Chapter 8. PLANT GROWTH COMPONENT

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8.1 Introduction

A continuous simulation erosion model, such as WEPP, requires a plant growth component in order to simulate the growth of plants and their impact on the hydrologic and erosion processes. This chapter describes the growth models used within the WEPP computer program to predict the development of cropland and rangeland plants. The purpose of the growth models is to predict temporal changes in plant and residue variables such as canopy cover, canopy height, root development, and biomass produced by the plants which is removed during a harvest operation or ends up as surface residue material. Cropland and rangeland plant growth are simulated in separate submodels of the WEPP model.

The plant growth component provides information to the water balance component (Chapter 5) which allows estimation of daily water use by the plants and extraction of water from the soil layers. Canopy cover and height information are passed to the erosion component (Chapter 11) for use in estimation of interrill soil detachment. The amount of residue remaining after harvest, or residue created by leaf drop during senescence is sent to the residue decomposition and management component (Chapter 9) of the WEPP model. Crop yield predicted by the plant growth component is available as a model output, and the user may alter the biomass production and predicted crop yield through cautious adjustment of the plant-specific input parameters.

Several plant management options are available to the user, including harvesting for grain or silage for cropland annual plants, hay harvest and livestock grazing for cropland perennial plants, and burning, herbicide application and livestock grazing for rangeland situations. Management options related to residues produced by a plant are discussed in the following chapter (Chapter 9).

This chapter has been organized into five sections. Sections 8.2 and 8.3 discuss plant growth and management options for cropland simulations, respectively. Sections 8.4 and 8.5 discuss plant growth and management options for rangeland simulations. Management and decomposition of residues resulting from the plant growth described in this chapter are discussed in Chapter 9.

8.2 Cropland Plant Growth Model

The crop model in WEPP was modified to make it similar to the EPIC crop model (Williams et al., 1989). WEPP uses EPIC concepts of phenological crop development based on daily accumulated heat units, harvest index for partitioning grain yield, Montieth's approach (Montieth, 1977) for determining potential biomass, and water and temperature stress adjustments. However, the nutrient cycling routines in EPIC are not included. A single model is used for simulating several crops by changing model parameters. WEPP is capable of simulating crop growth for both annual and perennial plants. Annual crops grow from planting date to harvest date or until accumulated heat units equal the potential heat units for the crop. Perennial crops maintain their activity throughout the year, although the plant may become dormant after frost.

Phenological development of the crop is based on daily heat unit accumulation. Heat units are computed using the equation:

$$HU_i = \frac{T_{mx,i} + T_{mn,i}}{2} - T_{b,j} \qquad [8.2.1]$$

where HU, T_{mx}, and T_{mn} are the values of heat units, maximum temperature, and minimum temperature in ^oC on day i, and T_b is the crop-specific base temperature in ^oC (no growth occurs at or below T_b) of crop j. A heat unit index (HUI) ranging from 0 at planting to 1 at physiological maturity is computed as follows:

$$HUI_i = \frac{\sum_{k=1}^{i} HU_k}{PHU_j} \qquad [8.2.2]$$

where HUI is the heat unit index for day i and PHU is the potential heat units required for maturity of crop j.

8.2.1 Potential Growth

Interception of photosynthetic active radiation (PAR) is estimated with Beer's law (Monsi and Saeki, 1953):

$$PAR_i = 0.02092\ (RA)_i\ (\ 1.0 - e^{-0.65\ LAI}\ )_i \qquad [8.2.3]$$

where PAR is photosynthetic active radiation ($MJ \cdot m^{-2}$), RA is solar radiation (Ly), LAI is leaf area index, and subscript i is the day of the year. Potential biomass production per day is estimated with the equation (Montieth, 1977):

$$\Delta B_{p,i} = 0.0001\ BE_j\ (PAR)_i \qquad [8.2.4]$$

where $\Delta B_{p,i}$ is the potential increase in total biomass on day i ($kg \cdot m^{-2}$), and BE_j is the crop parameter for converting energy to biomass for crop j ($kg \cdot MJ^{-1}$). The potential increase in total biomass is adjusted daily according to the growth constraints. The adjusted daily total biomass production (ΔB_i) is accumulated through the growing season (B_m).

$$B_m = \sum_{i=1}^{ndays} \Delta B_i \qquad [8.2.5]$$

where $ndays$ is the total number of days from the starting day.

8.2.2 Canopy Cover and Height

Canopy cover and height for annual and perennial crops are calculated as functions of vegetative biomass:

$$C_c = 1 - e^{-\beta_c B_m} \qquad [8.2.6]$$

where C_c is canopy cover (0-1). The variable β_c is defined as:

$$\beta_c = \frac{-\beta_1}{\ln\left(1 - \frac{R_w}{\beta_2}\right)} \qquad [8.2.7]$$

where R_w is the row width (m), β_1 is a plant-dependent constant, and β_2 is the maximum canopy width at physiological maturity. β_c is an input parameter (BB). For crops not grown in rows, R_w is set equal to the plant spacing (P_s).

$$H_c = \left(1 - e^{-\beta_h\, B_m}\right) H_{cm} \qquad [8.2.8]$$

where H_c is the canopy height (m), H_{cm} is the maximum canopy height (m), and β_h is a plant-dependent constant.

8.2.3 Senescence

When the fraction of growing season (F_{gs}) is equal to the fraction of the growing season when senescence begins (GSSEN), canopy cover (C_c) starts declining linearly for a given time period (S_p). The daily decline in canopy cover can be predicted with the equation:

$$\Delta C_c = C_{cm} \left(\frac{1 - f_{cs}}{S_p} \right) \qquad [8.2.9]$$

where ΔC_c is the daily loss of canopy cover (0-1), C_{cm} is canopy cover fraction at maturity (0-1), f_{cs} is the fraction of canopy cover remaining after senescence, and S_p is the number of days between the beginning and end of leaf drop. f_{cs} and S_p are user inputs to the model. Canopy cover is adjusted using:

$$C_{c\,(i)} = C_{c\,(i-1)} - \Delta C_c. \qquad [8.2.10]$$

where $C_{c\,(i)}$ is the canopy cover for the current day i, and $C_{c\,(i-1)}$ is the canopy cover for the previous day.

Because leaves are falling during the senescence period, live above-ground biomass (B_m) decreases while flat residue mass (M_f) increases. The daily decline in above-ground biomass due to senescence (ΔB_{ms}) is predicted using the equation:

$$\Delta B_{ms} = B_{mx} \left(\frac{1 - f_{bs}}{S_p} \right) \qquad [8.2.11]$$

where B_{mx} is the above-ground biomass at crop maturity ($kg \cdot m^{-2}$) and f_{bs} is the fraction of above-ground biomass remaining after senescence. f_{bs} is a user input to the model. Above-ground biomass is then adjusted using the following equation:

$$B_{m\,(i)} = B_{m\,(i-1)} - \Delta B_m \qquad [8.2.12]$$

Flat residue mass is increased by same amount (the change in vegetative biomass:

$$M_{f\,(i)} = M_{f\,(i-1)} + (B_{m\,(i-1)} - B_{m\,(i)}) \qquad [8.2.13]$$

where $M_{f\,(i-1)}$ is flat residue mass of the previous day, and $B_{m\,(i-1)}$ is vegetative biomass of the previous day.

8.2.4 Growth Limitations

The potential biomass predicted with Eq. [8.2.4] is adjusted daily if one of the plant stress factors (water or temperature) is less than 1.0 using the equation:

$$\Delta B_i = (\Delta B_{p,i})\,(REG) \qquad [8.2.14]$$

where REG is the crop growth regulating factor (the minimum of the water and temperature stress factors).

Water Stress -- The water stress factor is computed by considering supply and demand in the equation

$$WS = \frac{\sum_{l=1}^{nl} u_l}{E_P} \qquad [8.2.15]$$

where WS is the water stress factor (0-1), u_l is plant water use in soil layer l (mm), nl is the number of soil layers, and E_P is the potential plant evaporation (mm). The value of E_P is predicted in the evapotranspiration component of WEPP (Chapter 5).

Temperature Stress -- The temperature stress factor is computed with the equation:

$$TS = \sin\left(\frac{\pi}{2}\ \frac{T_a - T_b}{T_o - T_b}\right) \qquad [8.2.16]$$

where TS is the temperature stress factor (0-1), T_a is the average daily temperature (°C), T_b is the base temperature for the crop (°C), and T_o is the optimum temperature for the crop (°C).

8.2.5 Crop Yield

The economic yield of most grain and tuber crops is a reproductive organ. Crops have a variety of mechanisms which insure that their production is neither too great to be supported by the vegetative components nor too small to insure survival of the species. As a result, harvest index (economic yield/above-ground biomass) of unstressed crops is often relatively stable across a range of environmental conditions. Crop yield for annual crops is estimated using the harvest index concept, which is adjusted throughout the growing season according to water stress constraints.

$$YLD_j = (HIA_j)\,(B_{AG}) \qquad [8.2.17]$$

where YLD is crop yield ($kg{\cdot}m^{-2}$), HIA is adjusted harvest index at harvest, and B_{AG} is cumulative above-ground biomass ($kg{\cdot}m^{-2}$) before senescence occurs. Harvest index increases nonlinearly from zero at planting using the equation:

$$HI_i = HIO_j\,(HUFH_i - HUFH_{i-1}) \qquad [8.2.18]$$

where HI_i is the harvest index on day i, HIO_j is the harvest index under favorable growing conditions for crop j, and $HUFH$ is the heat unit factor that affects harvest index for day i and the previous day $i-1$.

The harvest index heat unit is computed with the equation:

$$HUFH_i = \frac{HUI_i}{HUI_i + e^{(6.50 - 10.0\,HUI_i)}} \qquad [8.2.19]$$

The constants in Eq. [8.2.20] are set to allow $HUFH_i$ to increase from 0.1 at HUI_i= 0.5 to 0.92 at HUI_i=0.9. This is consistent with economic yield development of grain crops which produce most economic yield in the second half of the growing season.

Most grain crops are particularly sensitive to water stress from shortly before until shortly after anthesis (Doorenbos and Kassam, 1979). Optimum conditions for growth may reduce harvest index slightly if dry matter accumulation is large and economic yield is limited by sink size. The harvest index is affected by water stress using the equation:

$$HIA_i = \frac{HI_i}{1.0 + WSYF_j\ (FHU_i)\ (0.9 - WS_i)} \qquad [8.2.20]$$

where HIA is the adjusted harvest index, $WSYF$ is a crop parameter expressing drought sensitivity (assumed to be a constant 0.01 in the WEPP model), FHU is a function of crop stage, and WS is the water stress factor for day i. Notice that harvest index may increase slightly on days with WS values greater than 0.9. The maximum value for HIA_i is limited to HI_i within the WEPP code. The crop stage factor, FHU, is estimated with the equation:

$$FHU_i = \sin \frac{\pi}{2} \left(\frac{HUI_i - 0.3}{0.3} \right) \qquad 0.3 < HUI_i < 0.9 \qquad [8.2.21]$$

$$FHU_i = 0.0 \qquad HUI_i \le 0.3 \quad or \quad HUI_i \ge 0.9$$

8.2.6 Yield Adjustment

Currently, the crop growth model in WEPP does not account for biomass and yield variation due to nutrient, pest, or other management factors. The impact of these factors on erosion rates has to be estimated and crop yield can be adjusted in one of two different ways. The recommended approach is to alter crop yields through careful direct adjustments to the BE_j and HI_j user input parameters for the specific crop. An alternative method is to use an algorithm which allows the WEPP user to adjust BE_j indirectly though inputting of an optimum crop yield (yop_{in}), assuming the plant experiences no growth stresses. At the start of the simulation, the model calculates an optimum yield (yop_{calc}) based on Eq. [8.2.3] and [8.2.4] for potential growth (no stress). The biomass conversion factor is then adjusted with the equation:

$$BE_{adj} = \frac{yop_{in}}{yop_{calc}}\ BE_j \qquad [8.2.22]$$

where BE_{adj} is the adjusted biomass conversion factor for crop j ($kg \cdot MJ^{-1}$), yop_{in} is the optimum crop yield input by the user ($kg \cdot m^{-2}$), and yop_{calc} is the optimum crop yield calculated by the model ($kg \cdot m^{-2}$). During a WEPP simulation, BE_{adj} can then be used in Eq. [8.2.4] and the potential growth stressed according to Eq. [8.2.15].

8.2.7 Root Growth

Ratios to describe partitioning between root biomass and above-ground vegetative biomass (root to shoot ratios) are used to grow plant roots for all annual and perennial crops. Total root mass (B_{rt}) on any day (i) is predicted with the equation:

$$(B_{rt})_i = (B_{rt})_{i-1} + \Delta B_i\ (R_{sr})_j \qquad [8.2.23]$$

where R_{sr} is the root to shoot ratio, a plant-dependent constant.

Total root mass is partitioned into the 0- to 0.15-, 0.15- to 0.30-, and 0.30- to 0.60-m soil zones (B_{r1}, B_{r2}, B_{r3}) as follows:

If root depth is < 0.15 m:

$$B_{r1(i)} = B_{r(i-1)} + \Delta B_r$$
$$B_{r2(i)} = 0.0$$
$$B_{r3(i)} = 0.0$$

If root depth is > 0.15 m and < 0.30 m:

$$B_{r1(i)} = B_{r1(i-1)} + (0.60\ \Delta B_r)$$
$$B_{r2(i)} = B_{r2(i-1)} + (0.40\ \Delta B_r)$$
$$B_{r3(i)} = 0.0$$

If root depth is > 0.30 m and < 0.60 m:

$$B_{r1(i)} = B_{r1(i-1)} + (0.45\ \Delta B_r)$$
$$B_{r2(i)} = B_{r2(i-1)} + (0.30\ \Delta B_r)$$
$$B_{r3(i)} = B_{r3(i-1)} + (0.25\ \Delta B_r)$$

If root depth is > 0.60 m:

$$B_{r1(i)} = B_{r1(i-1)} + (0.42\ \Delta B_r)$$
$$B_{r2(i)} = B_{r2(i-1)} + (0.28\ \Delta B_r)$$
$$B_{r3(i)} = B_{r3(i-1)} + (0.20\ \Delta B_r)$$

where ΔB_r is the daily change in total root mass ($kg \cdot m^{-2}$).

For a perennial crop, live root mass accumulates until a maximum amount of root biomass is reached (*RTMMAX*), which often occurs after three years of growth. After *RTMMAX* is reached, root growth and death are assumed equal.

An equation adopted from Borg and Williams (1986) is used to predict root depth for annual crops:

$$R_d = (R_{dx})_j \left(0.5 + 0.5 \sin \left[3.03 \left(HUI\right) - 1.47\right]\right) \qquad [8.2.24]$$

where R_{dx} is the maximum root depth (m) for crop j.

For perennial crops, Eq. [8.2.25] is used to compute the minimum root depth. Daily additions to the root depth are a linear function of root biomass addition:

$$(R_d)_i = (R_d)_{i-1} + \frac{\Delta B_i (R_{sr})_j}{RTMMAX}\ (R_{dx})_j \qquad [8.2.25]$$

The computed root depth cannot exceed the value of $(R_{dx})_j$ or the maximum input soil depth.

8.2.8 Leaf Area Index

An equation described in EPIC (Williams et al., 1984) is used to predict leaf area index (LAI) for annual crops: If $HUI_i < F_{lai}$ then,

$$LAI = \frac{LAI_{mx}\ B_m}{B_m + 0.552 e^{-6.8 B_m}} \qquad [8.2.26]$$

If $HUI_i > F_{lai}$ then,

$$LAI = LAI_d \left(\frac{1 - HUI_i}{1 - F_{lai}} \right)^2 \qquad [8.2.27]$$

where LAI_{mx} is the maximum leaf area index potential, LAI_d is the leaf area index value when LAI starts declining, and F_{lai} is the value of the heat unit index when leaf area index starts declining.

The equation to predict leaf area index for a perennial crop is:

$$LAI = \frac{LAI_{mx}\ B_m}{B_m + 0.276\ e^{-13.6\ B_m}}. \qquad [8.2.28]$$

8.2.9 Plant Basal Area

Plant basal area is calculated as a function of plant population (P_m) and single stem area (A_{sp}):

$$A_{bm} = P_m\ A_{sp} \qquad [8.2.29]$$

where A_{bm} is the plant basal area at maturity (m^2) per square meter of soil area, P_m is the plant population per square meter of soil area, and A_{sp} is the area of a single stem at maturity (m^2). Plant population is predicted from:

$$P_m = \frac{1}{A_p} \qquad [8.2.30]$$

where A_p is the area associated with one plant (m^2). A_p is a function of plant spacing and row width:

$$A_p = P_s\ R_w \qquad [8.2.31]$$

where P_s is the in-row plant spacing (m), and R_w is the row width (m). If R_w is zero because seed is broadcast, R_w is set equal to P_s.

The area of a single stem is:

$$A_{sp} = \pi \left(\frac{D}{2} \right)^2 \qquad [8.2.32]$$

where D is the average stem diameter at maturity (m).

Plant stem diameter is assumed to increase linearly from emergence until maturity. Based on this assumption, plant basal area (A_b) is calculated from:

$$A_b = A_{bm} \frac{B_m}{B_{mx}}. \qquad [8.2.33]$$

8.2.10 Crop Parameter Values and User Inputs

Table 8.2.1 presents parameter values for corn, soybeans, grain sorghum, cotton, winter wheat, spring wheat, oats, alfalfa, bromegrass, peanuts, tobacco, and annual ryegrass required by the cropland plant growth model. Values for corn, soybeans, and wheat parameters were obtained from the literature or estimated using measured field data. Several of the parameters were determined based upon long-term model simulations using climate input files for the major U.S. states producing those crops. Be sure to obtain the most recent version of the WEPP user documentation, as it will contain any updates to these parameters. Also, the Crop Parameter Intelligent Database System (CPIDS) (Deer-Ascough et al., 1993) was developed to assist users in developing WEPP plant growth parameters for crops not already parameterized.

For cropland plant growth simulation, the user is generally required to provide the following information:

1. number of overland flow elements - (nelem)
2. number of different crops in the simulation - (ncrop)
3. cropping system (annual, perennial, or fallow) - (imngmt)
4. crop types in the simulation - (itype)
5. number of tillage sequences in the simulation - (nseq)
6. number of tillage operations within each sequence - (ntil)
7. Julian day of tillage (mdate), tillage depth (tildep), and tillage type (typtil)
8. initial conditions at the start of simulation, including canopy cover (C_c), interrill residue cover (C_{ri}), rill residue cover (C_{rr}), and prior crop type (IRESD)
9. crop information including planting date (JDPLT), row width (R_w), and harvesting date (JDHARV)
10. base harvest index which is used for partitioning live biomass into that removed as a harvested crop material (grain, silage, etc.) and that converted to dead crop residue. Default values for harvest index are provided in Table 8.2.1 for annual crops normally harvested as grain. These values may have to be increased if harvested for silage.
11. plant management information for annual crops including date of application of a contact herbicide (JDHERB) to convert living biomass to dead residue
12. plant management information for perennial crops that are cut, including the number of cuttings (*NCUT*), cutting dates (*CUTDAY*), and cutting height (*CUTHGT*)
13. plant management information for perennial crops that are grazed, including the date that grazing begins (*GDAY*), the date that grazing ends (*GEND*), the number of animal units (N_a), average body weight (B_w), field size (A_f), and the digestibility of the forage (D_g).

Table 8.2.1. Parameter values used in the cropland growth submodel.†

Symbol	Variable	Corn	Soybeans	Sorghum	Cotton	Winter Wheat	Spring Wheat	Oats
β_c	BB	3.60	14.00	3.60	5.89	5.20	5.20	5.20
β_h	BBB	3.00	3.00	3.00	3.50	3.00	3.00	3.00
BE_j*	BEINP ($kg \cdot MJ^{-1}$)	18/28/35	20/23/25	12/17/25	17.5	25/30/35	25/30/35	17/20/23
T_b	BTEMP (^oC)	10.0	10.0	10.0	12.0	4.0	4.0	4.0
cf	CF ($m^2 \cdot kg^{-1}$)	2.3	7.2	3.0	3.0	5.4	5.4	5.4
-	CRIT (^oC)	60	60	60	90	60	60	60
-	CRITVM ($kg \cdot m^{-2}$)	-	-	-	-	-	-	-
$CUTHGT$	CUTHGT (m)	0.304	0.152	0.609	0.900	0.152	0.152	0.152
f_{cs}	DECFCT	0.65	0.10	0.90	0.25	1.00	1.00	1.00
D	DIAM (m)	0.0508	0.0095	0.0317	0.0127	0.0064	0.0064	0.0079
D_g	DIGEST	-	-	-	-	-	-	-
F_{lai}	DLAI	0.80	0.90	0.85	0.85	0.80	0.80	0.90
f_{bs}	DROPFC	0.98	0.10	0.98	0.10	1.00	1.00	1.00
-	EXTNCT	0.65	0.45	0.60	0.65	0.65	0.65	0.65
-	FLIVMX	0.00	0.00	0.00	3.00	3.00	3.00	3.00
G_{dm}**	GDDMAX ($^oC \cdot d$)	1700	1150	1450	2200	1700	1700	1500
HI	HI	0.50	0.31	0.50	0.50	0.42	0.42	0.42
H_{cm}	HMAX (m)	2.60	1.01	1.01	1.06	0.91	0.91	1.14
T_o	OTEMP (^oC)	25.0	25.0	27.5	27.5	15.0	15.0	15.0
-	PLTOL	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P_s	PLTSP (m)	0.219	0.025	0.130	0.101	0.005	0.005	0.005
R_{dx}	RDMAX (m)	1.52	1.00	1.50	1.20	0.30	0.30	0.30
R_{sr}	RSR	0.25	0.25	0.25	0.25	0.25	0.25	0.25
-	RTMMAX ($kg \cdot m^{-2}$)	-	-	-	-	-	-	-
S_p	SPRIOD (d)	30	14	40	30	14	14	14
T_{cu}	TMPMAX (^oC)	-	-	-	-	-	-	-
T_{cl}	TMPMIN (^oC)	-	-	-	-	-	-	-
LAI_{mx}	XMXLAI	3.5	5.0	5.0	6.0	5.0	5.0	8.0

† A "-" indicates not applicable. Please check the current version of the WEPP User Summary document for updated values for these parameters.

* Three values of BEINP have been provided for most crops illustrated, representing the crops grown under Low/Medium/High fertility levels.

** Growing degree days for crops to reach maturity varies by variety and region. Values listed here are typical for crop varieties grown near Indianapolis, Indiana. A value of 0 may be input to the model for any crop, and WEPP will internally compute a value for GDDMAX based upon the planting and harvest dates for an annual crop, and for the entire year for a perennial crop.

Table 8.2.1 (Cont.). Parameter values used in the cropland growth submodel.†

Symbol	Variable	Alfalfa	Brome-grass	Peanut	Tobacco	Annual Ryegrass	Canola
β_c	BB	14.00	14.00	12.00	6.60	14.00	5.20
β_h	BBB	23.00	23.00	6.92	7.00	23.00	3.00
BE_j*	BEINP ($kg \cdot MJ^{-1}$)	8/13/15	15/25/35	9/11/13	25.0	20/25/30	30/45/60
T_b	BTEMP (^oC)	4.0	10.0	13.50	10.0	10.0	2.0
cf	CF ($m^2 \cdot kg^{-1}$)	5.0	5.0	2.7	3.0	5.0	5.0
-	CRIT (^oC)	30	30	60	60	30	45
-	CRITVM ($kg \cdot m^{-2}$)	0.10	0.10	-	-	-	-
$CUTHGT$	CUTHGT (m)	0.152	0.152	0.000	0.000	0.152	0.152
f_{cs}	DECFCT	0.70	0.70	1.00	0.75	1.00	0.10
D	DIAM (m)	0.0045	0.0022	0.0090	0.0510	0.0064	0.0060
D_g	DIGEST	0.60	0.50	-	-	-	-
F_{lai}	DLAI	0.85	0.85	1.00	0.70	0.85	0.49
f_{bs}	DROPFC	0.90	0.90	1.00	0.70	1.00	0.10
-	EXTNCT	0.65	0.65	0.65	0.90	0.65	0.65
-	FLIVMX	12.00	12.00	0.00	0.00	3.00	3.00
G_{dm}**	GDDMAX ($^oC \cdot d$)	0 **	0 **	1500	1500	1000	1500
HI	HI	0.90	0.90	0.42	0.90	0.42	0.30
H_{cm}	HMAX (m)	0.80	0.51	0.66	1.06	0.80	0.90
T_o	OTEMP (^oC)	20.0	25.0	25.0	25.0	15.0	21.0
-	PLTOL	0.25	0.25	0.25	0.25	0.25	0.25
P_s	PLTSP (m)	0.006	0.006	0.076	0.220	0.038	0.100
R_{dx}	RDMAX (m)	2.43	0.30	1.20	0.76	0.30	1.40
R_{sr}	RSR	0.33	0.33	0.33	0.33	0.33	0.25
-	RTMMAX ($kg \cdot m^{-2}$)	0.60	0.34	-	-	-	-
S_p	SPRIOD (d)	14	14	14	14	14	14
T_{cu}	TMPMAX (^oC)	32.0	32.0	-	-	-	-
T_{cl}	TMPMIN (^oC)	0.5	1.1	-	-	-	-
LAI_{mx}	XMXLAI	6.0	9.0	4.5	3.4	6.0	4.5

† A "-" indicates not applicable. Please check the current version of the WEPP User Summary document for updated values for these parameters.

* Three values of BEINP have been provided for most crops illustrated, representing the crops grown under Low/Medium/High fertility levels.

** Growing degree days for crops to reach maturity varies by variety and region. Values listed here are typical for crop varieties grown near Indianapolis, Indiana. A value of 0 should be input for GDDMAX for perennial crops which will be grown during the simulation, A value of 0 may be input to the model for any crop, and WEPP will internally compute a value for GDDMAX based upon the planting and harvest dates for an annual crop, and for the entire year for a perennial crop.

8.2.11 Model Summary

Procedures followed in the plant growth model are:

1. Initialize the crop parameter values (Table 8.2.1).
2. Adjust the biomass conversion factor (*BE*) by the ratio of the optimum crop yield input by the user and the optimum crop yield calculated by the model, if this option is selected.
3. User initializes canopy cover (C_c) at the start of the simulation. If canopy cover exists, the model calculates initial vegetative biomass (B_m), canopy height (H_c), and leaf area index (*LAI*) values. If no crop exists on first day of simulation, the continuous simulation model resets canopy cover to 0.
4. Calculate growing degree days, and cumulative growing degree days ($\sum HU$).
5. Initiate plant growth when conditions for emergence are met.
6. Compute B_m, C_c, H_c, B_{rt}, B_{r1}, B_{r2}, B_{r3}, R_d, *LAI*, and A_b.
7. Continue plant growth simulation until cumulative growing degree days ($\sum HU$) are equal to the growing degree days at maturity ($HUI = 1$).
8. When $HUI = 1$ is reached, plant growth stops (senescence begins).
9. Starting at senescence, canopy cover and live biomass decrease due to leaf drop.
10. Growth of annual and perennial crops is stopped when the average daily air temperature (T_a) is less than the base temperature of the plant (T_b).
11. Perennial crops become dormant when a five-day average minimum temperature is less than the critical minimum temperature (T_{cl}).
12. Perennial crops become dormant when a five-day average maximum temperature is greater than the critical maximum temperature (T_{cu}).

The model does not calculate nutrient and aeration stress factors commonly found in more comprehensive plant growth models. These factors are accounted for in the grain or biomass yields or other growth parameters specified by the user.

8.3 Cropland Plant Management Options

The cropland plant growth model can accommodate fallow, mono, double, rotation, strip, and mixed cropping practices. A mixed cropping practice is one where two or more individual cropping practices (e.g. mono and double) are used in the simulation. The models are applicable to the annual and perennial crops specified in WEPP User Requirements including corn, soybeans, grain sorghum, cotton, winter wheat, spring wheat, oats, alfalfa, and bromegrass. Default parameter values required to simulate the growth of peanuts, tobacco, and annual ryegrass are also provided.

8.3.1 Management Options For Annual Crops

8.3.1.1 Herbicide Application

There are two situations where foliar contact herbicides are used to convert live vegetative biomass into standing dead residue. The first is in the defoliation of cotton. The second is killing a winter annual cover crop either prior to or at row-crop planting. The user must input the date of herbicide application (JDHERB). All living above-ground vegetative biomass is converted into standing dead residue on JDHERB. In situations where another crop is not planted soon after the killing of the previous crop with the herbicide, additional management of the now standing dead residue mass is accomplished through use of fallow period residue management options (Chapter 9).

The model does not consider the effect of herbicides on broadleaf weeds or grasses, unless the user has entered a set of plant growth parameters and is simulating growth of the weeds or grasses as a separate crop.

8.3.1.2 Silage

There are two ways in which a user may simulate harvest of an annual crop as silage. The first option is to enter the normal crop parameters and then alter the input value for harvest index so that it reflects the greater removal of biomass as silage. For example, if the default value for the harvest index for corn (harvested as grain) is 0.50, the user could increase this to a value of about 0.95 and set the harvest date to the date of silage harvest.

The second option is to use the "silage" management option. Here, the user must input the date that silage is removed from the field (JDSLGE). The WEPP model then converts any living vegetative biomass (roots) into dead and assumes that all above-ground residue is removed from the field. No adjustments are made to flat residue mass and cover. The first option is the preferred method, as it gives the user control over the amount of residue remaining after the harvest operation.

8.3.1.3 Small Grain Harvest for Hay

The user may simulate the cutting of a small grain crop for hay in one of two ways. The first way is to simulate the plant using an annual management system and adjust the input value for harvest index to represent the amount of plant material that will be removed in the haying operation (similar to the first silage option above).

The other way to simulate hay harvesting of a small grain crop is by using perennial plant management, entering appropriate parameters to simulate the growth of the plant, then simulating a hay harvest on the appropriate day. A kill date should also be entered after the hay harvest date.

8.3.2 Management Options For Perennial Crops

8.3.2.1 Hay Harvesting

The user inputs the number of cuttings (*NCUT*) for each year, cutting dates (*CUTDAY*), and cutting height (*CUTHGT*) for each cutting. At each cutting date a certain fraction (F_{rm}) of live above-ground biomass (B_m) is harvested. The remaining live biomass is calculated from rearrangement of equation 8.2.7:

$$\text{for } CUTHGT \geq CANHGT \qquad B_m = B_m$$

$$\text{for } CUTHGT < CANHGT \qquad B_m = \frac{1}{\beta_h} \log \left(1 - \frac{H_c}{H_{cm}} \right) \qquad [8.3.1]$$

The model assumes a uniform distribution of vegetative material with plant height. Eq. [8.2.29] is used to compute a new value for LAI for the newly cut crop. A new value for adjusted cumulative growing degree days ($\sum HU$) is then computed using:

$$\sum HU = PHU \left(\frac{LAI}{LAI_{mx}} \right) \qquad [8.3.2]$$

The adjusted $\sum HU$ is used as the initial value at the start of the next growth period. A similar adjustment based upon B_m left after harvest is made to C_c, using equation 8.2.6.

Root biomass (B_{rt}) and root depth (R_d) continue to increase, even if the above-ground biomass is harvested, until they are equal to the maximum root biomass (RTMMAX) and maximum root depth (R_{dx}), respectively. Once maximum root mass is reached, the increment in live root biomass is assumed equal to the amount of root mass that dies daily.

After the last cutting, growth continues until a five-day average minimum temperature (TMNAVG) is equal to a critical freezing temperature (T_{cl}). Then, all standing live biomass (B_m) is transferred to standing dead mass (M_s). Plant growth variables such as B_m, C_c, H_c, and LAI are set to zero. Regrowth is initiated when TMNAVG is greater than T_{cl}.

8.3.2.2 Livestock Grazing

The approach taken for cropland grazing is similar to that for rangeland grazing. The user must input the date that grazing begins (GDAY) and ends (GEND). The number of animals (N_a), their average body weight (B_w), and the size of the pasture being grazed (A_f) are also user input variables. The daily total vegetative uptake (F_t) is predicted from:

$$F_t = 0.1 \left(\frac{B_w^{0.75}}{D_g} \right) \left(\frac{N_a}{A_f} \right) \qquad [8.3.3]$$

where D_g refers to the digestibility of the vegetation and is a plant-dependent constant for perennial crops. Vegetative biomass cannot decrease below a critical value (CRITVM) under heavy grazing, which is also a user input variable.

8.4 Rangeland Plant Growth Model

Initiation and growth of above- and below- ground biomass for range plant communities are estimated by using a potential growth curve. The potential growth curve can be defined with either an unimodal or a bimodal distribution (Fig. 8.4.1 and 8.4.2). The potential growth curve (Eq. [8.4.1]) is described by a modification of the generalized Poisson density function (Parton and Innis, 1972; and Wight, 1987). The potential growth curve should be defined to represent the aggregate total production for the plant community. The flexibility of the potential growth curve allows for description of either a warm or cool season plant community or for a combination of the two communities.

For a unimodal potential growth curve:

$$g_i = G_1 \left(\alpha\, e^{\frac{c}{d}(1-\beta)} \right) \qquad [8.4.1]$$

where

$$\alpha = \left(\frac{t_i - G_b}{P_d - G_b} \right)^c \qquad [8.4.2]$$

$$\beta = \left(\frac{t_i - G_b}{P_d - G_b} \right)^d \qquad [8.4.3]$$

g_i is the increment of growth expressed as a fraction of 1.0, G_1 is the fraction of maximum live biomass at the first peak, P_d is the Julian day peak live biomass occurs, G_b is the Julian day the growth curve begins, c is the shape parameter for the ascending side of the curve, d is the shape parameter for the descending side of the curve, and t_i is the current Julian day.

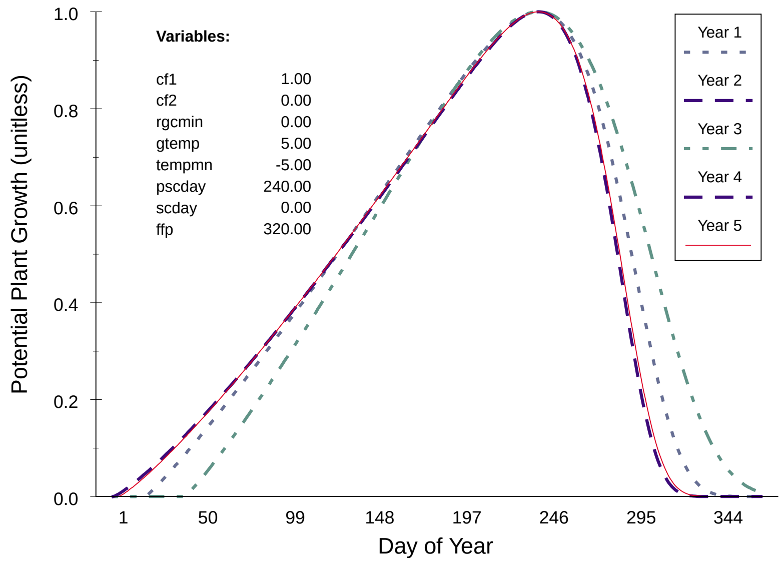

Figure 8.4.1. Unimodal potential plant growth for a five year period.

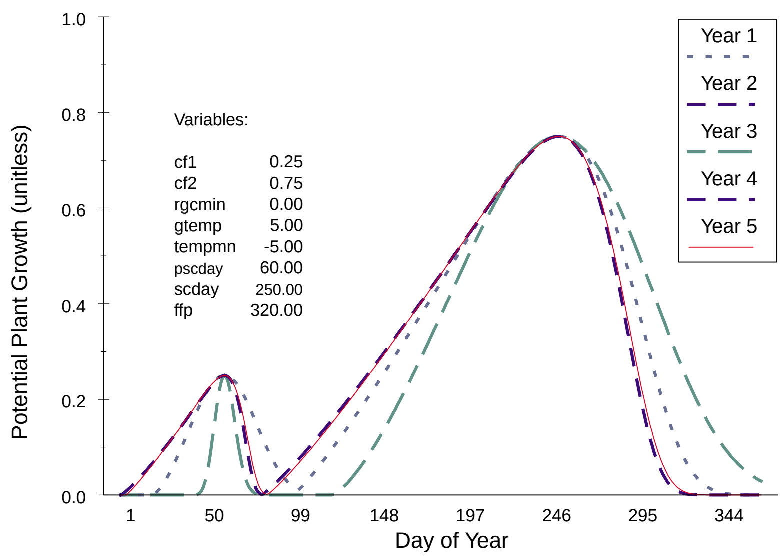

Figure 8.4.2. Bimodal potential plant growth for a five year period.

An optimization routine was developed to predict the shaping parameters c and d based on G_b, f_p, and P_d, where f_p is the frost-free period in Julian days.

$$c = 8.515 - 22.279\,a + 16.734\,a^2 \qquad [8.4.4]$$

$$d = 12.065 - 63.229\,a + 87.34\,a^2 \qquad [8.4.5]$$

where

$$a = \frac{P_d - G_b}{\left(\frac{G_1\, f_p}{G_1 + G_2}\right)}. \qquad [8.4.6]$$

The user must enter the potential maximum live above-ground biomass (P_{mx}). This value can be obtained from the USDA Natural Resource Conservation Service Range Site guide as total annual production for the site (section 5) with favorable growing season precipitation. The user can adjust the total annual potential production to reflect the condition of the site based on its current range condition (ecological status). The initiation of growth and senescence for the plant community for the growth curve are predicted based on air temperature. The physiological information necessary to define the growth curve is the minimum temperature necessary for initiation of growth in the spring (GTEMP) and a critical sustained minimum temperature which will induce dormancy (TEMPMN). Where the average daily temperature (T_a) is calculated as $T_a = (T_{mx} + T_{mn})/2$. T_{mx} and T_{mn} are defined as the maximum and minimum daily temperature (°C), respectively.

Plant growth is initiated when g_i is greater than 0.001. Once g_i has reached 1.0, plant growth stops for that growth period. Change from standing live biomass (L_t) to standing dead biomass (R_a) is a function of the decay rate of the growth curve, a minimum temperature which induces dormancy, and drought stress. Once a 5 day average minimum temperature is equal to a minimum temperature (TEMPMN) all standing live biomass is transferred to standing dead.

The drought stress (D_s) transfers old standing live to standing dead biomass as a function of actual evapotranspiration, potential evapotranspiration, and a plant specific available soil water variable (PLTOL). D_s has been defined such that the maximum single day reduction in old standing live biomass is 3%. The daily water stress (W_a) is calculated as a running four day average of the calculated water stress (WST).

$$D_s = 1 - e^{-3.5 W_a} \qquad [8.4.7]$$

Increments of new growth are calculated as:

$$L_i = g_i\, P_{mx} \qquad [8.4.8]$$

where L_i is the new plant growth on day of simulation, g_i is the positive increment between today's and yesterday's g_i, and P_{mx} is the potential maximum live biomass ($kg \cdot m^{-2}$).

Water stress is calculated as the ratio of actual transpiration to potential transpiration. If available soil water is limiting then W_a is utilized to kill standing live biomass and transfer the recently killed biomass to standing dead biomass. W_a is only calculated when the actual soil water content is below a plant specific critical soil water content (PLTOL). If PLTOL is not known for a specific plant community then set PLTOL to 0.0 and the model will use a default value of 25% of the soil water content at field capacity. After 20 consecutive days of water stress development of new phytomass ceases. Initiation of growth is reactivated after 80 mm of precipitation.

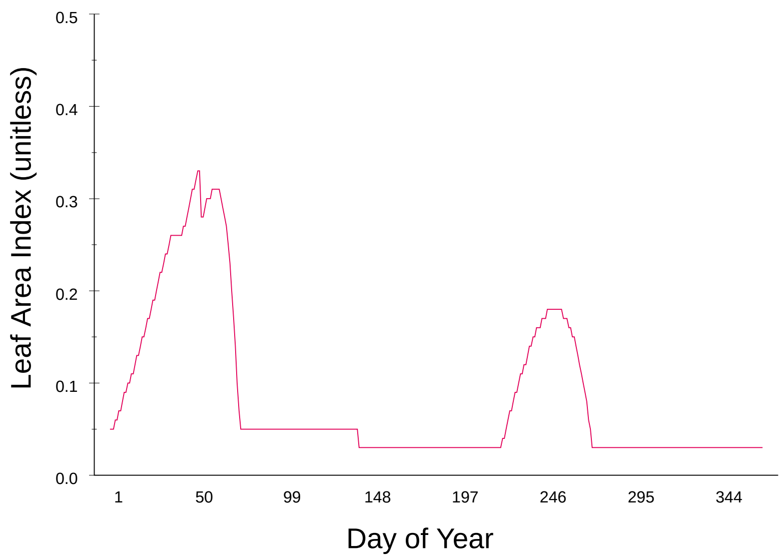

Figure 8.4.3. Bimodal plant growth depicted to illustrate leaf area index over time with a minimum evergreen function initialized (RGCMIN).

For plant communities with an evergreen component the RGCMIN parameter can be initialized to maintain the live biomass at a given fraction of maximum live biomass for the entire year. When the calculated value of g_i is less than RGCMIN, g_i is set to RGCMIN. This modification allows for a daily leaf area index value for evergreen communities like sagebrush, and creosote bush which may actively transpire water throughout the entire year (Fig. 8.4.3).

For a bimodal potential growth curve two potential growth curves are calculated and then spliced together. To describe the second peak in potential live biomass, the user must define two additional parameters, G_2 and P_2. G_2 is the fraction of maximum live biomass at the second peak. P_2 is the Julian day the second peak in live biomass occurs. The shaping coefficients e and f for the second growth curve are calculated in a similar manner as c and d for the first growth curve. For the second growth curve the coefficient, a, is calculated as:

$$a = \frac{P_2 - \left(\frac{G_1 \, f_p}{G_1 \, G_2} + G_b \right)}{f_p - \frac{G_1 \, f_p}{G_1 + G_2}} \qquad [8.4.9]$$

The user must initialize both above ground standing dead biomass and litter and organic residue on the soil surface. The transfer of standing live biomass (L_t) to R_a is calculated as a function of the rate of decline in the potential growth curve. The transfer (δ) of R_a to R_g is a function of daily rainfall, R (m). δ has been defined such that the maximum single day reduction in old standing dead is 5%.

$$\delta = e^{-3.5R} \tag{8.4.10}$$

The decomposition of litter and organic residue on the soil surface is a function of antecedent rainfall, average daily temperature, and the carbon-nitrogen ratio of the residue and was based on the work of Ghidey et al. (1985).

$$R_g = (R_g \ \omega_L) - B_c \tag{8.4.11}$$

$$\omega_L = 1 - (\alpha_f \ \tau)^2 \tag{8.4.12}$$

$$\tau = \frac{S_{mi} \ T_a}{C_n} \tag{8.4.13}$$

where ω_L is the fraction of litter after decay, α_f is the litter decay coefficient, and B_c is a daily disappearance of litter as a function of insects and rodents. τ is a function of the antecedent moisture index, average daily temperature, and the carbon-nitrogen ratio of dead leaves and roots (C_n). S_{mi} is the amount of rainfall recorded in the last 5 days (*mm*). S_{mi} values greater than 100 millimeters are set to 100 millimeters to reduce the decomposition rate of litter and organic residue during high rainfall periods.

For woody plant communities the trunks, stems, branches, and twigs (W_n) of the plants are considered to be nondecomposable but are important components in the calculation of foliar cover and ground surface cover. W_n is estimated on day one of the simulation as the product of N_a and R_a. W_n is held constant until management changes.

Plant characteristics that the model currently calculates are plant height (H_c), projected plant area (P_a), foliar canopy cover (C_c), ground surface cover (C_g), and leaf area index (*LAI*). The height of the plant canopy is calculated as the weighted average of coverage between the woody and the herbaceous plant components. The canopy height for the woody component (H_t and H_s) are input by the user and are held constant for duration of the simulation or until management changes.

$$H_c = \frac{(H_t \ E_t) + (H_s \ E_s) + (H_g \ E_g)}{A \ / \ P_a} \tag{8.4.14}$$

A is the representative total vertical surface area of the overland flow plane (m^2), P_a is the effective projected plant area ($m^2 \cdot m^{-2}$), H_t, H_s, and H_g are canopy heights for the tree, shrub, and herbaceous plant components (m), respectively, and E_t, E_s, and E_g are the vertical area of the tree, shrub, and herbaceous components (m^2), respectively.

The canopy height for the herbaceous community, H_g (m), is estimated with an exponential function and is updated daily. The parameters necessary to estimate herbaceous plant height are the live standing biomass, L_t ($kg \cdot m^{-2}$), dead standing biomass, R_a ($kg \cdot m^{-2}$), maximum herbaceous plant height, H_{cm} (m), and a shaping coefficient, B_h ($m^2 \cdot kg^{-1}$). Plant canopy height is defined not as the uppermost extension of the canopy, but where the maximum amount of rainfall interception occurs.

$$H_g = H_{cm}(1 - e^{-B_h L_t + R_a}) \tag{8.4.15}$$

The effective projected plant area is calculated as a function of the plant height (m), average canopy diameters (m), number of plants along a 100 meter transect, and a geometric shape coefficient for the various plant components (Eq. [8.4.15]) and is based on work done by Hagen and Lyles (1988). The effective projected plant area, P_a, is defined as the fraction of vertical cover and is used in calculating the distribution and depth of the snow pack.

$$P_a = \frac{E_a}{A} \qquad [8.4.16]$$

The total projected area of the vegetation, E_a (m^2), for the overland flow plane is computed as:

$$E_a = E_g + E_s + E_t \qquad [8.4.17]$$

E_t, E_s, and E_g are computed in a similar manner and are a function of plant height, plant diameter, plant density, and the geometric shape coefficient for each plant component, respectively. Eq. [8.4.18] shows the calculation for the herbaceous plant component.

$$E_g = H_g \; G_{di} \; G_c \; G_p \qquad [8.4.18]$$

The geometric shape coefficients G_c, S_c and T_c vary between 0.0 and 1.0. Where the geometric shape of a square has been defined as 1.0, a cylinder as 0.78, a trapezoid 0.75 (the bottom diameter is one-half of the top diameter), a parabola as 0.67, and a equilateral triangle as 0.43. The total vertical surface area is calculated from the taller of the two plant components as:

$$A = L \; H_t \qquad [8.4.19]$$

where L is some distance perpendicular to a slope. L has been set to 100 meters.

The WEPP model partitions the erosion process into rill and interrill erosion areas. The potential rill and interrill areas and the fraction of ground surface cover for both rill and interrill areas must be estimated. Spatial distribution of interrill and rill cover data for 34 rangeland locations from the USDA WEPP and IRWET (Interagency Rangeland Water Erosion Team) are summarized in Table 8.4.1. The area between plant canopies (interspace area) is defined as the potential rill area. A tentative relationship has been developed to estimate the distance between the center of the potential rills based on plant spacing. The plant spacing (number of plants along a 100 meter transect perpendicular to the slope) should be define to reflect the number of concentrated flow paths to be represented on the hillslope. The WEPP model is sensitive to plant spacing (i.e. rill spacing) when rill ground surface cover is insufficient to provide protection from rilling (i.e. when the estimated concentrated flow velocity exceeds the critical shear stress of the soil) (Fig. 8.4.4). The lower and upper boundary constraints on rill spacing are 0.5 and 5 meters, respectively, and L has been defined as 100 meters.

$$R_s = \frac{L}{B_p + S_p + T_p + 1} \qquad [8.4.20]$$

where R_s is the rill spacing (m).

Table 8.4.1. Mean canopy and ground cover spatial distribution characteristics from USDA-IRWET[1] rangeland rainfall simulation experiments used to develop WEPP.

	Interrill cover (fraction)					Rill cover (fraction)					Total Ground cover (fraction)	Canopy cover (fraction)
Location	Litter	Rock	Basal	Crypto	Soil	Litter	Rock	Basal	Crypto	Soil		
1) Prescott, AZ	0.144	0.016	0.121	0.000	0.196	0.123	0.039	0.031	0.000	0.329	0.474	0.477
2) Prescott, AZ	0.164	0.018	0.148	0.000	0.180	0.096	0.041	0.033	0.001	0.318	0.502	0.511
3) Tombstone, AZ	0.110	0.130	0.000	0.000	0.084	0.077	0.487	0.020	0.000	0.094	0.823	0.323
4) Tombstone, AZ	0.052	0.001	0.014	0.000	0.117	0.120	0.033	0.176	0.000	0.488	0.396	0.184
5) Susanville, CA	0.208	0.011	0.044	0.000	0.024	0.371	0.138	0.074	0.000	0.132	0.844	0.286
6) Susanville, CA	0.112	0.013	0.022	0.000	0.038	0.340	0.209	0.063	0.000	0.204	0.758	0.184
7) Akron, CO	0.280	0.000	0.099	0.016	0.048	0.294	0.000	0.120	0.046	0.097	0.855	0.443
8) Akron, CO	0.224	0.000	0.015	0.012	0.028	0.463	0.001	0.056	0.050	0.151	0.821	0.278
9) Akron, CO	0.423	0.000	0.095	0.001	0.019	0.346	0.000	0.088	0.002	0.025	0.956	0.538
10) Meeker, CO	0.074	0.000	0.002	0.000	0.030	0.226	0.000	0.113	0.005	0.550	0.420	0.106
11) Blackfoot, ID	0.634	0.000	0.044	0.000	0.029	0.216	0.000	0.007	0.000	0.070	0.902	0.707
12) Blackfoot, ID	0.760	0.000	0.071	0.000	0.039	0.090	0.000	0.003	0.000	0.037	0.924	0.870
13) Eureka, KS	0.218	0.000	0.006	0.000	0.157	0.334	0.000	0.023	0.000	0.261	0.582	0.382
14) Sidney, MT	0.049	0.001	0.007	0.046	0.019	0.230	0.002	0.159	0.320	0.170	0.812	0.120
15) Wahoo, NE	0.495	0.000	0.121	0.029	0.063	0.199	0.000	0.012	0.028	0.053	0.884	0.707
16) Wahoo, NE	0.450	0.000	0.093	0.127	0.022	0.192	0.000	0.011	0.090	0.016	0.962	0.692
17) Cuba, NM	0.171	0.000	0.006	0.000	0.033	0.663	0.000	0.025	0.000	0.103	0.864	0.209
18) Los Alamos, NM	0.214	0.000	0.011	0.000	0.048	0.515	0.000	0.056	0.000	0.157	0.796	0.272
19) Killdeer, ND	0.495	0.000	0.121	0.029	0.063	0.199	0.000	0.012	0.028	0.053	0.884	0.707
20) Killdeer, ND	0.450	0.000	0.093	0.127	0.022	0.192	0.000	0.011	0.090	0.016	0.962	0.692
21) Chickasha, OK	0.338	0.000	0.096	0.000	0.026	0.395	0.001	0.115	0.000	0.030	0.945	0.460
22) Chickasha, OK	0.064	0.000	0.005	0.004	0.072	0.425	0.001	0.168	0.036	0.225	0.703	0.145
23) Freedom, OK	0.200	0.000	0.114	0.015	0.060	0.294	0.003	0.046	0.045	0.225	0.716	0.388
24) Woodward, OK	0.214	0.001	0.102	0.018	0.117	0.193	0.002	0.049	0.042	0.264	0.619	0.450
25) Cottonwood, SD	0.181	0.000	0.156	0.013	0.110	0.286	0.010	0.034	0.002	0.209	0.682	0.460
26) Cottonwood, SD	0.126	0.004	0.172	0.006	0.034	0.298	0.013	0.171	0.019	0.158	0.808	0.341
27) Amarillo, TX	0.201	0.000	0.030	0.000	0.001	0.631	0.000	0.109	0.000	0.029	0.970	0.231
28) Amarillo, TX	0.101	0.000	0.003	0.000	0.000	0.736	0.000	0.027	0.000	0.133	0.867	0.104
29) Sonora, TX	0.176	0.032	0.005	0.019	0.162	0.139	0.124	0.155	0.031	0.158	0.681	0.394
30) Buffalo, WY	0.362	0.002	0.051	0.000	0.115	0.162	0.004	0.004	0.001	0.299	0.587	0.530
31) Buffalo, WY	0.387	0.025	0.030	0.000	0.242	0.131	0.029	0.004	0.000	0.153	0.605	0.683
32) Newcastle, WY	0.057	0.000	0.014	0.016	0.021	0.343	0.000	0.105	0.233	0.211	0.768	0.108
33) Newcastle, WY	0.474	0.000	0.014	0.002	0.065	0.302	0.000	0.016	0.001	0.125	0.810	0.556
34) Newcastle, WY	0.137	0.001	0.038	0.022	0.126	0.185	0.003	0.045	0.039	0.406	0.468	0.323

[1] Interagency Rangeland Water Erosion Team is comprised of ARS staff from the Southwest and Northwest Watershed Research Centers in Tucson, AZ and Boise, ID, and NRCS staff members in Lincoln, NE and Boise, ID.

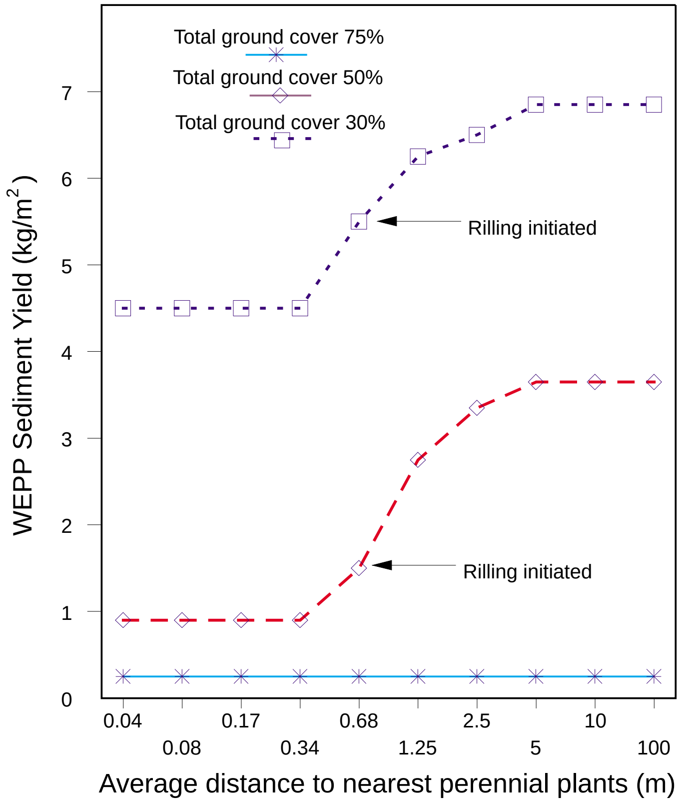

Figure 8.4.4. Relationship between plant spacing and estimated sediment yield for a desert grassland plant community on a clay loam soil with a 25 year return period rainfall event (rainfall depth = 76 *mm*, rainfall intensity = 100 $mm \cdot h^{-1}$)

The WEPP model is very sensitive to both total surface ground cover and the spatial distribution of its components. The model requires the user to define the proportion of ground surface cover that is in both rill and interrill areas. The rill area is equivalent to the interspace area, i.e. the area that is between plants (total surface area minus canopy cover) (Fig. 8.4.5). The user must define the fraction of total surface area occupied by rill litter cover (RESR), rill rock cover (ROKR), rill basal cover (BASR), and rill cryptogamic cover (CRYR). The interrill area is equal to the canopy cover area. Interrill ground surface cover is defined as the fraction of the ground surface that is underneath plants (canopy cover) that is occupied by either litter (RESI), rock (ROKI), basal (BASI), or cryptogamic crusts (CRYI), all user inputs.

It is often difficult to determine where canopy cover ends for areas that have been heavily grazed, for many prostrate growth form plant types, and on sites with high surface roughness and pedestalled plants. For the WEPP model, canopy cover is defined as any live or dead standing plant part elevated 2.5 cm or more from the soil surface. If the entire plant height is less than 2.5 cm and will not grow to a height that exceeds 2.5 cm then it is considered rill basal cover. Cryptogams are defined here as all mosses, lichens, and algae that occur on the soil surface. The rock and cryptogamic crusts are fixed variables and do not change as a function of plant growth or management options. Exposed bare soil is calculated as the difference between total surface area (100%) and total ground surface cover. The model does not address redistribution of litter from interrill to rill area as a function of wind, water or debris dam formation. The spatial distribution of ground surface cover between rill and interrill areas is user specified and held constant during the simulation.

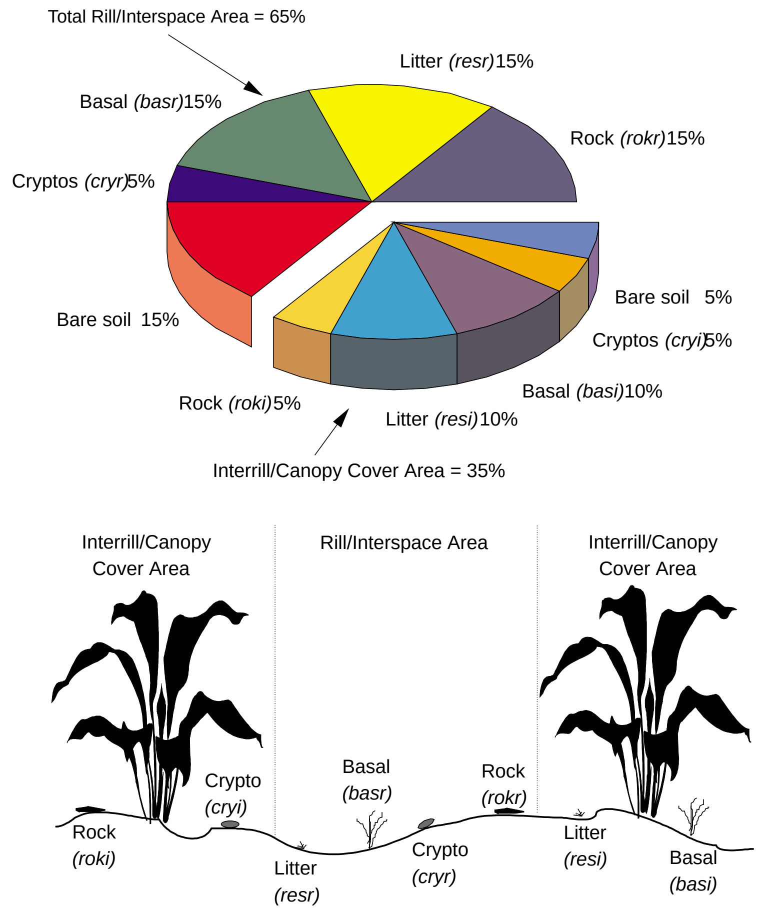

Figure 8.4.5. Distinction between rill and interrill areas used to define spatial attributes of ground cover components for WEPP Rangeland model.

Total ground surface cover is calculated as the sum of litter, rock, basal, and cryptogamic crust in both the rill and interrill areas. Total litter cover is estimated with an exponential function and then proportioned between rill and interrill areas based on the user specified distributions.

$$C_r = 1 - e^{-c_f R_g} \qquad [8.4.21]$$

where c_f (RESCOF) is a user-defined shaping coefficient ($m^2 \cdot kg^{-1}$), and R_g is total litter and organic residue mass on the soil surface ($kg \cdot m^{-2}$). If the user does not know the relationship between litter mass and litter cover (c_f is equal to 0.0) a default coefficient will be estimated from litter mass and total litter cover to provide the model with a means of estimating litter cover as litter mass and litter cover are updated during continuous simulation (Table 8.4.2). If the user specifics 0.0 for litter mass, litter cover, and c_f then the shaping coefficient is set to 63.9 and was solved from a desert grassland on the Walnut Gulch Experimental Watershed (Fig. 8.4.6). Table 8.4.2 lists the c_f coefficients that were calculated from the USDA WEPP and Interagency Rangeland Water Erosion Team field data. This data is representative of the default solution where the relationship between litter cover and litter mass are solved based on a point in time solution and should be used with caution.

Table 8.4.2. Default root biomass (ROOT10), canopy (CANCOF) and litter (LITCOF) coefficients from USDA rangeland rainfall simulation experiments used to develop the WEPP model from point-in-time samples.

Location	MLRA[1]	Rangeland cover type[2]	Range site	Dominant species by weight (dec. order)	Eco-logical status[3]	Cover coefficients Canopy	Cover coefficients Litter	Root biomass ($kg \cdot m^{-2}$)
1) Tombstone, AZ	41	Creosotebush-Tarbush	Limy upland	Tarbush Creosotebush	38	5.0	4.6	0.12
2) Tombstone, AZ	41	Grama-Tobosa-Shrub	Loamy upland	Blue grama Tobosa Burro-weed	55	1.7	8.0	0.45
3) Susanville, CA	21	Basin Big Brush	Loamy	Idaho fescue Squirreltail Wyoming big sagebrush	55	5.3	5.7	2.23
4) Susanville, CA	21	Basin Big Brush	Loamy	Idaho fescue Squirreltail Wyoming big sagebrush	55	7.0	5.7	2.23
5) Meeker, CO	34	Wyoming big sagebrush	Clayey slopes	Salina wildrye Wyoming big sagebrush Western wheatgrass	60	2.5	6.3	0.36
6) Sidney, MT	54	Wheatgrass-Grama-Needlegrass	Silty	Dense clubmoss Western wheatgrass Needle & thread grass	58	0.8	7.3	1.82
7) Cuba, NM	36	Blue grama-Galleta	Loamy	Galleta Blue grama Broom snakeweed	47	1.8	12.9	0.90
8) Los Alamos, NM	36	Juniper-Pinyon Woodland	Woodland community	CO rubberweed Sagebrush Blue grama	NA[4]	2.5	14.2	0.12
9) Chickasha, OK	80A	Bluestem prairie	Loamy prairie	Indiangrassa Little bluestem Sideoats grama	60	3.7	4.1	0.97
10) Chickasha, OK	80A	Bluestem prairie	Eroded prairie	Oldfield threeawn Sand paspalum Little bluestem	40	3.7	10.1	0.72
11) Freedom, OK	78	Bluestem prairie	Loamy prairie	Hairy grama Silver bluestem Sideoats grama	30	4.9	4.6	1.16
12) Woodward, OK	78	Bluestem-Grama	Shallow prairie	Sideoats grama Hairy grama Hairy goldaster	28	2.6	5.6	0.65
13) Cottonwood, SD	63A	Wheatgrass-Needlegrass	Clayey west central	Green Needle grass Scarlet globemallow Western wheatgrass	100	2.6	8.9	3.21

Table 8.4.2 - continued

Location	MLRA[1]	Rangeland cover type[2]	Range site	Dominant species by weight (dec. order)	Ecological status[3]	Cover coefficients Canopy	Cover coefficients Litter	Root biomass ($kg \cdot m^{-2}$)
14) Cottonwood, SD	63A	Blue grama-Buffalograss	Clayey west central	Blue grama Buffalograss	30	10.5	26.9	4.10
15) Sonora, TX	81	Juniper-Oak	Shallow	Buffalograss Curly mesquite Hairy tridens	35	2.9	5.6	0.86

[2] USDA-Soil Conservation Service. 1981. Land resource regions and major land resource areas of the United States. Agricultural Handbook 296. USDA-SCS, Washington, D.C.

[3] Definition of Cover Types from: T.N. Shiflet, 1994. Rangeland cover types of the United States, Society for Range Management, Denver, CO.

[4] Ecological status is a similarity index that expresses the degree to which the composition of the present plant community is a reflection of the historic climax plant community. This similarity index may be used with other site criterion or characteristics to determine rangeland health. Four classes are used to express the percentage of the historic climax plant community on the site (I 76-100; II 51-75; III 26-50; IV 0-25). USDA, National Resources Conservation Service. 1995. National Handbook for Grazingland Ecology and Management. National Headquarters, Washington, D.C. in press.

[5] NA - Ecological status indicies are not appropriate for woodland and annual grassland communities.

$$c_b = \frac{\ln(1.0 - C_r)}{R_g} \qquad [8.4.22]$$

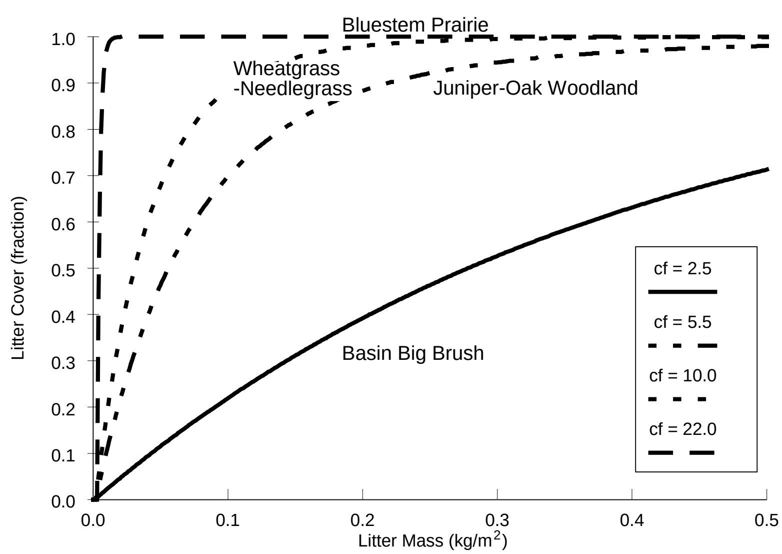

Figure 8.4.6. Relationship of litter mass to litter cover as a function of c_f for selected plant communities solved from a point-in-time sample.

Total basal cover is estimated as a linear function of canopy cover and then proportioned between rill and interrill areas based on the user specified distributions. For grasslands basal cover is estimated as 0.429 times canopy cover. For shrub and woodlands, basal cover is estimated as 0.335 times canopy cover. These coefficients were estimated from the USDA WEPP field data.

The relationship between standing biomass and canopy cover (C_c) is difficult to estimate for complex plant communities. The relationship between standing biomass and canopy cover is a function of specie, plant height, density, and architecture. No continuous function was found that would describe the relationship across all lifeforms. Canopy cover is estimated using an exponential function, where f_c (CANCOF) is a shaping coefficient based on plant community and B_t is total standing biomass ($kg \cdot m^{-2}$).

$$C_c = 1.0 - e^{-f_c\, B_1} \qquad [8.4.23]$$

The shaping coefficient f_c is a user-specified coefficient. If the user does not know the relationship between standing biomass and canopy cover (f_c is equal to 0.0) a default coefficient will be estimated from standing biomass and canopy cover to provide the model with a means of estimating canopy cover as standing biomass and canopy cover are updated during continuous simulation. If the user specifics 0.0 for standing biomass, canopy cover, and f_c then the shaping coefficient is set to 31.5 and was solved from a desert grassland on the Walnut Gulch Experimental Watershed (Fig. 8.4.7). Table 8.4.2 lists the f_c coefficients that were calculated from the USDA WEPP and Interagency Rangeland Water Erosion Team field data. This data is representative of the default solution where the relationship between canopy cover and standing biomass are solved based on a point in time solution and should be used with caution (Fig. 8.4.7).

$$f_c = \frac{\ln\,(1.0 - C_c)}{B_t} \qquad [8.4.24]$$

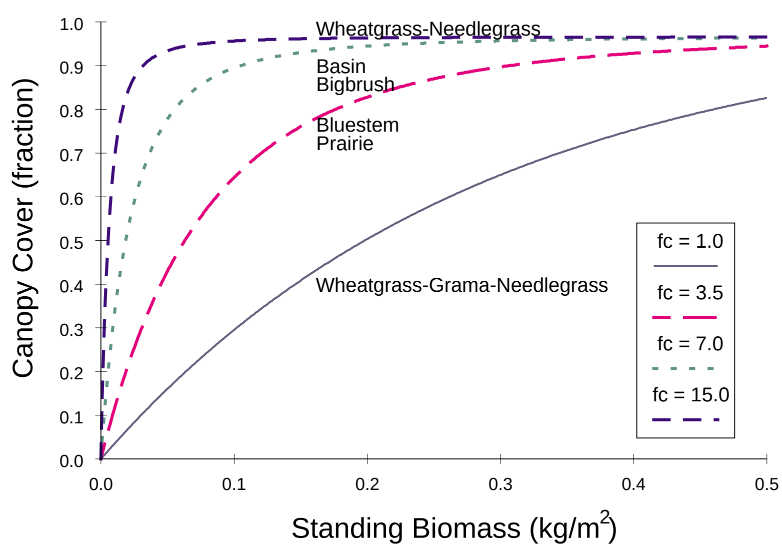

Figure 8.4.7. Relationship of above-ground standing biomass to canopy cover as a function of f_c for selected plant communities solved from a point-in-time sample.

Leaf area index is difficult to estimate for complex plant communities. Weltz et al. (1992) has shown that leaf area index can be computed as a function of dry leaf weight to leaf (single side) area divided by the area of the canopy. Leaf weight per unit area is not constant over the growing season. Leaf weight per unit area increases with time during the growing season and reaches a maximum value after the leaf reaches maturity. At this time no functional equation has been developed to account for this change in leaf weight to leaf area term. At the present the model uses a weighted mean average leaf weight to leaf area coefficient (L_c) for all plants across the growing season. Table 8.4.3 provides a list of leaf area coefficients for selected range plant species that can be utilized to define a weighted mean average leaf coefficient based on green standing biomass for the plant community.

$$LAI = L_t \, L_c \qquad [8.4.25]$$

The range plant growth model estimates root mass by soil layer. For perennial ecosystems the roots are assumed to have reached a maximum rooting depth (RTD). RTD has been defined as equal to depth of the soil profile. The initial distribution of root mass by depth is calculated by soil horizon using an exponential function.

Table 8.4.3. Reference values for calculating leaf area index for typical rangeland plant species.*

	ALEAF ($m^2 \cdot kg^{-1}$)	r^2		ALEAF ($m^2 \cdot kg^{-1}$)	r^2
Grasses			Forbs		
Buffalo grass	568	0.97	Perennial	105	0.92
Scribners dichanthelium	1611	0.96	Annual	88	0.96
Sand paspalum	689	0.95			
Slim tridens	93	0.95	Shrubs		
White tridens	583	0.98	Broom snakeweed	270	0.96
Curly mesquite	167	0.99	Burroweed	122	0.95
Blue grama	122	0.98	Creosotebush	366	0.86
Black grama	104	0.90	Desert zinnia	570	0.89
Hairy grama	107	0.89	False mesquite	100	0.99
Sprucetop grama	122	0.97	Little leaf sumac	470	0.91
Needle-and-thread	104	0.98	Mariola	569	0.84
Sand muhly	99	0.93	Sand sagebrush	201	0.98
Sand dropseed	97	0.83	Shadscale saltbush	264	0.98
Sideoats grama	142	0.96	Tarbush	610	0.97
Threeawn	74	0.96	Texas colubrina	1020	0.98
Western wheatgrass	291	0.98	Wyoming big sagebrush	334	0.97
Big bluestem	1297	0.86			
Indiangrass	944	0.96	Trees		
Little bluestem	1078	0.98	Lime prickly-ash	870	0.98
Sand lovegrass	1138	0.98	Mesquite	870	0.98
Tall dropseed	939	0.99	Texas persimmon	1050	0.98
Texas wintergrass	672	0.95			

* Values taken from Weltz, M.A., W.H. Blackburn, and J.R. Simanton. 1992. Leaf area ratios for selected rangeland species. Great Basin Naturalist 52:237-244, and B.F. Goff, 1985. Dynamics of canopy and soil surface cover in a semiarid grassland. MS Thesis, University of Arizona, Tucson, Arizona.

Table 8.4.4. Selected reference values for carbon-nitrogen ratios and digestibility for typical rangeland plant species[1].

Species	C:N	Digestibility	Species	C:N	Digestibility
Grasses			Forbs		
Bermudagrass	29	46-60	Buffalo gourd	NA[2]	54-80
Bermudagrass, Costal	49	49-64	Croton	NA	46-62
Bluegrass, Canada	15	48-71	Dayflower	NA	60
Bluegrass, Kentucky	33	48-72	Sweetclover, yellow	18	54
Bluestem	51	53-68	Trefoil, birdsfoot	18	59-66
Brome	29	55-74			
Broom, smooth	48	53-73	Shrubs		
Bufalograss	27	56	Algerita	NA	85-89
Canarygrass, reed	28	55-60	Sensitivebriar	NA	68-78
Dropseed, sand	59	59	Sagebrush, black	35	49
Fescue	29	48-61	Sagebrush, big	31	50
Galleta	48	48	Sagebrush, fringed	36	51
Needle & Thread	38	49	Saltbush, nuttall	34	36
Orchardgrass	33	54-72	Winterfat	24	35
Pangolagrass	52	40-55	Yucca	NA	42-89
Redtop	25	53-67			
Ryegrass, Italian	52	54-62	Trees		
Saltgrass	65	51-53	Mesquite	NA	44-68
Sedge	31	52	Hackberry	NA	52
Squiletail	83	54	Juniper, ash	NA	48-70
Timothy	36	52-72	Juniper, redberry	NA	57-66
Tobosa	NA	56	Oak, Plateau	NA	38-77
Vinemesquite	NA	42-53	Oak, white shin	NA	35-77

[1] Additional references for range plants can be found in: Nutrient requirements of beef cattle: Sixth Ed. 1984, National Academy of Sciences, and Huston, J. E., B. S. Rector, L.B. Merrill, and B. S. Engdahl, Nutritional value of range plants in the Edwards Plateau region of Texas. Texas A&M University Publication B-1357, College Station, Texas.

[2] Data not available.

$$R_i = R_t\, R_o (100\, S_d)^{R_f} \qquad [8.4.26]$$

where R_i is the total mass of roots ($kg \cdot m^{-2}$) in the soil horizon, R_t is the fraction of maximum roots on January 1 (estimated from root turnover studies and ranges from 0.50-0.80), S_d is the depth of the bottom of the soil layer (m), R_f is a root depth coefficient and has been set at 0.43, and R_o is a root biomass coefficient and is estimated from the root mass (R_{10}) in the top 0.1 meter of the soil surface. Table 8.4.2 provides the user with a list of root biomass estimates in the top 0.1 m of the soil for 34 range plant communities from the USDA WEPP and Interagency Rangeland Water Erosion Team field data. These field experiments were conducted during the summers of 1987 through 1993. If these data are utilized to parameterize the model, then R_t should be initialized to 0.66 to reflect the decomposition that would occur between the end of the growing season and January 1 of the next year.

$$R_o = \frac{R_{10}}{10^{R_f}} \qquad [8.4.27]$$

From the initial root mass distribution the percentage of roots in each soil horizon is calculated (R_p). B_{rt} is the total root mass in the soil profile ($kg \cdot m^{-2}$).

$$R_p = \frac{R_i}{B_{rt}} \qquad [8.4.28]$$

The daily increment of root growth is calculated in a similar manner as above-ground plant growth using the potential growth curve function. The range plant model does not separate roots into live and dead components within the soil profile. Roots are grown and decayed as a single unit.

$$B_{rt(i)} = B_{rt(i-1)} + (R_t \; g_i \; W_a \; B_{rt(i-1)}) \qquad [8.4.29]$$

The decomposition of roots is calculated in a similar manner as is litter and organic residue.

$$B_{rt(i)} = B_{rt(i-1)} \; \chi \qquad [8.4.30]$$

$$\chi = 1 - \left(\alpha_r \frac{S_r \; T_a}{C_n} \right)^2 \qquad [8.4.31]$$

where χ is the fraction of roots after decay, and α_r is the root decay coefficient.

Table 8.4.4 provides a list of carbon-nitrogen ratios for selected range plant species that can be utilized to define a weighted mean average carbon-nitrogen ratio based on standing biomass for the plant community. S_r is the antecedent soil moisture index for root decomposition calculated from the amount of rainfall recorded in the last 5 days.

8.5 Rangeland Management Options

The following section contains the management options currently available to the user and the parameters necessary for running the range plant growth model. The management options currently supported by the WEPP model are no plant growth, plant growth, grazing by livestock, burning, and herbicide application. The model currently does not support mechanical practices on rangeland. Tables 8.5.1 and 8.5.2 define the variables and coefficients required to be parameterized for both the single event and continuous option of the model.

8.5.1 No Plant Growth

The rangeland plant growth subroutine can be initialized for no above- and below- ground biomass production. Additionally, the model can be parameterized to simulate a wide range of user-defined initial above- and below- ground biomass conditions (Table 8.5.1).

Table 8.5.1. Options for initial above-ground standing dead biomass, litter, root biomass conditions, and model parameters for rangeland plant communities with no plant growth during simulation.

Standing dead biomass ($kg \cdot m^{-2}$)	Litter ($kg \cdot m^{-2}$)	Root biomass ($kg \cdot m^{-2}$)	Variable	Model Parameters
Yes	Yes	Yes	P	PLIVE = 0
			R_{10}	ROOT10 > 0
			R_a	RMOGT > 0
			R_g	RMAGT > 0
			R_t	ROOTF > 0
Yes	None	Yes	P	PLIVE = 0
			R_{10}	ROOT10 > 0
			R_a	RMOGT = 0
			R_g	RMAGT > 0
			R_t	ROOTF > 0
None	Yes	Yes	P	PLIVE = 0
			R_{10}	ROOT10 > 0
			R_a	RMOGT > 0
			R_g	RMAGT = 0
			R_t	ROOTF > 0
None	None	None	P	PLIVE = 0
			R_{10}	ROOT10 = 0
			R_a	RMOGT = 0
			R_g	RMAGT = 0
			R_t	ROOTF = 0

8.5.2 Plant Growth

The rangeland plant growth subroutine can be initialized for either a unimodal or bimodal growth sequences. The user may choose to define the plant growth parameters for the plant community or utilize the default parameters. To initialize the unimodal growth sequence the parameters P_2 and G_2 must be initialized to 0. The user must initialize the fraction of the soil surface covered by cryptogamic crust (C_{cr}), and rocks, gravel and other impervious substances (C_{cf}). The initial standing dead biomass and the initial residue mass on the soil surface must also be initialized by the user before the start of every simulation. To simulate a bimodal growing season parameters P_2 and G_2 must be initialized to > 0. In addition, the user must also initialize the same parameters as for a unimodal growth sequence.

8.5.3 Grazing Management Option

The grazing subroutine allows for multiple grazing periods and multiple herbs. The model currently allows for 10 grazing periods per year within each of the 10 pastures. Pastures are equivalent to overland planes. The grazing animals, number of animals, and accessibility of forage within each pasture can be defined uniquely for each pasture. Currently, the model does not allow for a change in the attributes of the grazing animals within a year. However, the model does allow for changes in the grazing animals characteristics and grazing sequences across years.

The grazing period is initialized by the user by entering the Julian day for the start of the grazing period (GDAY) and the last day of the grazing period (GEND). The grazing routine estimates the daily amount of forage required for the average grazing animal. The total daily forage requirement is calculated as the daily forage intake times the number of grazing animals. The daily forage requirement is a function of body size (*kg*) and digestibility of the forage.

Digestibility (D) of forage changes with time (Eq. [8.5.1]). Currently, the mean average digestibility of standing live leaves (D_{mx}) and old standing dead leaves (D_n) of the plant community are user inputs (See Table 8.4.3 for representative species). Digestibility (Eq. [8.5.2]) is calculated as a function of the live-dead leaf ratio (D_l), where D_l is calculated as L_t / R_a. If $D_l < 0.1$ then digestibility is equal to the minimum digestibility. If $D_l > 1.0$ then digestibility is equal to the maximum digestibility. Table 8.4.4 provides a list of digestibility coefficients for selected range plant species that can be utilized to define a weighted mean average digestibility coefficient based on standing biomass for the plant community.

$$D = (D_r \; D_{mx}) + [(1 - D_r) D_{mx}] \qquad [8.5.1]$$

$$D_r = 1 - e^{-5 \, D_1} \qquad [8.5.2]$$

The physiological limit on forage intake is estimated (Eq. [8.5.3]) as a function of body weight (B_w) based on the work of Brody (1945). Animal weight gains and animal performance are not modeled in the grazing subroutine. The total forage demand (F_i) by a single grazing animal is estimated as:

$$F_i = 0.1 \left(\frac{B_w^{0.75}}{D} \right) \qquad [8.5.3]$$

Supplemental feed (SUPPMT) can be given to the grazing animals between user-defined Julian days (SSDAY and SEND). The grazing animals consume all of the supplemental feed first, before consuming any of the available forage. The grazing animal consumes forage as a homogeneous unit since no individual species are grown.

The availability of forage (B_a) is a function of two parameters N_d and A_c. N_d is the parameter used to define the fraction of standing biomass that is woody. This fraction of biomass is considered to be unavailable for consumption, can not be broken down by trampling and will not decompose (Eq. [8.5.4]). A_c is the parameter used to determine the fraction of standing biomass available for consumption.

$$W_n = N_d R_a \qquad [8.5.4]$$

The available forage is composed of two fractions: live (L_t) and dead (R_a). If the parameter N_d has been used, then only a fraction of the standing dead is available. If a portion of the forage is unavailable for consumption due either to height, palatability, or location in the grazing area, that fraction can be removed from the available forage with the parameter A_c. If available forage is less than or equal to a ten day supply of forage, then the model automatically supplies supplemental feed to the animals.

$$B_a = [A_c (R_a + L_t)] + (R_a - W_n) \qquad [8.5.5]$$

The utilization (U) of available forage is calculated as:

$$U = \frac{F_t}{Y + 0} \qquad [8.5.6]$$

where F_t is the total forage consumed, Y is total standing biomass produced that year, and Y_0 is the initial standing biomass on January 1.

The model allows the grazing animals to consume the evergreen fraction of the standing biomass (X). In subsequent growing periods the evergreen component is replaced. Unavailable forage (U_b) is calculated as:

$$U_b = (1 - A_c)\,(R_a + L_t) \qquad [8.5.7]$$

Trampling by cattle accelerates the transfer of standing dead material to litter. The trampling effect (t_r) by cattle is limited to 5% of the standing dead material on any given day. The trampling effect is estimated with an exponential function. The rate of transfer of standing material is a function of the stocking density. Stock density, (S), is defined as the number of animals divided by the pasture area (A_f).

$$t_r = 0.05 R_a (1 - e^{-0.01\,S}) \qquad [8.5.8]$$

8.5.4 Burning

The user must define the Julian date that the pasture is burned. A minimum fuel load of 800 $kg \cdot ha^{-1}$ is required for the model to allow burning of the area (Wink and Wright, 1973; Beardall and Sylvester, 1976). If rainfall is greater than 7.5 millimeters, or if the 5 day antecedent rainfall is greater than 25 millimeters, then the model will delay burning until moisture conditions are favorable. The entire pasture will be burned on that date. The user can control the effects of the fire with the parameters: A_l, B, C, H, and R.

Wildfires and prescribed burning can result in changes to accessibility of forage for grazing animals. To reflect the change in accessibility as a result of burning a pasture the parameter C should be initialized greater then 0.0. If C is initialized to 0.0 then all forage will be inaccessible to the grazing animals and the grazing animals should be removed from the pasture. The product of C and A_c can not exceed 1.0.

$$A_c = A_c C \qquad [8.5.9]$$

The effectiveness of burning on removal of standing woody biomass depends upon environmental and plant conditions at the time of the burn. Therefore, the user must input the percent reduction in standing woody biomass. The remaining standing woody biomass is calculated as:

$$W_n = W_n B \qquad [8.5.10]$$

The potential growth rate of above-ground biomass (Eq. [8.4.11]) and root biomass (Eq. [8.4.12]) may be affected by both prescribed and wild fires. The percentage change in growth rate depends on the time of year, the intensity of the burn and the plant species involved. Therefore, the user must input the percent increase or decrease in growth rate. The new growth rates are calculated as:

$$P = PC \qquad [8.5.11]$$

$$R_o = R_o C \qquad [8.5.12]$$

The quantity of live above-ground herbaceous biomass that is consumed as a result of burning depends on environmental conditions and the spatial arrangement of the plants in the pasture. The dynamics of burning are not simulated in WEPP. Therefore, the user must input the percent reduction (*H*) in above-ground herbaceous biomass as a result of burning. The standing herbaceous biomass after burning is computed from:

$$L_{t(i)} = L_{t(i-1)}\ H \qquad [8.5.13]$$

The percent reduction in the live evergreen leaf biomass (Eq. [8.5.14]) and the herbaceous standing dead biomass (Eq. [8.5.15]) is a function of R_l. R_l also reduces the litter and the organic residue mass on the soil surface (Eq. [8.5.16]).

$$L_t = [R_l(L_t - X)] + X\ R_l \qquad [8.5.14]$$

$$R_a = R_l\ R_a \qquad [8.5.15]$$

$$R_g = R_l\ R_g \qquad [8.5.16]$$

8.5.5 Herbicides

The user must define the Julian date the herbicide is applied. The herbicide management option is only operational if live aboveground biomass is greater than 0.0 $kg \cdot ha^{-1}$. If rainfall is greater than 10 millimeters on the day of application, then the application date is delayed one day. The user can choose between two methods of herbicide activity: 1) A foliar herbicide which kills on contact; 2) A soil applied herbicide which is activated when sufficient rainfall has occurred to dissolve the herbicide and transport it into the root zone. The user can control the effect of the herbicide with the parameters: ACTIVE, WOODY, L_k, H_k, R_e, and U_l.

ACTIVE is a flag to determine which type of herbicide activity will be used. If ACTIVE is equal to 0 then a foliar contact herbicide is applied and death is instantaneous. If ACTIVE is equal to 1, then a pelleted soil herbicide is applied. The effect of the pelleted herbicide will be delayed until 12.5 millimeters of rainfall has occurred. Once the rainfall limit has been achieved, death is instantaneous.

The effectiveness of herbicides in killing herbaceous vegetation depends upon the type of herbicide, time of year, and the plant species involved. The WEPP model does not simulate the processes involved in plant growth and death from herbicide application. Therefore, the user must input the percent reduction (L_k) in above-ground live herbaceous biomass as a result of herbicide application. The reduction in live herbaceous biomass is computed differently for herbaceous plant communities and plant communities with both herbaceous and evergreen components. The reductions in herbaceous biomass are computed as:

For herbaceous species only:

$$D_r = L_t - (L_t L_k) \quad [8.5.17]$$

For herbaceous species within evergreen plant communities:

$$H_o = (L_t - X) - [L_k\ (L_t - X)] \quad [8.5.18]$$

The percent reduction in the live evergreen biomass from herbicide application is a user input (H_k). The remaining evergreen leaf biomass after herbicide application is computed as:

$$A_d = X - (XH_k) \quad [8.5.19]$$

The application of herbicides may affect the percent increase or decrease in the potential growth rate of above-ground herbaceous biomass (Eq. [8.5.20]) and root mass (Eq. [8.5.21]). The effect of the herbicide on individual plant species is not being modeled. However, the user can increase or decrease the potential growth rate for the plant community. The new potential growth rate after herbicide application is calculated as:

$$P = PR_e \quad [8.5.20]$$

$$R_o = R_o R_e \quad [8.5.21]$$

The application of herbicides can affect plant distribution, plant height, and accessibility of forage. The application of herbicides can result in either an increase or decrease in forage accessibility. The change in accessibility of forage is a user input (U_d) and is calculated as:

$$A_c = U_d A_c \quad [8.5.22]$$

If U_d is initialized as 0.0, then all forage is inaccessible and grazing should not be allowed. Accessibility of forage should not exceed 1.0.

WOODY is a flag which allows the user to determine if defoliation is instantaneous or if defoliation will occur over several months. If WOODY is initialized to 0, then defoliation will be instantaneous. The increase in litter and organic residue mass from herbicide application is computed separately for herbaceous plant communities and plant communities with both herbaceous and evergreen components as:

For herbaceous plants:

$$R_g = R_g + D_r \quad [8.5.23]$$

For evergreen plants:

$$R_g = R_g + A_d + H_o \quad [8.5.24]$$

Table 8.5.2. Rangeland WEPP model inputs for single event and continuous plant growth model.

Parameter	Units	Variable name	Event[1]	Continuous	Sensitivity
Plant height coefficient	NOD	BBB	no 1	yes	Slight[2]
Average grass height	m	GHGT	no 1	yes	Slight
Average shrub height	m	SHGT	no 0	yes	Slight
Average tree height	m	THGT	no 0	yes	Slight
Maximum herbaceous plant height	m	HMAX	no 1	yes	Slight
Average number of grasses plants per 100m	NOD	GPOP	yes	yes	Moderate
Average number of shrubs plants per 100m	NOD	SPOP	no 0	yes	Moderate
Average number of trees plants per 100m	NOD	TPOP	no 0	yes	Moderate
Grass project area coefficient	NOD	GCOEFF	no 1	yes	Slight
Shrub project area coefficient	NOD	SCOEFF	no 0	yes	Slight
Tree project area coefficient	NOD	TCOEFF	no 0	yes	Slight
Grass canopy diameter	m	GDIAM	no 1	yes	Slight
Shrub canopy diameter	m	SDIAM	no 0	yes	Slight
Tree canopy diameter	m	TDIAM	no 0	yes	Slight
Canopy cover	Fraction	CANCOV	no 1	yes	High
Canopy cover coefficient	NOD	RESCOF	no 1	yes	High
Litter cover coefficient	NOD	LITCOF	no 1	yes	High
Rock cover in interrills	Fraction	ROKI	yes	yes	High
Cryptogam cover in interrills	Fraction	CRYI	yes	yes	High
Litter cover in interrills	Fraction	LITI	yes	yes	High
Basal plant cover in interrills	Fraction	BASI	yes	yes	High
Rock cover in rills	Fraction	ROKR	yes	yes	High
Cryptogam cover in rills	Fraction	CRYR	yes	yes	High
Litter cover in rills	Fraction	RESR	yes	yes	High
Basal cover in rills	Fraction	BASR	yes	yes	High
Random roughness	m	RROUGH	yes	yes	High
Minimum temperature for growth	C	GTEMP	no 1	yes	Moderate
Maximum temperature for growth	C	TEMPMN	no 1	yes	Moderate
Potential plant productivity	$kg\ m^{-2}$	PLIVE	no 1	yes	Moderate
Day of peak standing crop, 1st peak	Julian date	PSCDAY	no 1	yes	Moderate
Day of peak standing drop, 2nd peak	Julian date	SCDAY2	no 0	yes	Moderate
Fraction of 1st peak of growing season	NOD	CF1	no 1	yes	Moderate
Fraction of 2nd peak growing season	NOD	CF2	no 0	yes	Moderate
Minimum fraction of live biomass	Fraction	RGCMIN	no 0	yes	Moderate
Initial woody biomass	Fraction	WOOD	no 0	yes	Moderate
Biomass removal by insects	$kg\ m^{-2}$	BUGS	no 0	yes	Moderate
Litter biomass	$kg\ m^{-2}$	RMOGT	no 1	yes	Moderate
Standing biomass	$kg\ m^{-2}$	RMAGT	no 1	yes	Moderate
Root biomass in top 10 cm	$kg\ m^{-2}$	ROOT10	yes	yes	High
Root biomass at beginning of year	Fraction	ROOTF	no 1	yes	High
Litter decay coefficient	NOD	ACA	no 1	yes	Moderate
Root decay coefficient	NOD	AR	no 1	yes	Moderate
Leaf area index coefficient	$m^2\ kg^{-1}$	ALEAF	no 1	yes	Moderate
Drought tolerance coefficient	NOD	PLTOL	no 0	yes	Moderate
Carbon nitrogen ratio of litter	NOD	CN	no 1	yes	Moderate

[1] For single event simulation these parameters have no impact on erosion and can be defaulted to the suggested value.

[2] Plant height and projected area of plants do not impact the estimate of soil erosion, however they will be required in future versions of the WEPP model when there impact on soil erosion can be defined for rangelands.

If WOODY is initialized to 1, then the dead leaves, branches, and stems of the evergreen plants will be retained on the plant.

$$D_d = H_o + A_d \qquad [8.5.25]$$

The rate of decomposition and transfer of the dead leaves retained on the trees and shrubs to litter is computed at the same rate as decomposition of litter on the soil surface (Eq. [8.5.26]). The dead stems, branches, and twigs of shrubs and trees decompose at a slower rate than do the dead leaves. The rate of transfer of dead stems has been estimated at 25% of the transfer of leaves (Eq. [8.5.27]). The rate of decomposition is computed as a function of the average air temperature, rainfall, and the carbon-nitrogen ratio of the material in a similar manner as the decomposition of litter.

$$R_g = R_g + [D_d - (D_d\ \omega_L)] \qquad [8.5.26]$$

$$R_g = R_g + \left[W_n - \left\{ W_n \left(\frac{1 - \omega_L}{4} \right) \right\} \right] \qquad [8.5.27]$$

8.6 References

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8.7 List of Symbols

Symbol	Definition	Units	Variable	Land Use*
A	Total vertical projected area	m^2	TAREA	R
A_b	Plant basal area in one square meter	m^2	BASAL	C
-	Interrill basal area cover	*Fraction*	BASI	R
-	Rill basal area cover	*Fraction*	BASR	R
A_{bm}	Plant basal area at maturity in one square meter	m^2	BASMAT	C
A_c	Forage available for consumption	*NOD*	ACCESS	R
-	Flag for soil or foliar applied herbicide	-	ACTIVE	R
A_d	Evergreen phytomass after herbicide application	$kg \cdot m^{-2}$	ADHERE	R
A_f	Pasture size being grazed	m^2	AREA	C,R
A_p	Soil area associated with one plant	m^2	AREACV	C
A_{sp}	Single plant stem area	m^2	STEMAR	C
A_l	Change in forage accessibility from burning	*NOD*	ALTER	R
α_f	Decay coefficient for litter	*NOD*	ACA	R
α_R	Decay coefficient for roots	*NOD*	AR	R
a	Coefficient used to compute rangeland growth curve shaping parameters	*NOD*	-	R
B	Reduction in standing dead biomass from burning	*NOD*	BURNED	R
BE	Crop parameter for converting energy to biomass	$kg \cdot MJ^{-1}$	BEINP	C
BE_{adj}	Adjusted biomass conversion factor	$kg \cdot MJ^{-1}$	BE	C
B_{AG}	Above-ground biomass	$kg \cdot m^{-2}$	VDMT	C
B_a	Available standing biomass for grazing animals	$kg \cdot m^{-2}$	AVABIO	R
B_c	Daily removal of surface organic material by insects	$kg \cdot m^{-2}$	BUGS	R
B_h	Shaping coefficient for rangeland growth	$m^2 \cdot kg^{-1}$	-	R
B_p	Daily potential increase in total biomass	$kg \cdot m^{-2}$	DDM	C
B_m	Above-ground vegetative biomass	$kg \cdot m^{-2}$	VDM	C
B_{mx}	Vegetative biomass at maturity	$kg \cdot m^{-2}$	VDMMAX	C
ΔB^i	Daily change in total above-ground biomass	$kg \cdot m^{-2}$	-	C
ΔB_{ms}	Daily decrease in above-ground biomass due to senescence	$kg \cdot m^{-2} \cdot d^{-1}$	-	C
ΔB_r	Daily change in total root biomass	$kg \cdot m^{-2}$	DELT	C
ΔB_p	Daily potential change in total biomass	$kg \cdot m^{-2}$	-	C
B_{rt}	Total root biomass of an annual crop	$kg \cdot m^{-2}$	RTMASS	R,C
-	Maximum root biomass of a perennial crop	$kg \cdot m^{-2}$	RTMMAX	C
B_{r1}	Root biomass in the 0- to 0.15-m soil zone	$kg \cdot m^{-2}$	RTM15	C
B_{r2}	Root biomass in the 0.15- to 0.30-m soil zone	$kg \cdot m^{-2}$	RTM30	C
B_{r3}	Root biomass in the 0.30- to 0.60-m soil zone	$kg \cdot m^{-2}$	RTM60	C
B_1	Total above ground standing biomass	$kg \cdot m^{-2}$	VDMT	C
B_t	Total above-ground standing biomass	$kg \cdot m^{-2}$	VDMT	R
B_w	Average body weight of a grazing animal	kg	BODYWT	R,C
β_c	Parameter for canopy cover equation	*NOD*	bb	C
β_h	Parameter for canopy height equation	*NOD*	bbb	R,C
β_1	Plant-dependent constant to compute canopy cover	*NOD*	b1	C
β_2	Maximum canopy width at maturity	*NOD*	b2	C
C	Change in potential above- and below- ground biomass production from burning	*NOD*	CHANGE	R
-	Parameter for estimating canopy cover from standing biomass	*NOD*	CANCOF	R
C_c	Canopy cover fraction	*NOD*	CANCOV	R,C

C_n	Carbon-nitrogen ratio of litter and roots	*NOD*	CN	R
C_r	Total litter cover	Fraction	RESCOV	R
ΔC_c	Daily loss of canopy cover	*NOD*	DEC	C
-	Interrill cyrptogamic cover	*Fraction*	CRYI	R
-	Rill cryptogamic cover	*Fraction*	CRYR	R
C_{os}	Fraction of canopy cover remaining after senescence	*NOD*	DECFCT	C
C_{cf}	Soil surface cover by coarse fragments	*NOD*	WCF	R,C
C_{cr}	Soil surface covered by cryptogams	*NOD*	CRYPTO	R
cf	Parameter for flat residue cover equation	*NOD*	CF	R
C_g	Total soil cover including residue and rocks	*NOD*	GCOVER	R
c	Shaping coefficient for ascending side of first growth curve	*NOD*	CSHAPE	R
C_{cm}	Canopy cover fraction at maturity	*NOD*	CANCMX	C
-	Growing degree days to plant emergence	$^oC \cdot d$	CRIT	C
-	Critical biomass for a perennial crop below which grazing animals no longer consume vegetation	$kg \cdot m^{-2}$	CRITVM	C
-	Integer that represents whether a cultivator is front or rear mounted	*NOD*	CULPOS	C
CUTDAY	Cutting or harvesting day for a perennial crop	*Julian day*	JDCUT	C
CUTHGT	Cutting height at crop harvest	m	CUTHGT	C
C_{rr}	Rill residue cover fraction	*NOD*	RILCOV	C
C_{ri}	Interrill residue cover fraction	*NOD*	INRCOV	C
D	Plant stem diameter at maturity	m	DIAM	C
D_d	Decomposable standing dead biomass after herbicide application	$kg \cdot m^{-2}$	SDEAD	R
D_g	Digestibility of a perennial crop being grazed	*NOD*	DIGEST	R,C
D_l	Dead/live ratio of leaves	*NOD*	DL	R
D_{mx}	Maximum digestibility of forage	*NOD*	DIGMAX	R
D_n	Minimum digestibility of forage	*NOD*	DIGMIN	R
D_r	Digestibility coefficient	*NOD*	DLR	R
D_s	Reduction in live above-ground biomass from drought stress	*NOD*	DEATH	R
d	Shaping coefficient for descending side of first growth curve	*NOD*	DSHAPE	R
E_a	Total plant projected area	m^2	TOTPAI	R
E_g	Herbaceous projected plant area	m^2	GPAI	R
E_p	Potential plant evaporation	mm	EP	C,R
E_s	Shrub projected plant area	m^2	SPAI	R
E_t	Tree projected plant area	m^2	TPAI	R
e	Shaping coefficient for ascending side of second growth curve	*NOD*	ESHAPE	R
FHU	Crop stage factor	*NOD*	FHU	C
F_c	Fraction of standing residue mass mechanically shredded or cut	*NOD*	FRCUT	C
F_{gs}	Current fraction of the growing season	*NOD*	FGS	C
F_i	Quantity for forage consumed by grazing animals	$kg \cdot day^{-1}$	FEED	R,C
F_{lai}	Fraction of growing season when leaf area index starts declining	*NOD*	DLAI	C
F_{rm}	Fraction of vegetative or flat residue mass removed from a field	*NOD*	FRMOVE	C
F_t	Daily total vegetative uptake by livestock	$kg \cdot m^{-2}$	TFOOD	R,C
f	Shaping coefficient for descending side of second	*NOD*	FSHAPE	R

	growth curve			
f_{bs}	Fraction of above-ground biomass remaining after senescence	*NOD*	DROPFC	C
f_c	Coefficient for canopy cover	$m^2 \cdot kg^{-1}$	FFK	R
f_{cs}	Fraction of canopy cover remaining after senescence	*NOD*	DECFCT	C
f_p	Frost-free period	*Julian day*	FFP	R,C
GDAY	Date that grazing begins	*Julian day*	GDAY	R,C
GEND	End of a grazing period	*Julian day*	GEND	R,C
G_b	Day on which first growth period begins	*Julian day*	STRRGC	R
G_c	Projected plant area coefficient for herbaceous plants	*NOD*	GCOEFF	R
G_{di}	Average diameter for herbaceous plants	*m*	GDIAM	R
G_{dm}	Growing degree days at maturity	$°C \cdot d$	GDDMAX	C
G_p	Average number of herbaceous plants along a 100 m transect	*NOD*	GPOP	R
G_1	Proportion of biomass produced during the first growing season	*NOD*	CF1	R
G_2	Proportion of biomass produced during the second growing season	*NOD*	CF2	R
g_i	Daily increment of relative growth curve	*NOD*	RGC	R
-	Number of days from planting to harvest	*NOD*	GS	C
-	Fraction of growing season to reach senescence	*NOD*	GSSEN	C
-	Minimum temperature to initiate growth	$°C$	GTEMP	R
-	Flag for grazing rangelands	*NOD*	GRAZIG	R
H	Reduction in above-ground standing biomass from after burning	*NOD*	HURT	R
HI	Harvest index at harvest	*NOD*	HI	C
HIA	Harvest index adjusted for water stress	*NOD*	HIA	C
HIO	Harvest index under favorable growing conditions	*NOD*	HIO	C
HU	Daily heat units	$°C \cdot d$	GDD	C
HUI	Heat unit index	*NOD*	FPHU	C
HUFH	Heat unit index that affects harvest index	*NOD*	HUFH	C
$\sum HU$	Accumulated heat units	$°C \cdot d$	SUMGDD	C
H_c	Canopy height	*m*	CANHGT	R,C
H_{cm}	Maximum canopy height	*m*	HMAX	R,C
H_g	Initial canopy height for herbaceous plants	*m*	GHGT	R
H_k	Decrease in evergreen phytomass from herbicide application	*NOD*	HERB	R
H_o	Live evergreen phytomass retained after herbicide application	$kg \cdot m^{-2}$	HOLD	R
H_s	Average shrub height	*m*	SHGHT	R
H_t	Average tree height	*m*	THGT	R
η	Ratio of total vertical area to prospected area	*NOD*	--	R
-	Integer that represents a certain crop type	*NOD*	ITYPE	R,C
-	Integer that represents a double-cropping system	*NOD*	IDBCRP	C
-	Integer that indicates whether a critical freezing temperature has occurred	*NOD*	IFREEZ	C
-	Julian date of herbicide application rangelands	*Julian day*	IHDATE	R

-	Integer that represents annual, perennial, or fallow cropping	*NOD*	IMNGMT	C
-	Integer used to identify the simulation year for a perennial crop	*NOD*	IPRNYR	C
-	Integer that indicates a well-defined ridge-furrow system	*NOD*	IRDG	C
-	Integer that represents the crop grown prior to the start of simulation	*NOD*	IRESD	C
-	Integer that indicates the first cutting of a perennial crop has occurred	*NOD*	ISTART	C
-	Integer that represents a certain primary, secondary, planting, or cultivating implement used in one tillage sequence	*NOD*	ITILL	R,C
-	Integer that represents the number of crops grown in the simulation	*NOD*	NCROP	R,C
-	Number of landscape segments that have uniform cropping, management, soil, and topography	*NOD*	NELEM	R,C
-	Integer that indicates that weed canopy cover is important during the non growing season	*NOD*	IWEED	C
-	Julian day of burning residue	*Julian day*	JDBURN	C
-	Julian day of burning rangeland	*Julian day*	JFDATE	R
-	Julian day of residue shredding or cutting	*Julian day*	JDCUT	C
-	Julian day of grain or biomass harvest	*Julian day*	JDHARV	C
-	Julian day of herbicide application	*Julian day*	JDHERB	C
-	Julian day of residue removal from a field	*Julian day*	JDMOVE	C
-	Julian day of planting	*Julian day*	JDPLT	C
-	Julian day of silage removal from a field	*Julian day*	JDSLGE	C
-	Julian day to permanently stop the growth of a perennial crop	*Julian day*	JDSTOP	C
L_p	Distance perpendicular to the slope profile	m	-	R
LAI	Leaf area index	*NOD*	LAI	
c_f	Parameter for estimating litter cover from litter mass	$m^2 \cdot kg^{-1}$	RESCOF	R
LAI_d	Leaf area index value when leaf area index starts declining	*NOD*	XLAIMX	C
LAI_{mx}	Maximum leaf area index potential	*NOD*	XMXLAI	R
L_c	Leaf weight to leaf area coefficient	$m^2 \cdot kg^{-1}$	-	R
L_i	Live phytomass produced today	$kg \cdot m^{-2}$	SLIVE	R
L_k	Reduction in live above-ground biomass from herbicide application	*NOD*	DLEAF	R
-	Minimum amount of live biomass	$kg \cdot m^{-2}$	RGCMIN	R
L_t	Total live phytomass	$kg \cdot m^{-2}$	TLIVE	R
-	Julian day of tillage in one tillage sequence	*Julian day*	MDATE	C
-	Integer that represents a management option for a perennial crop	*NOD*	MGTOPT	C
-	Number of annual cuttings of a perennial crop	*NOD*	NCUT	C
-	Number of annual grazing cycles	*NOD*	NCYCLE	C
-	Number of tillage sequences used during the simulation	*NOD*	NSEQ	C
-	Number of tillage operations within one tillage sequence	*NOD*	NTILL	C
-	Integer that represents the number of crops grown annually	*NOD*	NYCROP	C
M_f	Plant residue mass lying on the ground	$kg \cdot m^{-2}$	RMOG	C
M_s	Plant residue mass standing above-ground	$kg \cdot m^{-2}$	RMAG	C
nl	Number of soil layers	*NOD*	NSL	C
N_a	Number of grazing animals	*NOD*	ANIMAL	R

N_d	Initial standing non-decomposable woody biomass	*NOD*	WOOD	R
ω_L	Litter after decay biomass	*NOD*	SMRATI	R
P	Plant population	*NOD*	POP	C
P_a	Projected plant area	*NOD*	BASDEN	R
-	Plant drought tolerance factor	*NOD*	PLTOL	R
P_d	Day of peak standing crop, 1st peak	*Julian day*	PSCDAY	R
P_g	Annual growing season precipitation	*m*	PPTG	R
P_m	Plant population at maturity	*NOD*	POPMAT	C
P_{mx}	Maximum potential standing live above-ground biomass	$kg \cdot m^{-2}$	PLIVE	R
P_s	In-row plant spacing	*m*	PLTSP	C
P_2	Day of peak standing crop, 2nd peak	*Julian day*	SCDAY2	R
PAR	Photosynthetic active radiation	$MJ \cdot m^{-2}$	PAR	C
PHU	Potential heat units to crop maturity	°C	GDDMAX	C
R	Daily rainfall amount	*m*	RAIN	R
RA	Solar radiation	*Ly*	RAD	C
REG	Crop growth regulating factor - minimum stress	*NOD*	REG	C
R_a	Standing above-ground dead biomass	$kg \cdot m^{-2}$		
R_d	Root depth	*m*	RTD	R
R_{dx}	Maximum root depth	*m*	RDMAX	C
R_e	Change in potential above- and below- ground potential biomass production from herbicides	*NOD*	REGROW	R
R_f	Root distribution coefficient for mass by depth	*NOD*	RDF	
-	Integer to indicate a plant or residue management option	*NOD*	RESMNG	C
R_g	Litter and organic residue mass	$kg \cdot m^{-2}$	RMOGT	R
-	Interrill litter cover	*Fraction*	RESI	R
-	Rill litter cover	*Fraction*	RESR	R
-	Interrill rock surface cover	*Fraction*	ROCKI	R
-	Rill rock surface cover	*Fraction*	ROKR	R
R_i	Root mass in a soil horizon	$kg \cdot m^{-2}$	ROOT	R
R_l	Reduction in litter and organic residue from burning	*NOD*	REDUCE	R
R_o	Root mass coefficient	$kg \cdot m^{-2}$	PROOT	R
R_p	Proportion of root mass in soil layer to total root mass in soil profile	*NOD*	DROOT	R
R_{sr}	Root to shoot ratio	*NOD*	RSR	C
R_s	Potential rill spacing	*m*	RSPACE	C,R
R_t	Root turn-over coefficient	*NOD*	ROOTF	R
R_w	Row width	*m*	RW	C
R_{10}	Root mass in top 0.10 m of soil profile	$kg \cdot m^{-2}$	ROOT10	R
S	Stock density	$animal\ ha^{-1}$	SD	R
S_c	Projected plant area coefficient for shrubs	*NOD*	SCOEFF	R
S_d	Depth of soil layer	*m*	SOLTHK	R
-	Day supplemental feeding ends	*Julian day*	SEND	R
S_p	Average number of shrubs along a 100m transect	*NOD*	SPOP	R
S_p	Number of days between the beginning and end of leaf drop	*NOD*	SPRIOD	C
-	Day on which second growth period begins	*Julian day*	STRGC2	R
-	Average amount of supplement feed per day	$kg \cdot animal^{-2}$	SUPPMT	R
τ	Weighted-time variable for standing and flat residue	*NOD*	TAU	R
τ_2	Weighted-time variable for buried residue and roots	*NOD*	TAU2	R
TS	Temperature stress	*NOD*	TEMSTR	C
T_a	Average daily air temperature	^{o}C	TAVE	C,R

T_b	Base daily air temperature of a growing plant	^oC	BTEMP	C
T_c	Projected plant area coefficient for trees	*NOD*	TCOEFF	R
-	Minimum temperature to induce dormancy	^oC	TEMPMN	R
T_{cl}	Critical freezing temperature of a perennial crop	^oC	TMPMIN	C
T_{cu}	Critical upper temperature of a perennial crop that induces dormancy	^oC	TMPMAX	C
T_{mx}	Maximum daily air temperature	^oC	TMAX	C,R
T_{mn}	Minimum daily air temperature	^oC	TMIN	C,R
-	5-day average daily minimum air temperature	^oC	TMNAVG	C
-	5-day average daily maximum air temperature	^oC	TMXAVG	C
-	Vegetative dry matter of a perennial crop not harvested or grazed	$kg \cdot m^{-2}$	TOTHAV	C
-	Integer that represents whether tillage is primary or secondary	*NOD*	TYPTILL	C
T_o	Optimum temperature for crop growth	°C	TO	C
T_p	Average number of trees along a 100m transect	*NOD*	TPOP	R
t_i	Current Julian date	*Julian day*	SDATE	R
t_r	Amount of standing dead biomass transferred to litter as a result of grazing animals	$kg \cdot m^{-2} \cdot d^{-1}$	TR	R
-	Amount of standing dead biomass transferred to litter as a result of precipitation	$kg \cdot m^{-2} \cdot d^{-1}$	TRANS	R
U	Utilization of available forage by grazing animals	*NOD*	UTILIZ	R
U_b	Unavailable standing biomass for grazing animals	$kg \cdot m^{-2}$	UNBIO	R
U_d	Change in forage accessibility from herbicide application	*NOD*	UPDATE	R
W_a	Four day average water stress	*NOD*	STRESS	R
-	Flag for decomposition of woody biomass as a of herbicide application	-	WOODY	R
U_l	Soil water plant uptake in layer l	*mm*	U	C
W_n	Standing woody biomass	$kg \cdot m^{-2}$	DECOMP	R
WS	Daily water stress index starts declining	*NOD*	WATSTR	R
$WSYF$	Crop parameter expressing drought sensitivity	*NOD*	WSYF	C
X	Evergreen phytomass	$kg \cdot m^{-2}$	XLIVE	R
Y	Total above-ground biomass produced	$kg \cdot m^{-2} \cdot y^{-1}$	YIELD	R
Y_0	Initial above-ground biomass	$kg \cdot m^{-2} \cdot y^{-1}$	-	R
-	Yield at each cutting date for a perennial crop	$kg \cdot m^{-2}$	YILD	C
yop_{calc}	Optimum crop yield calculated by the model	$kg \cdot m^{-2}$		
yop_{in}	Optimum crop yield input by the user	$kg \cdot m^{-2}$	YLD	C
YLD	Grain or biomass yield	$kg \cdot m^{-2}$	YIELD	C

* C and R refer to cropland and rangeland.