DYMEX uses this window as a standard throughout the Model Builder. Under the white screen is a scroll button which gives access to the library of mathematical functions contained in DYMEX. When a function is selected, its shape is illustrated on the screen. The **'Parameters'** button (in the row of buttons at the bottom) is used to set default and limiting values of the parameters for the function variables. A **'Comments'** edit box can be used to record pertinent information such as a reference to the source of the data used to estimate parameter values.

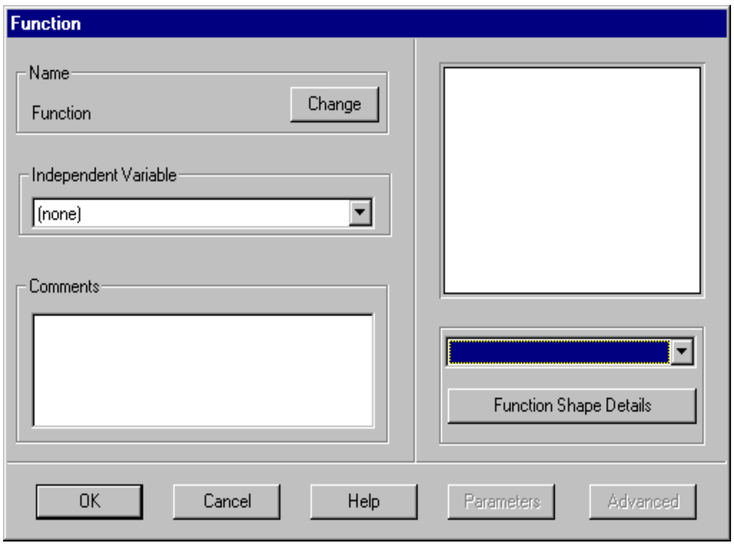


Figure 1.7 Function Selection Window

3. Using the function scroll button, select **'Step'**;
4. Using the **'Independent Variable'** list box, select **'Chronological Age'**.

*A **'Step'** function will now be illustrated in the screen and **'Chronological Age'** will have appeared in the **'Name'** panel's box. The **'Step'** function which defines the **'Seed to Adult Plant Stage Transfer'** requires two parameters: the chronological age at which the seeds germinate to become adult plants and the proportion of seeds which actually become adults during that time step. For the Gen-weed model, the two parameters are the width of the step (the chronological age) and the height of the step (the proportion of seeds becoming adult plants).*

5. Give the transfer function a suitable name by selecting the **'Change'** button (eg. 'Seed to Adult Plant transfer function');
6. Select **'OK'**;
7. Select **'Parameters'** button.

The **'Parameters'** button opens the **'Set Parameter Properties'** dialogue box (figure 1.8). The list box shows which parameters are required to be set and each is selected in turn.

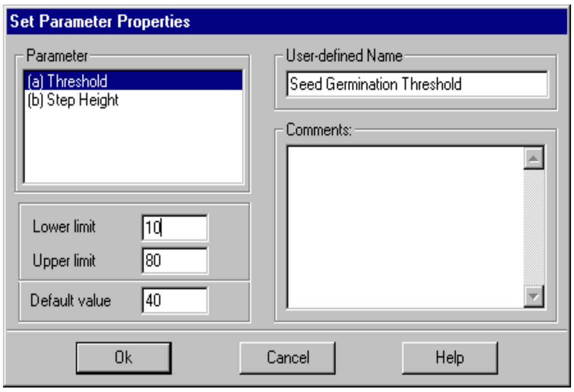


Figure 1.8 Set Parameter Properties Dialogue Box

The parameter values are entered in three edit boxes titled 'Lower limit, Upper limit' and 'Default value'. For Gen-weed, the default Threshold value is 40; the lower and upper limits define the range over which the parameter can be varied while the model is in DYMEX's Simulator. If no limits are set, the Threshold value of 40 weeks can be varied to any value; if upper and lower limits are both set equal to 10, the parameter cannot be varied at all. With different limits (eg 10 and 80), the Threshold value is restricted to that range. An edit box allows a user-defined name to be inserted for the parameter and this should always be done as otherwise the DYMEX Simulator will confuse parameters with the same names. A comment edit box is provided for explanatory remarks.

8. Ensure **'(a)Threshold'** is selected in the **'Parameter'** list box;
9. Select **'Lower limit'** edit box, type in the value 10;
10. Select **'Upper limit'** edit box, type in the value 80;
11. Select **'Default value'** edit box, type in the value 40;
12. Select **'User-defined Name'** edit box, amend **'Threshold'** to a suitable name (eg. 'Seed Germination Threshold');
13. Type in comments if required by selecting **'Comments';**

The second parameter to be set in the 'Set Parameter Properties' dialogue box is the proportion of seeds that become adults at the 40 week point. DYMEX uses a decimal fraction to indicate this proportion; a value of 1 indicates ***all*** seeds become adult plants and since the function is a step function, all seeds germinate to become adult plants simultaneously.

14. From the **'Parameter'** list box select **'(b) Step Height'**;
15. Select in turn each limit edit box and type in the value 1;
16. Select **'Default value'** edit box, type in the value 1;
17. Select **'User-defined Name'** edit box, delete **'Step Height'** and type in a suitable name (eg. 'Proportion of seeds germinating');
18. Type in comments if required by selecting **'Comments'**;
19. Select **'OK'** in the dialogue boxes as necessary and return to the life cycle window.
20. Save the model by selecting **'File'** on the main menu bar, followed by **'Save'** from the drop down menu. (*For this initial occasion, **'Save'** will also open a sub-window allowing the user to set the name and location of the model file. Once a model file's name and location have been set, **'Save'** automatically saves the model file using those settings on all future occasions and does not reopen the file naming window.*)

The **'Stage Transfer'** button will now have a red tick to indicate its parameters are set and this completes the settings for the Seed lifestage.

1.3.8 Completing the Adult Plant Lifestage

The simplicity of the present Gen-weed model means that the two buttons **'Development'** and **'Next Stage/Stage Transfer'** can be ignored for the Adult Plant lifestage: the former because the model uses chronological age (see 1.3.7, p.9) to transfer the seeds to the adult plant lifestage and the latter because all adult plants die, so there is no 'next lifestage'. Data output from the stage is obtained by selecting the **'Lifestage Outputs'** button. A red tick will appear on each button after the dialogue and edit boxes have been set correctly.

1. Select the **'Lifestage Outputs'** button to obtain the **'Adult Plant Outputs'** selection window;
2. In the **'Module Output Variables'** list box, highlight **'Total Number'** then click on the **'Select'** button;
3. Select the **'Rename'** button and type in suitable name (eg. 'Total Number of Adult Plants';
4. Select **'OK'** until back at the **'Lifecycle'** window.

Because all Gen-weed plants die at the end of the Adult Plant lifestage, the **'Mortality'** button parameters need to be set. There are two types of Mortality process: 'Continuous' and 'Establishment'. Continuous mortality operates throughout the lifestage, however certain species pass through life cycle stages where considerable mortality occurs when the organism tries to gain a 'foothold' in its new stage (eg. orchid seeds released for germination - perhaps two out of a hundred thousand released will find a suitable substrate and form a new plant). Organisms such as this will require an 'Establishment' Mortality process in addition to, or instead of, the 'Continuous' Mortality process. Gen-weed requires only the 'Continuous' process. Since the adult plants all die at the end of a fixed time period, their mortality inducing variable is chronological age which in turn is defined by a step function. The threshold value will be 15 and the constant value will be 1. (Note that the parameter values for each stage are determined by the length of the interval **within that stage**. Strictly, each Gen-weed individual is dying at the end of a 25 day life span when counting both seed and adult plant, however each plant dies at the end of 15 days *as an adult* and since only the Adult Plant lifestage is considered when setting ***its*** parameter values, 15 days is the correct value of the parameter.)

1. Select the **'Mortality'** button on the **'Adult Plant'** lifestage;
2. From the **'Adult Plant Mortality'** selection box, select the **'Continuous'** button;
3. In the **'Adult Plant - Continuous Mortality'** selection window, select **'Function'** to obtain the **'Function'** selection window;
4. Using the function scroll button, select **'Step'**;
5. Using the **'Independent Variable'** list box, select **'Chronological Age'**;
6. Select the **'Change'** button, suitably rename the function (eg. 'Adult Plant Continuous Mortality Function') and then select **'OK'**;
7. Select the **'Parameters'** button to obtain the **'Set Parameter Properties'** dialogue box;
8. Ensure **'(a)Threshold'** is selected in the **'Parameter'** list box;
9. Select the lower and upper limit edit boxes and type 14 in each;
10. Select **'Default value'** edit box, type in the value of 14;
11. Select **'User-defined Name'** edit box, delete 'Threshold' and type in a suitable name (eg. 'Adult Plant Cont. Mort. Threshold');
12. Type in comments if required by selecting **'Comments'**;
13. From the **'Parameter'** list box select **'(b) Step Height'**;
14. Select **'Default value'** edit box, type in the value of 1;
15. Select the lower and upper limit edit boxes and type 1 in each;
16. Select **'User-defined Name'** edit box, delete **'Step Height'** and type in a suitable name (eg. 'Proportion of adult plants dying');
17. Type in comments if required by selecting **'Comments'**;
18. Select **'OK'** as necessary to exit and return to the life cycle window.

Note again how a red tick will be displayed on the 'Mortality' button once the dialogue boxes are all closed, indicating that all functions and parameters are correctly set.

Reproductive parameters are set from the **'Reproduction'** dialogue box (figure 1.9) and its two components are **Fecundity** and **Progeny Production**. Fecundity is the total number of seeds that can possibly be produced by a plant. A value of 15 was chosen for Gen-weed. Fecundity will usually vary with environmental factors, but in this simplistic model, it does not occur.

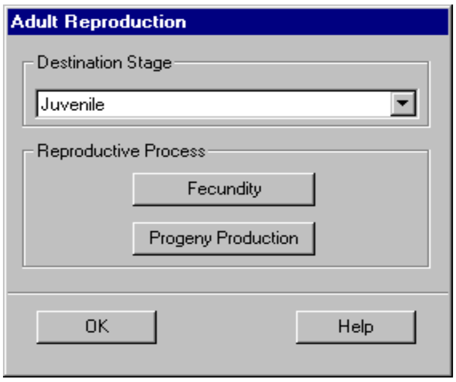


Figure 1.9 Reproduction Dialogue Box

'Progeny Production' defines the rate at which the seeds are produced. For example, some plant species produce all their seeds in a once only batch; others produce batches of offspring at regular/irregular intervals, while others may steadily increase production of seeds as the plant reaches full maturity and then decrease the production rate gradually to zero with senility.

1. In the **'Adult Plant'** lifestage, select the **'Reproduction'** button;
2. Select the **'Fecundity'** button to obtain the **'Adult Plant - Fecundity'** selection window;

The 'Fecundity' window has the standard format. Nothing in the Gen-weed model affects fecundity so it remains constant at 15, however different upper and lower limits have been suggested so that the user may alter the fecundity.

3. Select the **'Parameter'** button to obtain the **'Set Parameter Properties'** text entry window;
4. Select **'Lower limit'** edit box, type in the value 10;
5. Select **'Upper limit'** edit box, type in the value 80;
6. Select **'Default value'** edit box, type in the value 15;
7. Select **'User-defined Name'** edit box and type in a suitable a suitable name (eg. 'Adult Plant Seed Fecundity');
8. Select **'OK'** until the **'Adult Plant - Reproduction'** dialogue box is reached.

Since each Gen-weed plant produces a batch of 15 seeds on the 12th week, a step function is again indicated. The driving variable will be chronological age. For this step function, the threshold is the day seed production commences, the step height is the number of seeds produced per plant per day. Since there will be a single batch, the step height will equal the fecundity.

9. Select **'Progeny Production'** to obtain the **'Adult Plant - Progeny Production'** selection window;
10. Select **'Function'**;
11. Using the function scroll button, select **'Step'**;
12. Using the '**Independent Variable'** list box, select **'Chronological Age'**;

13. Select **'Change'** and rename the function suitably (eg. 'Seed production function');
14. Select **'Parameters'** button to obtain the 'Set Parameter Properties' dialogue box with **'(a)Threshold'** as default parameter;
15. Select **'Lower limit'** edit box, type in the value 8;
16. Select **'Upper limit'** edit box, type in the value 20;
17. Select **'Default value'** edit box, type in the value 12;
18. Select **'User-defined Name'** edit box, amend 'Threshold' to a more suitable name (eg. 'Seed Production Threshold');
19. Type in comments if required;
20. From the **'Parameter'** list box select **'(b) Step Height'**;
21. Set the limits to 10 and 80 and the default to 15;
22. Select **'User-defined Name'** edit box, delete **'Step Height'** and type in a suitable name (eg. 'Seeds produced per plant per week');
23. Type in comments if required;
24. Select **'OK'** as required and exit to the life cycle window;
25. Save the model.

Assuming all has been correctly done, there will now be 5 red ticks on the life cycle diagram; one each on the 'Lifestage Output' and 'Lifestage Transfer' buttons of the Seed lifestage, and one each on the 'Lifestage Output, Mortality' and 'Reproduction' buttons of the Adult Plant stage.

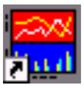
26. Select **'Window'** and then the file name to return to the **'Model'** window.

While in the **'Model'** window, it is worth seeing first how steps 1-5 have altered the model and second, examining the model by expanding its 'tree diagram'. Try clicking once on the **'+'** for the **'Lifecycle'** module; then try opening each **'+'** button as it is reached. Eventually, the ends of each branch will be the parameter values that have been set during the procedures just covered. The values can be edited from the **'Model'** window by double clicking on the terminal text values of the tree diagram; the values are then altered from the resulting windows.

****

This completes the formation of the Gen-weed initial model. The user may now wish to use the Simulator to examine the model immediately. Before exiting from the Model Builder, read the first paragraph of the Simulator tutorial.

1.5 Using DYMEX to Run the Model

1.5.1 Starting 

The DYMEX Simulator can be started from the desktop either by selecting its desktop icon, or from by opening the **'Start'** button for programs. If the user is using the Model Builder, DYMEX provides a short cut to the Simulator. After having saved the Gen-weed file, select **'File'** on the main menu bar and then select 'Run' from the drop down menu. Note however that this procedure does not ***close*** the Model Builder, so that it will remain in memory. This may be impractical if the computer in use does not have a large memory.

(**Note**: the sequence of sections 1.5.1-1.5.3 assumes the user has opened the Simulator from the Model Builder window. If the user opened the Simulator from the desk top, commence with section 1.5.3, then go back to 1.5.2 and then proceed through the rest of the tutorial as normal.)

The Simulator can provide the user with hints on operation and also has a button bar which allows a number of short cuts. The **'Hints'** dialogue box can be turned on or off during any operating session by selecting **'Preferences'** from the main menu bar followed by **'Show Hints'** in the drop down menu: a tick will appear beside **'Show Hints'** while the **'Hints'** dialogue box is present on the screen. The **'Hints'** dialogue box can be turned off permanently by setting the user preferences - see 1.5.2 below.

1.5.2 User Preferences

The 'Operating Preferences' selection box allows personal preferences to be set for the operating conditions of the Simulator. Until the user is more familiar with DYMEX, the default settings (figure 1.10) are likely to prove acceptable.

1. Select **'Preferences'** from the menu bar;
2. Select **'Operating'** from the drop-down menu;
3. In the **'Operating Preferences'** selection box check that the options are set to the defaults shown in figure 1.10;
4. Select **'OK'**.

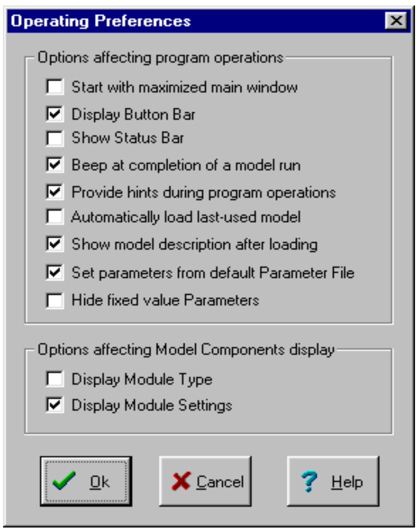


Figure 1.10 Operating Preferences Selection Box

1.5.3 Loading Files

Files are loaded into the DYMEX Simulator by using either the button bar or the menu bar. If the menu bar is used, DYMEX's ‘ready-use’ option allows selection of any of the last four files that have been run. All model files have the form ‘∗.gmd’.

To use the **button bar**:

1. Select  ;
2. From the **‘Open’** selection window, select the Gen-weed file;
3. Select **‘Open’**;
4. Select the **‘OK’** button on the **‘Model Description’** window.

To use the **menu bar**:

1. Select **‘File’** from the Menu bar;
2. From the drop-down menu select **‘Open’**;
3. From the **‘Open’** selection window, select the Gen-weed file;
4. Select **‘Open’**.
5. Select the **‘OK’** button on the **‘Model Description’** window.

DYMEX now loads and checks the model ‘gmd-file’ while creating other auxiliary files; respond **‘Yes’** when DYMEX requests permission to create any auxiliary files. Any problems found are reported as error messages. During the loading of the Gen-weed file for the first time, the Simulator will also report that a parameter file is missing and request permission to build it - the user should respond with **‘Yes’**.

While operating the Simulator, the user can alter parameter values within the ranges set by the default and limiting values that were incorporated into the model while it was being built in the Model Builder. The Simulator is prohibited from altering the master ‘gmd-file’ and so during the loading of a file, the program makes a working copy of the files' parameters, the ‘gmp-file’, which can then be altered as the user requires. The ‘ini-file’ is a record of the user's personal settings for the Simulator. Normally, neither the ‘gmp’ nor the ‘ini’ files require any direct user action, but it is useful to know that alterations to the working file in the Simulator do not mean that the original model values have been destroyed.

If at any time, the gmd-file is copied to another computer or placed in a different directory, it is useful to copy the ‘ini’ and ‘gmp’ files also. If they are not copied across, all user settings will have to be re-entered before the model will run in the new location.

From this point on, the tutorial assumes that the Gen-weed model has been correctly built and is loaded in the Simulator.

Once a model file is successfully loaded, the Simulator window changes: additional items appear on the main menu, more buttons on the button bar are activated, the Simulator status is shown on the bottom window bar, and the ‘Model Components’ window appears (Figure 1.11).

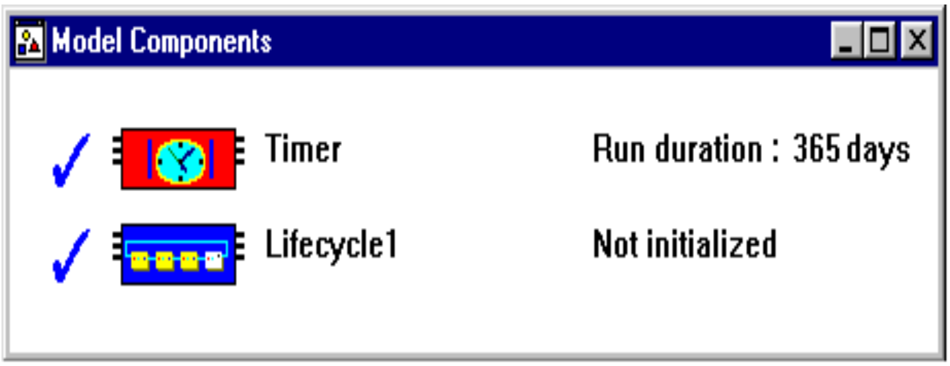


Figure 1.11 'Model Components' window before Timer has been set to the two years (730 days) run duration.

The 'Model Components' window (Figure 1.11) indicates that a model is loaded in the Simulator and lists the number and type of modules present. If a there is a tick beside a module, it indicates that the module will be accepted for processing by the Simulator although it may not produce particularly useful output. Figure 1.11 was produced by the Simulator after loading the Gen-weed model: it indicates that both the 'Timer' and 'Lifecycle' modules are correctly constructed. If no tick appears beside a module, it indicates that the module requires further information before the model will be accepted for processing by the Simulator. If any attempt is made to run the model, the Simulator will only report that the file requires initialisation. If the 'Close' button at the top right corner is selected, the model file will be closed and must be re-loaded if further work is required.

1.5.4 Module Initial Settings

Assuming all modules are shown as correctly constructed, initial parameter values will need to be entered or re-set for each module. There are two ways of selecting the initialisation dialogue boxes: either from the menu bar by selecting **'Initialisation'** or from the **'Model Components'** window. Each method opens the same series of dialogue and edit boxes.

Each module icon within the 'Model Components' window acts as a button to a dialogue box and module settings can then be made. Since an annual flowers once a year, two years is the minimum time required to examine the progress of the model.

1.5.4.1 Timer Module

1. Select the **'Timer'** module icon;
2. From the drop-down menu, select **'Initialise Module'** to open the **'Simulation Duration'** edit box (Figure 1.12);
3. Set the simulation run to 730 days;
4. Select **'OK'**.

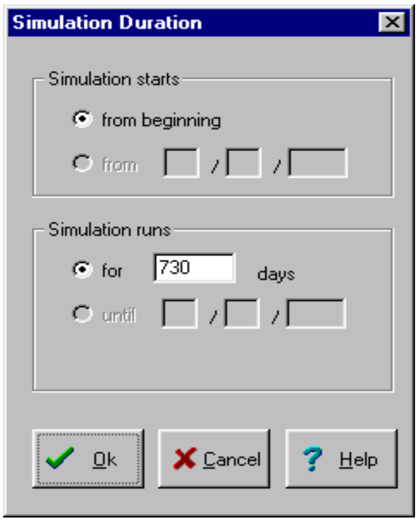


Figure 1.12 Simulation Duration Edit Box

1.5.4.2 Lifecycle Module

1. Select the **'Lifecycle'** module icon;
2. From the drop-down menu select **'Initialise Module'**;

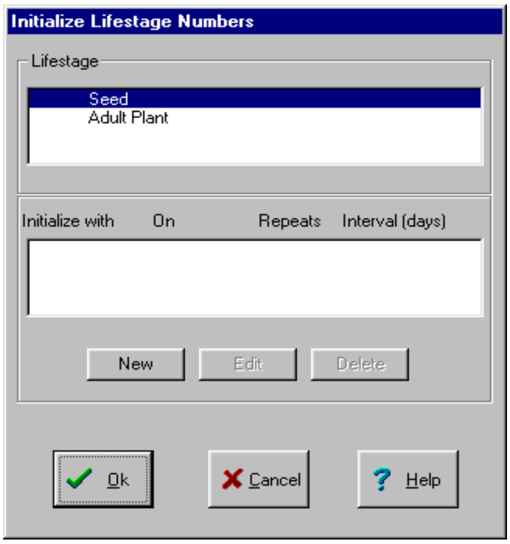


Figure 1.13 Initialise Lifestage Numbers Window

The 'Initialise Lifestage Numbers' window (figure 1.13) allows the user to set the initial number of individuals present in each lifestage. Inspection of figure 1.13 will show that the Seed stage is 'selected by default' and no initialisation settings are present. DYMEX will still run the Gen-weed model and produce cohort duration lengths, however it will not produce Gen-weed population results because there are no individuals within the model. This is the situation that was implied by the discussion on the previous page. So that DYMEX can produce a useful output, a single individual will be added to the Seed lifestage to start the population.

1. With **‘Seed’** highlighted in the **‘Lifestage’** list box, select the **‘New’** button in the **‘Initialize with’** panel to open the **‘Edit Lifestage Initialisation Set’** edit box;
2. Select the text entry area for **‘Add .... Individuals’**;
3. Type in the value 1;
4. Select **‘OK’**;

This returns the user to the ‘Initialise Lifestage Numbers’ window and if it has been correctly set, the list box will show that the Seed lifestage has been initialised with one individual at the start and there are to be no repeats.

5. Select **‘OK’**.

The current structure of the Gen-weed lifecycle can be shown using the ‘Lifecycle’ module icon.

1. Select **‘Lifecycle’** module icon;
2. From the drop-down menu select **‘Toggle Lifecycle Diagram’**;

A diagram will appear showing the lifecycle of the Gen-weed. Like the ‘Model Components’ window (Figure 2), the lifestages of the lifecycle can be used as button icons.

3. Select the **‘Seed’** lifestage icon;
4. Examine and then close the window;
5. Select the **‘Adult Plant’** lifestage icon;
6. Examine and then close the window;
7. Select **‘Lifecycle’** module icon;
8. From the drop-down menu select **‘Toggle Lifecycle Diagram’** to close the lifecycle structure window.

1.5.5 Running the Model 

DYMEX allows two methods of starting a model run using either of the menu or the button bars. From the menu bar, **‘Execution’** produces a drop-down menu containing **‘Run’**, or the **‘Run’** button (lightning flash) on the button bar produces the same result.

1. Select  from the button bar to produce the **‘Run Model’** selection window.

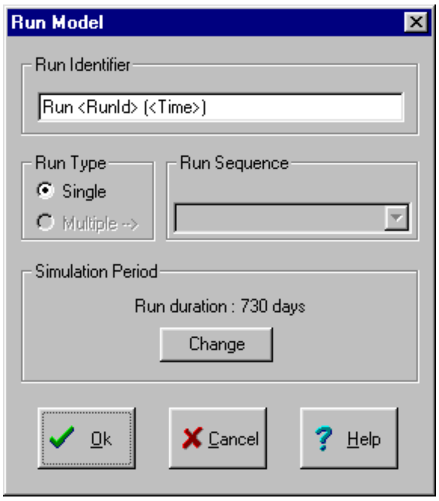


Figure 1.14 Run Model Dialogue Box

The 'Run Model' dialogue box (figure 1.14) allows the user to set the run conditions. Within the dialogue box, the 'Run Identifier' edit box allows the insertion of a suitable title for the run. The 'Run Model' dialogue box can be used to insert commands about the initialisation options used and the start date of the model, but these commands are not required for the Gen-weed model. Only a single run will be used for the Gen-weed and therefore the 'Run Type' and 'Run Sequence' edit boxes can be ignored. The 'Change' button permits alteration of the duration of the run time. For the Gen-weed it has a previously set value of 730 days.

1. Select **'OK'**;

The model will now run and a 'Running Model' window (figure 1.15) will appear briefly to indicate the progress of the Simulator.

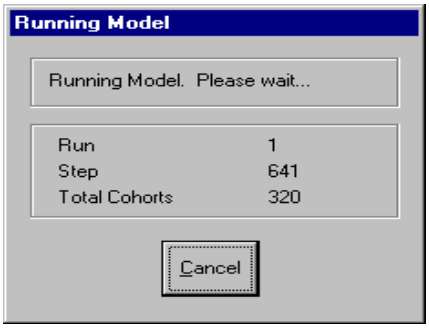


Figure 1.15 Running Model window

On completion, a 'Run' window will appear (figure 1.16) which summarises information on the run. For Gen-weed, this is very limited due to the simplicity of the model, however the 'Run' window summary becomes more complex in direct relation to the complexity of the model.

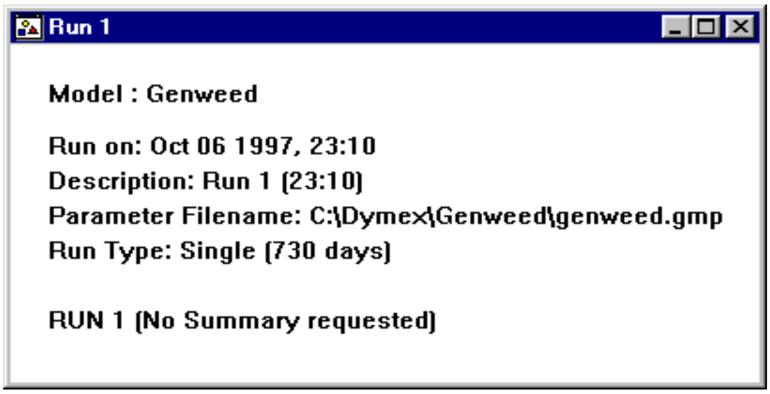


Figure 1.16 Run window

1.6 Producing Model Outputs

1.6.1 The Button Bar

On completion of a run, DYMEX outputs may be obtained using either the menu bar or the button bar. If the menu bar is used, select **'Results'** and then choose from the drop-down menu. The button bar offers the same processes with a single selection. Since a model has now been run, two more buttons on the button bar are activated:

 - Charts output button.

 - Tables output button.

These buttons allow the model output to be presented in either chart or tabular form respectively. They open a series of dialogue and edit boxes which permit selection of the variables to be presented and the user can define the format of the presentation.

1.6.2 Opening Table Displays

1. Select  button;

The **'Select Variables for Table'** dialogue box is now open (figure 1.17). For Gen-weed, four options are presented in the **'Available Variables'** list box. **'Step'** represents the time interval used in calculating the lifecycle and for the Gen-weed model this is measured in weeks. **'Days Since Start'** counts the number of days since the commencement of the run. The remaining variables were selected for the Gen-weed model during its building in the Model Builder. Any combination of the variables can be selected for presentation in the output.

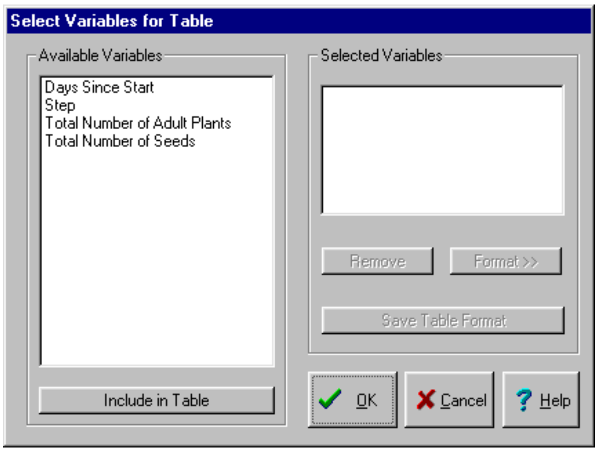


Figure 1.17 Select Variables for Table Dialogue Box

1. From the 'Available Variables' edit box, select **'Step'**;
2. Select **'Include in Table'** button;
3. Repeat steps 1 & 2 above for the remaining variables.

Variables can be removed from the **'Selected Variables'** list box by highlighting them and then selecting the **'Remove'** button. The procedure used above will select all variables for the output table.

DYMEX can format any selected variable. In figure 1.17 the Format button is greyed out, but with the selection of any of the available variables, the Format button becomes active and opens the **'Table Format'** window (figure 1.18) which allows the table's data to be displayed in any suitable format. Each column can be selected individually and its required format set. The format options include whether: numerical data will be displayed as integers or floating point decimals, the number of decimal places to be used if the floating point option is used, the width for each data column, and whether or not a data column should be shaded for emphasis. Once a table format is fully defined, it can be saved using the **'Save Table Format'** option in the **'Select Variables for Table'** selection box (figure 1.17). The **'Save Table Format'** option opens a standard dialogue box in which the name of the format can be entered for future use.

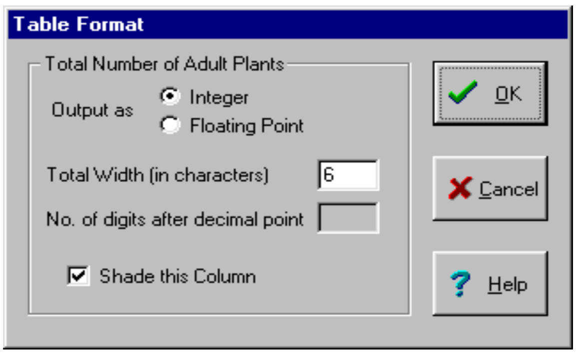


Figure 1.18 Table Format window

4. With **'Step'** highlighted, select the **'Format'** button and set the output to integers with the column width to 6 characters, then select **'OK'**;
5. Repeat step 4 for **'Days Since Start'**;
6. With **'Adult Plants'** highlighted, set its display to shaded format and then select **'OK'** to return to the **'Select Variables'** window;
7. Finally, select **'OK'** to produce the output table (figure 1.19).

When first opened, a scroll column is not displayed but it can be obtained by selecting the 'grey' area within the window beside the last column: scroll controls then appear. DYMEX constructs condensed headings for each of the columns of the table . The data can be printed in full by selecting the **'Print'** button on the button bar. Selected parts of the table can also be printed separately, by first marking the required area followed by **'Print Selection'** from a drop-down menu (see below).

Table-1 [Run 1]

Genweed
Generated: Wed Oct 08 22:04 1997
Parameter File: C:\Dymex\Genweed\genweed.gmp

Step	aysSincSt	ToNuofAdPl	TotNumofSee
1.00	1.00	0.00	1.00
2.00	8.00	0.00	1.00
3.00	15.00	0.00	1.00
4.00	22.00	0.00	1.00
5.00	29.00	0.00	1.00
6.00	36.00	0.00	1.00
7.00	43.00	0.00	1.00
8.00	50.00	0.00	1.00
9.00	57.00	0.00	1.00
10.00	64.00	0.00	1.00
11.00	71.00	0.00	1.00

Figure 1.19 Formatted output Table for Gen-weed (first 11 steps of 730 day run)

A **'Quick Graph'** procedure is available directly from the **'Tables'** display and it automatically uses the **'Step'** variable for the X-axis. To commence the 'Quick Graph' procedure, place the cursor in the data column for which a 'Quick Graph' is required and 'double click' the left mouse button. A drop-down menu is produced which permits three options: saving of the table data in a separate file, examination of the variable description and production of a 'Quick Graph'.

1. Place the cursor in the **'Step'** column and double click the left mouse button;
2. From the drop-down menu, select **'Variable description'**;
3. After inspecting the **'Details of Variable'** list box, select **'OK'**;

The **'Details of Variable'** list box summarises all the information about the particular variable of the selected column and the procedure is available for any column.

1. Select the **'Step'** column by double clicking;
2. From the drop-down menu, select **'Quick Graph'**;

The resulting graph is a straight line (Figure 1.20) which is to be expected as it is simply plotting 'Step' against 'Step'.

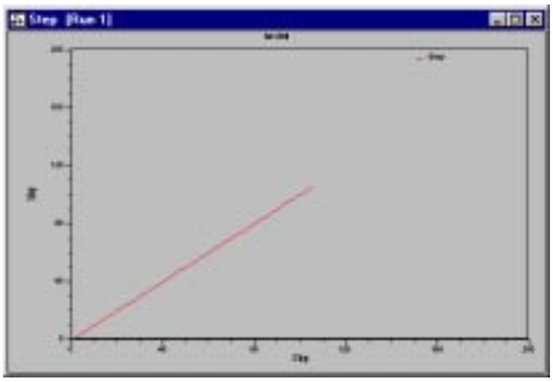


Figure 1.20 'Quick Graph' for 'Step' column

A similar procedure can be used for the other columns. (eg. figure 1.21).

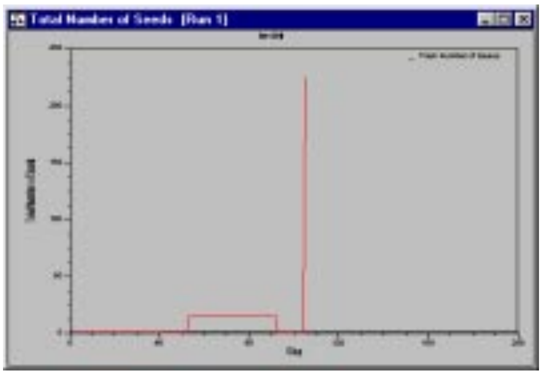


Figure 1.21 'Quick Graph' for Total Numbers of Seeds

The populations of Seeds and Adult Plants have essentially the same shaped graphs except that for each moment of time the sizes of the two populations will differ. The 'curve' is discontinuous and shows distinct 'gaps' where the seeds transfer to adult plants. The size of the gaps depends on the settings for the maturation period required for the seeds and the time of seed production. Over a longer period of time, the numbers show extremely rapid increase very clearly.

While in the table mode, an ‘area selection’ mode is also available. If the cursor is ‘clicked’ on a column, it immediately changes to a ‘cross’ shape. It can now be used to ‘mark/select’ an area of the table by the standard ‘Windows’ technique of holding the left mouse button down while dragging the cursor across the required area. When this is done the area is highlighted and the right hand mouse button can then be used to open a drop down menu while the cursor remains in the highlighted area .

The drop-down menu contains the following options which are explained here for use as required:

Copy Selection	Places a copy of the selected area into the clipboard. The copy can then be accessed by the usual ‘Paste’ command of the wordprocessor, spreadsheet or other program in use.
Selection Width	Selects column width. An alternative is the standard ‘Windows’ method of placing the cursor at the top of the column and altering the column width by moving the sides of the column.
Selection Format	The user is able to decide how the selected area will be displayed.
Print Selection	Sends the highlighted area to the printer. The dialogue box that appears, refers **strictly** to the highlighted area.
Scale of Printout	The user is able to decide on the scale of the printout.
Print Table	Prints the whole table.

This completes the introduction to the table displays and the user should now close the table by using the standard ‘Windows’ procedures:

1. Select **top right ‘Windows’ X-button of the Table and ‘click’ once**.

1.6.2 Opening Chart Displays

DYMEX provides two methods of presentation for chart outputs: the charts may be either separate or on a common X-axis and an exemplar display is presented by the window (figure 1.22). The default selection is ‘Common X-axis’.

1. Select the Chart button  to open the **‘Chart Type’** selection window (figure 1.22);
2. Select **‘OK’** to open the **‘Chart Specification’** window (figure 1.23)**.**

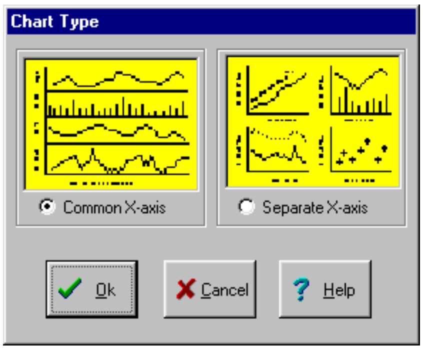


Figure 1.22 Chart Type selection window

The selection of either common or separate X-axes leads to the **'Chart Specification'** window (figure 1.23) which contains dialogue, list and edit boxes. This window determines which variables will be used for chart formation, the format of the charts including their axis labels, whether the output values will be natural or logarithmic and provides a save option for frequently used formats. With two output variables (total numbers of either Adult Plants or Seeds), either a single combined chart output could be used, or two separate output charts might be employed.

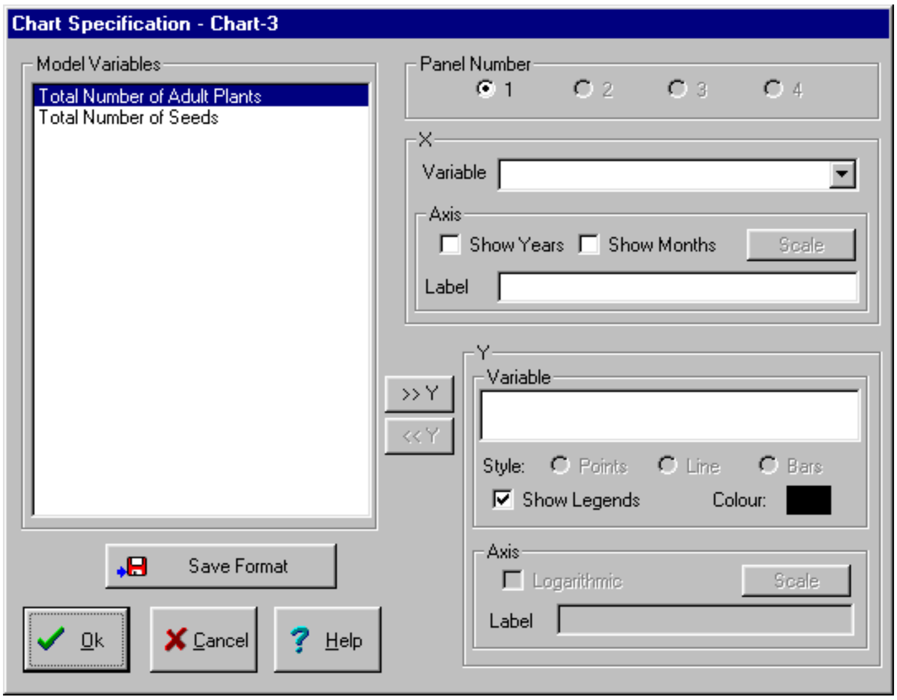


Figure 1.23 Chart Specification Window

Although for this initial display, a single chart with two panels on a common 'X'-axis was used, the option of completely separate charts might be considered where the values of the functions differ widely in magnitude. Insertion of user-defined axis labels should always be considered because in default, DYMEX supplies condensed versions of the Model Variable Names which are not always particularly suitable or easy to understand. The sequence of operations given below starts from the top of the right hand side of the window. With user familiarity, other methods of completing the window requirements will no doubt be suggested.

1. The **'Panel Number'** default is set to '1' and can be ignored for the moment.
2. From the **'X'** panel area select the scroll button of the **'Variable'** list box and select **'Step'**;

The user could now alter the name of the 'X'-axis variable by selecting the dialogue box named **'Label'** and inserting a suitable name, however **'Step'** will be present by default and is considered perfectly adequate. The Model Variable **'Total Number of Seeds'** will already be selected by default and in order to insert it into the graph, the user needs only select the transfer button.

3. Ensure **'Total Number of Seeds'** is highlighted and selected; (*if this has been done correctly -{place the cursor on the variable and click the left mouse button once}- a dotted frame appears around the selected variable and the **'Y-variable transfer button'** becomes active*);
4. Select the **'Y-variable transfer button'** 

;

After selection of this button, the **'Total Number of Seeds'** variable will appear in the **'Y-Variable'** text box, the **'Style'** buttons will become enabled and allow the user to select whether the graph will be a point, line or bar display and the colour will change automatically to red. (A second 'reverse' transfer button directly underneath the first transfer button will now be active and allow corrections if the wrong variable is transferred.) Simultaneously, the **'Axis Label'** text box will activate and display DYMEX's condensed name for the variable; in this case it will be 'TotaNumbofSeed'. If this is acceptable, it can be left; if it is not, the name should be edited.

5. Select the **'Axis Labels'** edit box; delete the current condensed name and insert **'Seed Totals'**;
6. Return to the top of the right hand side of the window and select the 'radio button' for **'2'** in the **'Panel Number'** area.

This will mean that two separate chart panels will be drawn on the same X-axis. If '1' is selected for the 'Number Panels' edit box, then ***both*** *the Seeds and Adult Plants graphs will be drawn in the same panel.*

7. Ensure that **'Total Number of Adult Plants'** is selected (*see the comments in step 3 above*) in the **'Model Variables'** list box;
8. **'Step'** is automatically selected by default in the **'X'-Variable** list box because both charts are being displayed on a common axis.
9. Select the **'Y-Variable transfer button'** to move **'Total Number of Adults'** into the **'Y-Variable'** list box.
10. Change the **'Y-Axis Label'** to **'Adult Plant Totals'**;
11. Select the **'Save Format'** button, save the display under a

suitable name and then return to the **Chart Specification** window;
12. Select **'OK'** and the chart will now be displayed. It should be similar to figure 1.24 .

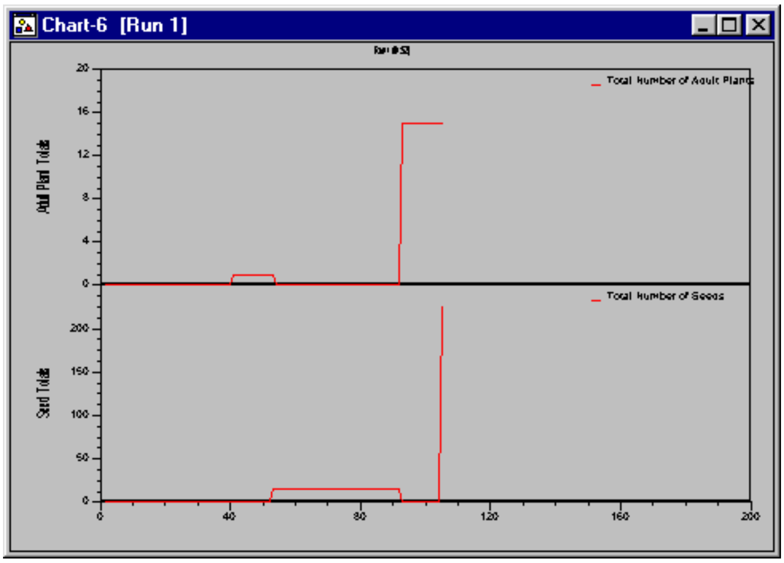


Figure 1.24 Gen-weed Chart Output

To place both curves on the one panel, return to the 'Model' window and re-select the charts button. From the 'Chart Type' dialogue box select 'Common X-axis' and then leave the number of panels set to '1' in the 'Chart Specifications' window. Select both variables and each will appear as a different colour in the common panel.

To produce completely separate panels, return to the 'Model' window and re-select the charts button. From the 'Chart Type' dialogue box, select 'Separate X-axes'; then proceed as before with the selection of the panel variables.

1.6.2.1 Saving and Deleting Chart Formats

The above procedures demonstrated the method of saving a chart format that may be frequently required (step 11). To delete a saved format, the user must have a chart displayed in the current window. The menu bar then has an option called **'Chart'**. If this is selected, a drop-dowm menu appears with the options of **Copy to Clipboard**, **Save Format** and **Delete Format**. The user now selects whichever option is required and follows the steps required by DYMEX. Note that this menu option means that the user can save a chart format from the **'Chart'** window as well as from the **'Chart Specifications'** window.

1.6.2.2 Saving Chart Formats to the Clipboard

The **'Chart'** menu bar option displayed while in chart display allows the user to copy the displayed chart to the system clipboard, from which it is then available to other programs that are currently running on the computer system. This is very useful for wordprocessing facilities.

1.6.3 Logarithmic Scaling

Without any controls, the current Gen-weed model's population increases exponentially. If the model is run for a period of 2500 days and the total number of plants is then charted using normal scaling, the resulting graph has little meaning as the numbers are so large that only the last years's population numbers are graphed. To overcome this, DYMEX contains logarithmic scaling.

1. Run the model for a period of 2500 days;
2. Open the **'Chart Specification'** window (figure 1.23) and select **'Total Number of Adult Plants'** for graph production;
3. From the **'Y-Axis'** region of the window select the **'Logarithmic'** button (it will then display a tick in its selection button);

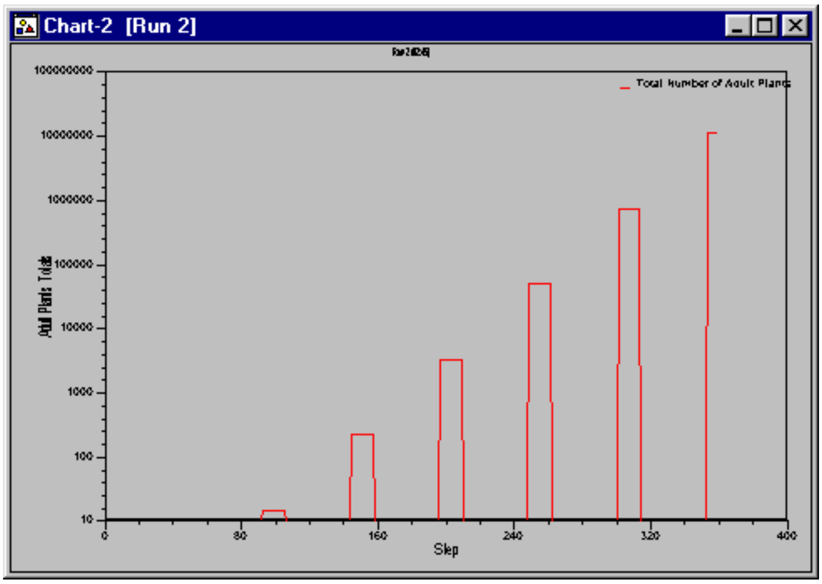


Figure 1.25 Yearly Populations of Gen-weed for a 2500 days period; logarithmic scaling.

4. Select the **'Scale'** button and ensure that the operation is set to Automatic then select **'OK'**;
5. Select the X-axis variable **'Step'**;
6. Select **'OK'** on the **'Chart Specification'** window and produce the logarithmic chart of the yearly plant populations. The result should resemble figure 1.25 .

All the Gen-weed charts show an uncontrolled increase in the population, especially if the model is run over several years. The model currently assumes that all seeds produced are viable and pass automatically to the adult stage. In the field this is not the case; temperature and rainfall both play a part in establishing germination rates. Ways of introducing these aspects will be the subject of the next tutorial.

1.7 Tutorial 1 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle

Timer

Set to 'Days since start'; timestep 7 days, run default 730 days.

Lifecycle

Initial numbers for run: 1 seed.

Seed

Transfer function
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Output: Total number

Adult Plant

Continuous mortality (step)
Independent variable: chronological age
Threshold: 14 weeks
Prop. adults dying: 1

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Driving variable: chronological age
Threshold: 12 weeks
Seeds/week step/adult: 15
Output: Total number

2.0 Seed Mortality

2.1 Introduction

The current Gen-weed model links mortality solely to chronological age: this is artificial but is adequate for the initial stages of model construction. Mortality in DYMEX may be either ‘continuous’ or ‘establishment’ and each can built into a lifestage and linked to any suitable user selected variable(s). The effects of ‘continuous mortality’ reduce an organism’s population over an interval of time and they are caused by any of the random environmental or genetic variables that influence the organism. Establishment mortality is restricted to the situation where an organism is trying to pass from one lifestage to another and occurs through special factors which apply to that process. Establishment mortality will not be used for Gen-weed in this tutorial.

During an annual’s reproductive cycle, the seed is at first dispersed into the environment to form what might be called a “seed bank”; losses of seeds from the ‘seed bank’ then occur through the operation of various environmental agents. Ants or other insects, small mammals and birds consume or remove quantities of seed steadily over time, while rotting due to fungal or bacterial pathogens will reduce the remaining seed bank still further. Depending upon the environment, as much as 80% of all seed produced will be lost each year. Eventually, seeds become discoloured or buried (and therefore difficult to find), extremely hard or unpalatable, etc. and so seed that has survived for some time has a better chance of surviving until diminished seed viability (“old age”) finally removes it from the “seed bank”. Despite the seed losses described above, the seed bank numbers are usually more or less constant within seasonal fluctuations and seed bank losses are generally well tolerated by the species as otherwise it becomes extinct.

The continuous seed mortality described above suggests that a suitable model would be one in which the seed death rate is constant. This produces a seed survival function that is exponential in form and is easily modelled in DYMEX using a constant function within seed mortality. The exponential curve fits very well with the idea that a seed’s chances of survival improve with time.

2.2 Alterations to the Model

The Gen-weed model will be changed to simulate seed mortality as follows:

The constant mortality rate will assume that from a batch of 5000 seeds produced, there will still be 1000 viable seeds remaining in 365 days (ie. 80% of all seeds produced will be dead by the end of one year).

2.3 The Continuous Mortality Model

The constant mortality rate is applied in a series of steps, each of which differs from the previous step by the value of the rate. For example, suppose the model starts with 100 seeds and the mortality rate is 0.1. After day 1, there will be 90 seeds remaining; after day 2, there will be 81 seeds left; after day 3, there will be 72.9 seeds left; and so on. Of course, fractional seeds are inapplicable to individual plants, however DYMEX is operating with populations and these mathematical fractions are therefore valid.

The Gen-weed model's mortality function assumes that 1000 seeds are still viable after 365 days from each batch of 5000 seeds produced. The resulting series produces an exponential decay curve for seed survival numbers and has an equation of the form:

$$\mathbf{y = Ae^{-kT}}$$

For this equation, 'y' is the number of seeds surviving after one year; 'A' is the starting number of seeds; 'T' is the time over which the function is to operate (in this case 365 days); and 'k' is the decay constant - for this model, it is the mortality constant that will be applied to each day's seed survivors. If these values are substituted into the equation, we have:

$$\mathbf{1000 = 5000\, e^{-k365}}$$

Dividing both sides by 5000 and then taking logarithms to both sides produces the result:

$$\mathbf{\ln 0.2 = -365k}$$

Which in turn produces the equation:

$$\mathbf{-365k = -1.609}$$

Therefore:

$$\mathbf{k = 0.00441}$$

If this mortality constant is run in a DYMEX model designed to show only the resulting numbers of seeds surviving, the results are as shown in figure 2.1

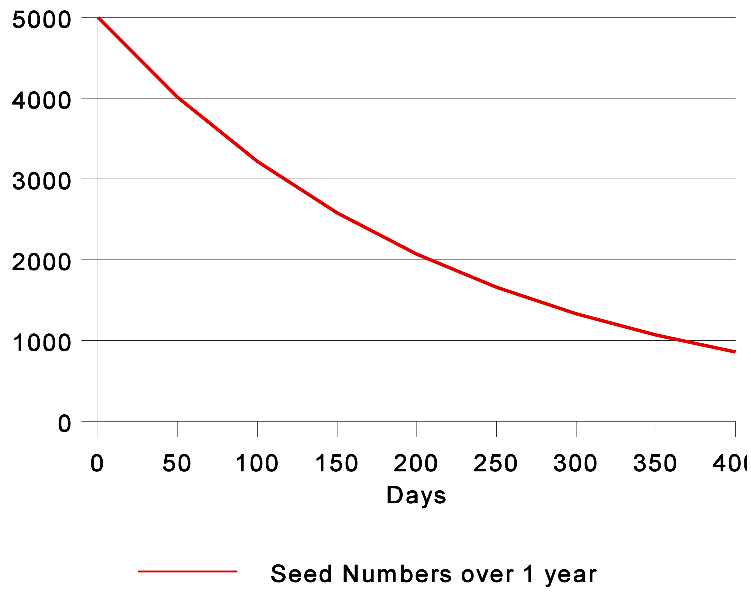


Figure 2.1 Seed Survival Curve under Constant Mortality Rate

2.3 Setting up the Model

1. Open the Model Builder and load the Gen-weed file;
2. Double click on **'Lifecycle'** to obtain the **'Lifecycle'** window;
3. Select the 'Seed' stage **'Mortality'** button to open the **'Seed Mortality'** selection box;
3. Select the **'Continuous'** button to obtain the **'Seed - Continuous Mortality'** dialogue box;
4. Select the **'Parameter'** button to obtain the **'Set Parameter Properties'** dialogue box;
5. Change the name to something more suitable (eg. 'Gen-weed seeds, continuous mortality');
6. Set the lower limit to 0, the upper to 1 and the default to 0.00441;
7. Select **'OK'** as necessary to return to the **'Lifecycle'** window.
8. Save the model.

2.4 Running the Model

The model is loaded into DYMEX’s Simulator exactly as previously described. Check during initialising that the initial population is 1 seed and that the model is to be run for **720** days.

A two panel chart output of Seed and Adult Plant populations will produce the results of Figure 2.2. This chart is almost identical to that produced in tutorial 1 but differs in that the introduced seed mortality rate is clearly visible from the negative slope of seed numbers over time. It is worth examining the tabular outputs from this tutorial to see exactly how the seed mortality is affected by the function. The user will easily see the very rapid drop of seed numbers at first followed by a more gradual decrease with time. A logarithmic scaled chart could also be done for these results but is probably best relevant for larger populations developed over longer times such as the 10 year period of the previous tutorial.

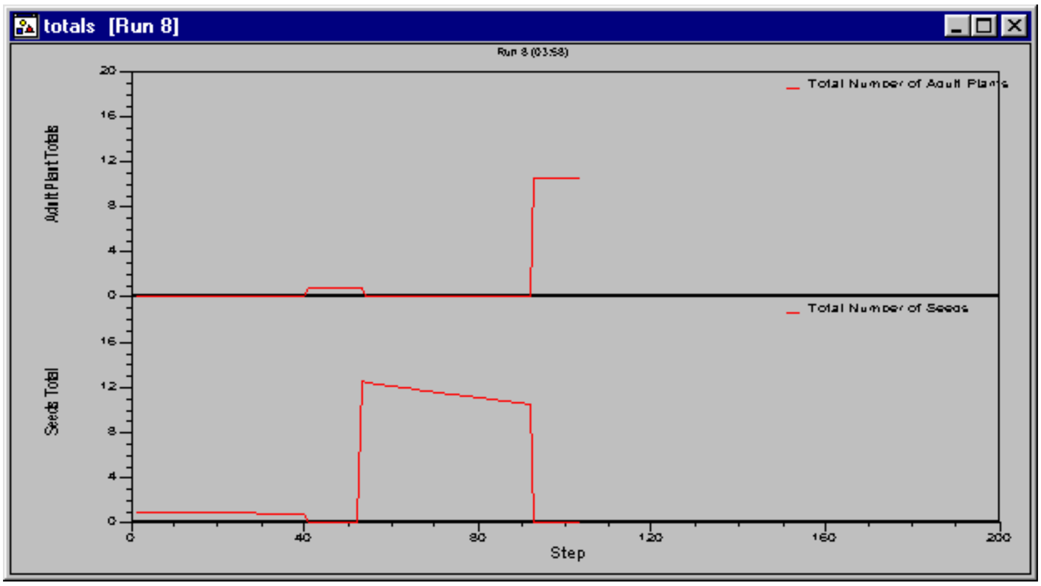


Figure 2.2 Seed and Adult Plant Populations for 720 days

The run time interval was set to 720 days rather than the 730 days of exactly two years. This value was chosen in order to show clearly the decreasing values of the seed bank. If the interval of 730 days is used, the second year’s production of Gen-weed seed has just arrived in the seed bank and its numbers are so large that the diminishing slope of the first year’s seed bank becomes very difficult to see.

2.5 Tutorial 2 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle

Timer

Set to 'Days since start', timestep 7 days, run default 720 days.

Lifecycle

Initial numbers for run: 1 seed.

Seed

Mortality
- Continuous
  - Constant: 0.00441

Transfer function
- Seed Maturation (step)
  - Independent variable: chronological age
  - Germination threshold: 40 weeks
  - Proportion of seeds transferred: 1

Output: Total number

Adult Plant

Continuous mortality (step)
- Independent variable: chronological age
- Threshold: 14 weeks
- Proportion of adults dying: 1

Reproduction
- Fecundity
  - Constant: 15 seeds per adult plant
- Progeny Production (step)
  - Independent variable: chronological age
  - Threshold: 12 weeks
  - Seeds/week step/adult: 15

Output: Total number

3.0 Temperature Induced Germination

3.1 Introducing Temperature

In the field, the germination of an annual is largely triggered by temperature, provided the dormancy period is complete and sufficient soil moisture is present. Whilst this is a simplistic view, it is sufficient to permit the addition of the next stage of the model: temperature controlled germination. In the present model, Gen-weed seeds suffer continuous mortality but the 'seed bank' residue automatically matures to become adult plants once the dormancy period of 40 weeks is complete. While it is essential that the dormancy period remains one of the germination conditions for Gen-weed, the next step is to add germination temperature conditions for the plant

Once an input of temperature is required, other alterations to the model are needed. First, there must be a way of reading meteorological data into DYMEX so that daily temperatures can be used to trigger germination. Next, it would be far more convenient for the average daily temperature to be used in the process and so a method must be found of combining the maximum and minimum daily temperatures into a single average value. Next, the stage transfer must be altered so that it combines both the seed maturing time of 40 weeks and the temperature requirement: this is done by using a combination function within DYMEX. Finally, the 'Timer' module must be altered so that it provides an actual date which will allow it to operate with the real time dates in the meteorological data file.

3.2 Altering the Model

The model will assume that Gen-weed requires a daily average temperature of 18^{o}C in order to germinate.

Since a meteorological database has actual dates, the 'Timer' module must be altered to produce an actual date output rather than a simple step

1. Start the DYMEX Model Builder program;
2. Open the Gen-weed file to obtain the **'Model'** window;
3. Open the **'Timer'** module by double clicking the text;
4. Select the **'Outputs'** button;
5. From the **'Module Output Variables'** scroll list, select **'Simulation Date'** so that it is highlighted;
6. Click on the **'Select'** button (the **'+>'** symbol will appear);
7. Select **'OK'** as necessary to return to the **'Model'** window.

The next procedure is to add a module so that the meteorological database can be included.

8. From the menu bar select **'Model'**;

9. From the drop-down menu select **‘Add Module’**;
10. From the selection box select **‘Metbase’** and then **‘OK’**;
11. Using the **‘Module Name’** edit box, re-name the ‘Metbase’ module (eg. ‘Meteorological Database’);

(In the ***‘Module Details’*** *panel of the window, each button has a description of its functions.)*

12. Select **‘Inputs’** to produce the **‘Inputs (Meteorological Database)**’ link window (figure 3.1);

Figure 3.1 Inputs (Meteorological Database) Link Window

The ‘Inputs to be linked’ panel will display ‘Simulation Date’ highlighted.

13. Using the **‘Link for selected variable’** scroll box, select **‘Simulation Date’**;

Both boxes will now display ‘Simulation Date’ in highlighted form.

14. Select **‘OK’** to return to the **‘Meteorological Database’** module window;
15. Select **‘Outputs’** to produce the **‘Outputs(Meteorological Database)’** selection window (figure 3.2);
16. With **‘Minimum Temperature’** highlighted, click on **‘Select’** button;
17. Select the **‘Rename’** button and give the output a suitable name (eg. ‘Daily minimum temperature’) if desired;

Since temperature is to be read from a data base, the user may feel that setting the minimum and maximum values is irrelevant however such settings can be useful as a check on incorrect or unusual values of data: if a value being read into the model falls outside the set range it will be reported as a possible error for user correction if necessary. When setting the range, consider whether the model is to be used for other locations where the temperature range may vary from the original location. There is little point in re-naming the temperature variables but it can be done if there is a necessity.

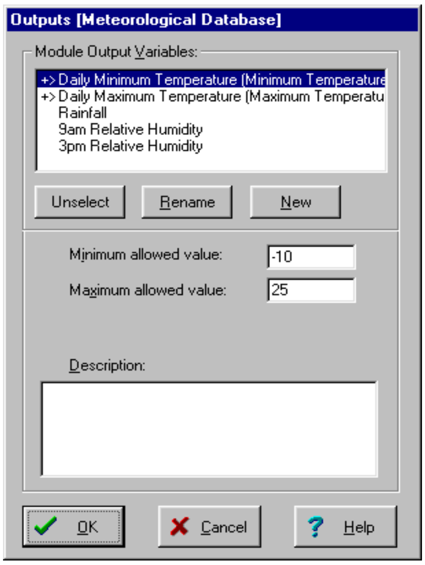


Figure 3.2 Outputs (Meteorological Database) Variables List Box

18. Set **'Minimum allowed value'** to -10;
19. Set **'Maximum allowed value'** to 25;
20. Repeat the procedure for **'Maximum Temperature'** and set minimum and maximum allowed values to 10 and 45 respectively.
21. Exit to the **'Model'** window.

The model window will now resemble figure 3.3 below.

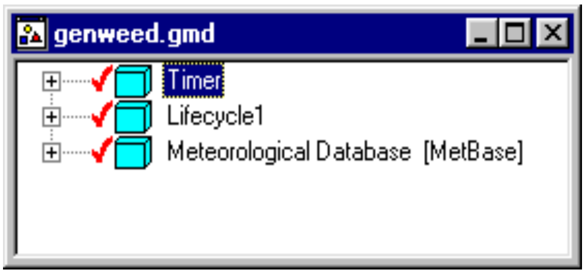


Figure 3.3 Partially completed Model window

The next procedure is to alter the model so that the Lifecycle will be able to have the germination triggered by the **average** daily temperature. To do this, a new module must be added.

1. Use **'Model'** on the main menu bar and select **'Add module'** from the drop-down menu;
2. Select **'Expression'** and then **'OK'**;
3. Rename the module **'Average Daily Temperature'**;
4. Select the **'Inputs'** button to obtain the **'Inputs (Average**

Daily Temperature)' selection window (figure 3.4);

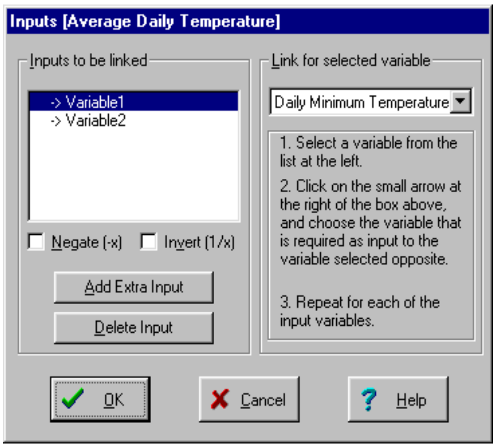


Figure 3.4 Inputs (Average Daily Temperature) selection window for linking variables. Two variables have been created for daily min./max. temperatures.

This box (figure 3.4) looks complex but its operation is quite simple: it links the module's internal variables to those nominated by the user. The user can set up as many internal module variables as needed and then each can be linked to some other variable within the model. The user first creates (using the 'Add Extra Input' button) expression variables within the left hand list box and since two temperature readings per day will be given, two variables are needed. These variables are the ones which will be used within the expression box calculations. Once the two variables are created, they must be linked to the values that are being read by the meteorological database and that is the operation that takes place in the right hand list box. (In figure 3.4, the two variables have already been created.)

5. Click twice slowly on the **'Add Extra Input'** button (this will make two items appear in the left hand list box called **'Variable1'** and **'Variable2'**);
6. With **'Variable1'** highlighted, click once on the right hand scroll box button (it currently has **'(none)'** displayed);
7. From the list that appears, select **'Daily Minimum Temperature'**;
8. Return to the left hand list box and select/highlight **'Variable2'**;
9. Now re-open the right-hand scroll box and select **'Daily Maximum Temperature'**;
10. Select **'OK'** to return to the **'Expression'** module box;

Each temperature variable has now been linked to a variable inside the Expression module. If the Inputs box is re-opened and Variable1 and Variable2 are each selected in turn, the linked variable will change as each is selected. The next procedure with the Expression module is to obtain an average daily temperature.

11. Select the **'Outputs'** button to obtain the **'Output Variables'**

dialogue box;

12. In the **'Module Output Variables'** list box, the words **'Expression Output'** will be highlighted - click on the **'Select'** button once to produce the **'+>'** symbol beside it;
13. Now select the **'Rename'** button and give the variable a suitable name (eg. Average daily temperature);
14. Select **'OK'** as required to return to the **'Expression'** module;

The final procedure with the Expression module is to alter the outputs so that the average daily temperature will be calculated in the module.

15. Select the **'Settings'** button to open its window;
16. From the list panel, select **'Average'**; the formula that corresponds to an average: V = (a+b+c+......)/n will be found beside the name;
17. Select **'OK'** to return to the main module window;
18. Save the model.

There will now be four modules in the model window: Timer, Lifecycle, Meteorological Database and Average Daily Temperature. The Model Builder is now used to alter the 'Lifecycle' module to accept new information about the transfer from seed to adult plant and to set the transfer function so that it is driven by the meteorological database module's output. For this tutorial, all Gen-weed seed will be assumed to germinate at 18^{o}C which will require a step function.

Since temperature is now an extra condition under which seeds germinate and move from the seed to adult plant lifestage, its effects must be combined with those of the 40 week seed maturation time. This is done by multiplying the two functions and the resultant can be easily understood if it is remembered that the output of the seed maturation function is either zero or one. If the seed is not mature, the output will be zero and even if the average daily temperature reaches 18^{o}C within that 40 week period, the multiplication of zero will produce no germination. After the 40 week period, the output from the seed maturation function will be one and so germination and stage transfer is then solely determined by the temperature function.

1. Open the **'Lifecycle'** window;
2. Select the **'Stage Transfer'** button of the **'Seed'** lifestage and open the **'Seed - Transfer'** dialogue box;
3. Select the **'Function'** button to open the **'Function'** dialogue box in order to add a new transfer function;

5. Rename the function **'Gen-weed temperature induced germination'** and then select **'OK'**;
6. Using the function scroll box select **'Step'**;
7. Select **'Average daily temperature'** as the independent variable;
8. Select the **'Parameters'** button and obtain the **'Set Parameter Properties'** dialogue box;
9. With '(a) Threshold' in the **'Parameters'** scroll box, insert a

suitable ‘User-defined Name’ (eg. ‘Germination threshold’);

10. Set the lower limit to 10, the upper to 30 and the default to 18;
11. Select **‘(b) Step Height’** in the **‘Parameters’** scroll box;

Since all seeds germinate simultaneously once the average daily temperature reaches 18^{o}C, the step height is given a value of one (1).

12. Set the default and limits all to 1;
13. Suitably re-name the variable (eg. ‘Proportion of seed germinating’);
14. Select **‘OK’** as necessary to return to the **‘Function’** dialogue box.

There will now be available an previously ‘greyed-out’ button, **‘Set Combination Rule’**. This button allows the setting of the rule under which two or more functions control the combination of the functions’ effects. As has already been noted, the transfer functions will be multiplied.

1. Select the **‘Set Combination Rule’** button and open its list box;
2. Select **‘Product; R= (a x b x...)’**;
3. Select **‘OK’** as necessary to return to the Lifecycle window;
4. Save the model.

This completes the model building procedure in the building program.

3.3 Initialising a Model with Meteorological Data

3.3.1 Loading the Model

1. Open the DYMEX Simulator and load the Gen-weed model.

Once the file is loaded into the DYMEX Simulator, a ‘Model Components’ window appears (figure 3.5). Since there is no tick beside either the ‘Timer’ or the ‘Meteorological Database’ module, it indicates that user initialisation of those module’s variables is required before the Simulator will process the model. The colour of the ticks indicates whether user initialisation may occur: a blue tick indicates that user alteration of the module variables may occur, a grey tick indicates that no user alteration is possible.

Figure 3.5 also displays information about the current settings for the model: its run duration is presently set to 365 days and the Lifcycle module has been initialised in the Seed lifestage. The Model window as shown in figure 3.5 is not as large as the actual screen display in the Simulator.

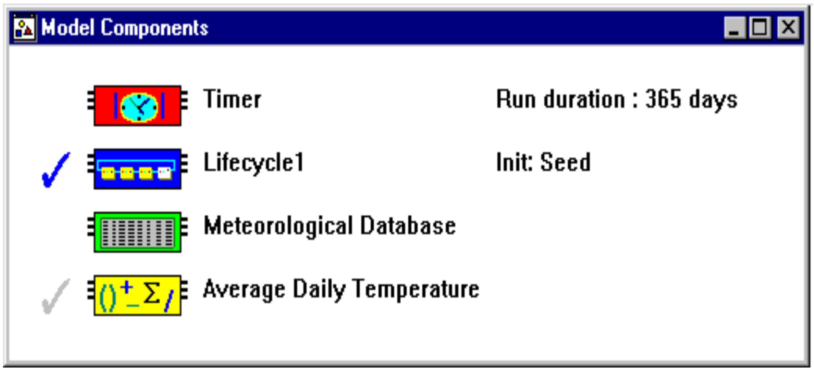


Figure 3.5 Model Components window

While the Simulator is operating, DYMEX extracts meteorological data from a previously constructed meteorological data file and applies it to the model. The Simulator can read meteorological information from almost any format but two provisos must be made:

1. **Each line of the file must have exactly the same format; and**
2. **The user must know the format of the file precisely.**

A typical meteorological file contains information on temperature, rainfall, humidity, air pressure, evaporation, etc. and may be daily, weekly, monthly etc. The exact format depends upon the circumstances under which the file was built and DYMEX must be told the precise format in order to find the necessary information.

3.3.2 The Amberley Meteorological File

The Amberley meteorological file (Table 3.1) will be used in the Gen-weed model. Only the first four lines are shown. Columns are counted from the left and blank columns must be included in the count. For the lines of data, column one is currently blank but is marked by the capital A at the start of the file's data location line, column two contains the numbers 1, 2 and 3, column three is blank, column four contains 1, 1 and 1, etc. The tutorial user ***must*** be familiar with the file structure before progressing further.

```
A      Amberley Airport    27.6 S   152.7 E    25
 1 165 18.0 30.0   0.   5.0 16.0 73. 17.3 17.0 46. 13.85   5.6 AMB
 2 165 17.0 32.0   0.   2.9 18.0 84. 21.1 17.0 41. 13.85   5.5 AMB
 3 165 19.0 33.0   0.   1.8 21.0 91. 22.2 18.0 41. 13.84   5.6 AMB
```

Table 3.1 Amberley Meteorological File

Structures in the file on which DYMEX will require information for this tutorial are:

- Line 1 of the file is an information 'header'.

- The first 6 columns of the file are date information with format 'ddmmyy'. (Notice that some of these columns are blank at first but will be filled when either double digit days or months are reached.)
- Columns 8-16 contain the daily temperatures.

The remainder of the file can be ignored for this tutorial. Of course, it would have been possible to have *only* temperatures in the meteorological file, however this would restrict the use of the file and the program to the effects of temperature only. Sooner or later, other meteorological variables will become necessary in the model and access to a complete file is preferable (eg. columns 17-22 contain daily rainfall.).

3.3.3 Initialising the Meteorological Database Module

The first set of procedures is to open the required meteorological database file and set DYMEX so that it can read the necessary data from the file.

1. Select the **'Meteorological Database'** button in the **'Model Components'** window followed by **'Initialise Module'** from the drop-down menu;

This will open the **'Datafiles'** dialogue box which will allow the user to find, open and format the meteorological file that is required for a field temperature run. The file that used for this tutorial is called 'Amberley.dat'.

2. Select **'Browse'** and scan the files/directories until **Amberley.dat'** is located;
3. Select **'Amberley.dat'** and then click on the **'Open'** button;
4. Select **'Format'** button to produce the **'Datafile'** window (fig 3.6).

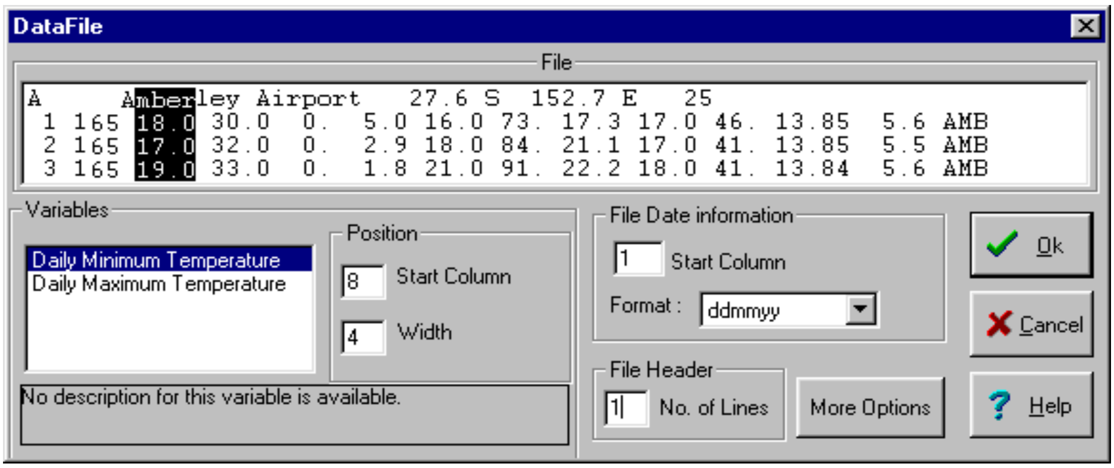


Figure 3.6 DataFile window with minimum temperature, file date format and file header settings shown.

The ‘Data File’ window (Figure 3.6) allows the user to inform DYMEX of the format of the loaded meteorological database so that data can be read into the model. For this tutorial the ‘More Options’ button may not required. If pressed, additional operations become available to the user. Once opened, the ‘More Options’ window remains open until the user returns to the ‘Model’ window.

3.3.3.1 *Header Lines*

The first step is to tell DYMEX how many lines at the top of the file contain information other than meteorological data. Once this is set, DYMEX will ignore these lines while reading data. Inspection of the file data list box shows that only one line contains such material.

1. Select **‘No. of Lines’** edit box;
2. Type in the value 1.

3.3.3.2 *Date Information*

The second step is to define for DYMEX the date format. The Simulator has a very large library of standard formats; the user selects the one corresponding to the datafile. The format is set to a default equivalent to the Amberley datafile date structure. Since the file dates start in column 1, this is the first information to provide for the Simulator. Use the box area marked ‘File Date Information’.

1. Select **‘Start Column’** edit box;
2. Ensure the value is set to 1;
3. Select the scroll button on the **‘Format’** list box;
4. Scroll until the correct format of ‘ddmmyy’ is obtained and then highlight it to select the format.

3.3.3.3 *Temperature Information*

The third step is to define the area of the file in which DYMEX will look for temperature information. DYMEX's Simulator provides a very simple method of area definition in which the user does not even have to count where the columns begin and end. The method used is the standard ‘Windows’ mouse procedure of marking an area of text: place the cursor at the start of the desired area, hold the left hand button down, slide the mouse until the desired area is highlighted and then release the button. (Once this method is known, it can be used to ‘track down’ the column number of any column if the user is unsure of a count.)

1. With **‘Minimum Temperature’** highlighted in the **‘Variables’** list box, place the cursor between the “A” and the “m” in “Amberley”;
2. With the left hand mouse button held down, slide the mouse until the column headed by 18.0 is highlighted;

3. Release the mouse button - the selected area of the file will remain highlighted and will extend to the full height of each selected column;
4. Inspect the ‘Position’ area of the window and the ‘Start Column’ edit box should now show 8 while the ‘Width’ box should now show 4; if it isn’t repeat the procedure until it is correct;
5. Now shift the cursor to the **‘Variables’** list box and select **‘Maximum Temperature’** so that it is highlighted in blue;
6. Move the cursor so that it is between the ‘l’ and the ‘e’ in Amberley;
7. With the left button held down, drag the cursor across the columns so that the column beginning ‘30.0' is highlighted, then release the mouse button;
8. The ‘Position” area of the window should have the ‘Start Column’ edit box showing 13 with a ‘Width’ of 4;
9. Select **‘OK’** as necessary to return to the main window;

NOTE: At this point, select the ‘More Options’ button. This will open an extra part of this window. As minimum or maximum temperature is selected, the limits of each will be shown.

The **‘Meteorological Database (Temperature)’** icon will now have a tick beside it. To complete the initialisation procedures

1. Select the **‘Timer’** module followed by **‘Initialise Module’**;
2. Set the run default to 730 days;
3. Select **‘OK’**.

The **Timer** module will now have a blue tick beside its icon to indicate it has been successfully initialised. There is no need to set the date; the program will do it for you as soon as you start the run. This completes initialisation of the model for the Simulator and it can now be run.

3.4 Running the Model

With the model now initialised, all that is required is to select 'Run'. The initial numbers of Gen-weed should be 1 seed, but it is worth checking just to make sure. Run the model for a period of 730 days and then produce a chart output with three panels containing average temperature, and total numbers of seeds and adult plants. To do this, select 3 panels in the Chart selection window and then place one of each of the variables in panel 1, 2 and 3, selecting the panel number and then the variable. The result should resemble figure 3.7

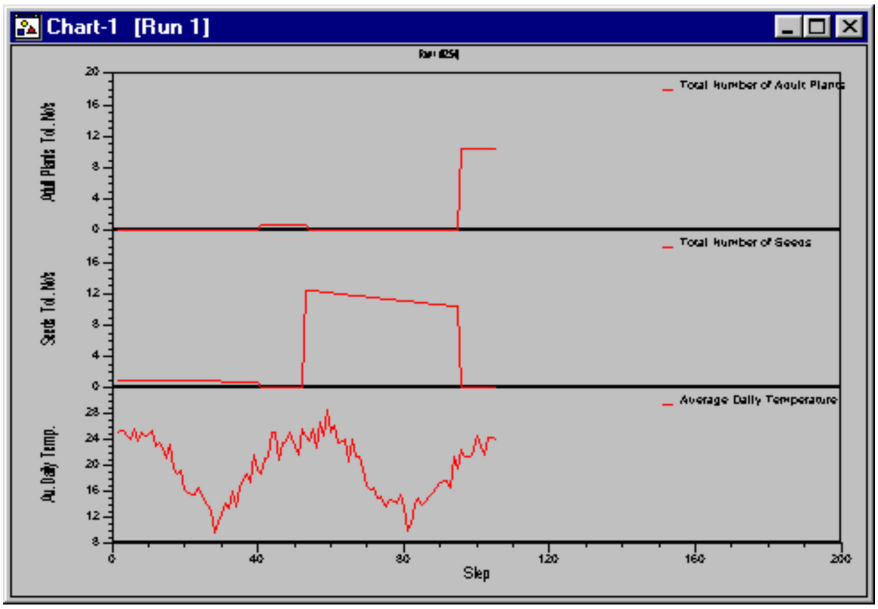


Figure 3.7 Gen-weed with germination triggered by daily average temperature of 18°C

The graphs clearly show that with the threshold set to 18°C the germination of Gen-weed is purely dependant on the 40 week dormancy period as the curves are virtually identical to those of tutorial 2.

It is worth investigating the effects of the temperature threshold on germination. If the model parameters are set so that the threshold is 30°C, the results are quite different. To try this, follow the following steps:

1. Close the run window so that only the model window is left;
2. Click once on the **'Lifecycle'** module to obtain the drop-down menu and select **'Show Parameters'**;
3. From the parameters list box, select the **'Seed Germination Threshold'** which is currently set to 18°C - alter it (by using the scroll buttons) to 30°C;
4. Close the parameters list box and re-run the model to produce the same average daily temperature and lifestage numbers

chart as before. The results should be similar to figure 3.8.

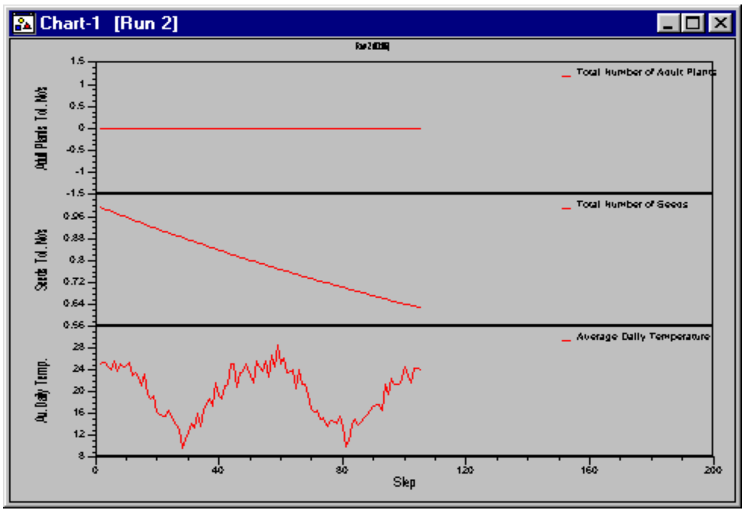


Figure 3.8 Genweed germination with Temperature Threshold set to 30°C

In this case the seed is unable to germinate as the average daily temperature is never able to reach 30°C. If the threshold is set to 25°C, the chart of figure 3.9 results. The temperature in the second year does not reach the germination threshold during the time length of the run, but if the model is run over three years, it will be seen that the germination of the seeds always occurs almost at the middle of the peak of the temperature cycle.

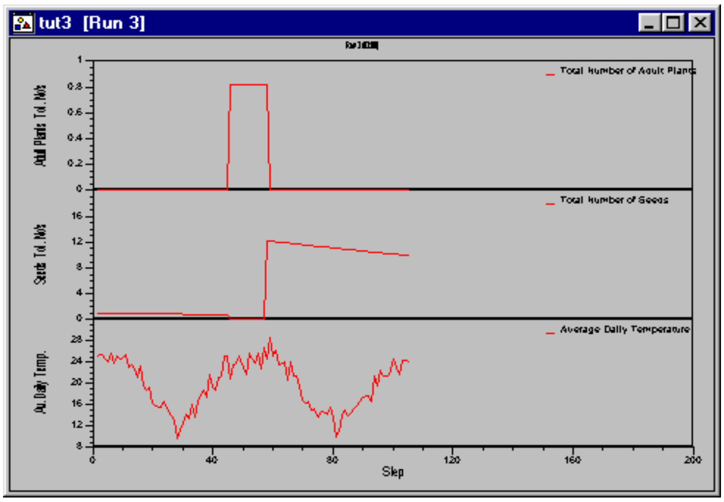


Figure 3.9 Seed Germination with the Temperature Threshold set to 25°C

This simple model uses a temperature threshold as the germination trigger. Actual plants do not require a single occurrence of the threshold temperature - it must be consistently above the threshold over several days which implies temperature controlled development and a requirement for physiological age rather than chronological age. This will be developed in future tutorials.

Note: when closing, you will be asked if you wish to save the altered parameters; select 'NO' as otherwise the next run will retain your temporary test settings. You can leave them provided they are returned to the default values for the next tutorial.

3.5 Tutorial 3 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Expression (Average Daily Temperature)

Timer

Set to 'Days since start' and 'Simulation Date', run default 730 days.
Timestep: weekly.

Lifecycle

Initial numbers for run: 1 seed.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop. seeds transferred: 1
Temperature induced germination (step)
Independent variable: average daily temperature
Temperature threshold: 18ºC
Proportion of seeds germinating: 1

Combination Rule: multiply

Output: Total numbers

Adult Plant

Continuous mortality (step)
Independent variable: chronological age
Threshold: 14 weeks
Proportion of adults dying: 1

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: chronological age

Threshold: 12 weeks
Seeds/week step/adult: 15
Output: Total numbers

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

4.0 Modifying Temperature Induced Germination

4.1 Changing the 'Step' Model

Germination in the Gen-weed model is presently controlled by a simple step function: if the average daily temperature reaches 18ºC, all seeds germinate. This is unsatisfactory because in the field, only a few seeds may germinate at 18ºC, but 100% of all seeds present may germinate once the daily temperature becomes a little higher. The model must also account for any negative effects of temperature: rates of germination may actually decrease if the temperature rises still further and germination may stop altogether at some higher limiting temperature.

Suppose Gen-weed has a germination process as displayed in Table 2.1 below.

Temperature (ºC)	Percentage of seeds germinating
15	No development
18	1
18.5	24
19	50
19.5	72
20	99
21	99
24	99
26	99
28	47
30	2

Table 4.1 Temperature effects on Gen-weed seed germination

This data suggests a three section, linear graph. If the data is 'smoothed', the threshold temperature for germination becomes 18ºC; the germination rate then increases and reaches 100% at a temperature of 20ºC; the germination rate then remains at 100% until the temperature rises to 26ºC; the germination rate then falls until it is zero for a temperature of 30ºC. Figure 4.1 displays these results.

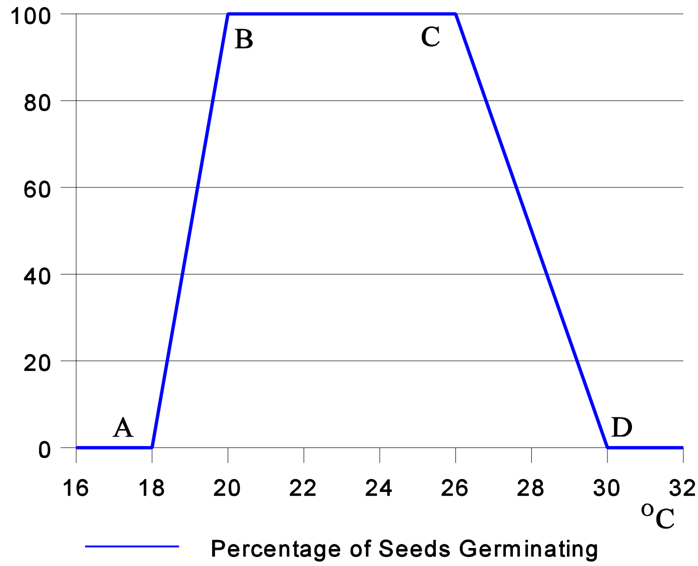


Figure 4.1 Percentage of Seed Germination for Gen-weed under varying temperature conditions.

From figure 4.1, the information required by the DYMEX model can be easily read:

1st Section (A-B)
Threshold: 18°C
Slope: 0.5

2nd Section (B-C)
Intersection point: 20°C
Slope: 0.0

3rd Section (C-D)
Intersection point: 26°C
Slope: -0.25

4.2 Building the Model

Start the DYMEX Model Builder and open the Gen-weed model. The 'Model' window will be displayed and four modules {Timer, Lifecycle, Meteorological Database and Average daily temperature(Expression)} will be shown.

1. Double click on the **'Lifecycle'** module to obtain the **'Lifecycle'** window;
2. Select the **Seed 'Stage Transfer'** button to obtain the **'Seed Transfer'** dialogue box;
3. Select and highlight the **'Temperature Induced Germination'**

function;

4. Select the **‘Delete Component’** button and respond **‘Yes’** to any deletion confirmation queries from the program;
5. Select the **‘Function’** button to obtain its dialogue box;
6. From the function list scroll box, select **‘3-segment Linear’**;
7. Change the function name to **‘Temperature Induced germination’**;
8. Select **‘Average daily temperature’** as the independent variable;
9. Select the **‘Parameters’** button.
10. The parameter **‘Line 1 X-intercept’** will be present in the list box and the values 15, 22 and 18 should be entered in the lower limit, upper limit and default boxes respectively;
11. Re-name the variable suitably if necessary (eg. ‘Germination threshold’);
12. Open the parameter scroll box and select **‘Line 1 Slope’**;
13. Set all default and limit values to 0.5, then re-name the parameter if required (eg ‘Initial rate of germination’);
14. Re-open the parameters scroll box and select **‘X value at intersection of lines 1,2'**;
15. Set the upper and lower limits to 18 and 25 and the default to 20;
16. Re-name the parameter suitably if required (eg Max. germination rate temp. Threshold’);
17. Re-open the parameter scroll box and select **‘Line 2 Slope’**;
18. Set all limits and the default to 0;
19. Re-name the parameter if required (eg ‘Germination rate plateau’);
20. Re-select the parameter scroll box and select **‘X-value at intersection of lines 2,3’**;
21. Set the lower and upper limits to 22 and 28 respectively and the default to 26;
22. Re-name the parameter if required (eg ‘Germination rate decrease threshold’);
23. Re-open the parameter scroll box and select **‘Line 3 Slope’**;
24. Set all limit and default values to -0.25;
25. Re-name the parameter if required (eg. ‘Rate of germination decrease’);
26. Select **‘OK’** as necessary to return to the model window;
27. Save the model.

There is no need to re-open the Combination Rule button - it has already been set to ‘multiply’ in the previous tutorial.

4.3 Module Order in the Model

Both the DYMEX Model Builder and the Simulator display the model structure by means of a series of module icons. It is important that the user be aware that when the model is run in the Simulator, **the program processes the modules in the order in which they appear on the screen**. This has critical implications for the mathematical processing of the model within the Simulator because if the sequence of the modules is altered, quite different outputs can be produced. The present Gen-weed model has only four modules and the model's simplicity means that output differences produced by sequence variations of the modules will be either very little or none, but this will not be the case as the number of modules increases.

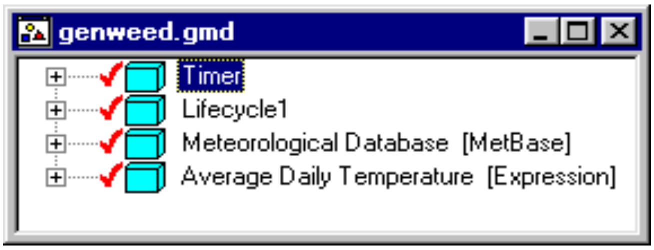


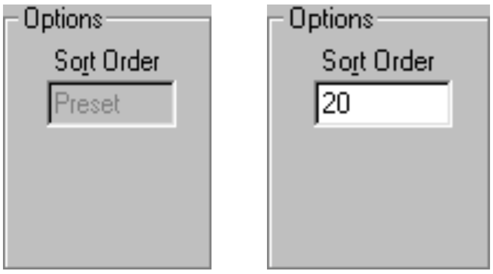
Figure 4.2 Module order in the current Gen-weed model

Initially, the order of the modules is set by the sequence in which they are added to the model. The **Timer module is by default the first module** of any model and is also the first module to be processed in the Simulator during the run of any model. The Timer's position in the model is pre-set and cannot be changed by the user and unless there are important reasons for not doing so, the **Lifecycle module should be the last module in the model.** In the current Gen-weed model (figure 4.2), the **Lifecycle** module is second in the list as the next two modules were added later. It is therefore necessary to move the Lifecycle module to the bottom of the module list and this can be done with the **'Sort Order'** facility.

DYMEX assigns each module a sort order number as it is placed in the model and it is this number which defines the module's location in the list and therefore its position in the processing sequence of a run. The Timer module may be thought of as having a pre-defined and unchangeable sort order value of '00' and so in figure 4.2, the Lifecycle module will have a sort order number of '10', the Meteorological Database will have a sort order number of '20', the Average Daily Temperature module will have a sort order number of '30', etc.

This 'x10' sequence provides the user with convenient intermediate module order values. For example, if it is desired to insert a new module between existing modules 3 and 4 the new module could be given a sort order of any value between 30 and 40 (e.g 32). After the new sort order value is inserted, the Model Builder will place the module in its correct sequence in the model. Alternatively, if a current module is required to be shifted to a different sequence location, its sort order number can be altered to an intermediate value and on returning to the model window, it will be seen that the sequence of modules has been altered.

Except for **Lifecycle**, the sort order of any module can be set by opening the module from the Model window and changing the sort order with the **Options** text entry panel. This panel is always found at the upper right of the module window and the panels for the Timer and any module, except for Lifecycle, are shown in figure 4.3.



A. **B.**

Figure 4.3 Sort Order panels: A - Timer module; B - other modules except Lifecyle

Because the Lifecycle module does not have the standard module window, the sort order of the Lifecycle module is set from the menu bar. In the current model (figure 4.2), the last module is the Expression module (Average Daily Temperature) and its sort order value will be '30'. The Lifecycle module can be moved to the last position in the sort order if its value is changed from '10' to '40'. Complete the following steps:

1. With the Gen-weed model open in the Model Builder, open the **'Lifecycle'** module;
2. Select **'Lifecyle'** from the menu bar followed by **'Sort Order'** from the drop-down menu to open its text entry box;
3. Change the sort order value from **'10'** to **'40'**;
4. Exit to the **'Lifecycle'** window and save the model;
5. Return to the **'Model'** window - it should resemble figure 4.4.

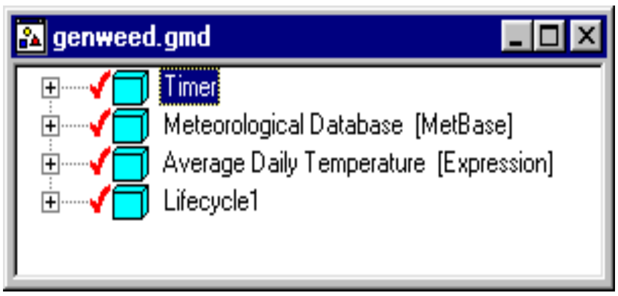


Figure 4.4 The Gen-weed model after the Lifecycle sort order is altered.

4.4 Running the Improved Model

Loading and running the temperature modified Gen-weed model is identical to the procedures already described. Use a default time length of 2 years (730 days) and **increase the number of**

seeds at the start of the run to 10. When this is done, a chart of daily average temperature, seeds and adult plants will produce a result similar to that of figure 4.5 .

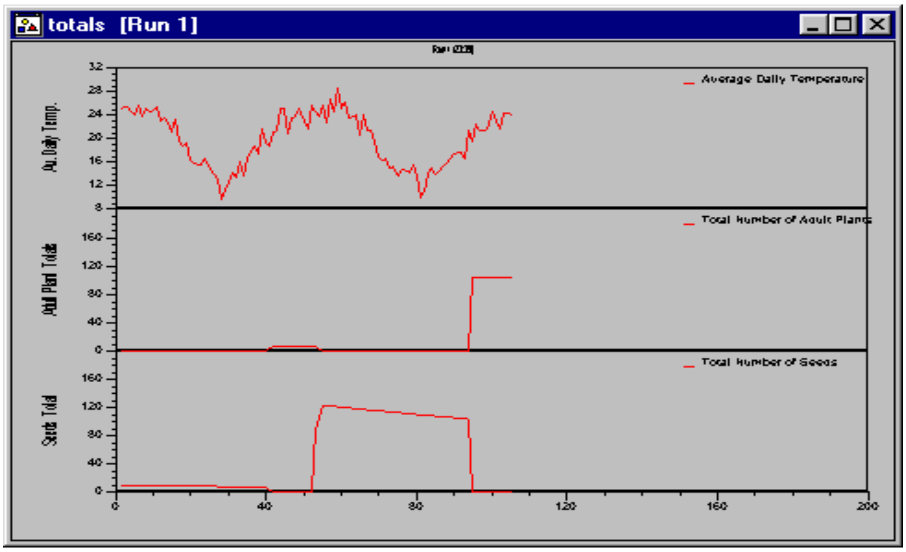


Figure 4.5 Temperature Induced Germination with varying rates according to applied temperatures

The difference that results from the modified germination rates is most easily seen from the varied slope of the number of seeds at the end of Gen-weed's flowering in year 1. This may seem unusual as the effect should be noticed in the appearance of the adult plants during germination, however the reason behind this effect is easily seen if the run is done for 400 days and the chart examined (figure 4.6)

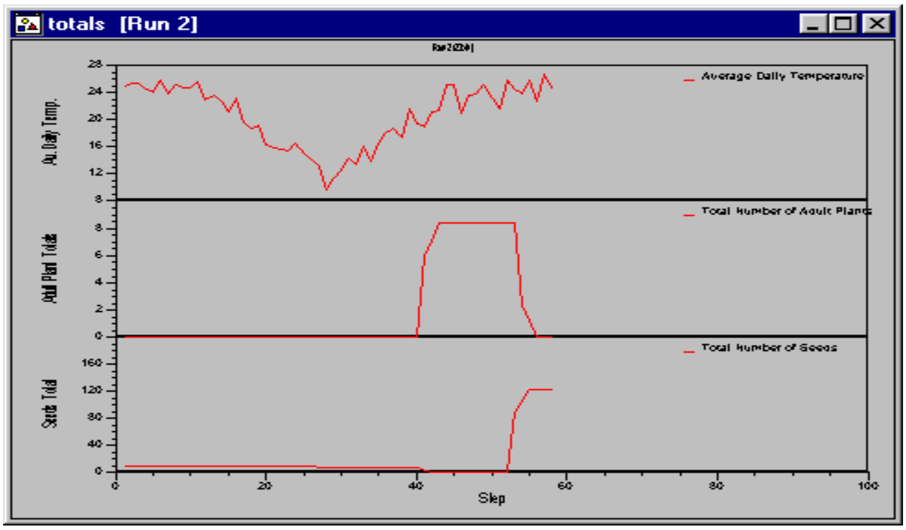


Figure 4.6 Gen-weed cycle over 400 days

The effects of temperature on germination are clearly seen in the appearance of the adult plants and because some plants are delayed in their germination, they are also delayed in their production of seeds. This produces the varying slope at the end of the adult lifespan and this in turn produces the varied slope in the seed production curve. The user may also note another aspect which appears because of the temperature effects: up to 4 cohorts appear momentarily in the run around day 250 because of the varying rates of germination. This latter aspect will be most easily seen if the tabular output is examined.

4.5 Tutorial 4 - Summary of Modules, Variables and Parameters

Modules: Timer, Gen-weed Lifecycle, Meteorological Database, Average Daily Temperature (Expression)

Timer

Set to 'Days since start' and 'Simulation Date', run default 730 days.
Timestep: weekly

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Temperature induced germination (3-segment linear)
Independent variable: average daily temperature
Line 1 X-intercept: 18
Line 1 slope: 0.5
X-value at intersection of lines 1,2: 20
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 26
Line 3 Slope: -0.25

Combination Rule: multiply

Output: Total numbers

Adult Plant

Continuous mortality (step)
Independent variable: chronological age
Threshold: 14 weeks
Proportion of adults dying: 1

Reproduction
Fecundity:

Constant: 15 seeds per adult plant

Progeny Production (step)

Independent variable: chronological age

Threshold: 12 weeks

Seeds/week step/adult: 15

Output: Total numbers

Meteorological Database

File: Amberley.dat

Output: Minimum temperature (column 8, width 4)

Maximum temperature (column 13, width 4)

Average Daily Temperature (Expression)

Inputs: Minimum and Maximum daily temperatures

Output: average daily temperature

Setup: average expression

5.0 Rainfall Induced Germination

5.1 Introducing Rainfall

As an annual, Gen-weed germinates when climatic variables are suitable. The effects of temperature have already been partially explored in tutorials 3 and 4, however a second and equally important climatic variable is rainfall. For the purposes of this tutorial, Gen-weed seeds will be assumed to germinate once 20 mm of rain have fallen. Of course, the rainfall threshold will be in addition to the maturation and temperature thresholds. The effects of mortality will still leave numbers of seeds that eventually must produce an exponential population increase.

In the field, automatic transfer of an annual seed to the adult plant lifestage does not occur: the *mature* seed germinates only if the two remaining thresholds are satisfied. Adequately modelling germination due to the presence of moisture requires more than linking germination to the quantity of rainfall in any one storm: other aspects such as humidity, available soil moisture, etc. could and should be considered, however to commence a simple simulation, the model will be changed so that a rainfall of 20 mm in any one day will be sufficient to trigger germination of all mature seeds. More complex models would at least consider whether or not sufficient soil moisture remained in order for the seedlings to continue their growth and this in turn might require additional lifestages.

To simulate rainfall in the model, structural changes are needed. First, the meteorological data file must be re-formatted so that daily rainfall can be obtained. Second, the seed to adult stage transfer must be altered so that it includes the requirement of 20 mm of rainfall in any one day before the seed will germinate. The combination function within stage transfer will remain the same.

5.2 Altering the Model

1. With the Model Builder open, load the Gen-weed file;
2. In the **'Model'** window, open the **'Meteorological Database'** dialogue box;
3. Select the **'Outputs'** button and open its list box;
4. Highlight **'Rainfall'** and then click on the **'Select'** button;

Since rainfall is to be read from a data base, the user may feel that setting its minimum and maximum values is irrelevant. This is not so because the minimum and maximum settings can be useful as a check on incorrect or unusual values of data: if a value being read into the model falls outside the set range it will be reported as a possible error for user correction if necessary. When setting the range, consider whether the model is to be used for other locations where the *rainfall range may vary from the original location. There is little point in re-naming the rainfall variables.*

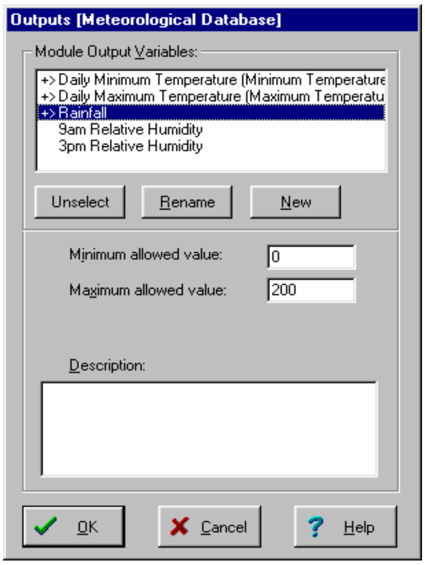


Figure 5.1 Output Variables Dialogue Box

5. Set **'Minimum allowed value'** to 0;
6. Set **'Maximum allowed value'** to 200;

This value of 200 seems high, however in the Amberley data file, there is a rainfall record of over 150 mm in one day. If the user wishes to see what happens if the value in step 7 is set lower, try entering a value of 50. If this is done, there is an extra procedure to be completed when initialising the Amberley file which ensures a value of 50 mm is cleared from the model.

7. Exit to the 'Model' window.

The model window will now resemble figure 5.2 below.

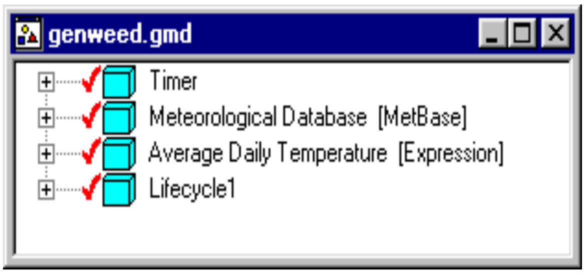


Figure 5.2 Completed Model Window

The final procedure in the Model Builder is to alter the 'Lifecycle' module to accept new information about the transfer from seed to adult plant and to set the transfer function so that the output from the meteorological database module will drive it. As previously defined, 20 mm is sufficient to permit the seeds to germinate. In the field, not all the seeds of an annual may germinate even if sufficient rain falls and depending upon the species of annual, the percentage germination may be larger or smaller. For this tutorial, Gen-weed will be assumed to produce complete germination after 20 mm of rain in any one day which will require a step function. The step height will be set at one.

There will now be three functions controlling the germination of the seeds: time, temperature and rainfall. Time and temperature effects have already been combined using a multiplication function and there is no need to alter this with the addition of rainfall.

1. Open the **'Lifecycle'** window;
2. Select the **'Stage Transfer'** button of the **'Seed'** lifestage and open the **'Seed - Transfer'** dialogue box;
3. Select the **'Function'** button to open the **'Function'** dialogue box in order to add a new transfer function;
5. Rename the function **'Gen-weed rainfall induced germination'** and then select **'OK'**;
6. Using the function scroll box select **'Step'**;
7. Select **'Rainfall'** as the independent variable;
8. Select the **'Parameters'** button and obtain the **'Set Parameter Properties'** dialogue box;
9. With '(a) Threshold' in the **'Parameters'** scroll box, insert a suitable 'User-defined Name" (eg. 'Rainfall germination threshold');
10. Set the lower limit to 10, the upper to 50 and the default to 20;
11. Select '(b) Step Height' in the **'Parameters'** scroll box;
12. Set the lower limit to 0, the upper to 1 and the default to 1;
13. Suitably re-name the parameter (eg. 'Prop. of seed germination');
14. Select **'OK'** as necessary to return to the **'Model Components'** window.
15. Save the model.

This completes the model building procedure in the Model Builder program.

5.3 Initialising The Model

1. Open the DYMEX Simulator and load the Gen-weed model.

Once the file is loaded into the DYMEX Simulator, a 'Model Components' window appears (Figure 5.3). Although a tick appears beside the Meteorological Database module, it must still be altered in order to provide the rainfall information required by the Simulator.

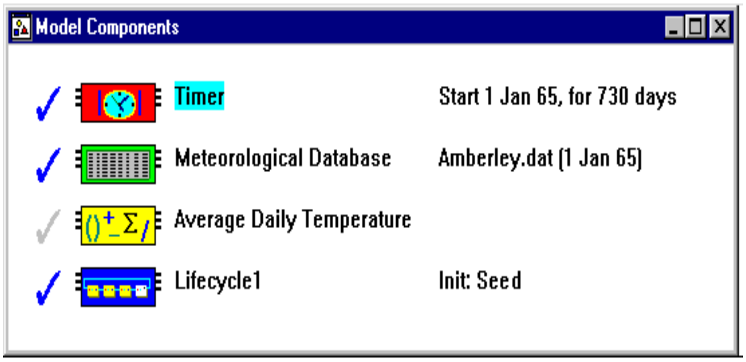


Figure 5.3 Model Components window

The next set of procedures is to open the meteorological database file and set DYMEX so that it can read the necessary data from the file.

2. Select the **'Meteorological Database (Gen-weed)'** button in the 'Model Components' (fig 5.3) window followed by **'Initialise Variable Manger'** from the drop-down menu;

This opens the 'Datafiles' dialogue box which allows the user to find, open and format the required meteorological file. The file used for this tutorial, 'Amberley.dat', has already been selected in a previous tutorial and will already be present in the 'Name' box.

3. Select **'Format'** button to produce the **'Datafile'** window (fig 5.4).

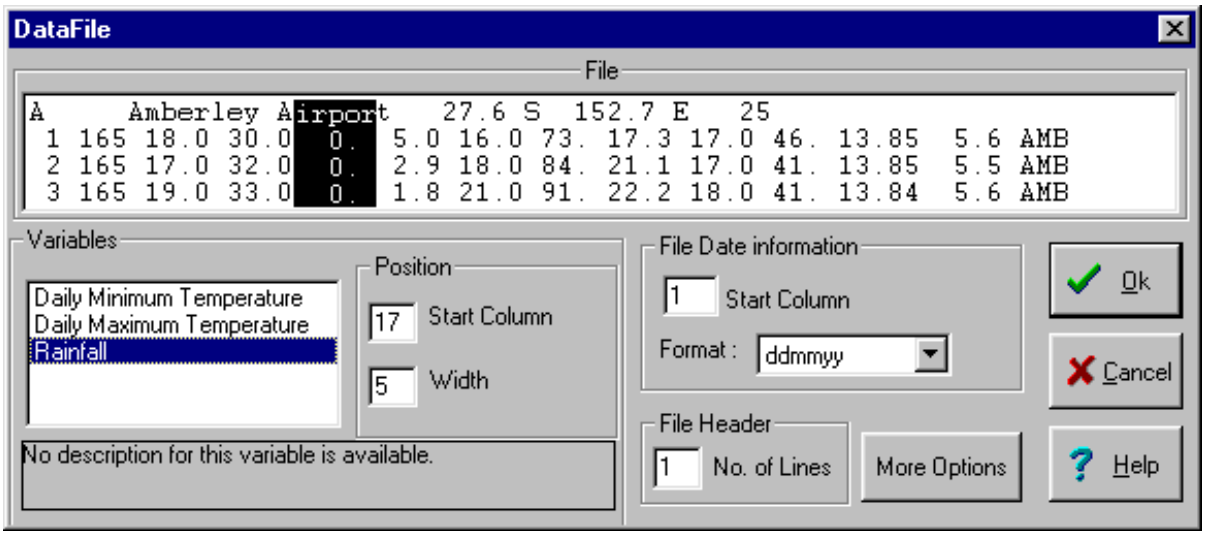


Figure 5.4 Data File Window

The final step is to define the area of the file in which DYMEX will look for rainfall information. This is done using the same 'mouse procedure' detailed in tutorial 3. Columns 17-22 contain the daily rainfall.

4. Place cursor just under the “I” in “Airport” on the top line;
5. With the left hand mouse button held down, slide the mouse until 5 columns are highlighted;
6. Release the mouse button - the selected area of the file will remain highlighted and will extend to the full height of each selected column;
7. Inspect the ‘Position’ area of the window and the ‘Start column edit box should now show 17 while the ‘Width’ box should now show 5;

NOTE: At this point, select the ‘More Options’ button. This will open an extra part of this window. Check to make sure that the rainfall is marked with limits of 0 and 200. If 200 is not set as a maximum because a smaller amount has been tried to see the results on the Simulator, re-set this value to 200 so that the Simulator will process all file data.

8. Select **‘OK’** as necessary and return to the ‘Model Components’ window.

This completes initialisation of the model for the Simulator and it can now be run.

5.4 Running the Model

With the model now initialised, ensure that the initial numbers of Gen-weed seeds is set to 10 and that the run period is set to 730 days. Run the model and produce a chart output with four panels containing temperature, rainfall, and total numbers of seeds and adult plants. The result should resemble figure 5.5 .

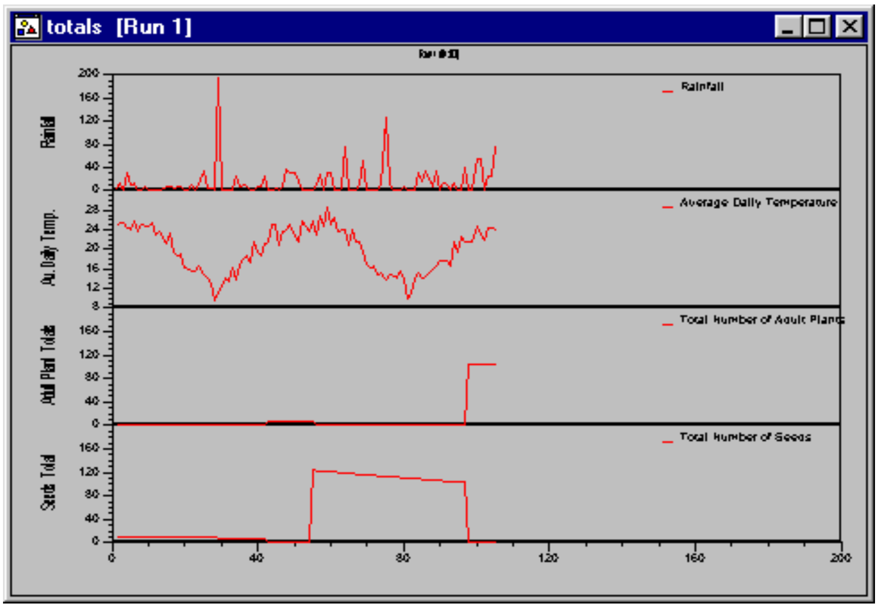


Figure 5.5 Gen-weed with Rainfall induced germination

Figure 5.5 does not show how the germination has become rainfall dependent, however if the run is reduced to 400 days, the results should resemble figure 5.6 which does show the linkage.

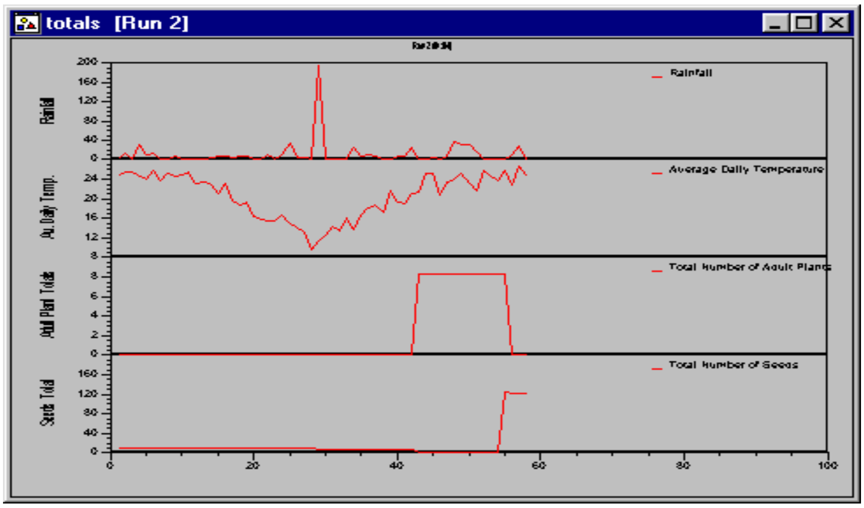


Figure 5.6 Rainfall induced germination for Gen-weed (400 day run)

An even better way of seeing the rainfall threshold is to use the table display and the appropriate area is shown in figure 5.7 . This clearly shows that the daily rainfall total of 25mm on day 287 triggered the germination because the dormancy period of 40 weeks was completed on day 280 and the average daily temperature was already 21.14°C implying that all seeds would immediately germinate. {This last temperature effect removes the varied slope on the transfer from seed to adult that is so noticeable in the previous tutorial (figure 4.3)}.

Table-1 [Run 2]

aysSincSt	imulaDate	Rainfall	erDailTem	tNumofSe	oNuofAdl
260.00	17/9/65	0.00	17.36	8.45	0.00
267.00	24/9/65	0.00	21.64	8.42	0.00
274.00	1/10/65	7.00	19.43	8.38	0.00
281.00	8/10/65	6.00	18.93	8.34	0.00
288.00	15/10/65	25.00	21.14	8.31	0.00
295.00	22/10/65	0.00	21.43	0.00	8.31
302.00	29/10/65	2.00	25.14	0.00	8.31
309.00	5/11/65	4.00	25.14	0.00	8.31
316.00	12/11/65	0.00	20.93	0.00	8.31
323.00	19/11/65	7.00	23.57	0.00	8.31

Figure 5.7 Tabular display for Gen-weed Rainfall induced germination

Rainfall induced germination allows some of the behaviour of an annual to be modelled, however it remains a very simplistic model. A better procedure is to use soil moisture as a trigger for germination since the seeds are in contact with the soil and respond to the soil moisture present. How this is done will be considered in the next tutorial.

****Note: If the model is run over 10 years, an error will be reported during January 1974**. This is because a daily rainfall was over 400 mm. The rainfall upper limit in the meteorological database initialisation will have to be reset to 500 mm and the model will then run satisfactorily.

5.5 Tutorial 5 - Summary of Modules, Variables and Parameters

Modules: Timer, Gen-weed Lifecycle, Meteorological Database, Average Daily Temperature (Expression)

Timer

Set to 'Days since start' and 'Simulation Date', run default 730 days.
Timestep: weekly

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Temperature induced germination (3-segment linear)
Independent variable: average daily temperature
Line 1 X-intercept: 18
Line 1 slope: 0.5
X-value at intersection of lines 1,2: 20
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 26
Line 3 Slope: -0.25
Rainfall induced germination (step)
Independent variable: daily rainfall
Rainfall threshold: 20mm
Prop. seeds germinating: 1

Combination Rule: multiply

Output: Total numbers

Adult Plant

Continuous mortality (step)
Independent variable: chronological age

Threshold: 14 weeks
Proportion of adults dying: 1

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: chronological age
Threshold: 12 weeks
Seeds/week step/adult: 15

Output: Total numbers

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

6.0 Soil Moisture

6.1 Introduction

Tutorial 5 implied that rainfall by itself is generally too erratic for it to be the sole determinant of moisture levels in a model. Saturation deficiency may be used as an alternative but this also produces problems. Calculation of the amount of water held in the soil at any given time has proven to be the best method of introducing moisture levels into a model, however when this technique is used, additional modules are needed.

Rainfall is usually the main source of water for soil moisture. Water losses are determined by evaporation (which is affected by relative humidity, season, hours of sunlight, intensity of sunlight, latitude, plant cover, etc.) and soil structure (ability to retain water, current soil moisture levels, etc.). These aspects require specialised DYMEX modules which allow the model to simulate their effects.

6.2 Modelling Soil Moisture

6.2.1 Modules Required

Four additional modules are required to model soil moisture: a soil moisture module to provide information on soil moisture levels to the lifecycle, an evaporation module to determine water loss from the soil, a daylength module to influence the rates of evaporation and a queryuser module to allow the setting of latitude effects.

6.2.2 Soil Moisture Module

A ‘Soil Moisture’ module is required to provide an output to the ‘Lifecycle’ module. The module provides seasonal parameter values in the range 0-1 (absolutely dry soil to completely saturated) and it requires both internal settings and inputs from other modules.

The settings required for the soil moisture module are: ‘Soil Moisture Capacity’, Evapotranspiration Coefficient’ and ‘Drainage Rate’. The Soil Moisture Capacity records the maximum water storage capacity of the soil and is normally between 50 and 200 mm. In practice, a setting of about 100-150 mm is typical of many soils and is adequate to permit modelling of a population to proceed. Sandy soils would have a low potential soil moisture store while clay soils would be quite high. The Evapotranspiration Coefficient sets the transpiration loss from plants and their land-surface compared with an equal area of water surface; a value of 0.8 is generally sufficient. The Drainage Rate sets the limit of soil water content below which it is impossible to remove further water. Normally, this variable is set to zero which implies that it is possible to remove all soil water.

The two main inputs to the 'Soil Moisture' module are values for 'Evaporation' and 'Rainfall'. Rainfall is obtained from the meteorological data base through the procedures already described for temperature but evaporation requires an additional module to be developed.

6.2.3 Evaporation, Daylength and Queryuser Modules

The 'Evaporation' module requires four climatic inputs: minimum temperature, maximum temperature, 9am relative humidity and 3pm relative humidity. All of these are obtained from the meteorological data base and only require that the relevant module be altered so that it is able to read the appropriate file and provide the information. The effect of each of these variables is directly dependent upon the hours of sunlight and a final input to the evaporation module is supplied by a 'Daylength' module. This module requires two inputs: the day of the year (which is obtained from the 'Timer' module) and the latitude which is set by a 'QueryUser' module. The best way to envisage the process is to examine a schematic diagram (Figure 6.1).

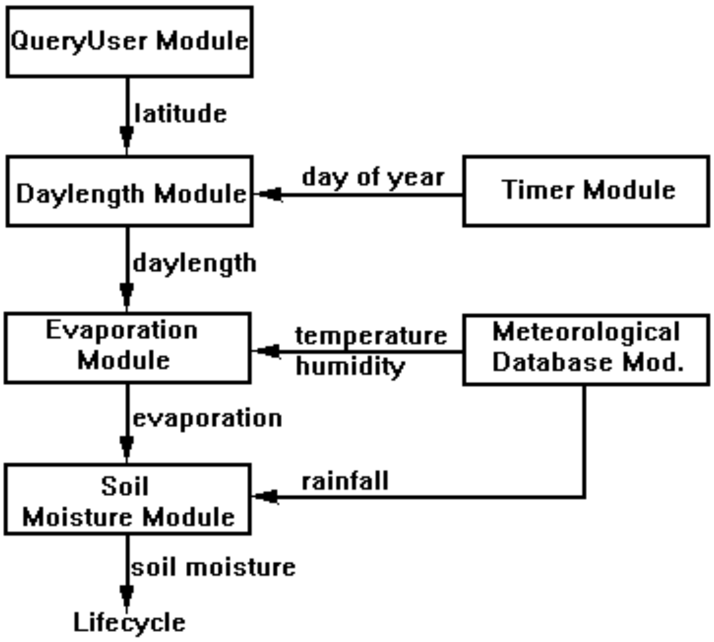


Figure 6.1 Modules for Soil Moisture

6.3 Building the Model

(Note: the user's knowledge of already covered DYMEX procedures is assumed. Individual key strokes may be omitted for well known procedures. Amberley's latitude is 27.6ºS.)

1. With the Model Builder open and the Gen-weed file loaded:
   a. select the **'Add Module'** procedure;

b. select a **‘QueryUser’** module;
c. rename it **‘Latitude’** ;
d. select the **‘Outputs’** button and obtain the **‘Output Variables’** dialogue box;
e. select the **‘New’** button and a variable named **‘Latitude Variable 1’** will appear highlighted in the list box;
f. click once on the **‘Select’** button and **‘+>’** will appear in front of the name ‘Latitude Variable 1’;
g. set the outputs to -27.6 for the default and -90 and 90 for the lower and upper limits respectively;
h. select **‘OK’** as necessary and return to the **‘Model’** window.

(These limit values allow the latitude of any world location to be inserted if desired.)

2. Select the **‘Timer’** module for editing and ensure that all possible outputs are selected (day of year, simulation date, days since start) then return to the **‘Model’** window;
3. Add **‘Daylength’** as a new module;
4. With the **‘Daylength’** module window open, select the **‘Inputs’** button then select as inputs **‘Latitude’** and **‘Day of Year’** and link them to the variables of the same name (or type) from the right hand list box - then return to the editing window;
5. Select the **‘Output’** button, ensure that **‘Daylength’** is selected **(‘+>’)** and return to the model window;
6. Select the **‘Metbase’** module for editing and ensure that **all** variables {temperature (max/min), relative humidity (9am/3pm) and rainfall} are selected as outputs, then return to the ‘Model’ window;
7. Add **‘Evaporation’** as a new module and obtain its editing window;;
8. Specify the inputs as **maximum temperature, minimum temperature, relative humidity 9am, relative humidity 3pm and daylength** and link them appropriately using the link list box;
9. Specify the output as ‘Evaporation’ and select it as a variable;
10. Exit back to the ‘Model’ window;
11. Select **‘Soil Moisture (1-layer)’** as a new module, then edit:
    a. Set linked inputs as ‘Rainfall’ and ‘Evaporation’;
    b. Select the output as ‘Soil Moisture’;
    c. Select the **‘Factors’** button;

There are three soil moisture factors, but all are constants so that no functions need be selected. Each is set by first selecting the factor name from the list box and then typing in the default and limiting values. Before proceeding to set the factors, it is worth re-considering the type of environment in which an annual would normally grow. Annuals are found under most Australian climatic conditions from the eastern coastline to the drier internal plains. These areas are usually not desert conditions although soils may range from sandy loams to heavy clay. Actual settings for the Soil Moisture (1-layer) module will depend on individual circumstances, however generalised settings can be used which can be modified for local *conditions. For Gen-weed, the Initial Soil Moisture will be set at 0.2, the Soil Moisture Capacity will be set to 100 mm, the Evapotranspiration Coefficient will be set to 0.8 while the Drainage Rate will remain at 0.*

d. Select **'Soil Moisture Capacity'** and then the **'Set parameter'** button;
e. Set the default to 100 and the lower and upper limits to 50 and 200 respectively;
f. Select '**Evapotranspiration coefficient**' followed by the **'Set Parameter'** button;
g. Set the default to 0.8 and the lower and upper limits to 0.5 and 1.2;
h. Set all values of the **'Drainage Rate'** to 0;
I. Exit to the 'Model' window (which will resemble figure 6.2) and **then open the Lifecycle window**.

There will now be 8 modules in the 'Model' window (figure 6.2). The user is reminded that the 'plus' icons allow checks to be made of all module structures if they are selected. Where parameter values have been set, these are also displayed.

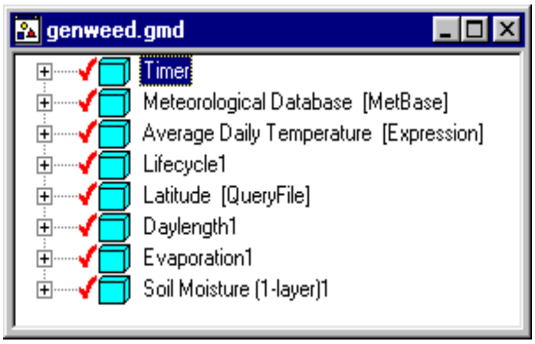


Figure 6.2 Modules present for Tutorial 6 Gen-weed Model

The 'Lifecycle' seed module presently uses rainfall as its input variable to germination. This will be amended so that soil moisture levels control this function but the step function will still be used. Germination will be set so that it is complete when soil moisture levels reach 0.2.

1. Select the **'Seed'** lifestage **'Stage Transfer'** button;
2. Highlight and select the **'Gen-weed Rainfall induced germination'** function;
3. Select the **'Edit Component'** button;
4. Change its name to **'Gen-weed Soil Moisture Induced Germination'**;
5. Change the Independent Variable to **'Soil Moisture'**;
6 Select **'Parameters'**;

7. For the threshold, set the default to 0.3 and the lower and upper limits to 0 and 1 respectively and alter its name suitably;
8. Set the step height to 1 for the default and the lower and upper limits and alter its name suitably;
9. Select **'OK'** as necessary to return to the lifecycle window;
10. Alter the sort order of the **'Lifecycle'** so that it is the last module in the processing order;
11. Save the model.

6.4 Running the Model

1. Load the Simulator and open the Gen-weed file;
2. The 'Model' window should resemble Figure 6.3;

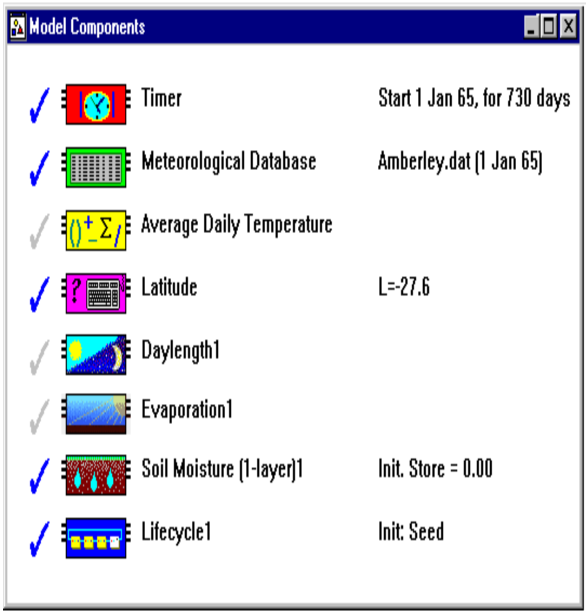


Figure 6.3 Model Components of Gen-weed model

3. Initialise the **'Soil Moisture (1-layer)'** module by setting the current value to 0.2;

This will reflect the soil moisture levels that would normally be expected in a 'generalised annual' environment.

4. Initialise the **'Meteorological Database'** module by setting:

9am Humidity: column 31, width 4
3pm Humidity: column 45, width 4.

5. Run the model for 730 days and include soil moisture, average daily temperature, seed totals and totals of adult plants; the results should be similar to Fig. 6.4.

The Gen-weed model has now not only responded to the temperature and maturation time thresholds, but is also responding to the changes in soil moisture. This is not at first apparent from the charts over a 2 year period but the effects can be easily seen if comparison runs of the model are made for a single growth season (use 400 days) and the table output is examined in the vicinity of the week 40 step: the point at which seed maturation is complete. If this is done, the user will see that soil moisture is the deciding factor once the 280 day period is complete. A sample table is shown in figure 6.5.

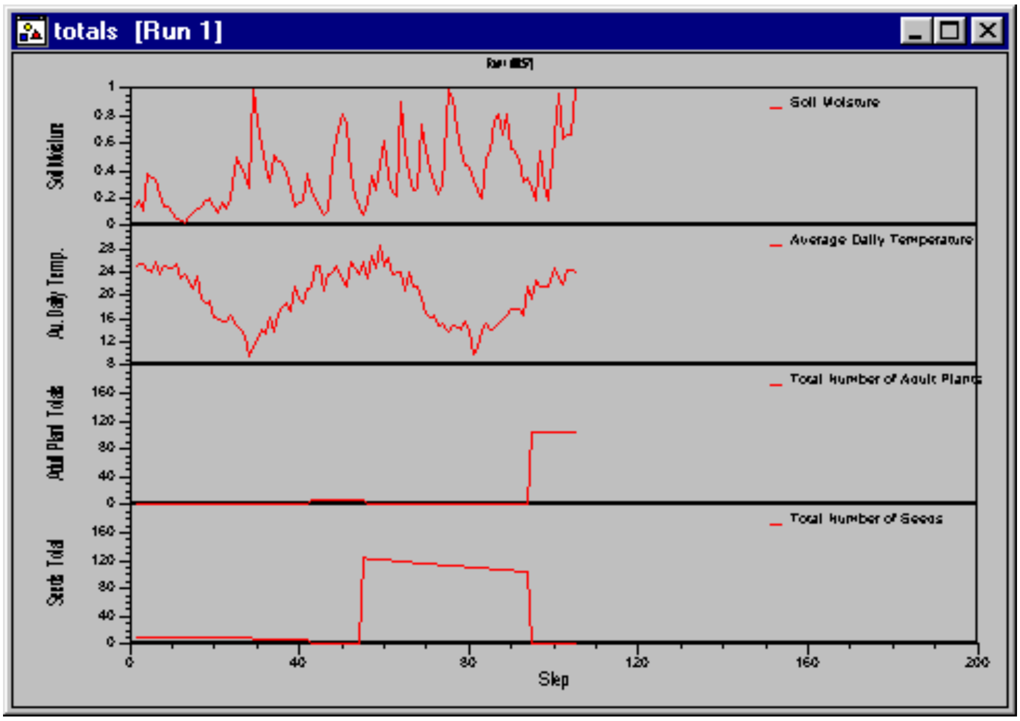


Figure 6.4 Gen-weed model - soil moisture included as a determinant for germination (Threshold 0.3). Run length 730 days.

Table-1 [Run 2]

Step	SoilMoistu	erDailTem	tNumofSe	oNuofAdF
38.00	0.27	17.36	8.45	0.00
39.00	0.14	21.64	8.42	0.00
40.00	0.17	19.43	8.38	0.00
41.00	0.19	18.93	8.34	0.00
42.00	0.38	21.14	8.31	0.00
43.00	0.26	21.43	0.00	8.31
44.00	0.18	25.14	0.00	8.31
45.00	0.14	25.14	0.00	8.31

Figure 6.5 Gen-weed model chart output, weeks 38-45
Soil moisture set at 0.3 for germination threshold

6.5 Tutorial 6 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation 1, Soil Moisture (1-layer), Average Daily Temperature.

Timer

Set to 'Days since start' and 'Simulation Date', run default 800 days.

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Temperature induced germination (3-segment linear)
Independent variable: average daily temperature
Line 1 X-intercept: 18
Line 1 slope: 0.5
X-value at intersection of lines 1,2: 20
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 26
Line 3 Slope: -0.25
Soil Moisture induced germination (step)
Independent variable: soil moisture
Rainfall threshold: 0.3
Prop. seeds germinating: 1

Combination Rule: multiply

Output: Total numbers

Adult Plant

Continuous mortality (step)
Independent variable: chronological age
Threshold: 14 weeks
Proportion of adults dying: 1

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: chronological age
Threshold: 12 weeks
Seeds/week step/adult: 15

Output: Total numbers

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:

Soil Moisture capacity: 50, 100, 200 for lower, default and upper values respectively
Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower, default and upper values respect.
Drainage rate: 0

Initialisation value for a model run: 0.2

7.0 Altering Germination Rates

7.1 Introduction and Model Changes

In Tutorial 6, soil moisture was defined in the model as one of the factors that affected seed germination. The soil moisture threshold was set at 0.3 and once this value was reached, all seeds were then considered to have germinated. This process was easily modelled by a step function with a threshold of 0.3 and a step height of 1 to indicate all seeds had germinated.

Although this model provides one way of considering seed germination, it is not the best way of dealing with the effects of soil moisture. For example, not all seeds will germinate on precisely the same day or week. Some seeds (usually a very small number) may not germinate at all and yet remain quite viable. They remain until later in the season or even perhaps retain their dormancy until the following spring.

If the model is to simulate a progressive germination over a few weeks, a better way of dealing with the process is to use a linear above threshold function. Suppose the seeds are observed to germinate in such a way that if soil moisture conditions are suitable, 99% of all the seeds have germinated by the end of three weeks. (This assumes that the seed bank 'carryover' from one season to the next is 1%, however this will not be specifically modelled in this tutorial.). As far as this tutorial's model is concerned, the number of seeds germinating might just as well be 100% and this occurs over three weekly time-steps. Assuming this is a linear function, the slope is one in three or approximately 0.33. The soil moisture threshold will remain at 0.3.

7.2 Altering the Model

For parts of the next section, the user's familiarity with the DYMEX modelling program is assumed and not all key strokes are given.

1. Start the model building program, open the Gen-weed model and obtain the lifecycle window;
2. Select the **'Stage Transfer'** button;
3. In the 'Seed - Transfer' dialogue box, ensure that in the **'Process Components'** list box, **'Soil Moisture induced germination'** is selected/highlighted;
4. Select the **'Edit component'** button;
5. Change the function to a **'Linear above threshold'** then select the **'Parameters'** button;
6. In the **'Set parameter properties'** dialogue box, select **'p1: Threshold'** then set the default to 0.3 and the lower and upper limits to 0 and 1;
7. Select 'Slope' and set the upper, lower and defaults to 0, 1 and 0.33;
8. Select **'OK'** as necessary to return to the model window and then

save the model.

7.3 Running the Model

Ensure that the model is initialised with 10 seeds and a run length of 730 days. If the average daily temperature, soil moisture and numbers of seeds and adult plants are graphed, the result should be similar to figure 7.1

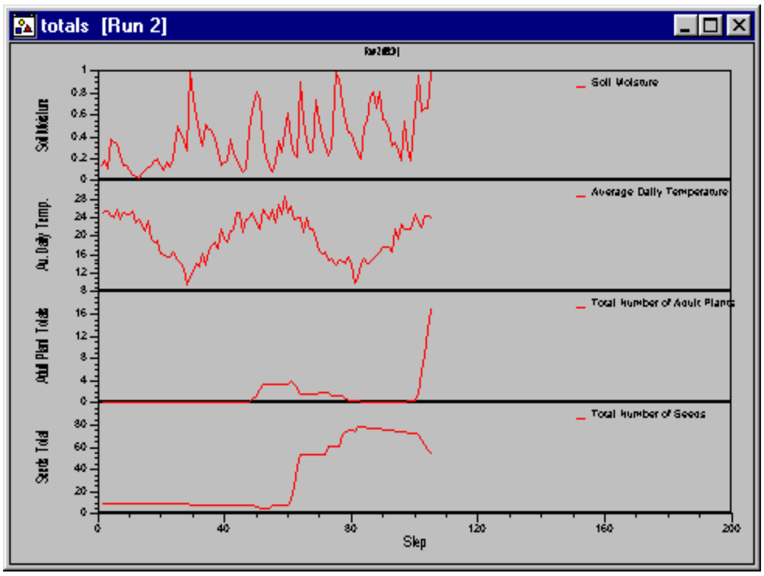


Figure 7.1 730 day run for Genweed

The output of figure 7.1 clearly shows that the alteration to the soil moisture induced germination process produces delays in the germination of the seeds. This can be seen in the numbers of plants present in the first year as they no longer rise and fall sharply. Another indication is that the numbers of seeds never falls to zero (the relevant chart scale range for seeds in fig. 7.2 is 4-12).

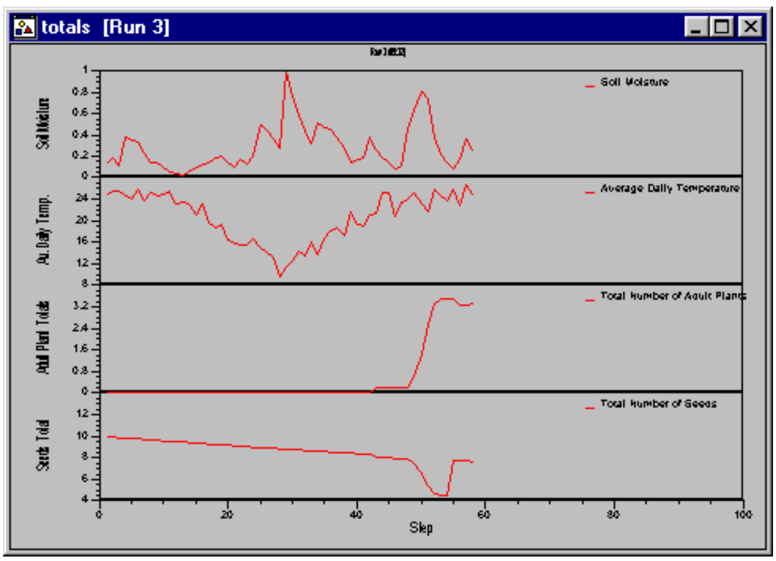


Figure 7.2 400 day run for Gen-weed

The user is strongly advised to open a tabular display for a model run over two years and include step, day of year, soil moisture, average temperature, total numbers of seeds and total numbers of adult plants. If this is done and the model examined near step 40 in the first year, the movement of seeds to adult plants will very clearly be seen to be conditional upon both average temperature and soil moisture and that the transfer is also controlled by the slopes of the germination functions.

In figure 7.2, germination is seen to occur day 280 however not all seeds germinate and conditions become unsuitable for further germination until at or near day 320 when the more of the seeds begin to germinate. The effect of soil moisture is very clearly seen as the levels fall away after the initial germination on day 280 and do not return to suitable levels for germination until about day 320. Again, if the user inspects a tabular output, the levels of seeds and adult plants (together with the effects of soil moisture and temperature) become much easier to see.

Figure 7.2 also clearly shows the effects of the daily seed mortality rate as the number of seeds remaining steadily decreases over time. If the model is run over longer periods of time, the ‘Running Model’ window (which appears while the model is being processed) indicates that the number of cohorts present rises - a clear indication that the model is no longer producing the situation where as one generation dies, the next appears.

7.4 Tutorial 7 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation 1, Soil Moisture (1-layer), Average Daily Temperature.

Timer

Set to 'Days since start' and 'Simulation Date', run default 730 days.

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
- Continuous
  - Constant: 0.00441

Transfer functions
- Seed Maturation (step)
  - Independent variable: chronological age
  - Germination threshold: 40 weeks
  - Prop.seeds transferred: 1
- Temperature induced germination (3-segment linear)
  - Independent variable: average daily temperature
  - Line 1 X-intercept: 18
  - Line 1 slope: 0.5
  - X-value at intersection of lines 1,2: 20
  - Line 2 Slope: 0.0
  - X-value at intersection of lines 2,3: 26
  - Line 3 Slope: -0.25
- Soil Moisture induced germination (linear above threshold)
  - Independent variable: soil moisture
  - Rainfall threshold: 0.3
  - Rate of germination: 0.33

Combination Rule: multiply

Output: Total numbers

Adult Plant

Continuous mortality (step)
- Independent variable: chronological age
- Threshold: 14 weeks
- Proportion of adults dying: 1

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: chronological age
Threshold: 12 weeks
Seeds/week step/adult: 15

Output: Total numbers

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:

Soil Moisture capacity: 50, 100, 200 for lower, default
and upper values respectively
Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower,
default and upper values respect.
Drainage rate: 0

Initialisation value for a model run: 0.2

8.0 Introducing Temperature Controlled Adult Plant Development

8.1 Chronological and Physiological Age

The present Gen-weed model uses chronological age to determine the sequence of reproduction in the adult plant. Chronological age is unsatisfactory as the sole controlling influence on a plant's lifecycle because a plant's physiological development (and by implication its reproduction and mortality) can be independent of chronological age and may be largely controlled by temperature and moisture. This DYMEX tutorial begins the process of modelling Gen-weed adult plant development based on physiological age and a temperature dependent rate of development. Since the process is complex, tutorials 8 and 9 form a sequence. An artifact is used in tutorial 8 in which the plant's physiological development is 'greenhouse temperature' controlled while the remainder of the plant's modelled functions are subject to field meteorological conditions. This is used to reduce the quantity of new DYMEX operations encountered in a single tutorial and the model will return to complete field conditions in tutorial 9.

Since physiological age now enters all further tutorial models, it is defined below:

> Physiological age measures the state of development of an individual with its units generally stated as a proportion (or percentage) of completed development. As an example, the germination of Gen-weed could be scaled to 0 and its arrival at adult reproduction scaled as 1. When plant development is temperature dependent, accumulation of physiological age is usually non-uniform.

8.2 Changing the Model

8.2.1 Gen-weed and Temperature

Since Gen-weed's lifecycle is 'well known from published papers', the effects of temperature on development are available and are presented in table form (Table 8.1).

Temperature (ºC)	No. of weeks to develop from germination to adult plant
10	No development
15	22
20	14
23	12
25	10
30	10
35	No development

Table 8.1 Temperature effects on Gen-weed adult plant development

The model developed in tutorial 7 remains essentially intact but the transition from germinated seedling to adult plant (currently determined by a chronological age of 12 weeks) becomes dependent upon physiological age and this in turn is dependent upon average daily temperature. All seedlings still become adults when they reach the required physiological age. Although the values of table 8.1 have been carefully ‘chosen’ to provide reasonably clear results, they demonstrate the principles on which DYMEX operates and the values have been selected with actual plant growth patterns under consideration .) As already noted, to preserve simplicity, this preliminary model will simulate temperature controlled development under greenhouse conditions so that temperatures can be pre-set; in tutorial 9 the model will return to full field conditions.

The results of Table 8.1 can be amended to display rate of development per week. This is done by calculating the reciprocal of the number of weeks taken to develop to adult (which assumes that the value ‘1' represents the physiological age of an adult). For example, suppose a herb takes 50 weeks to develop from germinated seedling to adult plant; its rate of development per week would therefore be 0.02 (ie. 0.02 * 50 = 1). Table 8.2 shows the results for Gen-weed.

Temperature (°C)	No. of weeks to develop to adult	Rate of development per week
10	No development	0
15	22	0.0454
20	14	0.0714
23	12	0.0833
25	10	0.1
30	10	0.1
35	No development	0

Table 8.2 Temperature controlled weekly development rates in Gen-weed

These results can now be transposed into graphical format (Figure 8.1) which shows that Gen-weed’s growth pattern conforms very well to a three segment linear function which is readily modelled by DYMEX. An inspection of the graph shows that the AB segment has a threshold of 10°C and a slope of approximately 0.0067; the section BC has a slope of 0.0 and the section CD has a slope of -0.02 .

The reproduction phase of the model will also require alteration since seed production will now be dependent upon the physiological maturation of the adult plants. This is easily done by changing the driving variable of seed production to physiological age with a setting of 1 .

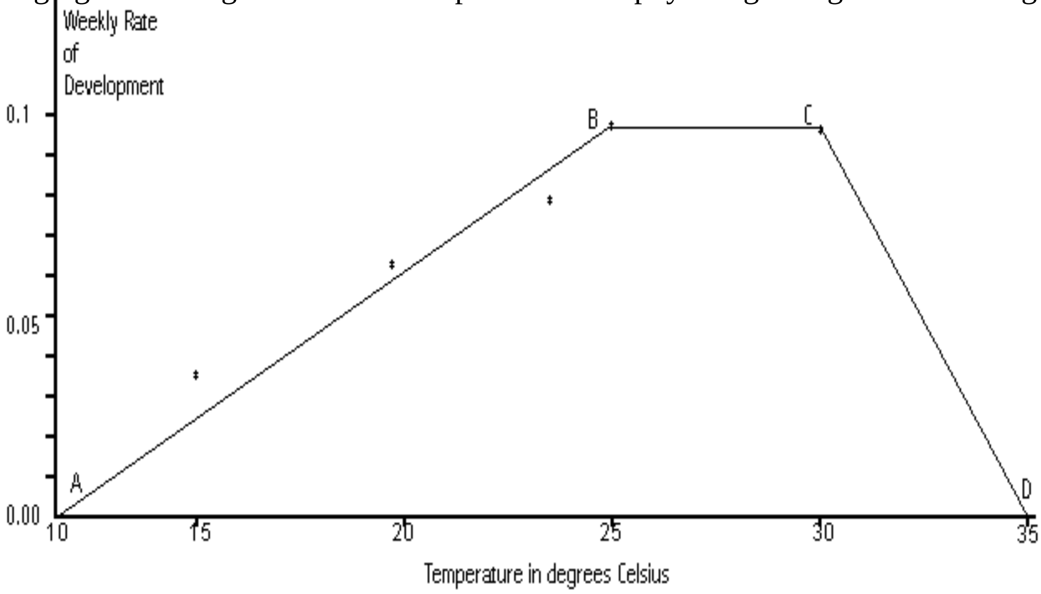


Figure 8.1 Rate of Physiological Development

8.2.2 Building the Model

Start the DYMEX Model Builder and open the Gen-weed model. The 'Model' window will be displayed and all modules (currently eight) will be shown. An additional module is added to control temperature and since the temperatures will be 'user defined' (set in the greenhouse), this will be a 'Query User' module.

1. Select **'Model'**;
2. From the drop-down menu, select **'Add Module'**;
3. From the **'Create Module of Type ?'** list box select **'Query User'**.
4. Select **'OK'** to obtain the **'Query User'** module window;
5. Name the module **'Greenhouse Temperature'**;
6. Select **'Outputs'** button to obtain the 'Output Variables' dialogue box.

The range of temperatures under which Gen-weed will be grown is now set. The values entered into DYMEX will be strictly a decision of the user, but for this tutorial, a suitable range might be 0-40 °C with 18 °C selected as the default value.

7. Select **'New'** button and the name **'Greenhouse Temperature Variable 1'** will appear in the 'Module Output Variables' dialogue box;

8. Click on **'Select'** button and '+>' will appear beside the variable name to indicate it is selected for alteration;
9. Select and set **'Minimum allowed value'** to 0, **'Maximum allowed value'** to 40 and **'Default value'** to 26;
10. Select **'OK'** as required to return to the 'Model' window.

The 'Model' window now shows a new module called 'Greenhouse Temperature'. If its '+' icon is selected, a sub-heading labelled 'Outputs' will appear, which if selected produces a new sub-heading labelled 'Greenhouse Temperature Variable 1'. [The user is reminded that while in the 'Model' window, it is worth exploring all the '+' icons for each module and checking that all values and inputs/outputs are set as required.]

The Gen-weed model now has a range of temperatures within which it can be run, however the adult lifestage must be changed to allow those temperatures to influence the adult plant appropriately. The development function driving variable must be set to 'Greenhouse Temperature' and the remaining parameters modified to reflect the data of Table 8.2.

1. Double click on **'Lifecycle'** text and obtain the 'Lifecycle' window;
2. Select the **'Development'** button of the **'Adult plant'** lifestage;

The 'Process Components' list box will already have 'Chronological Age - Function' in the box and it will be highlighted/selected.

3. Select **'Function'** to obtain the 'Function' dialogue box;
4. From the function scroll box select the **'3-segment Linear'** function;
5. Select **'Independent Variable'** scroll button;
6. From scroll list, select **'Greenhouse Temperature Variable 1'**;
7. From the 'Name' edit box, select the **'Change'** button;
8. In the resulting edit box, type in a suitable name (eg. **'Adult Plant Temperature controlled Development'**);
9. Select **'Parameters'** button and obtain 'Set Parameter Properties' dialogue box;

{The user may wish to set individual names for each of the following variables. This is not strictly necessary, but it can help later if the user is looking for easily recognised variables in the 'List parameters' mode.}

10. The parameter **'Line 1 X-intercept'** will be present in the list box and the values 0, 15 and 10 should be entered in the lower limit, upper limit and default boxes respectively;
11. Re-name the variable suitably if necessary (eg. 'Development threshold');
12. Open the parameter scroll box and select **'Line 1 Slope'**;
13. Set all the lower and upper limit values to 0 and 1 respectively, then set the default to 0.0067 and re-name the parameter if required (eg 'Initial rate of development');
14. Re-open the parameters scroll box and select **'X value at**

intersection of lines 1,2';

15. Set the upper and lower limits to 20 and 30 and the default to 25;
16. Re-name the parameter suitably if required (eg Max. development rate temperature threshold');
17. Re-open the parameter scroll box and select **'Line 2 Slope'**;
18. Set all limits and the default to 0;
19. Re-name the parameter if required (eg 'Development rate plateau');
20. Re-select the parameter scroll box and select **'X-value at intersection of lines 2,3'**;
21. Set the lower and upper limits to 25 and 35 respectively and the default to 30;
22. Re-name the parameter if required (eg 'Development rate decrease threshold');
23. Re-open the parameter scroll box and select **'Line 3 Slope'**;
24. Set the lower and upper limits to -1.0 and 0 respectively and the default value to -0.02;
25. Re-name the parameter if required (eg. 'Rate of development decrease');
26. Select **'OK'** as necessary to return to the model window;
27. Save the model.

The Adult Plant lifestage is now modified so that the reproductive step function is dependent upon the physiological age of the Gen-weed plants. Since the value of adult physiological age is 1, and at that point the plant produces its seeds in a single batch of 15, the modifications are to change the driving variable to physiological age, the default threshold to 1 and the lower and upper limits to 0 and 1 respectively.

1. Select the Adult Plant lifestage **'Reproduction'** button to obtain the **'Adult Plant Reproduction'** selection box;
2. Select the **'Progeny Production'** button to obtain its dialogue box;
3. Select the **'Edit Component'** button;
4. Set the **'Independent Variable'** to **'Physiological Age'**;
5. Change the function name if required;
6. Select **'Parameters'**;
7. With **'(a)Threshold'** in the parameter list box, set the lower and upper limits to 0.0 and 1.0 respectively and the default to 1.0;
8. Rename the parameter if necessary;
9. Ensure that the step height is set to 15 for all the limit and default values;
10. Select **'OK'** as required to exit to the **'Lifecycle'** window;
11. Alter the sort order of the **'Lifecycle'** so that it is last in the list;
12. Save the model.

There will now be a tick on the 'Development' button of the Adult Plant stage.

8.3 Running the Improved Model

8.3.1 Loading the Model

Loading and running the temperature modified Gen-weed file is identical to the procedures already described. An important difference with this new model is that the green-house temperature can be altered to examine temperature development dependency in the Gen-weed population.

8.3.2 Initialising the Model

A new 'Greenhouse Temperature' module will be present in the 'Model Components' window (Figure 8.2) and this should be checked before the model is run. Since the effects of the temperature controlled development in the adult plants produce long term effects, the model will be run over 1460 days (4 years). The number of seeds at the start of the run can be left at 10 .

Figure 8.2 Module Components Window

1. Select **'Greenhouse Temperature'**;
2. Select **'Initialise Variable Manager'**;
3. Ensure the Greenhouse Temperature has a default of 26 °C;
4. Select **'OK'** as necessary to return to the 'Model Components' window;

5. Run the model (Select ) for a period of 1460 days.

8.4 Results

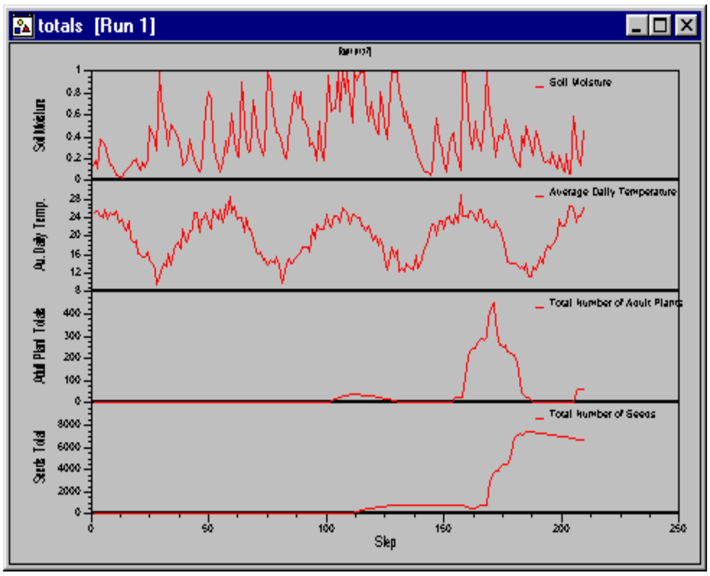


Figure 8.3 Temperature controlled Gen-weed development (4 year run, Greenhouse temperature 26°C)

As expected, the favourable greenhouse default temperature allows the plants to reproduce quite well. If however, the greenhouse temperature is set to 18°C, the Gen-weed seeds will still germinate but the temperature is too low to allow the adult plants to reach physiological maturity within their lifespan and the population dies out (figure 8.4).

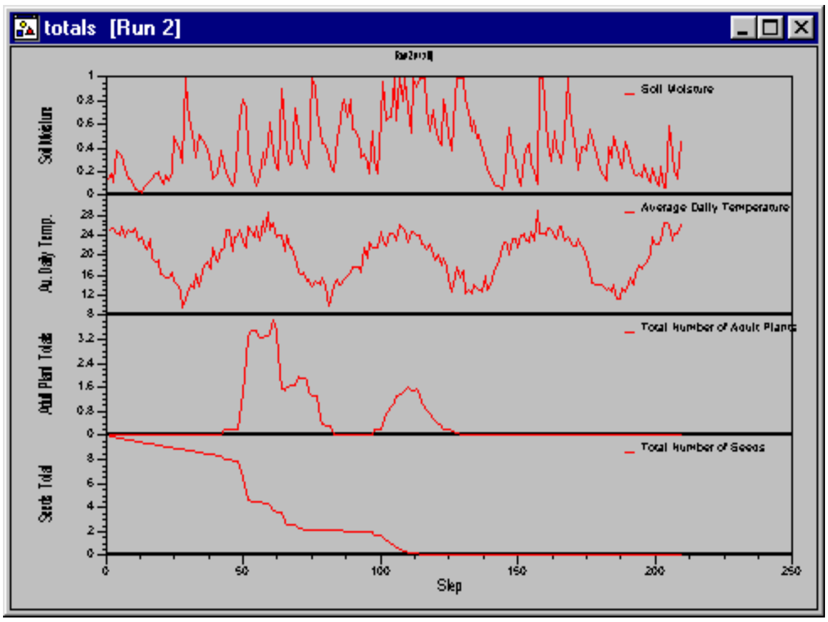


Figure 8.4   Gen-weed temperature controlled development
(4 year run, Greenhouse temperature 18ºC)

The user should experiment with other settings of the Greenhouse temperature to see the effects of the various temperatures and also try shorter lengths of time to explore the effects. If the Running Model window is examined, it will be found that often more than 50 cohorts are present in the model as the seeds do not all germinate at the same time and conditions then become unfavourable for further germination. The result is a permanent seed bank becomes established whether it is the favourable growing period or not.

It is also worth running the model for 10 years (3650 days) - **see note below** - with a greenhouse temperature of 26°C. If this is done using logarithmic scales, the result is as shown in figure 8.5.

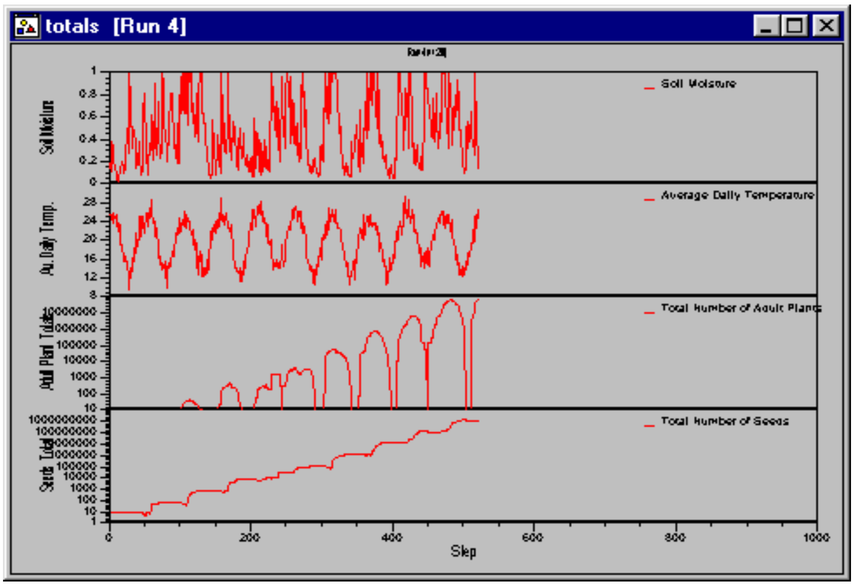


Figure 8.5   Gen-weed run for a period of 10 years under controlled temperature of 26°C; logarithmic scales shown.

Note: One minor problem may arise during the initial run: the program may report that there is a datum out of the set range. If this does occur, the most likely item is an unusual rainfall record for a day in which over 200mm of rain fell at Amberley, however the selected rainfall range for the Metbase initialisation is set from 0-200. The user can opt for one of two ways to 'fix' the problem. Open the Metbase initialisation window and select 'Format'. Then select the button 'More Options'. This will open an auxiliary area which has a 'Data Validity Checks' panel. Now select 'Rainfall' from the 'Variables' list. The validity checks panel should now have a tick in the box labelled 'Check maximum in range' and the value 200 set as a maximum. The two actions are either to re-select the tick box and remove the tick, or alternatively, set the maximum to 500. The model will then run.

Of course, the current model is extremely artificial. All other climatic variables are based on meteorological data and adult plant development should be no exception. The use of a greenhouse model allowed the processes of temperature controlled development to be explained simply. The next tutorial will replace the greenhouse with the field based temperatures of the metbase module and will also introduce the concepts of degree days as applied to physiological development.

8.5 Tutorial 8 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation 1, Soil Moisture (1-layer), Average Daily Temperature, Greenhouse Temperature.

Timer

Set to 'Days since start' and 'Simulation Date', run default 1460 days.

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
- Continuous
  - Constant: 0.00441

Transfer functions
- Seed Maturation (step)
  - Independent variable: chronological age
  - Germination threshold: 40 weeks
  - Prop.seeds transferred: 1
- Temperature induced germination (3-segment linear)
  - Independent variable: average daily temperature
  - Line 1 X-intercept: 18
  - Line 1 slope: 0.5
  - X-value at intersection of lines 1,2: 20
  - Line 2 Slope: 0.0
  - X-value at intersection of lines 2,3: 26
  - Line 3 Slope: -0.25
- Soil Moisture induced germination (linear above threshold)
  - Independent variable: soil moisture
  - Rainfall threshold: 0.3
  - Rate of germination: 0.33

Combination Rule: multiply

Output: Total numbers

Adult Plant

Continuous mortality (step)
- Independent variable: chronological age
- Threshold: 14 weeks
- Proportion of adults dying: 1

Development (3-segment linear)
Independent variable: Greenhouse temperature
Line 1 X-intercept: 10
Line 1 slope: 0.0067
X-value at intersection of lines 1,2: 25
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 30
Line 3 Slope: -0.02

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: physiological age
Threshold: 1
Seeds/adult: 15
Output: Total numbers

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:
- Soil Moisture capacity: 50, 100, 200 for lower, default and upper values respectively
- Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower, default and upper values respect.
- Drainage rate: 0

Initialisation value for a model run: 0.2

Expression (Greenhouse Temperature)

Outputs (user set default): 26^{o}C

9.0 Degree Days and Plant Development

9.1 Introduction

The use of physiological age rather than chronological age is the preferred approach when modelling organisms incapable of maintaining their own body temperature. In the previous tutorial, Gen-weed's physiological development was made temperature dependent, and its rate determined by the settings of greenhouse temperature. In the field, temperatures vary both on a daily and seasonal basis and these variations will now be applied to the Gen-weed model to give a more accurate picture of how the plant behaves under natural conditions.

9.2 The 'Degree Day' Concept

9.2.1 Calculating Degree Days Using Average Temperatures

Gen-weed has been given a development threshold of 5°C which implies that once the temperature rises above that threshold, development proceeds. Suppose that Genweed was growing under ideal conditions where the temperature was maintained at a steady 23°C. (This is in the mid-plateau area of the physiological development rate function.) The result would be that Gen-weed adult plants would develop without cessation and population growth would be limited only by other external climatic or physical factors. One way of considering the 'temperature-time bank account' for Gen-weed's growth is shown in Figure 9.1.

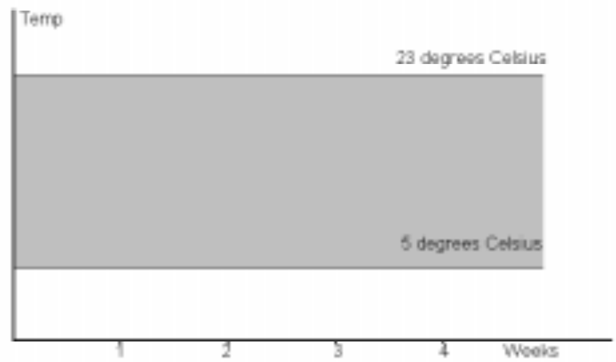


Figure 9.1 Degree Days for Gen-weed (shaded area shows day degree accumulation)

The shaded area represents the available 'degree days' for each Gen-weed plant over several weeks. Each day has a temperature difference of 18°C from the temperature threshold of 5°C.

and in this case the accumulation of day degrees can be worked out by simple products (1 day = 18 degree days, 2 days = 36, etc.). Figure 9.1 resembles a greenhouse controlled environment in which the total degree days for the four week period would be 504 degree days.

Suppose now the average temperature per week step is calculated and over a four week period is found to be 10°C, 4°C, 12°C and 18°C. Since for a simple average, the temperature is considered to be uniform throughout the weekly period, the result is a 'square wave' (Figure 9.2).

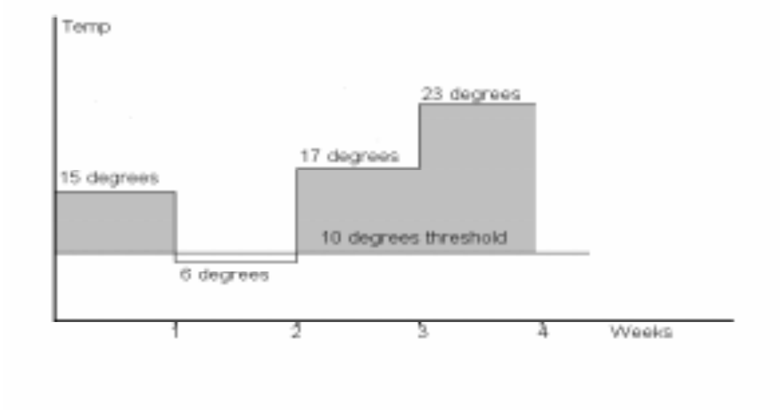


Figure 9.2 Degree days accumulation for Gen-weed over four weeks using average temperature (shaded area represents degree day accumulation.)

When the temperature is above the threshold of 10°C, the Gen-weed plants are able to develop and this is indicated by the shaded area; week 1 produces 35 degree days, none are produced in week 2, week 3 produces 49 and week 4 produces 91. During week 2, the temperature drops below the threshold for growth and the only effect on Gen-weed is that development temporarily ceases.

9.2.2 Calculating Degree Days Using the Circadian Cycle

Obviously, the 'square wave' of Figure 9.2 is also a poor approximation to the field situation because temperatures do not stay at the average value over the 24 hour period of a day. To compensate, DYMEX can apply a more or less sinusoidal wave shape for the 24 hour period. DYMEX uses the daily maximum and minimum temperatures of the meteorological database to fix the 'crest and trough' limits of a sinusoidal, circadian cycle of temperatures and interpolates for all the values it may require in between the two limits. Since the maxima and minima may fluctuate, DYMEX is able to smooth the 'circadian curve' so that it fits the daily fluctuations accurately (Figure 9.3). (DYMEX holds several variations on the simple sine curve so that variations in shape can modelled.)

Once the temperature fluctuations are correctly modelled, DYMEX determines the degree days available for an organism's development by calculating the area under the circadian curve and above the threshold temperature for development. It does this by splitting the day into segments and calculating the area in each of the rectangular approximations thus formed. (The user is able to tell DYMEX how many segments are required and thereby the accuracy of the area under the curve, however in practice, 12 two hour segments have been found to produce all the accuracy required for most situations.)

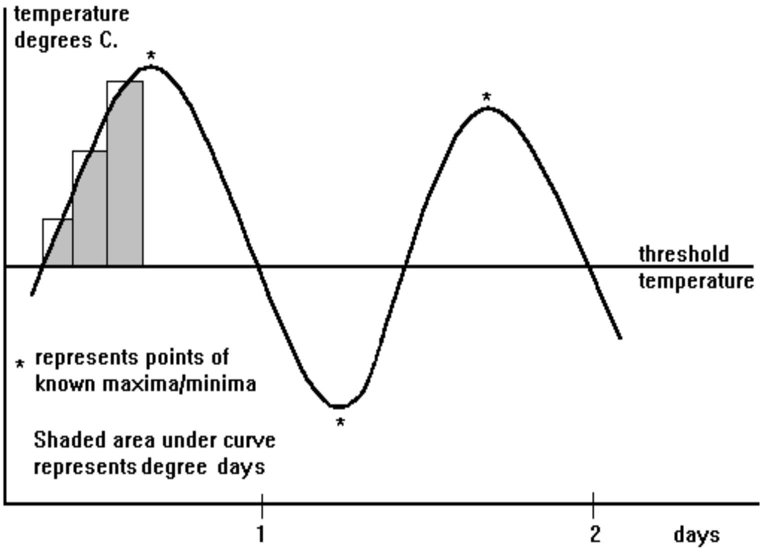


Figure 9.3 Circadian cycle and summation of degree days

The current Gen-weed model already uses degree days for determining physiological age, however they are calculated on the 'square wave' average method. In the following tutorial, the model will be modified so that circadian curve generated degree days will be incorporated into the model.

9.3 Modifying the Model

1. Start the Model Builder program and open the Gen-weed model;
2. Select **'Add Module'** from the drop down menu;
3. Select **'Circadian'**;
4. Rename the Circadian module **'Daily Temperature Cycle'**;
5. Select **'Inputs'**;
6. From **'Inputs to be Linked'** list box, select **'Daily Minimum Value'**;
7. From **'Link for Selected Variable'** list box, select **'Minimum Temperature'**;
8. Repeat steps 7 & 8 for **'Daily Maximum Value'** and **'Maximum Temperature'**;
9. Select **'OK'**;

10. Check **'Output'** is set to **'Daily Cycle'** and then click on **'Select'** to give **' +> '** beside the set variable;
11. Rename the variable **'Daily Temperature Cycle'**;
11. Select **'OK'** as necessary to exit to **'Model'** window.

With the circadian cycle set, the remaining modification takes place in the Adult plant lifestage within the development function which must be changed to use the 'Daily Temperature Cycle'.

1. With the **'Lifecycle'** module for open for editing, select the **'Development'** button of the **'Adult Plant'** lifestage;
2. Select the **'Edit Component'** button;
3. Select the **'Independent Variable'** list box;
4. Select **'Daily Temperature Cycle'**;
5. Suitably change the function name if necessary;
6. Select **'OK'** as necessary to return to the '**Model'** window;
7. Delete the **'Greenhouse'** module by selecting **'Module'** from the menu bar followed by **'Delete Module'** from the drop-down menu.

With physiological age now a factor in the model, it becomes useful to examine the rates of physiological growth in the adult plants. This can be done by changing the model so that phyiological growth is provided as an output.

1. With the **'Lifecycle'** module open for editing, select the **'Lifestage Outputs'** button for the Adult Plant;
2. Select **'Average physiological age'** as an output and return to the **'Lifecycle'** module window ;
3. Alter its sort order so that the **'Lifecycle'** module is last in the processing list;
3. Save and close the model.

9.4 Running the Model

Run the model for 7 years, (2555 days) and produce outputs for soil moisture, daily temperature cycle, numbers of adult plants and numbers of seed but use logarithmic scales for the total numbers of seeds and adult plants. The result will be similar to figure 9.4. It will be immediately noticed that Gen-weed, as it is currently described by the model parameters, is well able to survive under the field conditions of Amberley. The seeds germinate and the adult plants are able to complete their physiological development and produce sufficient seeds to maintain the population.

If the average physiological development rates are graphed (figure 9.5) the disjoint curves show the steady increase in development over time as the temperatures increase. The separate sections are caused by death of the annual populations each year and the low start is due to the lower temperatures at the start of the growth season. Notice that the rates of development fluctuate considerably depending upon the climatic variables and their effects on the population. It is left to the user to explore these areas of the model using tabular displays which show the actual values for each of the variables over time.

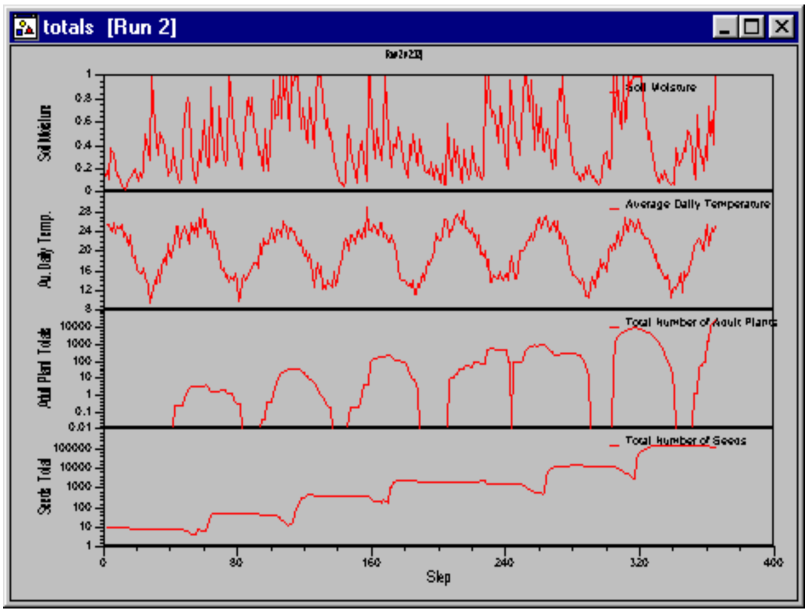


Figure 9.4 Gen-weed model 7 years run under daily temperature cycle; adult plant plateau cut-off set to 30°C. Logarithmic scaling.

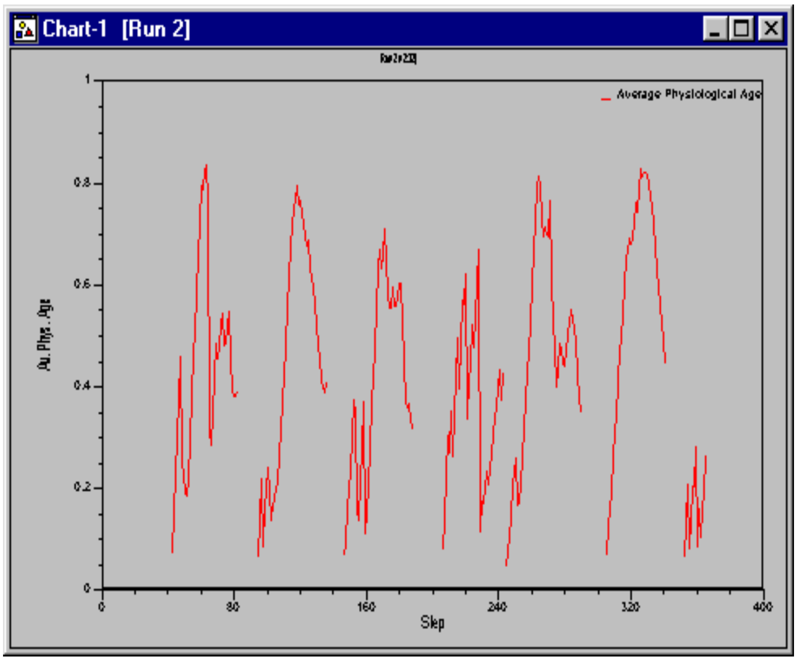


Figure 9.5 Gen-weed adult plant average physiological development; model run for a 7 year run under daily temperature cycle;

adult plant plateau cut-off set to 30°C

The sensitivity of the model can also be explored by altering the temperature development parameters. If the temperature plateau is decreased by changing the value of the end parameter from 30°C to 27.5°C (figure 9.6) the plants become extinct during the sixth year. Notice that the chart outputs are not implying that germination conditions are inadequate; germination occurs quite prolifically as long as seeds are present, however the adult plants are unable to reach physiological maturity and produce seeds. If the 'Running Model' window is examined while a model is running, it will be seen that the number of cohorts eventually drops to zero before the run is completed. This unsuitable development situation is also displayed if only physiological development is graphed (figure 9.7). All development ceases after the first five years.

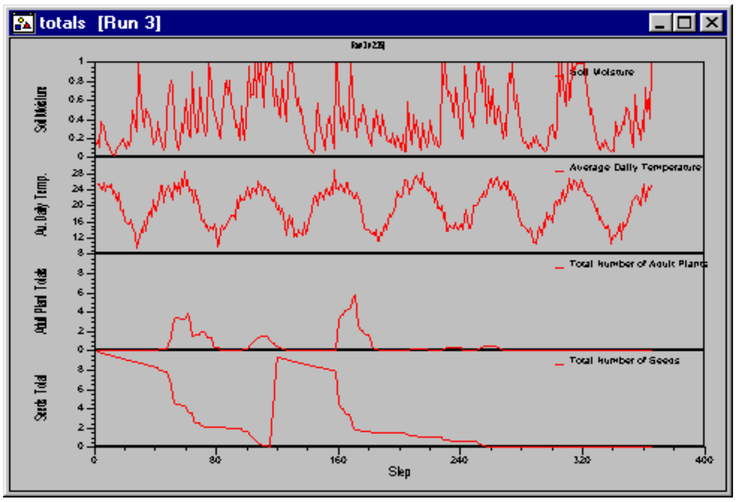


Figure 9.6 Gen-weed model run for 7 years under Circadian temperature temperature cycle; adult plant plateau cut-off set to 27.5°C

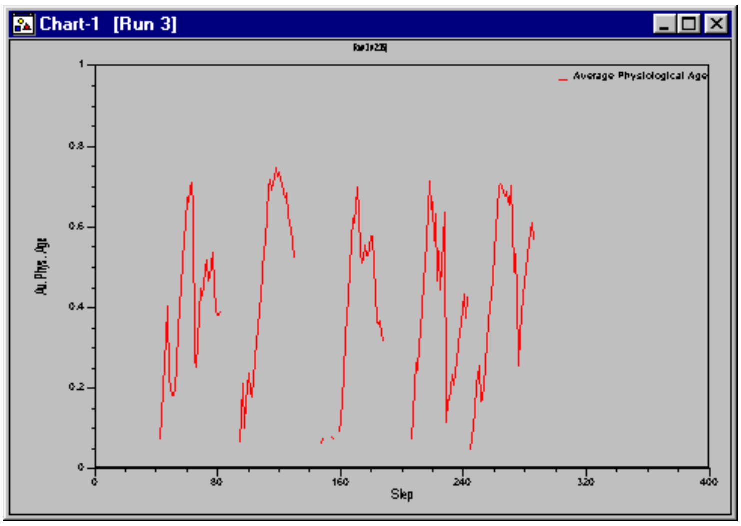


Figure 9.7 Physiological development in Gen-weed (7 year run, adult plateau cutoff set to 27.5°C

A comparison of the two physiological develoment rate graphs also shows marked differences. The unfavourable temperature situation (figure 9.7 - 27.5°C) displays much less development and if year 1 is examined it will be seen that for the 30°C run, the whole graph has been shifted upwards so that development proceeds at much greater rates. Similar alterations will be percieved if the two figures are further compared.

An interesting exercise is to run the present model with a series of plateau temperatures in the range 27.5-28.0°C . It will become apparent that there is a temperature in between at which the population is artificially stable for the climatic conditions at Amberley.

9.5 Tutorial 9 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation, Soil Moisture (1-layer), Average Daily Temperature, Greenhouse Temperature, Circadian (Daily Temperature Cycle).

Timer

Set to 'Days since start' and 'Simulation Date', run default 2555 days.
Timestep: weekly

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Temperature induced germination (3-segment linear)
Independent variable: average daily temperature
Line 1 X-intercept: 18
Line 1 slope: 0.5
X-value at intersection of lines 1,2: 20
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 26
Line 3 Slope: -0.25
Soil Moisture induced germination (linear above threshold)
Independent variable: soil moisture
Rainfall threshold: 0.3
Rate of germination: 0.33

Combination Rule: multiply

Output: Total numbers

Adult Plant

Continuous mortality (step)
Independent variable: chronological age
Threshold: 14 weeks

Proportion of adults dying: 1

Development (3-segment linear)
Independent variable: Daily temperature cycle
Line 1 X-intercept: 10
Line 1 slope: 0.0067
X-value at intersection of lines 1,2: 25
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 30
Line 3 Slope: -0.02

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: physiological age
Threshold: 1
Seeds/adult: 15

Outputs: Total numbers, Physiological development

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:
Soil Moisture capacity: 50, 100, 200 for lower, default and upper values respectively
Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower, default and upper values respect.
Drainage rate: 0

Initialisation value for a model run: 0.2

Circadian (Daily Temperature Cycle)

Inputs: Daily maximum temperature, daily minimum temperature, day length.
Output: Daily temperature cycle.

10.0 Setting up a New Cohort Property

10.1 Introduction to Cohorts

DYMEX has a default set of cohort properties (mortality, numbers, development, reproduction, etc. - see tutorial 1) that have all been used in the Gen-weed model. There are, however, occasions when a cohort property is required which is not included in the default set, and DYMEX contains operational procedures which allow the user to set up such properties.

This tutorial (and the next two) will develop the model so that it will finally examine the effects on the Gen-weed population when the growth of its members limits the numbers of individuals that can exist in a particular area. To do this, a new cohort property (to be called 'Canopy Area') will be set up and since the model will examine the numbers of individuals in a specific area, the 'Resource' button's function will also eventually be introduced.

In DYMEX, the term 'cohort' has a specific meaning which is repeated here to ensure no confusion results during the application of this tutorial:

'A cohort is a population subgroup whose individual organisms all begin a particular stage of their life cycle at the same time step interval.'

A cohort is the basic unit that is modelled in a DYMEX life cycle. Each cohort consists of a number of individuals, a single individual, or even fractions of an individual. (This last 'unusual' situation is caused by the attributes of a mathematical model: fractional individuals cannot occur in the field but they can appear in models which deal with populations and their behaviour.) All the individuals of a cohort belong to the same lifestage, occupy the same spatial unit, and share the same properties in common, like the time (day) they entered a lifestage, or the rate of physiological growth. **All the individuals within a cohort are assumed to experience the same conditions during the course of a simulation**. An example of a cohort would be all the seeds germinating on a particular day during the simulation. At any one time during a simulation, each lifestage may contain many cohorts.

Individuals can leave a cohort in a variety of ways: death and migration (e.g. seeds attached to an animal or carried by wind) are two examples, and both will produce a net reduction in cohort numbers. It is possible for either or both of these factors to produce situations in which the number of individuals in the cohort falls to zero: the cohort is then removed from the simulation.

10.2 Multiple Cohorts in a Model

The easiest method of understanding how numbers of cohorts can be present in a very simple model is to consider seed germination in a comparatively short lived species of *Acacia* where the event of a low intensity fire produces maximum germination, for example *A. fimbriata*. Suppose at the end of flowering, a small shrub of *A. fimbriata* produces 5000 seeds of which only 12 seeds survive to germinate because of the effects of various seed mortality factors. Assume the simplest case where a single shrub is present at the January start of the model and: all seeds are produced at the end of a single flowering period during late winter (August), all seeds germinate simultaneously through heat stimulation from a brush fire that just happens to occur each year in the second week of November and the seedlings then mature under identical conditions(soil, climate, etc.); all plants begin seed production at the age of two years, die only of old age and have a life span from seed germination of 8 years. The cohort numbers for three years would resemble the following summary:

Year 1

Jan. ⇨ Aug. 1 cohort with a single individual.
Sep.⇨ Dec. 2 cohorts; (cohort #1 has a single adult plant; by December, cohort #2 has 12 seedlings).

Year 2

Jan. ⇨ Aug. 2 cohorts.
Sep.⇨ Dec. 3 cohorts; (cohort #1 has a single adult plant; by December, cohort #2 has 12 juvenile plants and cohort #3 has 12 seedlings.)

Year 3

Jan. ⇨ Aug. 3 cohorts.
Sep.⇨ Dec. 4 cohorts; (cohort #1 has a single adult plant; by December, cohort #2 has 12 adult plants; cohort #3 has 12 juvenile plants and cohort #4 has 48 seedlings, 12 from each of the four adult plants contained in cohorts #1 & #2).

This process would continue to increase the number of cohorts present until year 8 was reached when the individual of cohort #1 would die. It is left to the user to extrapolate the model to see what the numbers of cohorts will eventually become.

Suppose however, that the artificially contrived November fire that is assumed for the above example occurs on random dates. Further, assume that the fire intensity varies depending upon the amount of litter and local weather conditions and also that the surviving seeds may be more or less buried in the topsoil. Under these more natural conditions, the germination dates of *A. fimbriata* seeds will vary considerably. From any batch of seeds which will form a single cohort, subgroups of seedlings will appear at a variety of times depending upon all the above fire conditions. Each of these new groups will be separated from other groups by intervals of time and will enter the various lifestages at different times. Each group is therefore a cohort and under these conditions, the number of cohorts progressing through the model will be quite large.

Further complexity can be suggested by the fact that each plant cohort may be spread over some considerable area and therefore its individuals will experience a range of soil types (and hence nutrient resources), water availability, light intensity, etc. and so have a range of individual physiological development. In its current form, DYMEX cannot model differing rates of individual physiological development within a cohort lifestage - all individuals are assumed to develop at the same physiological rate. This simplifies procedures but places limits on

DYMEX's ability to model complex situations in which cohorts are generated by differential physiological development. Instead, DYMEX can simulate this situation by using the stage transfer functions. If a simple step function is used in which all individuals from a single cohort cross to the next lifestage at a physiological age of 1, then a single cohort in the next lifestage will be produced. If a linear above threshold function is used instead, a series of cohorts will appear in the next lifestage, each of which will be separated from the others by time intervals and effectively simulating the varying rates of physiological development of the individuals in the previously single cohort.

10.3 Default Cohort Properties and Other Required Properties

A cohort property is a variable that each individual in the cohort shares. DYMEX has a number of default cohort properties which can be accessed and applied by the user. By now these properties will be quite familiar to the user and they include:

- the number of individuals in a cohort;
- the physiological age of individuals in a cohort;
- the chronological age of individuals in a cohort; and
- the density of individuals in a cohort.

These properties are limited in application, and the user may wish to apply other properties to the cohort as it passes through a lifestage. Some suggested additional properties are:

- sex ratio;
- stress;
- size of the individual; and
- toxin buildup.

It is important to note that the scope of the newly created cohort property must also be considered: it can be local or global. DYMEX modelling defines a cohort property to be **local** if the property variable is reset as the cohort passes from one lifestage to the next; the cohort property is defined to be **global** if the variable is carried over unchanged from one lifestage to the next. As noted already, the user defined cohort property that will be created and applied will be Canopy Area. This property will have no application within the model to be produced in **this** tutorial which is intended only to show how a user defined cohort property is set up; however it will be required in the next tutorial where Canopy Area will be used to show how the Gen-weed population is affected by resource competition from its own members. In addition, the effects will be made to vary according to the age of the cohort.

10.4 Model Parameters for the Canopy Area Cohort Property

Like all plants, Gen-weed has an optimum range of field conditions for which the plant's canopy grows to its maximum. If a plant has all conditions suitable at germination, the growth of its canopy will follow a distinct pattern: slow increase in Canopy Area to begin with, followed by rapid increase during intermediate plant size, followed by slow increase as the mature plant size is approached. In the field this situation is highly modified: annuals do not occur on their own and they compete with each other for resources such as nutrients, water and light. Initially, this model will be simplified to the extent that it ignores such growth patterns and competition so that Canopy Area will be determined purely by chronological age. The rate of Canopy Area increase will be determined by a constant 'function' with a time step increment set by the time taken for a plant to change from a seedling to a flowering adult.

Several assumptions about Gen-weed will now be made. First, the shape of the mature plant at the point of flowering will be defined as a circle (e.g. the 'rosette' of the dandelion, *Taraxacum officinale*) that is 10 cm in diameter. This will produce a mature plant Canopy Area of 0.00785 m^2. The germinating seedling will be assumed to have a 0.0001 m^2 Canopy Area (1 cm^2). Second, the time taken for a germinating seedling to become an adult is approximately 12 weeks and so the value of the constant area increment per time step will be 0.000646 m^2. [This constant increment value is obtained by subtracting the initial area of the seedling (0.0001 m^2) from the area of the adult plant (0.00785 m^2) and then dividing the result by 12.] For the model, the consequence will be that the Canopy Area function will develop the size of a single Gen-weed canopy over a 12 week interval and when this is multiplied by the numbers in a cohort, the result will be the total canopy area produced by the cohort itself.

DYMEX also provides options on how the effect of the newly created cohort variable will accumulate. Two accumulation methods can be applied: direct and proportional and these may be direct or inverted. Since Canopy Area is to be modelled, it will be used in the description that follows, however any variable name could be inserted.

Direct accumulation of Canopy Area is modelled by the equation:

$$\text{Canopy Area}_n = \text{Canopy Area}_{n-1} + r$$

(where 'r' is the latest value of Canopy Area increase as a result of the time step.)

This is the non-inverted mathematical model and obviously accumulates Canopy Area with each time step. It is also the default setting used by DYMEX. The user will also easily see that for this simple Gen-weed model, direct accumulation is the obvious choice for calculating Canopy Area of the Gen-weed cohorts.

If the inverted model is used, the equation becomes:

$$\text{Canopy Area}_n = \text{Canopy Area}_{n-1} - r$$

and in this case, Canopy Area is decreased with the addition of the 'r' value for each time step.

Proportional accumulation of Canopy Area for a non-inverted situation is modelled by the equation:

$$\text{Canopy Area}_n = \text{Canopy Area}_{n-1} * (1 + r)$$

Again, with increasing values of 'r', Canopy Area increases. For the inverted and therefore decreasing Canopy Area situation, the equation becomes:

$$\text{Canopy Area}_n = \text{Canopy Area}_{n-1} * (1 - r)$$

10.5 Building the Model

Start the DYMEX model builder and load the Gen-weed model. Continue with the following steps:

1. Open the **'Life cycle'** module for editing;
2. Select **'Life cycle'** from the main menu bar and then select **'User Defined Cohort Variables....'** from the drop down menu;
3. In the **'User Defined Variables'** dialogue box, select the **'Add'** button to obtain the **'Cohort Variable'** dialogue box (fig. 10.1);
4. Enter the name **'Canopy Area'** in the **'Name'** text entry box;
5. For **'Scope'** select the **'Global'** button (See **Notes** no. 2 below);
6. Ensure **'Adult Plant'** is selected in the **'Reset in stage'** scroll box;

Notes:

*1. The above settings in steps 5 & 6 above display DYMEX facilities. The Global button confirms that the variable is carried over into the next lifestage, but the Reset button setting ensures that the value of the variable is re-set to the default of zero as each cohort exits the Adult Plant lifestage; otherwise each new cohort would receive the Canopy Area previously accumulated and Canopy Area would simply increase without limit. There is no need to set either **'Proportional'** or **'Inverted'** buttons as they are not required. The program automatically selects **'Direct - Non-inverted'** as the default conditions (see previous section 10.4).*

*2. The **'Reset in Stage'** scrolled selection box only appears once **'Global'** is selected.*

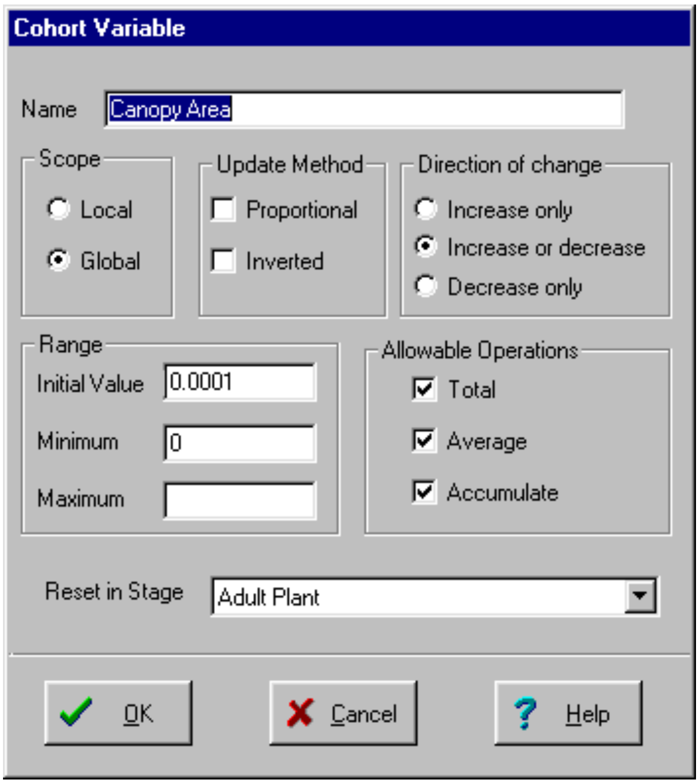


Figure 10.1 Cohort variable dialogue box

7. For the **'Range',** set the initial value to 0.0001 and the minimum value to 0; the maximum value can be left unset as it has no necessary use in this model.
8. **'Direction of Change'** is set to the default of **'Increase or Decrease'**;
9. For **'Allowable Operations',** all three should be retained as outputs.

The **'Allowable Operations'** facility permits the user to decide which operations are best suited to the model. Any combination of the operations can be set and it will be completely dependent upon the requirements of the user as to which operations will finally provide the most useful output. **'Total'** provides the sum of the cohort property for all the cohorts in the particular lifestage that is being addressed at the time. In this model, **'Total'** will construct the total Canopy Area value produced by all the individuals in all the cohorts in the model that are currently present in the Adult Plant lifestage. In the same way, **'Average'** will produce the average Canopy Area for all the individuals in all the cohorts in the Adult Plant lifestage by dividing the total Canopy Area by all the individuals in all the cohorts in the Adult Plant lifestage. The **'Average'** facility makes no differentiation between cohorts and therefore the resulting average covers not only adult plants but also seedlings for this model. **'Accumulate'** has a different application. It displays the total of the cohort property *for each cohort* as it leaves the particular lifestage. In this model, **'Accumulate'** will display the total Canopy Area produced by each cohort as it leaves the adult plant lifestage. Since the linear function under which this model operates has an upper limit, each cohort will reach the same limiting area as it leaves the Adult Plant lifestage; also, since each cohort then dies, and the property is reset as the cohort leaves the Adult Plant lifestage, the value will be set back to zero. The graph of **'Accumulate'** will display a disjoint series showing the appearance and disappearance of cohorts in the model.

10. Select **'OK'** as necessary to return to the **'Life cycle'** window.

The next procedure is to insert the values for the **'Canopy Area'** property in the Adult Plant lifestage. This can now be done as the user will see that a new button, the **'User-defined Cohort Properties'** button has now appeared on each lifestage icon (figure 10.2).

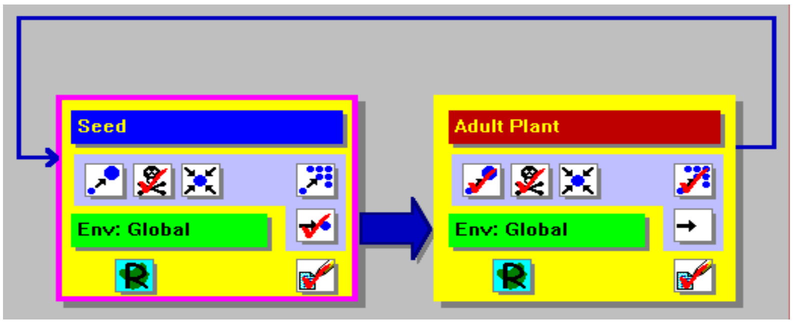


Figure 10.2 Lifestage icons with User-defined Cohort Properties button.

1. Select the **'User-defined Cohort Properties'** button in the **Adult Plant** lifestage to open the **'Adult Plant - Canopy Area'** window;
2. Select the **'Parameter'** button and open its edit window;
3. Rename the constant suitably (e.g. 'Canopy Area Increment');
4. Set the default value for to 0.000646, the lower limit to 0 and the upper limit to 1;
5. Exit back to the **'Life cycle'** window by selecting **'OK'** as necessary;
6. Select the **'Adult Plant Lifestage Outputs'** button and ensure that **'Total Canopy Area', 'Accumulated Canopy Area'** and **'Average Canopy Area'** are all selected as outputs;
7. Save the model.

10.6 Running the Model

Run the model for a period of 3 years (1095 days). If a chart containing all of the Canopy Area properties is now produced, it should resemble figure 10.3 . Total Canopy Area produces the total canopy area for all the cohorts within the Adult Plant lifestage at those time steps of the model. Since it sums all individuals of all cohorts, its values must be higher than the results displayed by the Average Canopy Area. Both graphs display disjoint curves indicative of the annual appearance and disappearance of the Gen-weed plants. It is interesting to note that the Average Canopy Area increases when the Total Canopy Area is decreasing towards the end of an annual growth cycle. This increase in the Average is because the number of small plants is decreasing and only adult plants remain even if they are also disappearing. Thus even with smaller numbers and less canopy, the average of the remaining plants must increase.

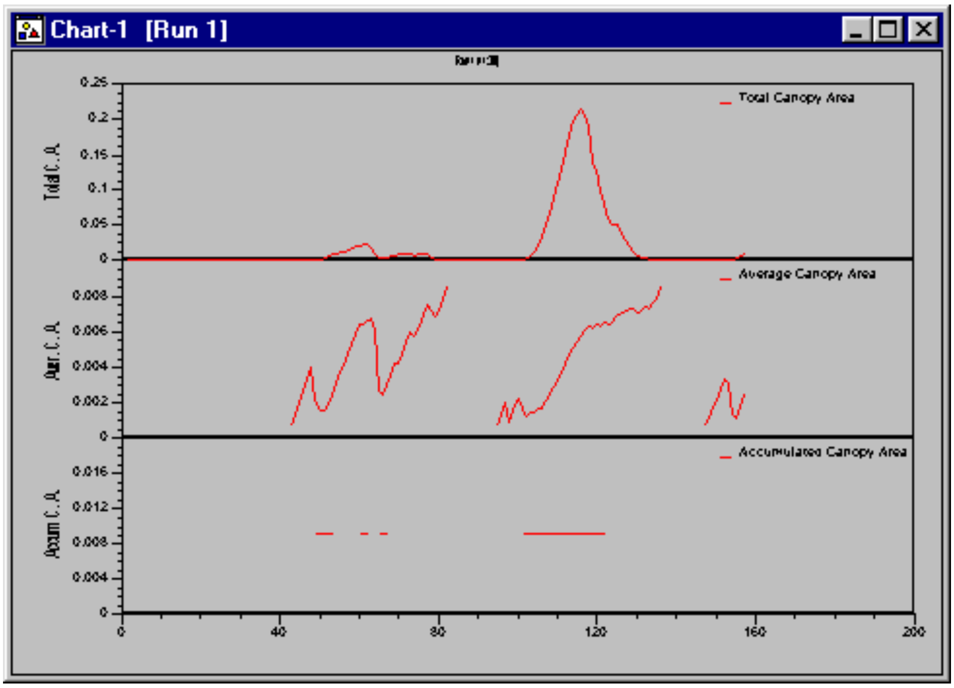


Figure 10.3 Total and Average and Accumulated Canopy Areas for the Gen-weed population over a 3 year period.

The Accumulated Canopy Area results are more or less as previously predicted (see section 10.5) and are not discussed further. For this model, Accumulated Canopy Area is not a useful operation and it could be deleted from the Allowable Operations box in the **Cohort Variable** window. The remainder of the model is identical to that of section 9 .

10.6 Tutorial 10 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation 1, Soil Moisture (1-layer), Average Daily Temperature, Circadian (Daily Temperature Cycle).

Timer

Set to 'Days since start' and 'Simulation Date', run default 1095 days.
Timestep: weekly

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Temperature induced germination (3-segment linear)
Independent variable: average daily temperature
Line 1 X-intercept: 18
Line 1 slope: 0.5
X-value at intersection of lines 1,2: 20
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 26
Line 3 Slope: -0.25
Soil Moisture induced germination (linear above threshold)
Independent variable: soil moisture
Rainfall threshold: 0.3
Rate of germination: 0.33

Combination Rule: multiply
Outputs: total numbers

Adult Plant

Continuous mortality (step)
Independent variable: chronological age
Threshold: 14 weeks
Proportion of adults dying: 1

Development (3-segment linear)
Independent variable: Daily temperature cycle
Line 1 X-intercept: 10
Line 1 slope: 0.0067
X-value at intersection of lines 1,2: 25
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 30
Line 3 Slope: -0.02

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: physiological age
Threshold: 1
Seeds/adult: 15

Canopy Area
Cohort Variable Properties
Scope: Global
Update method: default (direct, non-inverted)
Permitted change: increase or decrease
Range: Initial value: 0.0001
Minimum: 0
Maximum: no value set
Allowable Operations: Total, Average, Accumulate
Reset in Stage: Adult Plant
Lifestage (constant)
Independent variable: none
Constant increment: 0.000646

Outputs: total numbers, physiological age, average, total and accumulated canopy areas

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:

- Soil Moisture capacity: 50, 100, 200 for lower, default and upper values respectively
- Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower, default and upper values respect.
- Drainage rate: 0

Initialisation value for a model run: 0.2

Circadian (Daily Temperature Cycle)

Inputs: Daily maximum temperature, daily minimum temperature, day length.
Output: Daily temperature cycle.

11.0 Modifying the Canopy Area Property

11.1 Introduction

The user-defined cohort variable, Canopy Area, was set up in tutorial 10 to demonstrate how such a procedure is implemented. The ‘chronological age dependent linear function’ used in tutorial 10 is an extremely poor approximation to actual field conditions and much better simulations can be modelled by DYMEX. This tutorial examines a more accurate model. Since the process is somewhat complex, all the changes to the model which are completed in this tutorial will not yet be applied to the population operational area of the model - they will function as an ‘isolated off-shoot’ of the main model, however the eventual aim is to use these results to influence seedling mortality and subsequently predict Gen-weed population numbers per square metre. The last part of the tutorial will demonstrate how DYMEX can produce population densities.

If an annual plant’s growth from seed germination to adult plant is examined under ideal conditions, it will be found that the seedling at first grows quite slowly due to a number of factors. For example: it has only a small canopy/photosynthetic area; it has only a small root system and therefore limited ability in obtaining nutrients; the root symbionts have yet to invade efficiently and produce maximum nutrient uptake; etc. With increasing canopy area and more efficiently operating root system, the plant’s growth rate increases up to a maximum approximately halfway between the seedling and flowering stages. From there on, the growth rate decreases until with flowering, the annual’s resources are now fully diverted into seed production and growth virtually ceases.

Apart from greenhouses and artificially contrived agricultural monocultures, most plants do not grow in sufficient isolation to permit the above scenario to be the sole determinant of plant growth and its resultant canopy production. When seeds are scattered by an annual, there is a good possibility that many of them will fall in a small area and consequently the new generation will individually become competitors for the available resources. As roots extend into the soil, competition for water and nutrients occurs with consequent winners and losers depending upon the efficiency of individual root systems. In the canopy region, the plants that extend their leaves soonest will be most effective in trapping energy and thereby stimulating their own growth. Conversely, their effectiveness in extending their own canopies will inevitably lead to the suppression and probably deaths of less efficient plants. As a result, the effective growth of relatively few plants may bring about considerable mortality of germinated seedlings.

11.2 Modelling Growth Rates

The Gen-weed model assumes that each plant, when it is a seedling, has a canopy area of 1 cm^2 (ie. 0.0001 m^2). At maturity, each adult Gen-weed has a circular canopy 10 cm in diameter which can be shown to contain 0.00785 m^2 . If the canopy area is a function of physiological age, then the best approximation is given by a logistic function as shown in figure 11.1 .

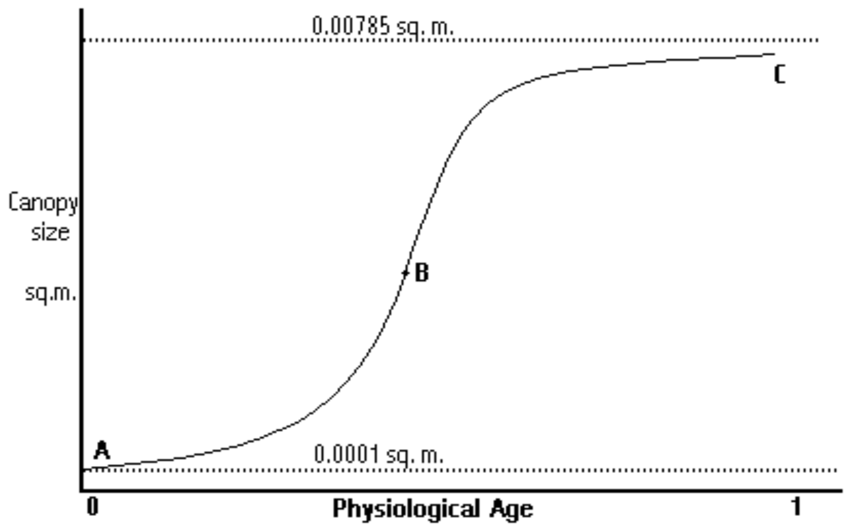


Figure 11.1 Canopy Size as a function of Physiological Age

The equation for this logistic function can be found in the DYMEX help files, however its slope very accurately reflects the rates of plant growth as stated in section 11.1 above. Commencing at 'A', the slope is at first small but with increasing physiological age, the slope also increases until it is at a maximum at the point of inflexion, 'B', the slope then decreases until it is once again minimal at 'C'. Values for the limiting canopy areas defined for Gen-weed have been placed at the appropriate locations on the graph. The Physiological Age value for 'B' is deduced from the symmetrical nature of the logistic function used here, and will have a value of 0.5 .

The slope of the logistic function (which is equivalent to the growth rate of the Canopy Area) can be modelled by reference to Pradhan's Function as shown below in figure 11.2 .

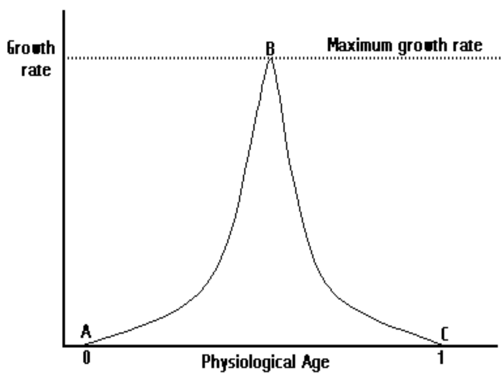


Figure 11.2 Gen-weed growth rates as modelled by Pradhan's Function

When this function is inserted into the Canopy Area property of the Adult Plant it will be called the 'Physiological Age Related Growth Rate' and will partially determine the development and size of the Canopy Area. The points A, B and C on figure 11.2 correspond to those marked accordingly on figure 11.1 . Point **A** therefore indicates a physiological age of zero and point

C indicates a physiological age of one. The area under the curve for Pradhan's Function will here have a value equal to the canopy area of one adult plant. Users should recognise that although the Growth Rate in figure 11.2 is driven by physiological age, physiological age is in turn dependent upon field temperatures and so ultimately, the canopy area is indirectly being determined by field temperatures; the model does not use soil moisture other than for germination.

The value of the maximum growth rate ('B' in figure 11.2) is unknown but can be modelled on a trial basis. If the logistic function of figure 11.1 is considered, its shape is always symmetrical but the slope at point 'B' depends on whether the function rises sharply or gently to the maximum canopy size asymptote. Obviously, for very long lived plants with slow growth rates, the slope at 'B' will be very small and the curve will extend far to the right of the graph. For short lived, rapid growth plants, the slope will be very steep and approach a 'step' function. To start model trials for the annuals, a simple solution is to assume a 45° slope and therefore the Growth Rate value assigned to 'B' for Pradhan's Function will be one(1) with a lower limit of zero(0) and an upper limit of about 100 ($\tan 89.43° \simeq 100$).

The second function that is required to set the Canopy Area is one that results from an increase in Canopy Area and is a direct result of successful germination and growth of the Gen-weed seedlings. As the more or less crowded Gen-weed seedlings grow and extend their canopies, they begin to interfere with each other's successful growth. Very little or no supression of other plants occurs when the seedlings are small, but as they grow, they inhibit nearby growth of other plants by preventing canopy spread or by competition for nutrients and water. The required function to model this situation is a 'mirror-image' logistic function in which the growth rate is at a maximum when the canopy area is least but at a minimum when the canopy area is at its greatest. This 'negative feedback' means that successful canopy area production contributes to decreasing growth rates and the situation for a single plant is modelled below in figure 11.3 .

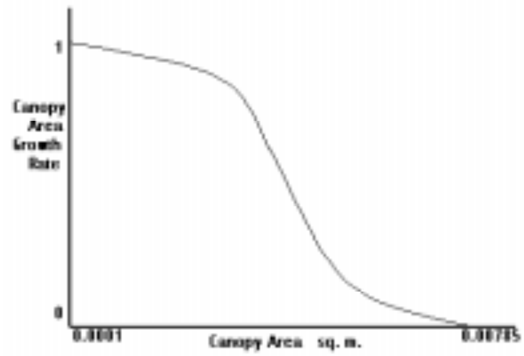


Figure 11.3 Self limiting Canopy Area Growth Rate

All of these functions will control the production of canopy area in the model and all will require to be combined within the single cohort property of Canopy Area. This will be done by using the multiplication combination function.

11.3 'Advanced Function Attributes' Operations

DYMEX does not not contain a 'mirror imaged' logistic function and therefore it must be 're-assembled' by the user. An expression module could be used, however **DYMEX** contains a procedure called **'Advanced Function Attributes'** which permits the user to manipulate the default set of functions so that functions such as the 'mirror image logistic function' can be easily obtained.

The **'Advanced Function Attributes'** dialogue box (figure 11.4) is opened from the **'Function'** window and this is done by selecting the button in the lower right of the window labelled **'Advanced'**.

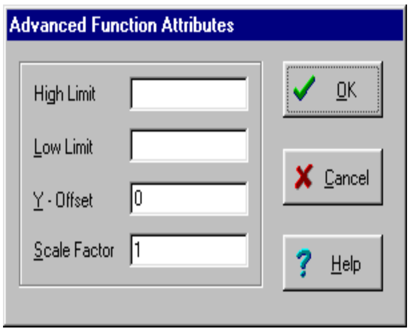


Figure 11.4 Advanced Function Attributes dialogue box. The default settings shown above mean that g(x) ≡ f(x) .

This box addresses values within the advanced function operation that is defined as shown:

$$g(x) \;=\; \max \{ \text{Min}, \;\; \min [\text{Max}, \; \text{offset} + \text{Scale} * f(x)] \}$$

In this advanced function,

- g(x) is the desired output; for Gen-weed, it will be the mirror imaged logistic function.
- f(x) is the default function whose attributes are being changed; for Gen-weed it will be the logistic function.
- Scale allows the function to be operated on by a constant multiplier; for Gen-weed it will be the value -1 which will 'mirror image' the logistic function; i.e. effectively rotating the function 180° .
- offset allows the initial Y-value of the function to be set; for Gen-weed it will be one (1).

The remainder of the advanced function operation equation can be ignored for this model as they deal with situations where upper and lower limits are set for the operational range of the particular modelling function **f(x)**. {Their operations are as follows: 'Min' and 'Max' are user-set lower and upper limits related to f(x); 'min' and 'max' are the operations which determine whether the model calculated value of the function f(x) or whether the user-set upper and lower limits will control the output given to g(x) . Since no values will be inserted for 'Min' or 'Max', their presence will be ignored in the operation of the advanced function which will simply produce an output from the mirror-imaged logistic function. Examination of the advanced function operation's equation will show that if no values are set for 'Min' or 'Max', a value of zero (0) is set for the offset and one(1)is used as the value for Scale, then the value of g(x) is solely determined by f(x) .}

11.4 Building the Model

Open the DYMEX Model Builder and load the Gen-weed model. With the model loaded, open the Lifecycle window and then complete the following steps:

1. In the **Adult** lifestage, select the user-defined **'Canopy Area'** button and open its dialogue box;
2. Select the **'Canopy Area Increment Parameter'** (this should be the only function present) and delete it;
3. Select the **'Function'** button to add a new function and open the **'Function'** window;
4. Name the function **'Canopy Growth Rate Function'**;
5. Select **'Physiological Age'** as the independent variable;
6. Select **'Pradhan'** as the required function and then select the **'Parameters'** button;

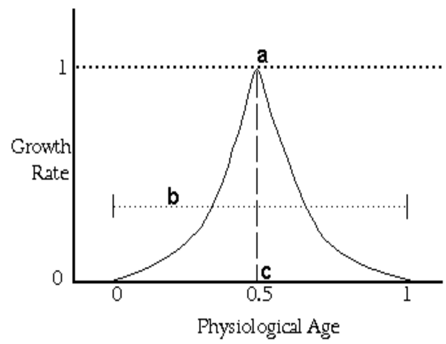


Figure 11.5 Pradhan's Function and its variables
a - parameter 3 (amplitude, set to 1 default)
b - parameter 2 (spread, set to 1 default)
c - parameter 1 (optimum, set to 0.5 default)

7. Set **'Optimum'** default to 0.5, the lower limit to 0 and the upper limit to 1;
8. Set **'Spread'** default to 1, lower limit to 0 and upper limit to 10;
9. Set **'Amplitude'** default to 1, lower limit to 0 and upper limit to 10;
10. Return to the **'Function'** window and select **'Function'** to add a

new function;

11. Name the function **'Self Limiting Growth Rate Function'** and select **'Total Canopy Area'** as the independent variable;
12. Select **'Logistic'** as the function and then the **'Parameters'** button to open the **'Set Parameter Properties'** window;

Note: The user is now reminded that the function that to be set up in the following steps will be 'mirror imaged' before finishing. Since **Total Canopy Area** is the Independent variable, the point of inflexion will occur when half the canopy area is reached. Since the total canopy area per plant is 0.00785 m^2, half this area is 0.00393 m^2 and this will be used as the point of inflexion.

13. Set **'(a) Asymptote'** default to 0.00785, the lower limit to 0 and the upper limit to 1;
14. Set **'(b) Inflexion Point'** default to 0.00393, the lower limit to 0 and the upper limit to 1;
15. Set **'(c) Slope at Inflexion'** default to 1, the lower limit to 0 and the upper limit to 100;
16. Return to the **'Function'** window and select the **'Advanced'** button to open the **'Advanced Function Attributes'** dialogue box (see fig. 11.4);

Note: Step 17 will 'mirror image' the logistic function.

17. Set the **'Y-offset'** to 1, the value of **'Scale Factor'** to -1 and leave the remainder blank;
18. Return to the **'Adult Plant - Canopy Area'** window and select the **'Set Combination Rule'** button;
19. Set the combination rule to **'Product'**;
20. Return to the **'Lifecycle'** window and save the model.

The model will now produce a more realistic simulation of self limiting canopy growth in each Gen-weed plant and all that remains is to adjust the model so that it can produce a reading of the density of the Gen-weed plants in a given area. The area selected is a 20 x 20 metre quadrat or 400 square metres. Larger areas could be selected but note that when inserting large numbers such as 10,000 the 'comma' (or spaces) indicating the 'thousands' position should not be inserted into the model; enter large numbers as if they were to be entered on a pocket calculator.

21. Close the **'Lifecycle'** window and return to the **'Module'** window;
22. Add a new **'Query User'** module and call it **'Sampling Area'**;
23. Select the **'Outputs'** button and open the **'Output Variables'** dialogue box;
24. Select the **'New'** button and a newly created variable will appear in the list box;
25. Select the **'Select'** button - this places the **'+>'** symbol beside the new variable;
26. Re-name the variable suitably (eg. 'Growth Area');

27. Set the default to 400, the lower limit to 0 and the upper limit to 10000;
28. Return to the **'Module'** window;
29. Save the model.

A final step needs to be completed before DYMEX can produce a plant density output. The model now has a defined area in which to operate, but it has no instructions as to what should be done with it. The last set of steps provides this information.

30. Return to the **'Lifecycle'** window and in the Adult Plant lifestage complete the following steps;
31. Select the **'Resource'** button to open the **'Adult Plant Resource Variable'** selection box;
32. Scroll down the list and select **'Growth Area'**;
33. Close the selection box and return to the **'Lifecycle'** window;
34. Make sure that **Total, Accumulated** and **Average** are selected as outputs for Canopy Area and that **'Average Density'** is also selected;
35. Change the sort order so that the **'Lifecycle'** module is last in the list;
36. Save the model.

11.5 Running the Model

The differences between this model and the previous model of tutorial 10 are purely in the method Canopy Area calculation and in the addition of a density operation. Neither affects the population modelling as yet. If a 10 year run is completed and a chart output for all three Canopy Area procedures is produced, the results should be similar to figure 11.6 .

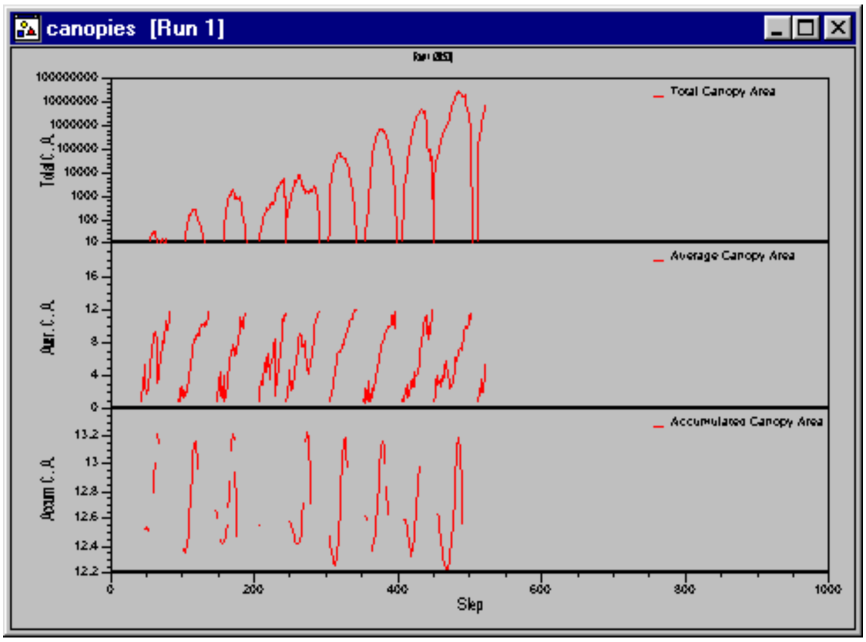


Figure 11.6 Annual Canopy Areas for Gen-weed; 10 year run

Average density can also be charted and if this is done, the results should be similar to figure 11.7.

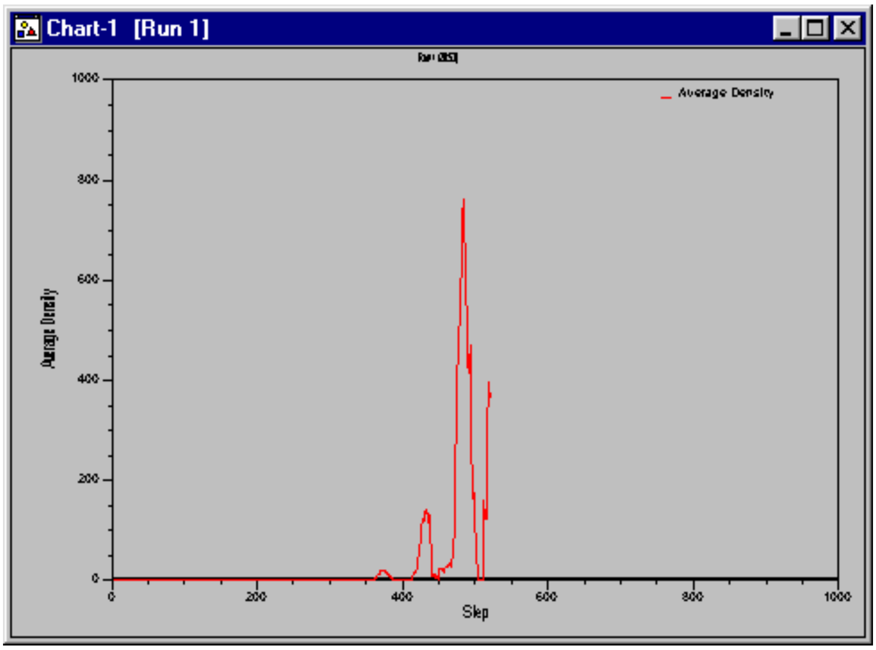


Figure 11.7 Average density of Gen-weed plants per square metre over a 10 year period.

As can be seen, the density of the plants is steadily increasing but Gen-weed has only a limited area in which to grow: one hectare. In the next tutorial, the program will be modified so that the successful population growth of Gen-weed inhibits further growth in the population once a certain limit is reached. Plant density will be one factor to be fed back into the model to produce this inhibition.

11.6 Tutorial 11 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation, Soil Moisture (1-layer), Average Daily Temperature, Circadian (Daily Temperature Cycle), Sampling Area

Timer

Set to 'Days since start' and 'Simulation Date', run default 3650 days.
Timestep: weekly

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Temperature induced germination (3-segment linear)
Independent variable: average daily temperature
Line 1 X-intercept: 18
Line 1 slope: 0.5
X-value at intersection of lines 1,2: 20
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 26
Line 3 Slope: -0.25
Soil Moisture induced germination (linear above threshold)
Independent variable: soil moisture
Rainfall threshold: 0.3
Rate of germination: 0.33

Combination Rule: multiply

Outputs: total numbers

Adult Plant

Continuous mortality (step)
- Independent variable: chronological age
- Threshold: 14 weeks
- Proportion of adults dying: 1

Development (3-segment linear)
- Independent variable: Daily temperature cycle
- Line 1 X-intercept: 10
- Line 1 slope: 0.0067
- X-value at intersection of lines 1,2: 25
- Line 2 Slope: 0.0
- X-value at intersection of lines 2,3: 30
- Line 3 Slope: -0.02

Reproduction
- Fecundity:
  - Constant: 15 seeds per adult plant
- Progeny Production (step)
  - Independent variable: physiological age
  - Threshold: 1
  - Seeds/adult: 15

Canopy Area
- Cohort Variable Properties
  - Scope: Global
  - Update method: default (direct, non-iverted)
  - Permitted change: increase or decrease
  - Range: Initial value: 0
    - Minimum: 0
    - Maximum: no value set
  - Allowable Operations: Total, Average, Accumulate
  - Reset in Stage: Adult Plant
- Lifestage (Adult)
  - Canopy Area Increment Function (Pradhan)
    - Independent variable: physiological age
    - Optimum: 0.5
    - Spread: 1
    - Multiplier: 1
  - Self Limiting Growth Rate F’n (Inverse Logistic)
    - Independent variable: Total canopy area
    - Asymptote: 0.00785
    - Inflexion point: 0.00393
    - Slope at inflexion: 1
  - Advanced function attributes
    - Y-offset: 1
    - Scale: -1

Combination Rule: multiply

Resource

Growth area

Outputs: total numbers, physiological age, average, total and accumulated canopy areas, average density

Meteorological Database

File: Amberley.dat

Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:
Soil Moisture capacity: 50, 100, 200 for lower, default and upper values respectively
Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower, default and upper values respect.
Drainage rate: 0
Initialisation value for a model run: 0.2

Circadian (Daily Temperature Cycle)

Inputs: Daily maximum temperature, daily minimum temperature, day length.
Output: Daily temperature cycle.

Query User (Sampling Area)

Outputs:
Growth area: 10000

12.0 Population Dependent Mortality

12.1 Introduction

Until now, the Gen-weed population has been uncontrolled in its size. In the field, this cannot happen as resources become too heavily depleted to sustain populations that simply continue to increase. There are also other controls on unlimited population growth such as parasites or (for plants) herbivores. For Gen-weed, the resources might include all the available nutrients and water, but to retain this model's simplicity, the supression on unlimited growth and appearance of new individuals in the model will be determined solely by total canopy area and the available resource area.

12.2 Modelling the Population Dependent Mortality

As the Gen-weed population number increases, the density of plants per square metre of the model also increases and as a consequence, the canopy area of the plants increases. DYMEX provides an output designated 'Total Canopy Area' which includes all members of all the cohorts in the adult lifestage and sums their combined canopy area. As this area increases, it suppresses the germination of the seeds present and in addition, the adult plant canopy area suppresses the canopy development of the canopies of the plants at earlier stages in their development. Many of these operations are extremely complex and although they can be modelled, their procedures are discarded for this model in favour of retaining simplicity.

The simple model used combines both Total Canopy Area and the Resource Area to give a value of Adult Plant Population Dependent Mortality Rate which can then be inserted in the overall Adult Plant mortality functions. The assumption will be made that once the Total Canopy Area reaches the value of the Resource Area, then Adult Plant mortality will commence and its rate will increase as the Total Canopy Area 'attempts' to increase beyond the limits of the Resource Area. This means that the Population Dependent Mortality Rate will be dervived from the canopy area functions which in turn are defined by the Logistic and Pradhan functions, and so despite the model's apparent simplicity, the mathematical procedures that are producing its operation are still quite complex.

The underlying mathematical concept for the population dependent mortality rate is defined by the following equation:

$$\text{Population Dependent Mortality Rate} = \frac{\text{Total Canopy Area}}{\text{Resource Area}} - 1$$

Examination of this equation will show that at first, with a low value of Total Canopy Area, (e.g. 20 square metres) and the Resource Area value of 400 square metres, the resultant value of the division will be less than 1 and so the value of the Population Dependent Mortality Rate will be negative. By default, DYMEX treats all negative Mortality Rates as irrelevant to mortality effects on the population, and so there is no alteration to the population numbers until the value of the Total Canopy Area reaches the value of the Resource. At this point, the Gen-weed population has exploited the whole of the available resource, the resultant of the area division will be one (1), and so the Mortality Rate will have a value of zero. As the Total Canopy Area increases, the value of the area division resultant will steadily increase, and once the value reaches two (2), the Mortality Rate will reach a value of one (1) and the entire population will die.

In practice, the model will not reach the extinction point. The Adult Plant population will steadily diminish and the number of seeds being produced will be lowered so that the total population will reach equilibrium.

To apply the above mortality rate equation, two steps are involved. First, an expression module must be developed which will combine the two areas into a single ‘Area/Population Dependent Mortality Rate’ value. Next, this Area/Population Dependent Mortality Rate must be inserted into an appropriate function which can be used to define this additional mortality in the Adult Plant lifestage.

The function which will use the the Area/Population Dependent Mortality Rate will have the form as shown:

$$\text{Pop. Dep. Mortality} = k_2 * (\text{Area/Pop. Dep. Mortality Rate}) - k_1$$

In the above function, ‘k_1’ is the threshold and ‘k_2’ is the slope. For this tutorial, both ‘k’ parameters will have the value of one (1) and Area/Population Dependent Mortality Rate will be the independent variable. The function will be of ‘linear above threshold’ form.

12.3 Building the Model

With the Gen-weed model loaded in the Model Builder and the model window open, complete the following steps:

1. Add an **‘Expression’** module using the main menu bar and its drop down menu;
2. Rename the module **‘Area/Pop. Dep. Mort. Rate’**;
3. Select the **‘Inputs’** button;
4. Add two extra inputs by selecting the **‘Add Extra Input’** button twice;

5. Link the first variable to **'Total Canopy Area'**;
6. Link the second variable to **'Growth Area'** and before exiting, **place a tick in the selection box marked 'Invert (1/x)'**;

{Step 6 will ensure that the Resource Area value is actually dividing the Total Canopy when the two values are multiplied together. DYMEX uses this procedure to change a multiplication into a division.}

7. Select **'OK'** to return to the module's window and then select the **'Outputs'** button;
8. Select the **'Select'** button to highlight the output variable and then rename it suitably (e.g. Pop./Area Dep. Mortality Rate);
9. Return to the module's window and then select the **'Settings'** button;
10. Set the function to **'Product'** and then return to the module's window and finally to the main model window; there will now be a tick beside the new expression module.

Steps 1-10 have set up the first part of the operation to produce population dependent mortality and the output of the new expression will produce the Independent variable for the linear above threshold function that will produce Population Dependent Mortality in the Adult Plants. The next procedure is to set up the linear above threshold function in the Adult Plant lifestage.

1. Open the lifecycle window;
2. Obtain the **'Adult Plant - Continuous Mortality'** dialogue box;
3. Select **'Function'** to set up a new function;
4. Set the Independent variable to **'Pop./Area Dep. Mortality Rate'**;
5. Rename the function **'Pop./Area Dep. Mortality'**;
6. Select a **'Linear above Threshold'** function;
7. Select the parameters button;
8. Set both the threshold and the slope to 1, and then set the lower and upper limits for each to 0 and 10 respectively;

{The user may wish to set some user-identified names for each of these parameters and it is left to the user to suitably name them if required.}

9. Return to the **'Lifecycle'** window;
10. Ensure that the sort order of the **'Lifecycle'** module has placed the module at the end of the processing order;
11. Save the model.

The model is now ready to run.

12.4 Running the Model

Run the model for a period of 10 years. If a chart output of the total numbers of seeds and adult plants is produced, it will resemble figure 12.1 in which the graph shows that the population has now become relatively stable.

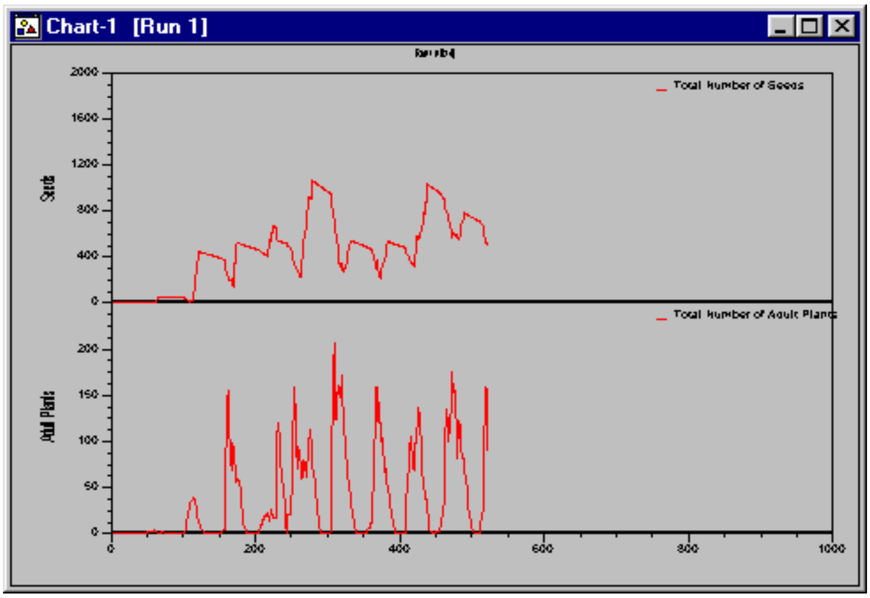


Figure 12.1 Total numbers ofGen-weed Adult Plants and Seeds for a 10year period with population dependent mortality.

If the user alters the resource area up or down, the graph remains more or less intact; only the total numbers alter. Similar patterns emerge if either the mortality threshold or the slope is altered.

12.5 Tutorial 12 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation, Soil Moisture (1-layer), Average Daily Temperature, Circadian (Daily Temperature Cycle), Sampling Area, Expression (Area/Population Dependent Mortality Rate)

Timer

Set to 'Days since start' and 'Simulation Date', run default 3650 days.
Timestep: weekly

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Temperature induced germination (3-segment linear)
Independent variable: average daily temperature
Line 1 X-intercept: 18
Line 1 slope: 0.5
X-value at intersection of lines 1,2: 20
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 26
Line 3 Slope: -0.25
Soil Moisture induced germination (linear above threshold)
Independent variable: soil moisture
Rainfall threshold: 0.3
Rate of germination: 0.33

Combination Rule: multiply

Output: total numbers

Adult Plant

Continuous mortality

Chronological (step)

Independent variable: chronological age

Threshold: 14 weeks

Proportion of adults dying: 1

Population/Area Dependency (linear above threshold)

Independent variable: Population/Area mortality rate

Threshold: 1

Slope: 1

Development (3-segment linear)

Independent variable: Daily temperature cycle

Line 1 X-intercept: 10

Line 1 slope: 0.0067

X-value at intersection of lines 1,2: 25

Line 2 Slope: 0.0

X-value at intersection of lines 2,3: 30

Line 3 Slope: -0.02

Reproduction

Fecundity:

Constant: 15 seeds per adult plant

Progeny Production (step)

Independent variable: physiological age

Threshold: 1

Seeds/adult: 15

Canopy Area

Cohort Variable Properties

Scope: Global

Update method: default (direct, non-inverted)

Permitted change: increase or decrease

Range: Initial value: 0

Minimum: 0

Maximum: no value set

Allowable Operations: Total, Average, Accumulate

Reset in Stage: Adult Plant

Lifestage (Adult)

Canopy Area Increment Function (Pradhan)

Independent variable: physiological age

Optimum: 0.5

Spread: 1

Multiplier: 1

Self Limiting Growth Rate F’n (Inverse Logistic)

Independent variable: Total canopy area

Asymptote: 0.00785
Inflexion point: 0.00393
Slope at inflexion: 1
Advanced function attributes
Y-offset: 1
Scale: -1
Combination Rule: multiply

Resource
Growth area

Output: total numbers, physiological age, average, total and accumulated canopy area, average density.

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:
Soil Moisture capacity: 50, 100, 200 for lower, default and upper values respectively
Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower, default and upper values respect.
Drainage rate: 0
Initialisation value for a model run: 0.2

Circadian (Daily Temperature Cycle)

Inputs: Daily maximum temperature, daily minimum temperature, day length.
Output: Daily temperature cycle.

Query User (Sampling Area)

Outputs:
Growth area: 10000

Expression (Area/Population Dependency Mortality Rate)

Inputs:
Total Canopy Area
Resource/Sampling Area (inverted)

Function: Product

Output:
Population/Area Dependency Mortality Rate

13.0 Adding an 'Event' Module

13.1 Introduction

Mortality in the Gen-weed population model is affected by several variables which are dependent upon either the age or the size of the population. Other aspects of mortality remain to be modelled amongst which are: the effects of too much or too little rainfall, herbivore destruction and parasite attack. Human induced mortality can also be added to the model. Assuming that Gen-weed is an agricultural pest which competes efficiently for crop or pasturage space and additionally is toxic to stock, an agriculturalist's problem resolves itself into either reducing population numbers to acceptable levels or (preferably) eradicating the Gen-weed population completely. To add this operation to the model, an 'Event' module is used.

An ***event*** is a particular occurrence which affects the lifecycle of the population and it can be a natural occurrence or human induced. Examples of events are the application of a spray, a fire, ploughing, heavy rainfall, or sudden loss of food. How DYMEX is used to model the event depends completely on how the user wishes to apply it.

13.2 Modelling an Event

13.2.1 The 'Event' Module

The Event module has several inputs, and for the Gen-weed model there is a single output which is directed to the Lifecycle module (Figure 13.1). The Timer module produces two of the inputs: Day of Year and Simulation Date. The Day of Year is a day count for the current year of the

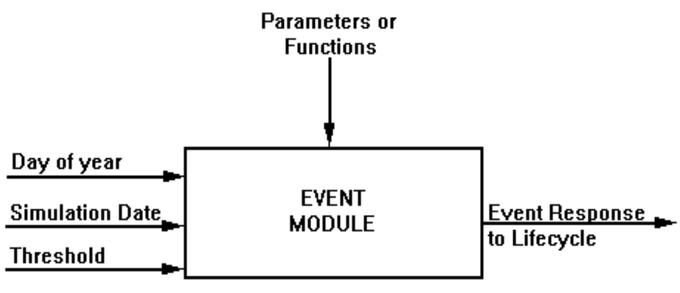


Figure 13.1 The 'Event' Module

model run. For example, if the model was run over ten years, the day of year count would go through ten cycles of 1-365, not a single cycle of 0-3650 days. The Simulation Date is the calendar date of the particular day of the model run. The Threshold value is the 'trigger' for the Event module if it is desired to link the module to events determined by the changes produced in an actual run. The user has complete flexibility in choosing what will be the 'trigger'. For example, it could be rainfall, temperature, the number of individuals in the population, or the number of individuals present in a host population.

Most plants show increasing resistance to herbicides with maturity and so an accurate model of Gen-weed population subjected to a herbicide spray would have high mortality levels in population members with low physiological maturity but reduced levels of mortality in the physiologically mature population; seeds would be unaffected. A model in which event mortality is dependent on physiological age requires more complexity than the simple two lifestage model of Gen-weed. At least four lifestages would be required: seed, seedling, juvenile and adult plant, and each stage's event mortality would then be set separately. For simplicity, this Gen-weed model will assume that an application of the herbicide produces mortality in the adult plant population and ignore all other effects due to plant physiological maturity.

Since, for this model, the event will be the administration of a herbicide spray (e.g glyphosate), the parameter or function input will determine the mortality rate for Gen-weed. Users will appreciate that a spray application and its consequent effects are determined by quite complex interactions: humidity, spray concentration, wind-drift, tolerance of the population, lessening effects over time, etc. and a series of additional functions or modules might have to be added to the events module to successfully model their effects. The Gen-weed adult plant population will be considered to suffer a 98% mortality on initial application of the spray followed by an exponential decay of the spray effects over the following 2 days. The 98% value (0.98) is used as the threshold value for the model's mortality function. Figure 9.2 shows where each parameter value is applied: 'A' will have the value 0.98, the curve will reach the x-axis in 2 days and the short linear section will disappear as it is set to zero (0). Application of the event is set in the Simulator.

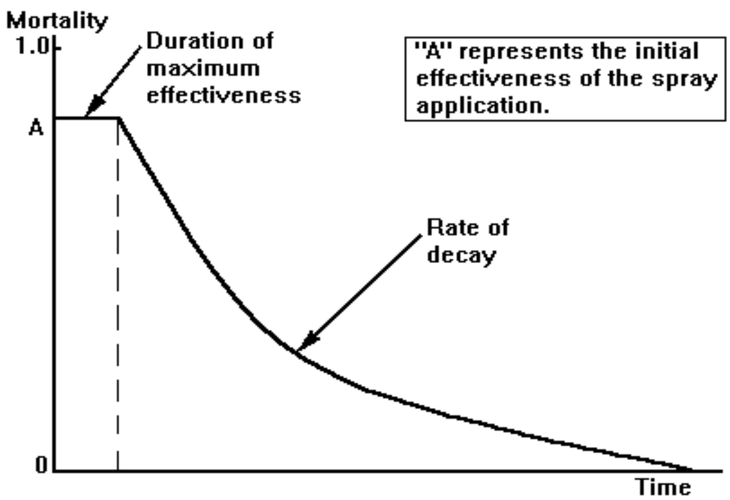


Figure 13.2 Mortality effects for the herbicide spray

13.2.2 Calculating the Exponential Decay

The decay rate of the herbicide spray has been set as exponential which means that the function describing the decay is of the type:

$$y = e^{-kT}$$

For the model, 'y' will be mortality and 'T' will be time in days; 'k' must be calculated to fit the model. Since an exponential decay curve never actually reaches zero (although it comes very close to it), the model will assume that after 2 days, the spray-induced effects on the Gen-weed population will be 5% or 0.05 mortality. If these values are substituted into the equation, we have:

$$0.05 = e^{-k2}$$

Taking logarithms to both sides produces the results:

$$\ln 0.05 = -2k$$

Which in turn produces the equation:

$$-2k = -2.99$$

Therefore:

$$k = 1.49$$

13.3 Forming the Model

13.3.1 Changing the Lifecycle Module

Two alterations are required so that the Lifecycle module reacts to the Event module. First, the Adult Plant Mortality function has to be altered so that it accepts mortality caused by the spraying event; and second, an 'Event' module (figure 13.3) has to be built so that it can supply the event parameter values to the Lifecycle module.

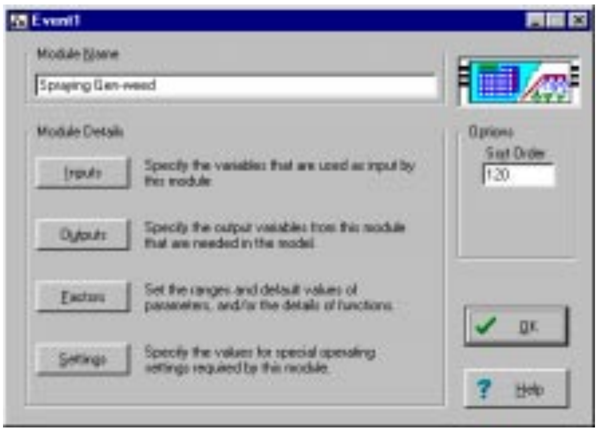


Figure 13.3 The 'Event' window

1. Load the Model Builder and open the Gen-weed file;

2. Select **‘Model’** from the menu-bar and add an **‘Event’** module;
3. Open the **‘Event’** module for editing (Figure 13.3);
4. Re-name the event ‘Spraying Gen-weed’;
5. Select the **‘Inputs’** button and obtain the link window (Figure 13.4);

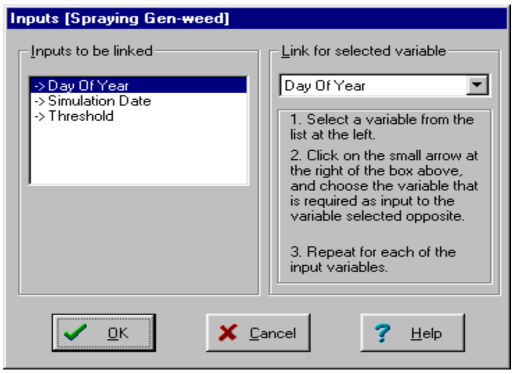


Figure 13.4 Event ‘Link’ window

6. Link the input **‘Day of Year’** with the same name for the selected variable and then repeat this for **‘Simulation Date’**;
7. Link **‘Threshold’** with **‘Total Numbers of Adult Plants’**;
8. Return to the **‘Event’** window;
9. Select the **‘Outputs’** button to obtain the **‘Output Variables’** dialogue box;
10. Select **‘Event Variable’ (+>)** and rename it **‘Spray Application’**;
11. Return to the **‘Event’** window;
12. Select the **‘Factors’** button to open its window (Figure 13.5);

Figure 13.5 Factors window

13. Select the **‘Set Function’** button to open its window;
14. Set the Independent Variable to **‘Days since Event’**;
15. Set the function to **‘Exponential Decay’**;
16. Set **‘(a) Threshold’** default to 0.99 and the lower and upper limits to 0.5 and 1 respectively;
17. Set **‘(b) Decay Constant’** default to 1.5 and the lower and upper limits to 0.5 and 2 respectively;
18. Set **‘(c) Scaling Factor’** to a default of 0.99 and the lower and upper

limits to 0.01 and 2 respectively;

19. Exit to the **'Model'** window and save the model.

The Lifecycle module must now be altered to accept the information from the Event module. The 'Direct' function will be used to introduce the Event module's information into the Lifecycle and therefore there will be no need to set any functional parameters.

1. Open the **'Lifecycle'** module for editing;
2. Select the Adult lifestage **'Mortality'** button;
3. Open the **'Adult Continuous Mortality'** dialogue window;
4. Select **'Function'** button;
5. In the **'Function'** dialogue box:
   a. Select **'Direct'** as the function;
   b. Select **'Spray Application'** as the independent variable;
   c. Return to the **'Lifecycle'** window;
6. Set the **'Lifecycle'** sort order so that this module is last in the list and then save the model.

13.4 Running the Model

Whilst it is true that the Gen-weed population will appear more or less around the same time each year, the exact dates on which the population will appear will vary widely from year to year due to variation in seasonal rains or temperatures. Because of these variations, the 'trigger' for spraying the population will not depend on a set date but rather on observations of actual field conditions. For a weed population, the simplest way to trigger the event is when the farmer is actually 'conscious' that there is a weed problem and for the tutorial, the assumption will be made that a decision to spray occurs if the weed population exceeds 200 plants in the resource/sampling area of 1000 square metres. This weed population corresponds to a plant density of 0.2 plants
per square metre and the event could be linked to plant density if required.

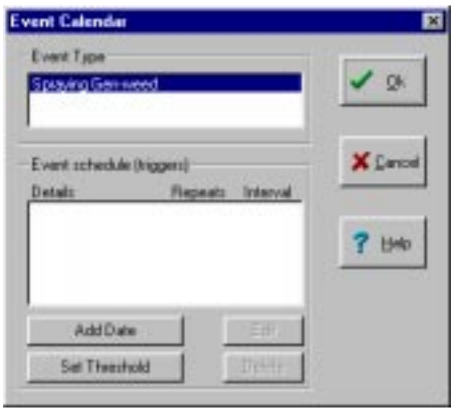


Figure 13.6 Event Calendar window

1. Start the Simulator and load the Gen-weed model;

2. Select the **‘Spraying Gen-weed’** module;
3. Select **‘Initialise Module’** from the drop-down menu (figure 13.6);
4. Select the **‘Set Threshold’** button to open its window (figure 13.7) and set the threshold to 200;

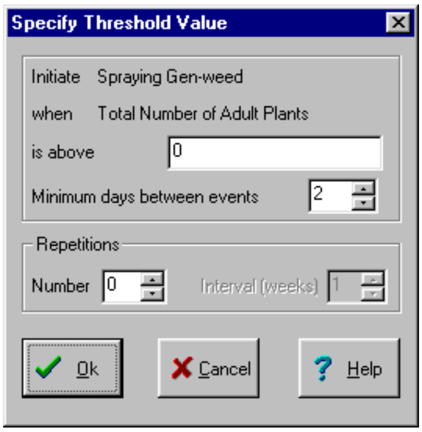


Figure 13.7 Specify Threshold Value Window

5. Ensure that the Repetitions scroll box is set to 0 and the minimum number of days between events is set to 14 (i.e. two model steps);
6. Exit to the ‘Model’ window and run the model for 10 years.

Once the model is run, open the chart procedures and include the Spraying Event, and the Total Numbers of both Seeds and Adult Plants. The result should be similar to Figure 13.8 .

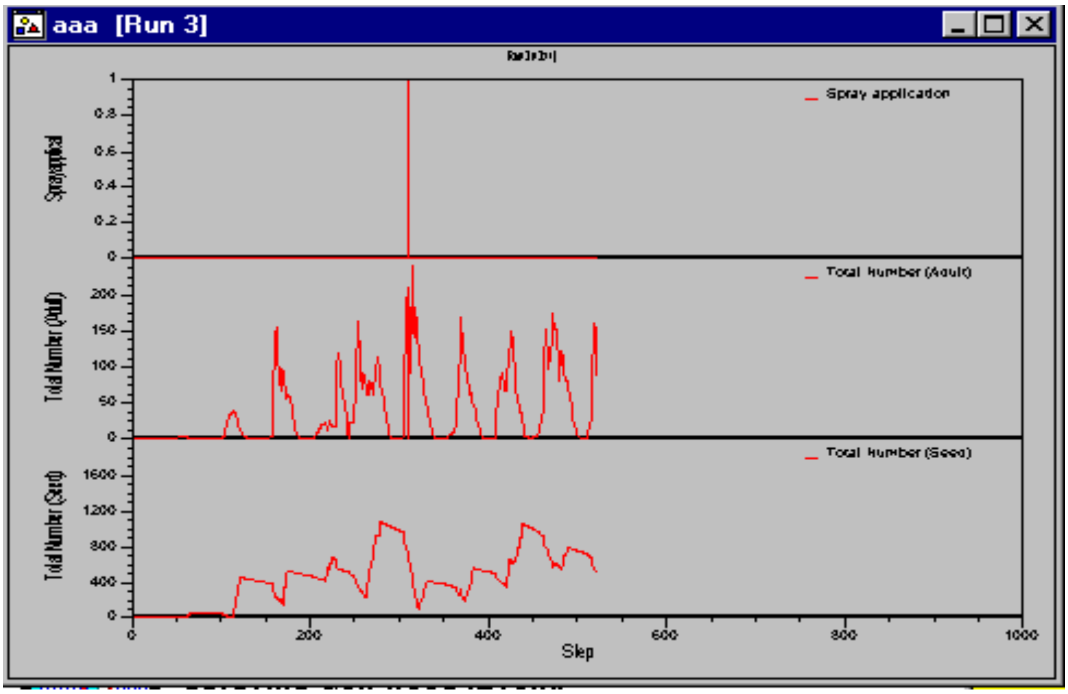


Figure 13.8 Effects of a herbicide event on Total Numbers of Seeds and Adult Plants. Herbicide applied if Adult Plants > 200.

If the graphs of figure 13.8 are compared with those of figure 12.1, the lower survival rate of adult plants will be very apparent. The events are very clearly marked as single spikes in the lowest third of figure 13.8 . The model clearly shows the difficulty involved in removing a successful annual from pasture or crop areas. While the herbicide attacks the adult plants and removes them from the model, it does nothing about the seed bank which continues to be replenished if the number of adult plants does not reach more than 200 present. Although the seed bank is reduced to some extent, it still remains with at least some potential to completely regenerate the population at the end of the 10 years run.

The user may like to try two other runs:

1. Try setting both the fecundity and progeny production to 100 seeds per plant. It becomes very difficult for the model to show any appreciable destruction of the Gen-weed population with its current settings.

2. Try reducing the threshold for spraying to 100 plants per 1000 square metres. There is some reduction in the seed bank.

The model clearly indicates that dependency on single sprays at some triggering threshold is probably not sufficient and suggests that as the population is reduced, spot spraying may be essential to completely control the Gen-weed numbers.

13.5 Tutorial 13 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation, Soil Moisture (1-layer), Average Daily Temperature, Circadian (Daily Temperature Cycle), Sampling Area, Expression (Area/Population Dependent Mortality Rate), Event (Spraying Gen-weed)

Timer

Set to 'Days since start' and 'Simulation Date', run default 3650 days.
Timestep: weekly

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
- Continuous
  - Constant: 0.00441

Transfer functions
- Seed Maturation (step)
  - Independent variable: chronological age
  - Germination threshold: 40 weeks
  - Prop.seeds transferred: 1
- Temperature induced germination (3-segment linear)
  - Independent variable: average daily temperature
  - Line 1 X-intercept: 18
  - Line 1 slope: 0.5
  - X-value at intersection of lines 1,2: 20
  - Line 2 Slope: 0.0
  - X-value at intersection of lines 2,3: 26
  - Line 3 Slope: -0.25
- Soil Moisture induced germination (linear above threshold)
  - Independent variable: soil moisture
  - Rainfall threshold: 0.3
  - Rate of germination: 0.33

Combination Rule: multiply

Output: total numbers

Adult Plant

Continuous mortality
Chronological (step)
Independent variable: chronological age
Threshold: 14 weeks
Proportion of adults dying: 1
Population/Area Dependency (linear above threshold)
Independent variable: Population/Area mortality rate
Threshold: 1
Slope: 1
Event - direct function
Combination rule: complement product

Development (3-segment linear)
Independent variable: Daily temperature cycle
Line 1 X-intercept: 10
Line 1 slope: 0.0067
X-value at intersection of lines 1,2: 25
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 30
Line 3 Slope: -0.02

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: physiological age
Threshold: 1
Seeds/adult: 15

Canopy Area
Cohort Variable Properties
Scope: Global
Update method: default (direct, non-iverted)
Permitted change: increase or decrease
Range: Initial value: 0
Minimum: 0
Maximum: no value set
Allowable Operations: Total, Average, Accumulate
Reset in Stage: Adult Plant

Lifestage (Adult)
Canopy Area Increment Function (Pradhan)
Independent variable: physiological age
Optimum: 0.5
Spread: 1
Multiplier: 1

Self Limiting Growth Rate F'n (Inverse Logistic)
Independent variable: Total canopy area
Asymptote: 0.00785
Inflexion point: 0.00393
Slope at inflexion: 1
Advanced function attributes
Y-offset: 1
Scale: -1
Combination Rule: multiply

Resource
Growth area

Outputs: total numbers, physiological age, average, total and accumulated canopy area, average density.

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:
- Soil Moisture capacity: 50, 100, 200 for lower, default and upper values respectively
- Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower, default and upper values respect.
- Base Evaporation rate: 0

Initialisation value for a model run: 0.2

Circadian (Daily Temperature Cycle)

Inputs: Daily maximum temperature, daily minimum temperature, day length.
Output: Daily temperature cycle.

Query User (Sampling Area)

Outputs:
- Growth area: 10000

Expression (Area/Population Dependency Mortality Rate)

Inputs:
- Total Canopy Area
- Resource/Sampling Area (inverted)

Function: Product

Output:
- Population/Area Dependency Mortality Rate

Event (Spraying Gen-weed)

Inputs:

Day of Year, Simulation Date, Threshold (link each to appropriate input but link Threshold to Total numbers of Adult Plants

Output

Spray Application

Factors (function - exponential decay)

Independent variable: days since event
Threshold: 0.99
Decay constant: 1.5
Scaling factor: 0.99

14.0 Finding the Best Time to Spray

14.1 Setting up a 'Run Sequence'

The previous tutorial used the value of "200 Gen-weed plants per 1000 square metres" as the trigger for the spraying event. This value was taken as an estimate of the numbers of plants required for the farmer/pastoralist to become 'conscious' that there was a weed problem from simple observations. In practice, decisions on spraying are always made after examination of the state of the 'crop' and the weed/plant causing the problem, but modelling can provide very good indications of when such examination should show problems and can also provide suggestions as to when the spray will be most effective. Population Explorer can do this by setting up a 'run sequence'.

A 'Run Sequence' is a series of runs of the same event where the time variable is altered a prescribed amount each time. Since Gen-weed populations rise and fall with the seasons, a simple way to find out where a single application of spray would do most good would be to test the spray's effectiveness for each week of the year and calculate the resulting year's end Gen-weed population. This would entail 52 runs of the program with the user then comparing the effects of each week's spray on the total population to find the greatest mortality. The operation could be done manually 52 times by the user, however Population Explorer has this procedure built into its software. Because Gen-weed is an annual, the results of administering a spray will be calculated for the same time in each year over a period of years.

1. Start the Simulator and open the Gen-weed file;
2. Select **'Execution'** from the menu bar followed by **'Define Run Summary Settings...'** to obtain its window (figure 14.1);

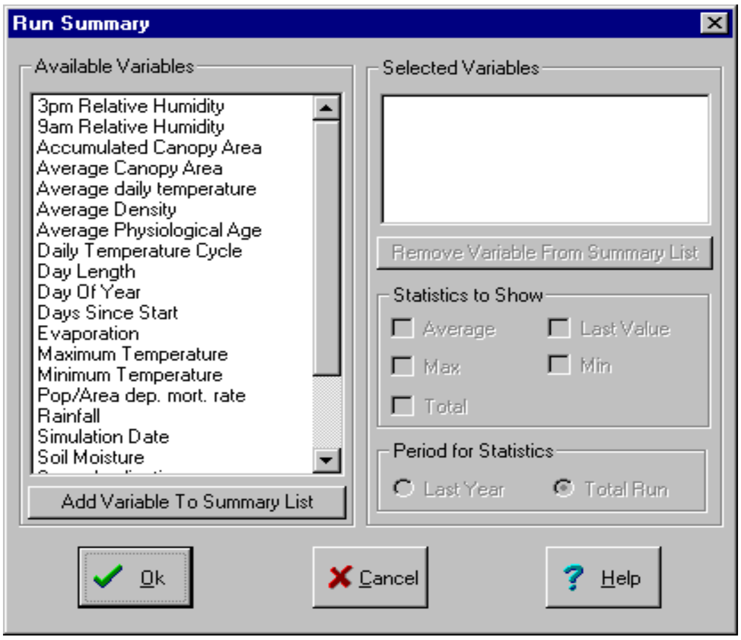


Figure 14.1 Run Summary Settings Window

3. Using the scroll button on the **'Available Variables'** list, find 'Total Numbers of Seeds', and 'Total Numbers of Adult Plants', select them one at at time, followed by selection of the button **'Add Variable to Summary List'**;

4. The list of selected variables to be displayed in the results of the run sequence will now have appeared in the **'Selected Variables'** list box at the top right of the window; select **'Total Number of Seeds'** and the previously greyed-out buttons on the lower right of the window will now become available for use.

[The user now has a variety of options available as to which summary values should be used. For this tutorial, the average value (from 'Statistics to Show) of each of the selected variables will be used and it will be taken from the last year (from 'Period for Statistics') of the run as this is where the results can be expected to be most clearly seen. Users should choose other variations to see how they affect the output.]

5. With **'Total Number of Seeds'** selected (highlighted), select **'Average'** (from 'Statistics to Show') and **'Last Year'** (from **'Period for Statistics'**);

6. Select **'Total Number of Adult Plants'** and repeat the selection procedure of step 5, then select **'OK'** to return to the model window.

7. Select **'Execution'** from the menu bar followed by **'Define Run Sequence'** to open its window (figure 14.2)

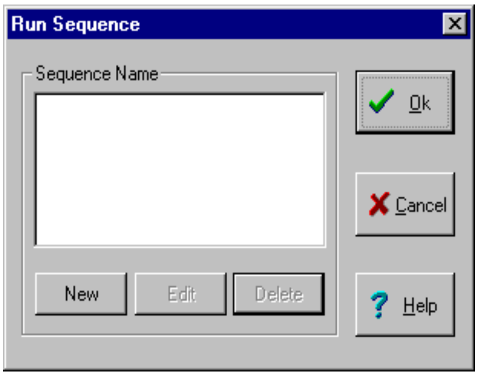


Figure 14.2 Run Sequence dialogue box

8. Select **'New'** to obtain the **'Sequence Types'** selection box, and then select **'Spraying Gen-weed'** from the list followed by **'OK'**;
9. In the **'Edit "Run Sequence" - Event'** dialogue box (figure 14.3) complete the following steps in the appropriate editing boxes;
   a. Name the sequence **'Spraying the Gen-weed'**;
   b. Select '**Vary Starting Date, fixed No of events'**
   c. Each event has only a single administration of the spray, so set the **'Number of events in group'** to one (1);

d. The **‘Spacing (in weeks)’** is set to zero (0);
e. The **‘Starting Week’** is set to one (1);
f. The **‘Increment Starting Week by’** is then set to 1 week;

{This allows the program to shift the event by seven days or one time step for each run in the sequence.}

g. The **‘No. of runs in sequence’** is set to 52.

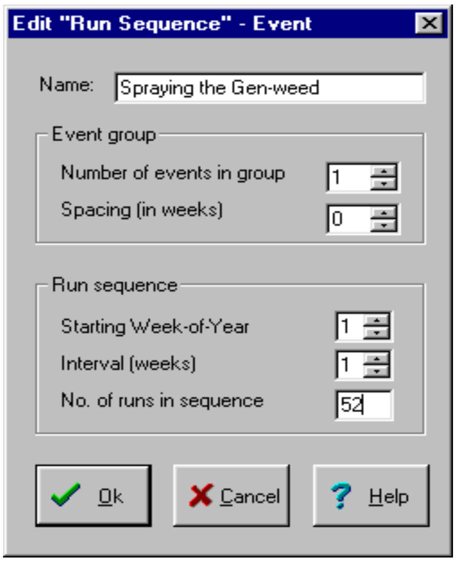


Figure 14.3 Edit “Run Sequence’ - Event Window

9. Exit back to the **‘Model Components’** window;

10. Select **‘Run’** and obtain the **‘Run Model’** window;

Note that a previously greyed-out selection is now able to be used: ‘Run Type’.

11. Select the **‘Multiple’** button in the **‘Run Type’** section of the **‘Run Model’** window - this will open the **‘Run Sequence’** scroll box;
12. Select **‘Spraying the Gen-weed’** from the **‘Run Sequence’** scroll box;
13. Ensure the **‘Simulation Period’** is set to 3650 days;
14. Select **‘OK’** to start the run.

IMPORTANT: The run sequence now has to process 52 runs over the ten years for a single model run. This will take some time - possibly between 5 and 20 minutes depending on the speed of the computer. **It is recommended that the tea urn (or coffee pot, etc.) be investigated at this stage.**

When the chart option is opened, the resultant graph should resemble figure 14.5

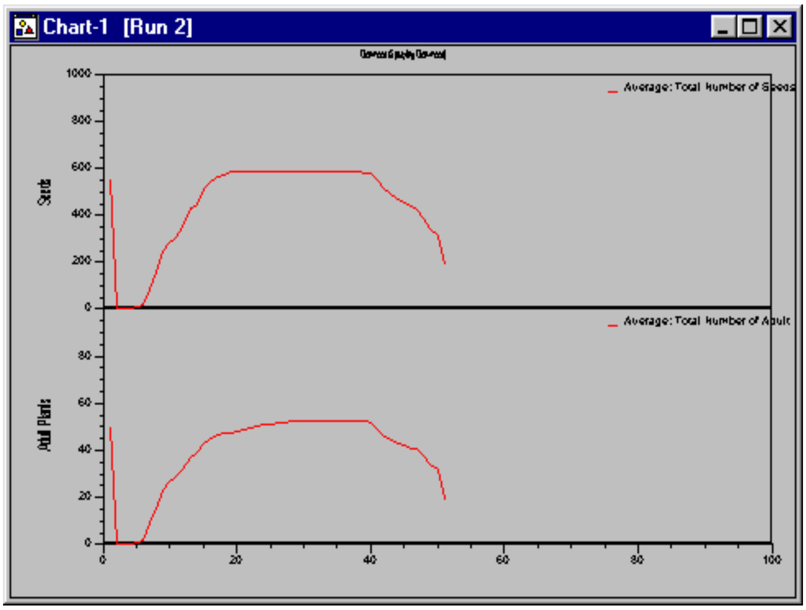


Figure 14.5 Summary run of Gen-weed Spraying over ten years, using 'Total Numbers of Adult Plants and Seeds' as the summary variables; starting point 10 seeds.

The graph shows that the best results from spraying occur if the spray is administered towards the beginning of the year - the exact dates can be obtained from the tabulation outputs. The chart of figure 14.5 is very strongly skewed towards the beginning of the year and it is very possible that this is an artifact caused by the small numbers of plants during the first years. To explore this possibility, a second run was completed in which the starting populations were 100 seeds and 100 adult plants. The results are shown in figure 14.6. Again, the most effective time for spraying is shown to be at the beginning of the year.

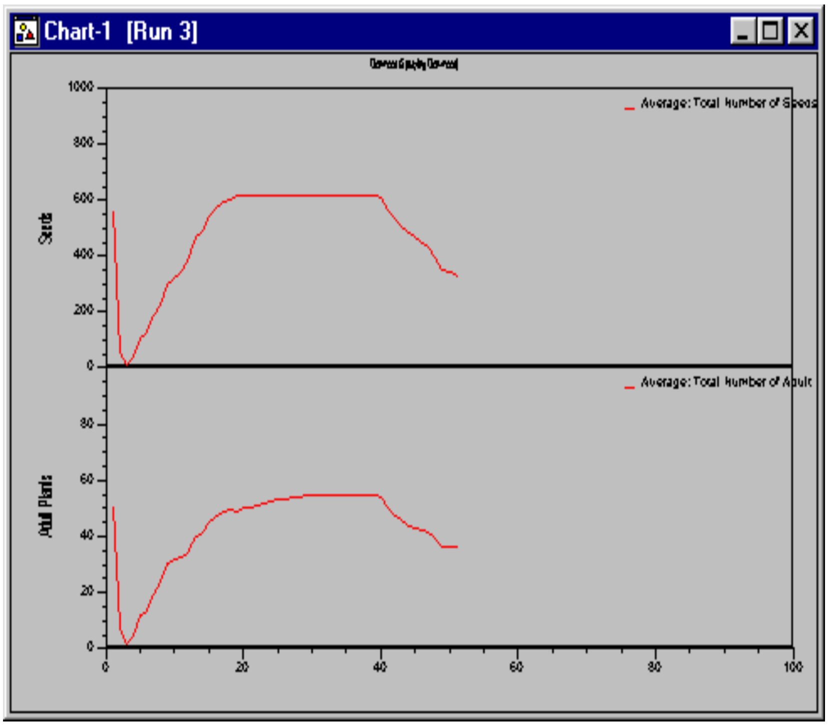


Figure 14.6 Summary run of Gen-weed Spraying over ten years, using 'Total Numbers of Adult Plants and Seeds' as the summary variables; starting point 100 seeds and 100 adult plants.

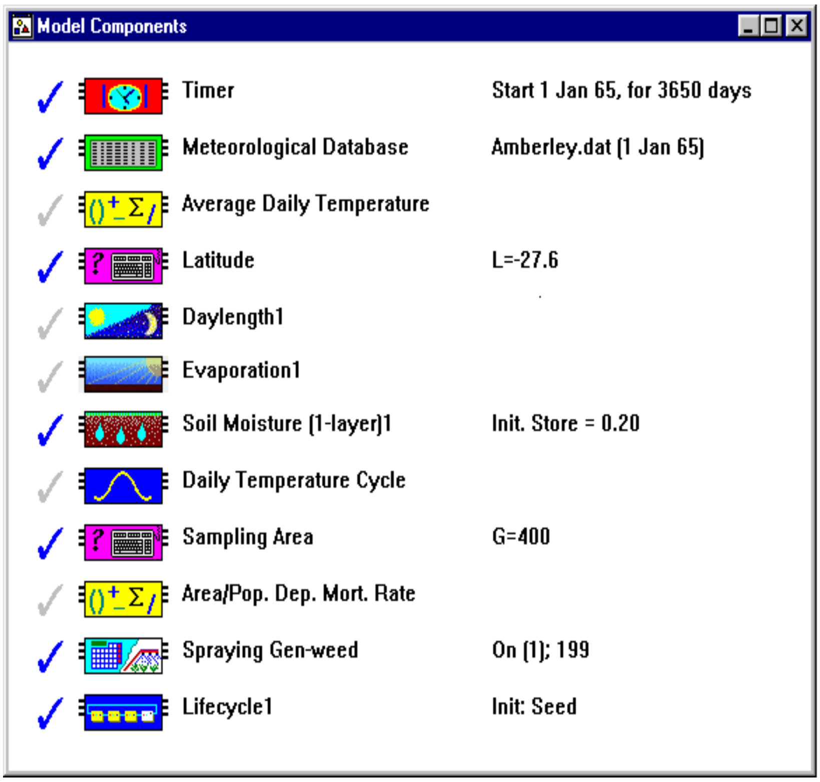


Figure 14.7 Current model's modules in the Simulator

14.2 Tutorial 14 - Summary of Modules, Variables and Parameters

Modules: Timer, Lifecycle, Meteorological Database, Daylength, Latitude, Evaporation, Soil Moisture (1-layer), Average Daily Temperature, Circadian (Daily Temperature Cycle), Sampling Area, Expression (Area/Population Dependent Mortality Rate), Event (Spraying Gen-weed)

Timer

Set to 'Days since start' and 'Simulation Date', run default 3650 days.
Timestep: weekly

Lifecycle

Initial numbers for run: 10 seeds.

Seed

Mortality
Continuous
Constant: 0.00441

Transfer functions
Seed Maturation (step)
Independent variable: chronological age
Germination threshold: 40 weeks
Prop.seeds transferred: 1
Temperature induced germination (3-segment linear)
Independent variable: average daily temperature
Line 1 X-intercept: 18
Line 1 slope: 0.5
X-value at intersection of lines 1,2: 20
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 26
Line 3 Slope: -0.25
Soil Moisture induced germination (linear above threshold)
Independent variable: soil moisture
Rainfall threshold: 0.3
Rate of germination: 0.33

Combination Rule: multiply

Output: total numbers

Adult Plant

Continuous mortality
Chronological (step)
Independent variable: chronological age
Threshold: 14 weeks
Proportion of adults dying: 1
Population/Area Dependency (linear above threshold)
Independent variable: Population/Area mortality rate
Threshold: 1
Slope: 1
Event - direct function
Combination rule: complement product

Development (3-segment linear)
Independent variable: Daily temperature cycle
Line 1 X-intercept: 10
Line 1 slope: 0.0067
X-value at intersection of lines 1,2: 25
Line 2 Slope: 0.0
X-value at intersection of lines 2,3: 30
Line 3 Slope: -0.02

Reproduction
Fecundity:
Constant: 15 seeds per adult plant
Progeny Production (step)
Independent variable: physiological age
Threshold: 1
Seeds/adult: 15

Canopy Area
Cohort Variable Properties
Scope: Global
Update method: default (direct, non-iverted)
Permitted change: increase or decrease
Range: Initial value: 0
Minimum: 0
Maximum: no value set
Allowable Operations: Total, Average, Accumulate
Reset in Stage: Adult Plant

Lifestage (Adult)
Canopy Area Increment Function (Pradhan)
Independent variable: physiological age
Optimum: 0.5
Spread: 1
Multiplier: 1

Self Limiting Growth Rate F'n (Inverse Logistic)
Independent variable: Total canopy area
Asymptote: 0.00785
Inflexion point: 0.00393
Slope at inflexion: 1
Advanced function attributes
Y-offset: 1
Scale: -1
Combination Rule: multiply

Resource
Growth area

Outputs: total numbers, physiological age, average, total and accumulated canopy area, average density.

Meteorological Database

File: Amberley.dat
Output: Minimum temperature (column 8, width 4)
Maximum temperature (column 13, width 4)
Rainfall (column 17, width 5)
Relative Humidity 9am (column 31, width 4)
Relative Humidity 3pm (column 45, width 4)

Expression (Average Daily Temperature)

Inputs: Minimum and Maximum daily temperatures
Output: average daily temperature
Setup: average expression

Latitude

Default -27.6; Upper limit 90, Lower limit -90

Daylength

Inputs: Latitude and Day of Year
Output: Daylength

Evaporation

Inputs: Maximum temperature, Minimum temperature, Relative humidity 9am , Relative humidity 3pm, Daylength
Output: Evaporation

Soil Moisture (1-layer)

Inputs: Rainfall, Evaporation
Output: Soil Moisture
Factors:
Soil Moisture capacity: 50, 100, 200 for lower, default and upper values respectively
Evapotranspiration coeffic: 0.5, 0.8, 1.2 for the lower, default and upper values respect.
Drainage rate: 0
Initialisation value for a model run: 0.2

Circadian (Daily Temperature Cycle)

Inputs: Daily maximum temperature, daily minimum temperature, day length.
Output: Daily temperature cycle.

Query User (Sampling Area)

Outputs:
Growth area: 10000

Expression (Area/Population Dependency Mortality Rate)

Inputs:
Total Canopy Area
Resource/Sampling Area (inverted)

Function: Product

Output:
Population/Area Dependency Mortality Rate

Event (Spraying Gen-weed)

Inputs:

Day of Year, Simulation Date, Threshold (link each to appropriate input but link Threshold to Total numbers of Adult Plants

Output

Spray Application

Factors (function - exponential decay)

Independent variable: days since event
Threshold: 0.99
Decay constant: 1.5
Scaling factor: 0.99

Run Sequence Values

Event group

Number of events: 1
Spacing between events: 0

Run sequence

Starting day of year: 1
Interval: 1 time step (seven days)
No of runs in sequence: 52
Time interval for complete multiple run: 3650 days.