USDA - WATER EROSION PREDICTION PROJECT:

HILLSLOPE PROFILE MODEL DOCUMENTATION

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ABSTRACT

The objective of the Water Erosion Prediction Project is to develop new generation prediction technology for use by the USDA-Soil Conservation Service, USDA-Forest Service, USDI-Bureau of Land Management, and other organizations involved in soil and water conservation and environmental planning and assessment. This improved erosion prediction technology is based on modern hydrologic and erosion science, process oriented, and computer implemented. The technology includes three versions: a hillslope profile version, a watershed version, and a grid version. This document is a detailed description of the hillslope profile version of the technology.

The hillslope profile erosion model is a continuous simulation computer model which predicts soil loss and deposition on a hillslope. It includes a climate component which uses a stochastic generator to provide daily weather information, an infiltration component which is based on the Green-Ampt infiltration equation, a surface runoff component which is based on the kinematic wave equations, a daily water balance component, a plant growth and residue decay component, and a rill-interrill erosion component. The profile erosion model computes spatial and temporal distributions of soil loss and deposition. It provides explicit estimates of when and where on the hillslope erosion is occurring so that conservation measures can be designed to most effectively control soil loss and sediment yield.

The hillslope profile erosion model is based on the best available science for predicting soil erosion on hillslopes. The relationships in the model are based on sound scientific theory and the parameters in the model were derived from a broad base of experimental data. The model runs on standard computer hardware and is easily used, applicable to a broad range of conditions, robust, and valid.

TABLE OF CONTENTS

Chapter 8. PLANT GROWTH COMPONENT

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8.1 Introduction

This chapter describes the approaches used in the WEPP model to simulate plant growth and residue decomposition for cropland and rangeland conditions. The growth and decomposition of cropland and rangeland plants are simulated in separate submodels.

The plant growth models were not developed to predict grain or biomass yield. Grain or biomass yield is a user input variable, which generally sets an upper boundary for vegetative plant growth. The purpose of these models is to predict temporal changes in plant and residue variables such as canopy cover, canopy height, and residue or litter cover that influence the runoff and erosion process.

Plant and residue management options available to the user such as herbicide application, silage removal, tillage, shredding, burning, or removing residue, hay harvesting, and livestock grazing are discussed in this chapter. Separate management sections for cropland and rangeland have been developed because of differences in user input variables.

This chapter has been organized into five sections. Sections 8.2, 8.3, and 8.4 discuss plant growth, residue decomposition, and management options for cropland, respectively. Sections 8.5 and 8.6 discuss plant growth, including residue decomposition, and management options for rangeland.

8.2 Cropland Plant Growth Model

8.2.1 Crop Growth Variables

The model simulates the growth of all annual crops specified in the WEPP User Requirements including corn, soybeans, grain sorghum, cotton, winter wheat, spring wheat, and oats. In addition, the growth of peanuts, potatoes, tobacco, and annual ryegrass can be simulated. The model also simulates the growth of perennial crops, including alfalfa and bromegrass. Growth functions are based on growing degree days (G_d) defined as:

$$G_d = \frac{T_{mx} + T_{mn}}{2} - T_b \qquad [8.2.1]$$

where T_{mx} and T_{mn} are the daily maximum and minimum air temperatures (^{o} C), and T_b is the base daily air temperature of a given plant (^{o} C).

G_d initiates plant growth when the average daily air temperature exceeds the base temperature of the plant. Otherwise, G_d is set to 0 and no plant growth occurs.

Growing degree days are accumulated ($\sum G_d$) beginning at planting. Plants emerge when $\sum G_d$ reaches a critical value (CRIT) or 14 days after planting, whichever occurs first. Growth of winter wheat stops when the average daily air temperature is less than the base temperature.

Plant variables predicted include vegetative biomass (B_m), canopy cover (C_c), canopy height (H_c), total living root mass (B_{rt}), root mass within 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}), root depth (R_d), leaf area index (LAI), and plant basal area (A_b).

VEGETATIVE BIOMASS

The general plant growth equation taken from Ghebreiyessus and Gregory (1987) is:

$$B_m = \left[\frac{\sum G_d}{G_{dm}} \right]^{\omega} B_{mx} \qquad [8.2.2]$$

where B_m is the vegetative biomass ($kg\ m^{-2}$), $\sum G_d$ is the cumulative growing degree days from planting (C), G_{dm} is the growing degree days at physiological maturity (C), ω is a plant-dependent growth parameter, and B_{mx} is the vegetative biomass at maturity ($kg\ m^{-2}$). For annual crops, B_{mx} is calculated as a function of plant grain or biomass yield:

$$B_{mx} = Y_g\ Y_c \qquad [8.2.3]$$

where Y_g is the plant grain or biomass yield ($kg\ m^{-2}$), and Y_c is residue mass produced per unit of grain or biomass yield.

If grain or biomass yield of an annual crop is unusually low because of poor soil or environmental conditions, and adjustment is made to increase the vegetative biomass that would be normally predicted.

The growth of a perennial crop in the Fall stops when a five-day average of minimum daily air temperatures (TMNAVG) is less than the critical growth temperature (T_{c1}). When this condition occurs, B_m is converted into standing dead residue mass. Growth is initiated in the spring when TMNAVG is greater than T_{c1}.

B_{mx} for a perennial crop is set equal to the biomass yield (YILD), which is a user input variable for all mangement options.

CANOPY COVER AND HEIGHT

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

$$C_c = 1 - e^{-\beta_c B_m} \qquad [8.2.4]$$

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

$$\beta_c = \frac{-\beta_1}{\ln\left[1 - \frac{R_w}{\beta_2}\right]} \qquad [8.2.5]$$

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. For crops not grown in rows, R_w is set equal to the plant spacing (P_s).

$$H_c = \left[1 - e^{-\beta_h B_m}\right] H_{cm} \qquad [8.2.6]$$

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

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:

$$\Delta C_c = C_{cm} \left[\frac{1 - C_{cs}}{S_p} \right] \quad [8.2.7]$$

where ΔC_c is the daily loss of canopy cover (0-1), C_{cm} is canopy cover at maturity (0-1), C_{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.

Canopy cover is adjusted from:

$$C_{c(t)} = C_{c(t-1)} - \Delta C_c . \quad [8.2.8]$$

Because leaves are falling during the senescence period, live above ground biomass (B_m) decreases while flat residue mass (M_f) increases. B_m is updated daily during this time period from:

$$B_{m(t)} = \frac{\ln (1 - C_{c(t)})}{-\beta_c} \quad [8.2.9]$$

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

$$M_{f(t)} = M_{f(t-1)} + (B_{m(t-1)} - B_{m(t)}) \quad [8.2.10]$$

where $M_{f(t-1)}$ is flat residue mass of the previous day, and $B_{m(t-1)}$ is vegetative biomass of the previous day. The effect of senescence on canopy cover is predicted for only the annual crops.

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 on any day (B_{rt}) is predicted with the equation:

$$B_{rt} = B_m R_{sr} \quad [8.2.11]$$

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:

$$B_{r1(t)} = B_{rt}$$
$$B_{r2(t)} = 0.0$$
$$B_{r3(t)} = 0.0$$

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

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

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

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

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

If root depth is > 0.60 m:

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

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.

The equation developed by Borg et al. (1986) is used to predict root depth:

$$R_d = R_{dx}\left[0.5 + 0.5 \sin\left[3.03\left[\frac{D_p}{D_m}\right] - 1.47\right]\right] \qquad [8.2.12]$$

where R_{dx} is the maximum root depth (m), D_p is the number of days after planting, and D_m is the number of days to reach maturity. For a perennial crop, Eq. [8.2.12] is used to predict root depth until the first harvest. Thereafter, R_d is assumed equal to R_{dx}.

LEAF AREA INDEX

An equation described in EPIC (Williams et al., 1984) is used to predict leaf area index (LAI) for annual crops:

If $F_{gs} < F_{lai}$ then,

$$LAI = \frac{LAI_{mx}\, B_m}{B_m + 0.552e^{-6.8B_m}} \qquad [8.2.13]$$

If $F_{gs} > F_{lai}$ then,

$$LAI = LAI_d\left[\frac{1 - F_{gs}}{1 - F_{lai}}\right]^2 \qquad [8.2.14]$$

where LAI_{mx} is the maximum leaf area index potential, LAI_d is the leaf area index value when LAI starts declining, F_{gs} is the fraction of the growing season (0-1), and F_{lai} is the fraction of growing season when leaf area index starts declining.

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

$$LAI = \frac{LAI_{mx}\, B_m}{B_m + 0.276\, e^{-13.6\, B_m}}. \qquad [8.2.15]$$

PLANT BASAL AREA

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

$$A_{bm} = P_m\, A_{sp} \qquad [8.2.16]$$

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:

$$P_m = \frac{1}{A_p} \qquad [8.2.17]$$

where A_p is the area associated with one plant (m^2).

A_p is a function of plant spacing and row width:

$$A_p = P_s\, R_w \qquad [8.2.18]$$

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:

$$A_{sp} = \pi \left[\frac{D}{2}\right]^2 \qquad [8.2.19]$$

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:

$$A_b = A_{bm}\, \frac{B_m}{B_{mx}}. \qquad [8.2.20]$$

8.2.2 Crop Parameter Values and User Inputs

Table 8.2.1 presents constant parameter values for corn, soybeans, grain sorghum, cotton, winter wheat, spring wheat, oats, alfalfa, and bromegrass required by the plant growth and decomposition models. Values for corn, soybeans, and wheat parameters were obtained from the literature or estimated using measured field data. More research data are needed to estimate some of the parameter values for

Table 8.2.1. Parameter values used in the cropland growth and decomposition submodels.†

Symbol	Variable	Corn	Soybeans	Sorghum	Cotton	Winter Wheat	Spring Wheat	Oats	Alfalfa	Brome-Grass	Peanut	Tobacco	Ryegrass
α_f	ACA	2.24	2.42	2.20	2.20	1.50	1.50	1.50	4.00	4.00	2.24	3.00	4.00
α_r	AR	2.87	2.96	2.85	2.85	2.50	2.50	2.50	4.25	4.25	2.87	3.25	4.25
α_b	AS	3.50	3.50	3.50	3.50	3.50	3.50	3.50	4.50	4.50	3.50	3.50	4.50
α_s	AST	0.22	0.24	0.22	0.22	0.15	0.15	0.15	0.40	0.40	0.22	0.30	0.40
β_h	bbb	3.00	3.00	3.00	3.50	3.00	3.00	3.00	23.00	23.00	6.92	7.00	23.00
β_1	b1	3.60	14.00	3.60	5.89	5.20	5.20	5.20	14.00	14.00	12.00	6.60	20.00
β_2	b2 (m)	1.31	0.96	1.31	1.31	0.26	0.26	0.26	0.26	0.26	1.31	1.50	0.20
T_b	BTEMP (C)	10.00	10.00	10.00	10.00	4.00	7.00	7.00	7.00	7.00	10.00	10.00	2.00
cf	CF	4.00	7.20	3.00	3.00	6.50	6.50	6.50	5.00	5.00	2.70	3.00	5.00
C_n	CN	62.00	31.00	60.00	40.00	107.00	107.00	107.00	30.00	80.00	30.00	80.00	80.00
-	CRIT (C)	60.00	60.00	60.00	90.00	60.00	60.00	60.00	30.00	30.00	60.00	60.00	30.00
-	CRITVM ($kg\ m^{-2}$)	-	-	-	-	-	-	-	0.10	0.10	-	-	-
C_{cs}	DECFCT	0.65	0.10	0.90	0.25	1.00	1.00	1.00	0.70	0.70	1.00	0.75	1.00
D	DIAM (m)	0.0508	0.0095	0.0317	0.0127	0.0064	0.0064	0.0079	0.0045	0.0022	0.0090	0.0510	0.0064
D_g	DIGEST	-	-	-	-	-	-	-	0.60	0.50	-	-	-
F_{lai}	DLAI	0.70	0.60	0.70	0.80	0.90	0.90	0.90	0.70	0.70	1.00	0.70	0.70
F_{ct}	FACT	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
G_{dm}	GDDMAX (C)	750.00	750.00	750.00	1750.00	750.00	750.00	750.00	600.00	600.00	1100.00	1000.00	680.00
ω	GRATE	2.60	2.60	2.60	1.60	2.60	2.60	2.60	2.60	1.50	2.60	2.60	1.75
-	GSSEN	0.75	0.70	0.85	0.85	1.00	1.00	1.00	0.85	0.85	1.00	0.75	1.00
H_{cm}	HMAX (m)	2.60	1.01	1.01	1.06	0.91	0.91	1.14	0.80	0.51	0.66	1.06	0.15
F_{pc}	PARTCF	0.40	0.00	0.75	0.85	0.65	0.65	0.50	-	-	0.00	0.00	0.00
P_s	PLTSP (m)	0.219	0.025	0.130	0.101	0.005	0.005	0.005	0.006	0.006	0.076	0.220	0.038
R_{dx}	RDMAX (m)	1.52	1.00	1.50	1.20	0.30	0.30	0.30	2.43	0.30	1.20	0.76	0.30
R_{sr}	RSR	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.33	0.33	0.33	0.33	0.50
-	RTMMAX ($kg\ m^{-2}$)	-	-	-	-	-	-	-	0.60	0.34	-	-	-
S_p	SPRIOD	30.0	14.0	40.0	30.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
T_{cu}	TMPMAX(C)	-	-	-	-	-	-	-	-	32.0	-	-	-
T_{cl}	TMPMIN(C)	-	-	-	-	-	-	-	4.0	1.1	-	-	-
Y_c	Y6	1.00	1.50	1.00	7.00	1.70	1.30	2.00	-	-	1.30	1.80	1.00
LAI_{mx}	XMXLAI	5.00	9.00	5.00	6.00	8.00	8.00	8.00	6.00	9.00	4.50	3.40	3.00

† Parameter values for potatoes are not determined. A "-" indicates not applicable.

the other crops. The flowchart in Fig. 8.2.1 presents the cropland plant management options available to the user. 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. implement code (itill), 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_{r1}), and prior crop type (IRESD)
9. crop information including planting date (JDPLT), row width (R_w), harvesting date (JDHARV), and grain or biomass yield (Y_g)
10. weed cover information, including the date that weed canopy cover becomes important (JDWDST), the date that weed canopy cover becomes unimportant (JDWEND), and the average weed canopy cover during the period (C_w)
11. plant and residue management information for annual crops (RESMNG), including the date of herbicide application (JDHERB), the date that silage or other living biomass is removed (JDSLGE), the date of residue shredding or cutting (JDCUT), the date of residue burning (JDBURN), and the date of residue removal from a field (JDMOVE)
12. plant management information for perennial crops that are cut, including the number of cuttings (NCUT), cutting dates (CUTDAY), and biomass yields (YILD)
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), digestibility of the forage (D_g), and the forage biomass produced during the grazing period (YILD).

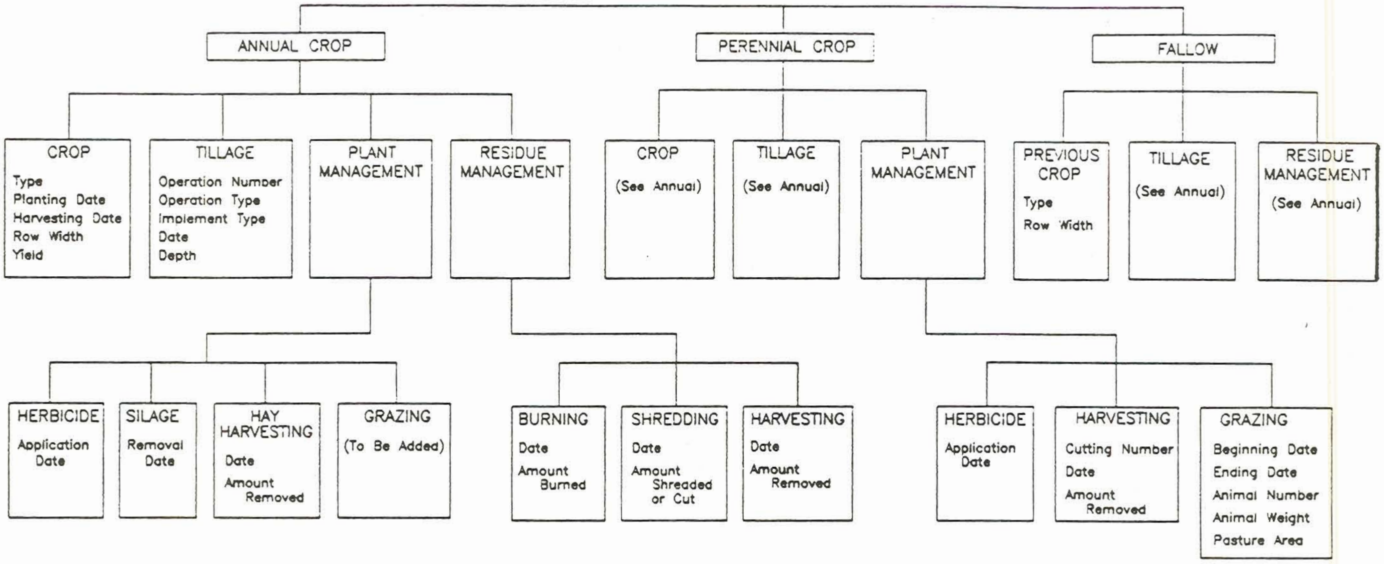

Figure 8.2.1. Flowchart of cropland options available to the user.

8.2.3 Model Summary

Procedures followed in the plant growth model are:

1. Initialize the following variables

- base daily air temperature of a plant, T_b
- growing degree days to emergence, CRIT
- parameter for plant growth equation, ω
- growing degree days at maturity, G_{dm}
- parameter for canopy cover equation, β_1
- parameter for canopy height equation, β_h
- maximum canopy height, H_{cm}
- maximum canopy width, β_2
- maximum root depth, R_{dx}
- root to shoot ratio, R_{sr}
- maximum root mass for a perennial crop, RTMMAX

- fraction of the growing season to senescence, GSSEN

- fraction of canopy cover remaining after senescence, C_{cs}

- days from the beginning until the end of leaf drop, S_p

- fraction of growing season when leaf area index starts declining, F_{lai}

- maximum leaf area index potential, LAI_{mx}

- stem diameter of a plant at maturity, D

- in-row plant spacing, P_s

- minimum air temperature that causes plant dormancy, T_{c1}

- maximum air temperature that causes plant dormancy, T_{cu}

- minimum vegetative biomass for heavy grazing, CRITVM

- parameters to convert user input grain or biomass yield into vegetative biomass, Y1-Y6

2. Compute vegetative biomass at maturity from average grain or biomass yield, with an adjustment for low yield if necessary. For perennial crops, maximum vegetative biomass (B_{mx}) at each harvest date is input by the user.

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.

4. Calculate growing degree days (G_d), and cumulative growing degree days ($\sum G_d$).

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 ($\sum G_d$) are equal to the growing degree days at maturity (G_{dm}).

8. When G_{dm} is reached, plant growth stops with no changes until leaf drop.

9. Starting at senescence, canopy cover decreases due to leaf drop. The variable S_p defines the number of days from the beginning until the end of leaf drop.

10. Growth of annual and perennial crops are 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_{c1}).

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 temperature, nutrient, and aeration stress factors commonly found in more complicated plant growth models. These factors are accounted for in the grain or biomass yields specificed by the user.

8.3 Cropland Residue and Root Decomposition Model

The model simulates the decomposition of standing and flat residue, buried residue, and roots within the 0- to 0.15-m soil layer for the annual and perennial crops specified in Section 8.2.1.

Total residue mass (M_{rt}) is partitioned into standing (M_s) and flat (M_f) components at harvest before residue management occurs:

$$M_{s(t)} = M_{s(t-1)} + (M_{rt}\, F_{pc}) \qquad [8.3.1]$$

$$M_{f(t)} = M_{f(t-1)} + (M_{rt} - M_{s(t)}) \qquad [8.3.2]$$

where F_{pc} is the fraction of residue mass partitioned into standing residue.

The model also sets the initial stubble population at harvest equal to the plant population (P_m) calculated in the plant growth model.

8.3.1 Decomposition

The general decomposition equation taken from Ghidey et al., 1985 is:

$$\frac{M_{(t)}}{M_{(t-1)}} = (1 - \alpha\tau)^2 \qquad [8.3.3]$$

where $M_{(t)}$ is the present standing residue (M_s), flat residue (M_f), buried residue (M_b), or root (M_r) mass ($kg\ m^{-2}$), $M_{(t-1)}$ is the prior day standing residue (M_s), flat residue (M_f), buried residue (M_b), or root (M_r) mass ($kg\ m^{-2}$), α is the constant used to calculate standing residue (α_s), flat residue (α_f), buried residue (α_b), or root (α_r) mass changes, and τ is the weighted-time variable calculated from air temperature, daily rainfall, and the initial C to N ratio of residue and root mass at senescence.

The variable, τ, is calculated from:

$$\tau = \frac{T_a\, a_m}{C_n} \qquad [8.3.4]$$

where T_a is the average daily temperature (C), a_m is the antecedent moisture index (m), and C_n is the carbon to nitrogen ratio of residue and roots at senescence.

The moisture index, a_m, is calculated from (Ligeon and Johnson, 1960):

$$a_m = \sum_{i=1}^{5} \frac{R_{(i)}}{i} \qquad [8.3.5]$$

where R is the depth of rainfall on a given day (m), and i is the day number with the present day being 1, previous day being 2, etc.

a_m values greater than 0.01 are set to 0.01 to reduce the rate of standing and flat residue decomposition during high rainfall periods. Another τ variable (τ_2) is calculated without the 0.01-m boundary and used to decompose buried residue and roots.

8.3.2 Stubble Population

The equation to compute stubble population is:

$$P_{(t)} = \frac{M_{s(t)}}{M_{so}} P_m F_{ct} \qquad [8.3.6]$$

where $P_{(t)}$ is the stubble population at time t, $M_{s(t)}$ is the standing residue mass at time t, M_{so} is the standing residue mass at harvest, P_m is the stubble population at harvest and F_{ct} is the adjustment factor to account for the effects of wind and snow on stubble population. The default value for F_{ct} is 0.99, but it can be adjusted by the user to account for local climatic conditions.

8.3.3 Standing to Flat Residue Conversion

The equation to calculate standing residue mass from the stubble population is:

$$M_{s(t)} = \frac{P_{(t)}}{P_m} M_{so} \qquad [8.3.7]$$

The equation to increase flat residue mass from the standing to flat residue conversion is:

$$M_{f(t)} = M_{f(t-1)} + (M_{s(t-1)} - M_{s(t)}) \qquad [8.3.8]$$

where $M_{f(t)}$ is the flat residue mass at time t.

8.3.4 Residue Cover

Gregory's (1982) equation is used to predict residue cover from flat residue mass:

$$C_{rf} = 1 - e^{-cf\,M_f} \qquad [8.3.9]$$

where C_{rf} is the flat residue cover (0-1), M_f is the flat residue mass ($kg\ m^{-2}$), and cf is a constant to calculate flat residue cover.

Soil cover from standing residue mass is predicted from:

$$C_{rs} = \frac{P_{(t)}}{P_m} A_{bm} \qquad [8.3.10]$$

where C_{rs} is the standing residue cover (0-1), $P_{(t)}$ is the stubble population per unit area at time t, P_m is the stubble population per unit area at harvest, and A_{bm} is the plant basal area at maturity (m^2) per square meter of soil area.

Total soil cover from residue is:

$$C_{rt} = C_{rf} + C_{rs} \qquad [8.3.11]$$

where C_{rt} is the total residue cover (0-1).

8.3.5 Interrill and Rill Residue Cover

The erosion model requires that interrill and rill residue cover terms be predicted (C_{ri} and C_{rl}). Interrill residue cover is the average residue cover on the soil surface and is equal to the total residue cover (C_{rt}). Rill residue cover is set equal to interrill residue cover for tillage systems that do not have well defined ridges and furrows. The model recognizes a ridge-furrow tillage system when any implement in a tillage sequence meets specific ridge height and ridge interval criteria. These criteria are that initial ridge height be equal to or greater than 0.10 m and ridge interval be equal to the row width (see Chapter 6 for more information).

Residue can be repositioned in a ridge-furrow system, either by wind blowing residue from the ridge into the furrow, by a planter with sweeps moving residue from the ridge into the furrow, or by a cultivator moving residue back to the ridge. For wind repositioning, the user must input the residue cover on the ridges at the end of the repositioning period (C_{sp}). Residue cover on the ridges is calculated from:

$$C_{rr(t)} = C_{rro} - \left[\frac{C_{rro} - C_{sp}}{60} \right] D_h \quad [8.3.12]$$

where $C_{rr(t)}$ is the residue cover on the ridges at time t, C_{rro} is the interrill residue cover immediately after harvest, C_{sp} is the residue cover on the ridges at the end of the repositioning period, and D_h is the days after harvest. All adjustments for wind moving residue from the ridge into the furrow are made within 60 days of harvest.

The daily mass of residue moved from the ridges into furrows (ΔM_w) is computed from:

$$\Delta M_w = \frac{\ln(1 - (C_{rr(t-1)} - C_{rr(t)}))}{-cf}. \quad [8.3.13]$$

Total residue mass in the furrows is:

$$M_{rl(t)} = M_{rl(t-1)} + \Delta M_w. \quad [8.3.14]$$

Rill cover, which is equal to the furrow cover, is then calculated from the adjusted residue mass:

$$C_{rl} = 1 - e^{-cf\, M_{rl}}. \quad [8.3.15]$$

Residue mass on the ridges (M_{rr}) is:

$$M_{rr(t)} = M_{rr(t-1)} - \Delta M_w. \quad [8.3.16]$$

Decomposition of residue on the ridges and in the furrows is accounted for separately. The partitioning coefficient (F_{pc}) is set to zero for a ridge-furrow system.

The average residue cover on the soil surface (C_{ri}) is predicted from:

$$C_{ri} = 0.5\, C_{rr} + 0.5\, C_{rl} \quad [8.3.17]$$

where ridge and furrow areas are assumed equal.

Residue repositioning at planting occurs if the user selects a planter with sweeps from the planter implement list. It is assumed that all remaining residue mass on the ridges is swept into the furrow at planting. C_{rl} is then computed from the adjusted residue mass. C_{rr} is set to zero. C_{ri} is computed from Eq. [8.3.17].

It is assumed in a ridge-furrow system that all flat residue mass is repositioned evenly over the soil surface at cultivation ($M_{rr} = M_{rl}$). Additional cultivations do not reposition residue. Interrill and rill residue covers are recomputed and are equal until grain or biomass harvest, when the effect of wind on residue cover is again predicted.

8.3.6 Ground Cover

Total ground cover from residue and rocks is calculated from:

$$C_g = C_{cf} + C_{ri}(1 - C_{cf}) \qquad [8.3.18]$$

where C_g is the total ground cover and C_{cf} is the weight fraction of coarse fragments in the soil, which is assumed equal to coarse fragment cover (0-1).

8.3.7 Cropland Residue Decomposition Model Summary

Procedures followed in the decomposition model include:

1. Initialize the following variables:

   - decomposition parameter for standing residue, α_s
   - decomposition parameter for flat residue, α_f
   - decomposition parameter for buried residue, α_b
   - decomposition parameter for roots, α_r
   - parameter for flat residue cover equation, cf
   - carbon to nitrogen ratio of residue and roots, C_n
   - standing to flat residue adjustment factor for wind and snow, F_{ct}
   - parameter to calculate standing residue mass at harvest, F_{pc}
   - residue cover on ridges after wind repositioning, C_{sp}.

2. User initializes interrill and rill residue cover. The model calculates initial standing residue mass (M_s), flat residue mass (M_f), buried residue mass (M_b), root mass in the 0- to 0.15-m zone (M_r), and plant population (P).

3. Calculates (from Eq. [8.3.3] and [8.3.4]):

   - weighted-time variables, τ and τ_2
   - standing residue mass change, ΔM_s
   - flat residue mass change, ΔM_f
   - buried residue mass change, ΔM_b
   - root mass change, ΔM_r.

4. Calculates residue and root mass (from Eq. [8.3.3]):

   - standing residue mass (M_s)
   - flat residue mass (M_f)

- buried residue mass (M_b)

- non-living root mass (M_r).

5. Converts standing residue mass to flat residue mass. Increments flat residue mass (Eq. [8.3.7] and [8.3.8]).
6. Computes standing, flat, total, rill, and interrill residue cover (from Eq. [8.3.10], [8.3.9], [8.3.11], [8.3.15], and [8.3.17]).
7. Check date to see if it is a day of tillage (MDATE). If it is, use equations given in section 8.4.2 to compute standing and flat residue mass remaining after tillage. Increment buried residue mass by the mass of flat residue incorporated into the soil by tillage.
8. Partition surface residue mass (M_{rt}) at harvest into standing (M_s) and flat (M_f) components using F_{pc}, which depends upon harvesting equipment and techniques.

8.4 Cropland Management Options

8.4.1 Plant Management

The cropland plant growth and decomposition models 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 and decomposition of peanuts, potatoes, tobacco, and annual ryegrass are also provided.

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 or perennial crop either prior to or at row-crop planting. The user must input the date of herbicide application (JDHERB). All vegetative biomass is converted into standing dead residue on JDHERB. For cotton, the fraction of the growing (F_{gs}) to JDHERB is computed and GSSEN is set equal to this value, which initiates leaf drop. The model does not consider the effect of herbicides on broad leaf weeds or grasses.

Silage

The user must input the date that silage is removed from the field (JDSLGE), which converts live vegetative biomass into dead. The model assumes that all above ground residue is removed from the field. Standing residue cover (C_{rs}) is calculated from Eq. [8.3.10] using plant population (P_m) and basal area (A_{bm}) values. No adjustments are made to flat residue mass and cover.

8.4.2 Small Grain Harvest for Hay

If small grain is cut for hay in the dough stage, the user must input the cutting date (JDCUT), the fraction of biomass cut (F_c), the removal date (JDMOVE), and the fraction of flat biomass removed from the field at harvest (F_{rm}). Residue mass above ground after cutting is calculated from:

$$M_{s(t)} = M_{s(t-1)} + B_m(1 - F_c) \qquad [8.4.1]$$

where M_s is residue mass above ground after cutting, B_m is vegetative biomass before cutting, and F_c is the fraction of biomass cut.

Flat residue mass is incremented by the change in standing residue mass on JDCUT:

$$M_{f(t)} = M_{f(t-1)} + (B_m F_c). \quad [8.4.2]$$

Flat residue mass remaining after hay removal from the field is calculated from:

$$M_{f(t)} = M_{f(t-1)}(1 - F_{rm}) \quad [8.4.3]$$

Flat and total residue cover values are updated based on changes in flat residue mass from the management operations.

8.4.3 Tillage

Effects of tillage on residue and soil properties are calculated in the model (see Chapter 6). Tillage intensity (T_i) is used as the classification variable to adjust standing and flat residue mass and cover, bulk density, random roughness, ridge height and ridge interval. T_i values are stored by implement and crop and range from 0 to 1. A residue mixing factor (R_{mf}) is calculated from:

$$R_{mf} = 1 - T_i \quad [8.4.4]$$

where R_{mf} is the ratio of flat residue cover after tillage to that before tillage. The residue mixing factor is adjusted for tillage depth by the equation:

$$R_{mf} = R_{mf} + \left[\frac{T_{dm} - T_d}{T_{dm}}\right](1 - R_{mf}) \quad [8.4.5]$$

where T_d is the tillage depth input by the user, and T_{dm} is the mean tillage depth for that implement. Only R_{mf}'s for certain primary and secondary tillage implements are adjusted for depth.

Two adjustments are made on residue mass and cover when tillage is performed. First, standing residue is converted to flat residue using an equation from EPIC (Williams et al., 1984). Standing residue mass remaining after tillage is calculated from:

$$M_{s(t)} = M_{s(t-1)}\, e^{-8.535\, T_i^2} \quad [8.4.6]$$

where $M_{s(t)}$ is the standing residue mass after tillage ($kg\ m^{-2}$), and $M_{s(t-1)}$ is the standing residue mass before tillage ($kg\ m^{-2}$).

Flat residue mass is incremented by the change in standing residue:

$$M_{f(t)} = M_{f(t-1)} + (M_{s(t-1)} - M_{s(t)}) \quad [8.4.7]$$

where $M_{f(t)}$ is the adjusted flat residue mass ($kg\ m^{-2}$), and $M_{f(t-1)}$ is the flat residue mass before tillage ($kg\ m^{-2}$).

Based on the adjusted residue masses, standing and flat residue covers are computed using the equations given in Section 8.3.4.

The second adjustment is the conversion of flat residue to buried residue. Flat residue cover remaining after tillage is predicted from the equation:

$$C_{rf(t)} = R_{mf}\, C_{rf(t-1)} \quad [8.4.8]$$

where $C_{rf\,(t-1)}$ and $C_{rf\,(t)}$ are flat residue covers before and after tillage, respectively.

Flat residue mass remaining after tillage is then calculated from:

$$M_{f\,(t)} = \frac{\ln(1 - C_{rf\,(t)})}{-cf} \qquad [8.4.9]$$

where cf is the constant used to calculate flat residue cover.

Following each tillage operation, buried residue mass (M_b) in the 0- to 0.15-m zone is increased by the mass of flat residue incorporated into the soil. Flat residue mass before tillage includes the mass of residue converted from standing to flat by the tillage operation.

8.4.4 Residue Management Options

When applicable, the user must specify a residue management option. Current options include shredding or cutting, burning, and harvesting. The date of shredding or cutting (JDCUT), burning (JDBURN), or harvesting (JDMOVE) is input by the user.

8.4.4.1 Shredding or Cutting

Standing residue (M_s) is converted into flat residue (M_f) depending upon the fraction of standing residue cut (F_c), which is a user input variable:

$$M_{f\,(t)} = M_{f\,(t-1)} + (M_{s\,(t)}\, F_c). \qquad [8.4.10]$$

Flat residue cover is calculated from the adjusted flat residue mass using Eq. [8.3.9].

8.4.4.2 Burning

The effectiveness of burning on standing and flat residue mass depends upon environmental and plant conditions at the time of the burn. Therefore, the user must input the fractions of standing and flat residue that are lost by burning. Standing and flat residue masses after burning are calculated from:

$$M_{s\,(t)} = M_{s\,(t-1)}\,(1 - F_{bs}) \qquad [8.4.11]$$

$$M_{f\,(t)} = M_{f\,(t-1)}\,(1 - F_{bf}) \qquad [8.4.12]$$

where F_{bs} and F_{bf} are the fractions of standing and flat residue lost by burning, respectively.

8.4.4.3 Harvesting

Small grain residue is often harvested for livestock bedding. If standing residue is cut, the user must input the cutting date (JDCUT), the fraction of residue cut (F_c), the removal date (JDMOVE), and the fraction of flat residue removed (F_{rm}). Standing and flat residue masses after cutting are predicted from:

$$M_{s\,(t)} = M_{s\,(t-1)}\,(1 - F_c) \qquad [8.4.13]$$

$$M_{f\,(t)} = M_{f\,(t-1)} + (M_{s\,(t-1)} - M_{s\,(t)}). \qquad [8.4.14]$$

Flat residue mass remaining after removal from the field is calculated from:

$$M_{f(t)} = M_{f(t-1)}\,(1 - F_{rm}). \qquad [8.4.15]$$

If standing residue is not cut and only the residue that passed through the combine is harvested, the user must input the removal date (JDMOVE) and the fraction of flat residue removed (F_{rm}). The flat residue mass remaining after removal of the residue is calculated from Eq. [8.4.15].

8.4.5 Management Options For Perennial Crops

8.4.5.1 Hay Harvesting

The user inputs the number of cuttings (NCUT) for each year, cutting dates (CUTDAY), and yield (YILD) 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:

$$B_m = B_m(1 - F_{rm}). \qquad [8.4.16]$$

Equation [8.2.2] is rearranged to compute an adjusted cumulative growing degree days term ($\sum G_d$), which is based upon the vegetative biomass left after harvest:

$$\sum G_d = G_{dm}\left[\frac{B_m}{B_{mx}}\right]^{\frac{1}{\omega}} \qquad [8.4.17]$$

The adjusted $\sum G_d$ is used as the initial value at the start of the next growth period. Similar adjustments based upon B_m left after harvest are made to C_c, H_c, and LAI.

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}.

8.4.5.2 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:

$$F_t = 0.1\left[\frac{B_w^{0.75}}{D_g}\right]\left[\frac{N_a}{A_f}\right] \qquad [8.4.18]$$

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

8.5 Rangeland Plant Growth Model

Initiation and growth of above and below ground biomass for range plant communities is estimated by using a potential growth curve. The potential growth curve can be defined with either a unimodal or a bimodal distribution (Fig. 8.5.1 and 8.5 2). The potential growth curve (Eq. [8.5.1]) 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:

$$g_i = G_1 \left[\alpha e^{\frac{c}{d}(1-\beta)} \right] \qquad [8.5.1]$$

where

$$\alpha = \left[\frac{t_i - G_b}{P_d - G_b} \right]^c \qquad [8.5.2]$$

$$\beta = \left[\frac{t_i - G_b}{P_d - G_b} \right]^d \qquad [8.5.3]$$

g_i is the increment of growth expressed as a fraction of 1.0, G_1 is the fraction of maximum live biomass at

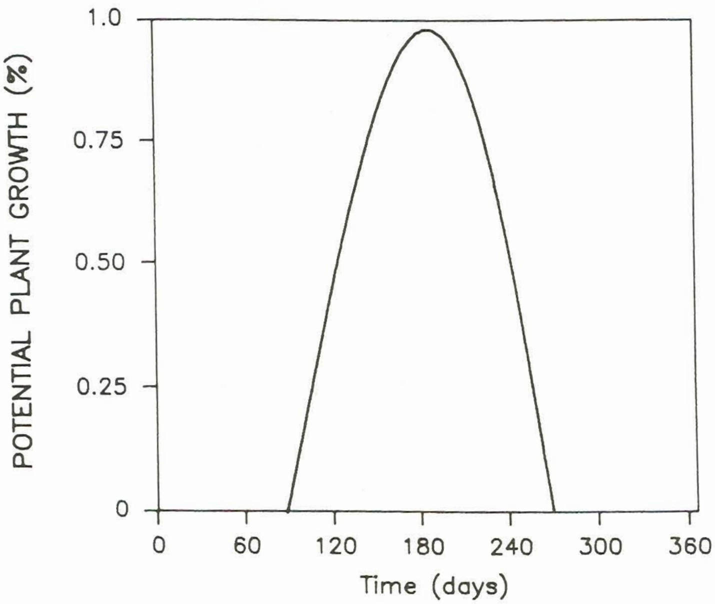

Figure 8.5.1. Unimodal potential plant growth.

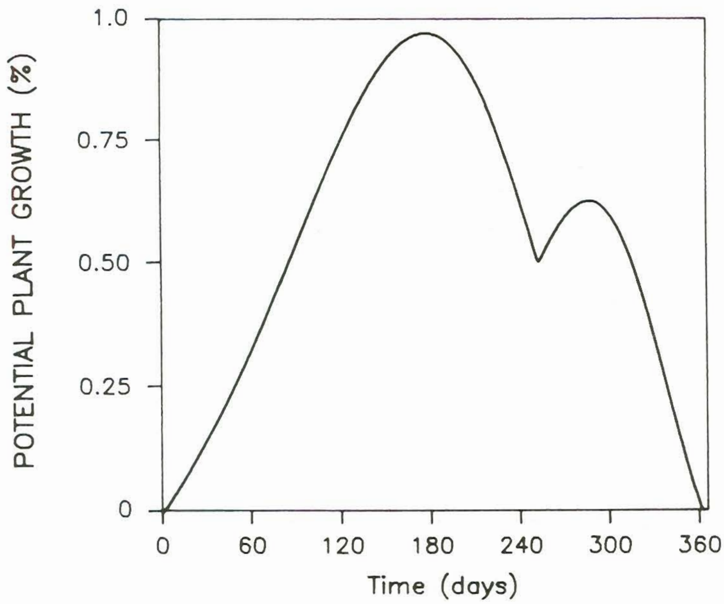

Figure 8.5.2. Bimodal potential plant growth.

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.

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.

$$c = 8.515 - 22.279\,a + 16.734\,a^2 \qquad [8.5.4]$$

$$d = 12.065 - 63.229\,a + 87.34\,a^2 \qquad [8.5.5]$$

where

$$a = \frac{P_d - G_b}{\left[\dfrac{G_1 f_p}{G_1 + G_2}\right]}.$$

The user may either enter the potential maximum live above ground biomass (P_{mx}) or the model can estimate this value as a function of growing season precipitation (P_g) for grasslands (Sims and Singh, 1978). The equations have not been validated for shrub and tree dominated landscapes and should be used with caution on these landscapes. To have the model estimate P_{mx} for grazed and ungrazed grasslands, P_{mx} must be initialized to 0.0.

For grazed areas:

$$P_{mx} = \frac{35.69 + 0.36 P_g}{100} \qquad [8.5.6]$$

For non-grazed areas:

$$P_{mx} = \frac{77.23 + 0.30P_g}{100} \qquad [8.5.7]$$

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 $T_a = \frac{T_{mx} + T_{mn}}{2}$. 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) (see chapter 7.2). 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; see chapter 7.2).

$$D_s = 1 - e^{-3.5W_a} \qquad [8.5.8]$$

Increments of new growth are calculated as:

$$L_i = g_i \, P_{mx} \qquad [8.5.9]$$

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 ($kg\ m^{-2}$).

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.

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. 8.5.3).

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 d and e 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:

$$a = \frac{P_2 - (\frac{G_1 f_p}{G_1 G_2} + G_b)}{f_p - \frac{G_1 f_p}{G_1 + G_2}} \qquad [8.5.10]$$

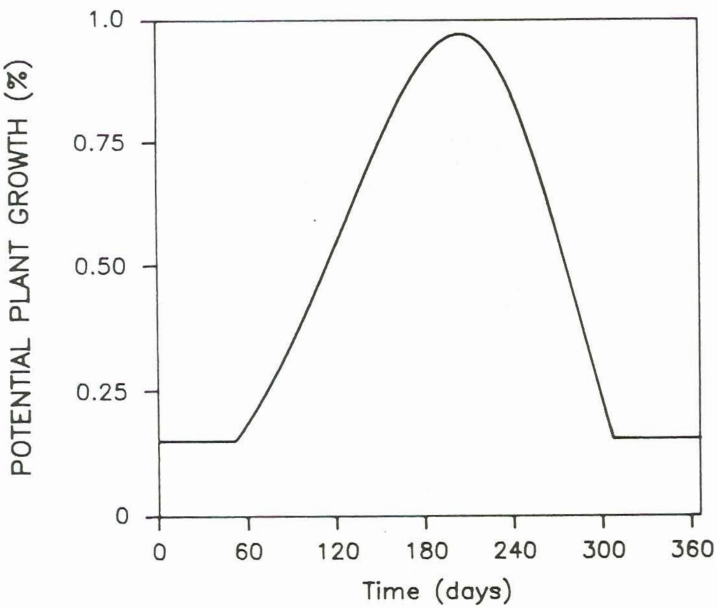

Figure 8.5.3. Bimodal potential plant growth with a minimum live component.

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 is the daily rainfall (m). δ has been defined such that the maximum single day reduction in old standing dead is 5%.

$$\delta = e^{-3.5\,R} \qquad [8.5.11]$$

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).

$$R_g = (R_g\, \omega_L) - B_c \qquad [8.5.12]$$

$$\omega_L = 1 - (\alpha_f\, \tau)^2$$

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

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. S_{mi} values > 100 mm are set to 100 mm 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 non-decomposable 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), litter and organic residue cover on the soil surface (C_{rt}), foliar canopy cover (C_c), ground surface cover (C_g), and leaf area index (LAI). The height of the plant canopy is calculated on 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.

$$H_c = \frac{(H_t E_t) + (H_s E_s) + (H_g E_g)}{\eta} \qquad [8.5.13]$$

where $\eta = \frac{A}{P_a}$. A is the representative total vertical surface area of the overland flow plane. P_a is the effective projected plant area. H_t , H_s, and H_g are canopy heights for the tree, shrub, and herbaceous plant components, respectively. E_t , E_s, and E_g are the vertical area of the tree, shrub, and herbaceous components, respectively.

The canopy height for the herbaceous community (H_g) 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), dead standing biomass (R_a), maximum herbaceous plant height (H_{cm}), and a shaping coefficient (B_h). Plant canopy height is defined not as the uppermost extension of the canopy, but where the maximum amount of rainfall interception occurs.

$$H_g = H_{cm}(1 - e^{-B_h L_t R_a}) \qquad [8.5.14]$$

The effective project plant area is calculated as a function of the plant height (m), average canopy diameters (m), number of plants along a 100m transect, and a geometric shape coefficient for the various plant components (Eq. [8.5.15]) and is based on work done by Hagen and Lyles (1988). The effective projected plant area is defined as the percent vertical cover and is used in calculating the distribution and depth of the snow pack.

$$P_a = \frac{E_a}{A} \qquad [8.5.15]$$

The total projected area of the vegetation for the overland flow plane is computed as:

$$E_a = E_g + E_s + E_t \qquad [8.5.16]$$

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. Equation [8.5.17] shows the calculation for the herbaceous plant component.

$$E_g = H_g G_{di} G_c G_p \qquad [8.5.17]$$

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:

$$A = LH_t \qquad [8.5.18]$$

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

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. The area between plant canopies 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 density (R_s). The lower and upper boundary constraints are 0.5 and 5m, respectively, and L has been defined as 100m.

$$R_s = \frac{L}{G_p + S_p + T_p + 1} \qquad [8.5.19]$$

The fraction of the soil surface covered with litter is estimated with an exponential function. Where C_f is a shaping coefficient and R_g is litter and organic residue mass on the soil surface. Rill ground surface cover (RILCOV) has been defined as equal to C_{rt}.

$$C_{rt} = 1 - e^{-C_f R_g} \qquad [8.5.20]$$

$$C_f = 10^{1.085\,(1.0 + 1.69\,e^{-12.61\,R_g}) - 0.583}$$

Ground surface cover is calculated with a multiple regression equation (developed from WEPP field data) and is equal to interrill ground cover (INRCOV).

$$C_g = 1.28C_{rt} + 0.947C_{cf} + 1.24C_{cr} \qquad [8.5.21]$$

C_{cf} is the fraction of soil surface covered by impervious material greater than 2 mm and is a user input. C_{cr} is the fraction of the soil surface covered by a cryptogamic crust, and is a user input. Cryptogams are defined here as all mosses, lichens, and algae that occur on the soil surface. The rock and cryptogamic crust are fixed variables and do not change as a function of plant growth. The rock and cryptogamic crust will change as a result of some management options when that subroutine is implemented. Exposed bare soil is calculated by difference from the other components of ground surface cover.

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 is a shaping coefficient based on plant community and B_t is total standing biomass. The shaping coefficient f_c is calculated as a function of the parameter C_o. C_o is defined as the standing biomass ($kg\ m^{-2}$) where canopy cover is 100% (Fig. 8.5.4).

$$C_c = 1 - e^{f_c B_t} \qquad [8.5.22]$$

$$F_c = 21.39 - 54.91\,C_o + 61.11\,C_o^2 - 30.44\,C_o^3 + 5.56\,C_o^4$$

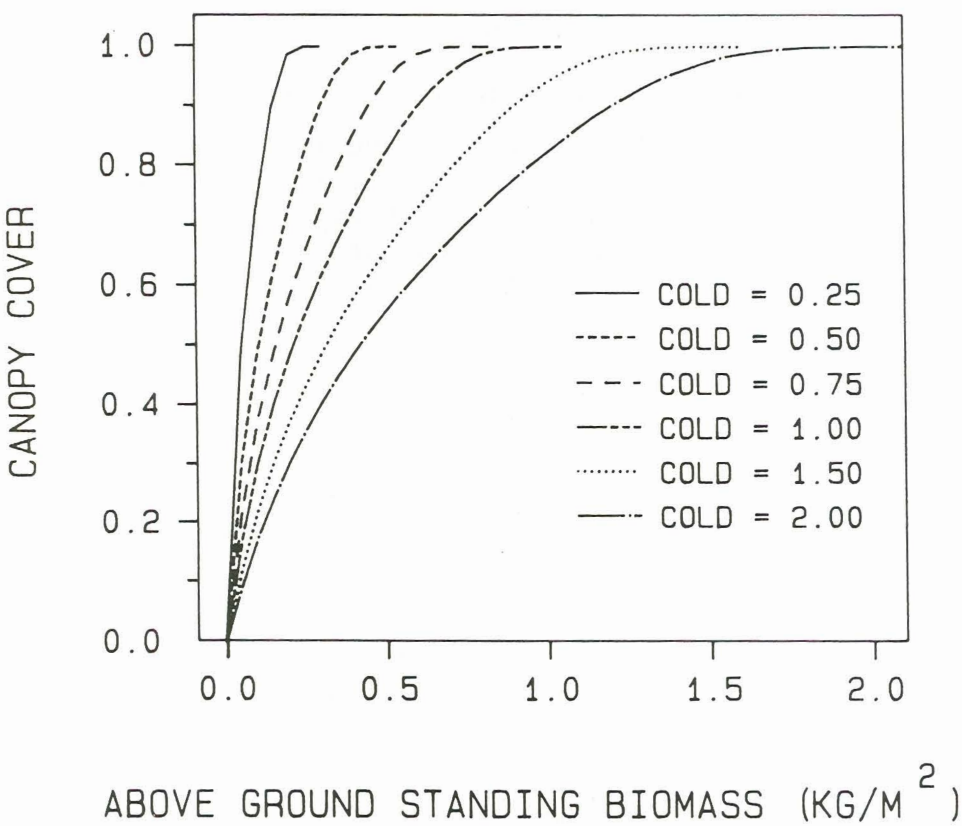

Figure 8.5.4. Relationship of above ground standing biomass to canopy cover as a function of COLD.

Leaf area index is difficult to estimate for complex plant communities. Weltz (1987) 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.

$$LAI = L_t L_c \qquad [8.5.23]$$

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 a exponential function.

$$R_i = R_t R_o (100\, S_d^{R_f}) \tag{8.5.24}$$

where R_i is the total mass of roots ($kg\ m^{-2}$) 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 ending depth of soil layer (m). R_f is a root depth coefficient and has been set at 0.43. R_o is a root biomass coefficient and is estimated from the root mass (R_{10}) in the top 0.1 m of the soil surface.

$$R_o = \frac{R_{10}}{10^{R_f}} \tag{8.5.25}$$

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.

$$R_p = \frac{R_i}{B_{rt}} \tag{8.5.26}$$

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.

$$B_{rt} = B_{rt} + (R_t g_i W_a B_{rt-1}) \tag{8.5.27}$$

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

$$B_{rt} = B_{rt}\, \chi \tag{8.5.28}$$

where $\chi = 1 - (\alpha_r\, \upsilon)^2$, χ is the fraction of roots after decay, α_r is the root decay coefficient, and $\upsilon = \frac{S_r T_a}{C_n}$. υ is carbon-nitrogen ratio of dead leaves and roots. S_r is the amount of rainfall recorded in the last 5 days.

8.6 Rangeland Management Options

The range plant growth subroutine contains default parameters for 7 plant communities. 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.

8.6.1 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 8.6.1).

Table 8.6.1. 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 m)	Litter (kg m)	Root biomass (kg m)	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

8.6.2 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.

8.6.3 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 the 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. [8.6.1]). 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. Digestibility (Eq. [8.6.2]) is calculated as a function of the live-dead leaf ratio (D_l). Where D_l is calculated as $\frac{L_t}{R_a}$. 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.

$$D = (D_r D_{mx}) + [(1 - D_r)D_{mx}] \qquad [8.6.1]$$

$$D_r = 1 - e^{-5D_1} \qquad [8.6.2]$$

The physiological limit on forage intake is estimated (Eq. [8.6.3]) 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:

$$F_i = 0.1 \left[\frac{B_w^{0.75}}{D} \right] \qquad [8.6.3]$$

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. [8.6.4]). A_c is the parameter used to determine the fraction of standing biomass available for consumption.

$$W_n = N_d R_a \qquad [8.6.4]$$

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 a equal to a ten day supply of forage then the model automatically supplies supplemental feed to the animals.

$$B_a = [A_c(R_a + L_t)] + (R_a - W_n) \qquad [8.6.5]$$

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

$$U = \frac{F_t}{Y + 0} \qquad [8.6.6]$$

where F_t is the total forage consumed, Y is total standing biomass produced that year, and 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:

$$U_b = (1 - A_c)\,(R_a + L_t) \qquad [8.6.7]$$

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 (ha).

$$t_r = 0.05R_a(1 - e^{-0.01S}) \qquad [8.6.8]$$

8.6.4 Burning

The user must define the Julian date that the pasture is burned. A minimum fuel load of 800 $kg\ ha^{-1}$ 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 mm or if the 5 day antecedent rainfall is greater than 25 mm 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.

$$A_c = A_c C \qquad [8.6.9]$$

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:

$$W_n = W_n B \qquad [8.6.10]$$

The potential growth rate of above ground biomass (Eq. [8.6.11]) and root biomass (Eq. [8.6.12]) maybe affected by both prescribed and wild fires. The percenter 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:

$$P = PC \qquad [8.6.11]$$

$$R_o = R_o C \qquad [8.6.12]$$

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:

$$L_t = L_t H \qquad [8.6.13]$$

The percent reduction in the live evergreen leaf biomass (Eq. [8.6.14]) and the herbaceous standing dead biomass (Eq. [8.6.15]) is a function of R_l. R_l also reduces the litter and the organic residue mass on the soil surface (Eq. [8.6.16]).

$$L_t = [R_l(L_t - X)] + X\, R_l \qquad [8.6.14]$$

$$R_a = R_l\, R_a \qquad [8.6.15]$$

$$R_g = R_l\, R_g \qquad [8.6.16]$$

8.6.5 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 $kg\ ha^{-1}$. If rainfall is greater than 10 mm on day of application then the application date is delayed one day. The user can chose 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 mm 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 compute as:

For herbaceous species only:

$$D_r = L_t - (L_t L_k) \qquad [8.6.17]$$

For herbaceous species within evergreen plant communities:

$$H_o = (L_t - x) - [L_k\,(L_t - X)] \tag{8.6.18}$$

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:

$$A_d = X - (XH_k) \tag{8.6.19}$$

The application of herbicides may affect the percent increase or decrease in the potential growth rate of above ground herbaceous biomass (Eq. [8.6.20]) and root mass (Eq. [8.6.21]). 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:

$$P = PR_e \tag{8.6.20}$$

$$R_o = R_o R_e \tag{8.6.21}$$

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

$$A_c = U_d A_c \tag{8.6.22}$$

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:

$$R_g = R_g + D_r \tag{8.6.23}$$

For evergreen plants:

$$R_g = R_g + A_d + H_o \tag{8.6.24}$$

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

$$D_d = H_o + A_d \tag{8.6.25}$$

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. [8.6.26]). The dead steams, 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. [8.6.27]). 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.

$$R_g = R_g + [D_d - (D_d\, \omega_L)] \qquad [8.6.26]$$

$$R_g = R_g + \left\{ W_n - \left[W_n \left[\frac{1 - \omega_L}{4} \right] \right] \right\} \qquad [8.6.27]$$

8.7 References

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8.8 List of Symbols

Symbols	Description	Unit	Variable	Land Use*
A	Total vertical projected area	m	TAREA	R
A_b	Plant basal area in one square meter	m^2	BASAL	C
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	$kg\ m^{-2}$	ADHERE	R
A_f	Pasture size being grazed	m^2	AREA	R,C
A_p	Soil area associated with one plant	m^2	AREACV	C
A_{sp}	Single plant stem area	m^2	STEMAR	C
A_1	Change in forage accessibility from burning	NOD	ALTER	R
a_m	Antecedent moisture index for standing and flat residue decomposition	m	AM	R,C
a_{m2}	Antecedent moisture index for buried residue and root decomposition	m	AM2	R,C
α_b	Decomposition constant to calculate mass change of buried residue	NOD	AS	C
α_f	Decomposition constant to calculate mass change of flat residue	NOD	ACA	R,C
α_r	Decomposition constant to calculate mass change of roots	NOD	AR	R,C
α_s	Decomposition constant to calculate mass change of standing residue	NOD	AST	C
B	Reduction in standing dead biomass from burning	NOD	BURNED	R
B_a	Available standing biomass for grazing animals	$kg\ m^{-2}$	AVABIO	R
B_c	Daily removal of surface organic material by insects	$kg\ m^{-2}$	BUGS	R
B_m	Vegetative biomass	$kg\ m^{-2}$	VDM	C
B_{mx}	Vegetative biomass at maturity	$kg\ m^{-2}$	VDMMAX	C
ΔB_r	Daily change in total root biomass	$kg\ m^{-2}$	DELT	C
B_{rp}	Live root biomass of a perennial crop	$kg\ m^{-2}$	TRTMASS	C
B_{rt}	Total root biomass of an annual crop	$kg\ m^{-2}$	RTMASS	R,C
-	Maximum root biomass of a perennial crop	$kg\ m^{-2}$	RTMMAX	C
B_{r1}	Root biomass in the 0- to 0.15-m soil zone	$kg\ m^{-2}$	RTM15	C
B_{r2}	Root biomass in the 0.15- to 0.30-m soil zone	$kg\ m^{-2}$	RTM30	C
B_{r3}	Root biomass in the 0.30- to 0.60-m soil zone	$kg\ m^{-2}$	RTM60	C
B_t	Total above ground standing biomass	$kg\ m^{-2}$	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

C_c	Canopy cover	NOD	CANCOV	R,C
ΔC_c	Daily loss of canopy cover	NOD	DEC	C
C_{cf}	Soil surface cover by coarse fragments	NOD	WCF	R,C
C_{cr}	Soil surface covered by cryptogams	NOD	CRYPTO	R
C_{cs}	Fraction of canopy cover remaining after senescence	NOD	DECFCT	C
cf	Parameter for flat residue cover equation	NOD	CF	R,C
C_g	Total soil cover including residue and rocks	NOD	GCOVER	R,C
C_{cm}	Canopy cover at maturity	NOD	CCMAT	C
C_n	Carbon to nitrogen ratio of residue and roots	NOD	CN	R,C
C_{ri}	Interrill residue cover	NOD	INRCOV	R,C
C_{rf}	Flat residue cover	NOD	FLRCOV	C
C_{rl}	Rill residue cover	NOD	RILCOV	R,C
C_{rr}	Residue cover on ridges	NOD	RIGCOV	C
C_{rs}	Standing residue cover	NOD	STRCOV	C
C_{rt}	Total residue cover	NOD	RESCOV	R,C
C_{sp}	Residue cover on ridges after wind repositioning	NOD	SPRCOV	C
C_w	Average weed canopy cover during the nongrowing season	NOD	WDCOV	C
c	Shaping coefficient for ascending side of first growth curve	NOD	CSHAPE	R
C_o	Standing biomass where canopy cover is 100%	$kg\ m^{-2}$	COLD	R
-	Growing degree days to plant emergence	C	CRIT	C
-	Critical biomass for a perennial crop below which grazing animals no longer consume vegetation	$kg\ m^{-2}$	CRITVM	C
-	Integer that represents whether a cultivator is front or rear mounted	NOD	CULPOS	C
-	Cutting or harvesting day for a perennial crop	Julian date	CUTDAY	C
D	Plant stem diameter at maturity	m	DIAM	C
D_d	Decomposable standing dead biomass after herbicide application	$kg\ m^{-2}$	SDEAD	R
D_g	Digestibility of a perennial crop being grazed	NOD	DIGEST	R,C
D_h	Number of days after harvest	NOD	DAH	C
D_l	Dead/live ratio of leaves	NOD	DL	R
D_{mx}	Maximum digestibility of forage	NOD	DIGMAX	R
D_m	Number of days to physiological maturity	NOD	DTM	C
D_n	Minimum digestibility of forage	NOD	DIGMIN	R
D_p	Number of days after planting	NOD	DAP	C
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 project area	m	TOTPAI	R
E_g	Herbaceous project plant area	m	GPAI	R
E_s	Shrub projected plant area	m	SPAI	R
E_t	Tree projected plant area	m	TPAI	R
e	Shaping coefficient for ascending side of second growth curve	NOD	ESHAPE	R
F_{bs}	Fraction of standing residue mass	NOD	FBRNAG	C

	lost by burning			
F_{bf}	Fraction of flat residue mass lost by burning	NOD	FBRNOG	C
F_c	Fraction of standing residue mass mechanically shredded or cut	NOD	FRCUT	C
F_{ct}	Standing to flat residue adjustment factor for wind and snow	NOD	FACT	C
F_{gs}	Current fraction of the growing season	NOD	FGS	C
F_i	Quantity for forage consumed by grazing animals	$kg\ day^{-1}$	FEED	R,C
F_{lai}	Fraction of growing season when leaf area index starts declining	NOD	DLAI	C
F_{pc}	Portion of vegetative biomass partitioned into standing residue mass at harvest	NOD	PARTCF	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	$kg\ m^{-2}$	TFOOD	R,C
f	Shaping coefficient for descending side of second growth curve	NOD	FSHAPE	R
f_c	Coefficient for canopy cover	NOD	FFK	R
f_p	Frost free period	Julian date	FFP	R,C
-	Date that grazing begins	Julian date	GDAY	R
G_b	Day on which first growth period begins	Julian date	STRRGC	R
G_c	Projected plant area coefficient for herbaceous plants	NOD	GCOEFF	R
$\sum G_d$	Cumulative growing degree days	C	SUMGDD	C
G_d	Growing degree days	C	GDD	C
G_{di}	Average diameter for herbaceous plants	m	GDIAM	R
G_{dm}	Growing degree days at maturity	C	GDDMAX	C
-	End of a grazing period	Julian date	GEND	R,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
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	$kg\ m^{-2}$	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 date	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 date	JDBURN	C
-	Julian day of burning rangeland	Julian date	JFDATE	R
-	Julian day of residue shredding or cutting	Julian date	JDCUT	C
-	Julian day of grain or biomass harvest	Julian date	JDHARV	C
-	Julian day of herbicide application	Julian date	JDHERB	C
-	Julian day of residue removal from a field	Julian date	JDMOVE	C
-	Julian day of planting	Julian date	JDPLT	C
-	Julian day of silage removal from a field	Julian date	JDSLGE	C
-	Julian day to permanently stop the growth of a perennial crop	Julian date	JDSTOP	C
-	Julian day that weed canopy cover becomes important	Julian date	JDWDST	C
-	Julian day that weed canopy cover becomes unimportant	Julian date	JDWEND	C
LAI	Leaf area index	NOD	LAI	R,C
LAI_d	Leaf area index value when leaf area index starts declining	NOD	XLAIMX	C
LAI_{mx}	Maximum leaf area index potential	NOD	XMXLAI	C
L_c	Leaf weight to leaf area coefficient	$m^2\ kg^{-1}$	ALEAF	R
L_i	Live phytomass produced today	$kg\ m^{-2}$	SLIVE	R
L_k	Reduction in live above ground biomass from herbicide application	NOD	DLEAF	R
L_n	Minimum amount of live biomass	NOD	RGCMIN	R
L_t	Total live phytomass	$kg\ m^{-2}$	TLIVE	R
-	Julian day of tillage in one tillage sequence	Julian date	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 growth annually	NOD	NYCROP	C
ΔM_b	Buried residue mass change	NOD	SMRATIO	R,C
M_b	Buried residue mass	$kg\ m^{-2}$	SMRM	C
ΔM_f	Flat residue mass change	NOD	FRATIO	C
M_f	Plant residue mass lying on the ground	$kg\ m^{-2}$	RMOG	C
M_r	Non-living root mass	$kg\ m^{-2}$	RTM	C
$\Delta M_{r,}\ \chi$	Root mass change	NOD	RRATIO	R,C
M_{rl}	Rill residue mass	$kg\ m^{-2}$	RILRM	C
M_{rr}	Residue mass on ridges	$kg\ m^{-2}$	RIGRM	C
M_{rt}	Total residue mass at harvest	$kg\ m^{-2}$	RESAMT	C
ΔM_s	Standing residue mass change	NOD	SRATIO	C
M_s	Plant residue mass standing above ground	$kg\ m^{-2}$	RMAG	C
M_{so}	Standing residue mass at grain or biomass harvest	$kg\ m^{-2}$	SRMHAV	C
ΔM_w	Residue mass moved from ridges to furrows by wind	$kg\ m^{-2}$	DELTRM	C
N_a	Number of grazing animals	NOD	ANIMAL	R,C
N_d	Initial standing non-decomposable woody biomass	NOD	WOOD	R
o	Initial standing above ground biomass	$kg\ m^{-2}$	OLDPLT	R
ω	Plant-dependent growth parameter	NOD	GRATE	C
ω_L	Litter after decay	NOD	SMRATI	R
P	Maximum potential standing live above ground biomass	$kg\ m^{-2}$	PLIVE	R
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 date	PSCDAY	R
P_g	Annual growing season precipitation	m	PPTG	R
P_m	Plant population at maturity	NOD	POPMAT	C
P	Plant population	NOD	POP	C
P_s	In-row plant spacing	m	PLTSP	C
P_2	Day of peak standing crop, 2nd peak	Julian date	SCDAY2	R
R	Daily rainfall amount	m	RAIN	R,C
R_a	Standing above ground dead biomass	$kg\ m^{-2}$	RMAGT	R
R_d	Root depth	m	RTD	R,C
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	R
-	Integer to indicate a plant or residue management option	NOD	RESMNG	C
R_g	Litter and organic residue mass	$kg\ m^{-2}$	RMOGT	R
R_i	Root mass in a soil horizon	$kg\ m^{-2}$	ROOT	R
R_l	Reduction in litter and organic residue from burning	NOD	REDUCE	R
R_{mf}	Residue mixing factor	NOD	RMF	C
R_o	Root mass coefficient	$kg\ m^{-2}$	PROOT	R
R_p	Proportion of within soil horizon to total root mass root mass in soil profile	NOD	DROOT	R
R_{sr}	Root to shoot ratio	NOD	RSR	C
R_s	Potential rill spacing	m	RSPACE	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	$kg\ m^{-2}$	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
S_m	Average canopy diameter for shrubs	m	SDIAM	R
S_{mi}	Antecedent moisture index for litter decomposition	m	AMC	R
-	Day supplemental feeding ends	Julian date	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
S_r	Antecedent moisture index for root decomposition	m	AMC2	R
-	Day supplemental feeding begins	Julian date	SSDAY	R
-	Day on which second growth period begins	Julian date	STRGC2	R
-	Average amount of supplement feed per day	$kg\ animal^{-2}$	SUPPMT	R
τ	Weighted-time variable for standing and flat residue	NOD	TAU	R,C
τ_2	Weighted-time variable for buried residue and roots	NOD	TAU2	R,C
T_a	Average daily temperature	^oC	TEMP	R
T_a	Average daily air temperature	^oC	TAVE	C
T_b	Base daily air temperature of a growing plant	^oC	BTEMP	C
T_c	Project plant area coefficient for trees	NOD	TCOEFF	R
T_{di}	Average canopy diameter for trees	m	TDIAM	R
T_d	Tillage depth	m	TILDEP	C
T_{dm}	Mean tillage depth	m	TDMEAN	C
-	Minimum temperature to induce dormancy	^oC	TEMPMN	R,C
T_i	Tillage intensity	NOD	MFO	C
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	R,C
T_{mn}	Minimum daily air temperature	^oC	TMIN	R,C
-	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	$kg\ m^{-2}$	TOTHAV	C
-	Integer that represents whether tillage is primary or secondary	NOD	TYPTILL	C
T_p	Average number of trees along a 100m transect	NOD	TPOP	R
t_i	Current Julian date	Julian date	SDATE	R,C
t_r	Amount of standing dead biomass transferred to litter as a result of grazing animals	$kg\ m^{-2}\ day^{-1}$	TR	R
-	Amount of standing dead biomass transferred to litter as a result of precipitation	$kg\ m^{-2}\ day^{-1}$	TRANS	R
U	Utilization of available forage by grazing animals	NOD	UTILIZ	R
U_b	Unavailable standing biomass for grazing animals	$kg\ m^{-2}$	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	-	WOODY	R

	of herbicide application			
W_n	Standing woody biomass	$kg\ m^{-2}$	DECOMP	R
W_s	Daily water stress index starts declining	NOD	WST	R
X	Evergreen phytomass	$kg\ m^{-2}$	XLIVE	R
-	Grain yield boundary below which an adjustment to residue biomass is made	$bu\ ac^{-1}$	Y1	C
-	Residue mass when grain yield is zero	$kg\ ha^{-1}$	Y2	C
-	Change in residue mass per unit change in grain yield between grain yield limits (0 and Y1)	$kg\ ha^{-1}/bu\ ac^{-1}$	Y3	C
-	Pounds of grain per bushel of grain	$lb\ bu^{-1}$	Y4	C
-	Pounds per acre to kilogram per hectare conversion	$kg\ ha^{-1}\ /\ lb\ ac^{-1}$	Y5	C
Y	Total above ground biomass produced	$kg\ m^{-2}\ year^{-1}$	YIELD	R
Y_c	Residue to grain weight ratio	NOD	Y6	C
-	Yield at each cutting date for a perennial crop	$kg\ m^{-2}$	YILD	C
Y_g	Grain or biomass yield	$kg\ m^{-2}$	YLD	C

* C and R refer to cropland and rangeland.