CHAPTER 14

SWAT INPUT DATA: PLANT.DAT

Information required to simulate plant growth is stored by plant species in the plant growth database file. This database file is supplied with the model. The plant growth database distributed with SWAT includes parameters for most of the common plant species. If a user needs to model a land use or plant not included in the database, please feel free to contact the SWAT development team for assistance in determining plant parameters. Appendix A documents the source of parameter values in the distributed database file.

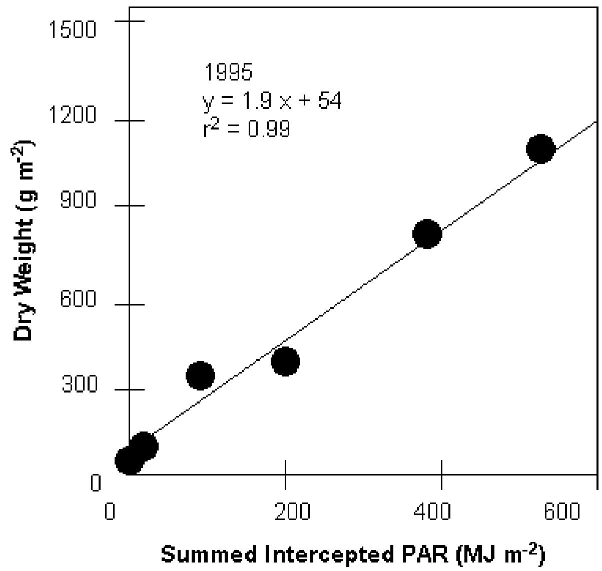
Following is a brief description of the variables in the land cover/plant growth database file. They are listed in the order they appear within the file.

Variable name	Definition
ICNUM	Land cover/plant code. The different plants listed in the plant growth database must have unique values for ICNUM. ICNUM is the numeric code used in the management file to identify the land cover to be modeled. Required.
CPNM	A four character code to represent the land cover/plant name. The 4-letter codes in the plant growth and urban databases are used by the GIS interfaces to link land use/land cover maps to SWAT plant types. This code is printed to the output files. When adding a new plant species or land cover category, the four letter code for the new plant must be unique. Required.
IDC	Land cover/plant classification: 1 warm season annual legume 2 cold season annual legume 3 perennial legume 4 warm season annual 5 cold season annual 6 perennial 7 trees Processes modeled differently for the 7 groups are: 1 warm season annual legume • simulate nitrogen fixation • root depth varies during growing season due to root growth 2 cold season annual legume • simulate nitrogen fixation • root depth varies during growing season due to root growth • fall-planted land covers will go dormant when daylength is less than the threshold daylength

Variable name	Definition
IDC, cont.	3 perennial legume • simulate nitrogen fixation • root depth always equal to the maximum allowed for the plant species and soil • plant goes dormant when daylength is less than the threshold daylength 4 warm season annual • root depth varies during growing season due to root growth 5 cold season annual • root depth varies during growing season due to root growth • fall-planted land covers will go dormant when daylength is less than the threshold daylength 6 perennial • root depth always equal to the maximum allowed for the plant species and soil • plant goes dormant when daylength is less than the threshold daylength 7 trees • root depth always equal to the maximum allowed for the plant species and soil • partitions new growth between leaves/needles (20%) and woody growth (80%). At the end of each growing season, a fraction of the biomass is converted to residue Required.
DESCRIPTION	Full land cover/plant name. This description is not used by the model and is present to assist the user in differentiating between plant species. Optional.
BIO_E	Radiation-use efficiency or biomass-energy ratio ((kg/ha)/(MJ/m^2)). Radiation-use efficiency (RUE) is the amount of dry biomass produced per unit intercepted solar radiation. The radiation-use efficiency is assumed to be independent of the plant's growth stage. BIO_E represents the potential or unstressed growth rate (including roots) per unit of intercepted photosynthetically active radiation.

Variable name	Definition
BIO_E, cont.	Determination of RUE is commonly performed and a literature review will provide those setting up experiments with numerous examples. The following overview of the methodology used to measure RUE was summarized from Kiniry et al (1998) and Kiniry et al (1999). To calculate RUE, the amount of photosynthetically active radiation (PAR) intercepted and the mass of aboveground biomass is measured several times throughout a plant's growing season. The frequency of the measurements taken will vary but in general 4 to 7 measurements per growing season are considered to be adequate. As with leaf area determinations, the measurements should be performed on non-stressed plants. Intercepted radiation is measured with a light meter. Whole spectrum and PAR sensors are available and calculations of RUE will be performed differently depending on the sensor used. A brief discussion of the difference between whole spectrum and PAR sensors and the difference in calculations is given in Kiniry (1999). The use of a PAR sensor in RUE studies is strongly encouraged. When measuring radiation, three to five sets of measurements are taken rapidly for each plant plot. A set of measurements consists of 10 measurements above the leaf canopy, 10 below, and 10 more above. The light measurements should be taken between 10:00 am and 2:00 pm local time. The measurements above and below the leaf canopy are averaged and the fraction of intercepted PAR is calculated for the day from the two values. Daily estimates of the fraction of intercepted PAR are determined by linearly interpolating the measured values.

Variable name	Definition
BIO_E, cont.	The *fraction* of intercepted PAR is converted to an *amount* of intercepted PAR using daily values of incident total solar radiation measured with a standard weather station. To convert total incident radiation to total incident PAR, the daily solar radiation values are multiplied by the percent of total radiation that has a wavelength between 400 and 700 mm. This percent usually falls in the range 45 to 55% and is a function of cloud cover. 50% is considered to be a default value. Once daily intercepted PAR values are determined, the total amount of PAR intercepted by the plant is calculated for each date on which biomass was harvested. This is calculated by summing daily intercepted PAR values from the date of seedling emergence to the date of biomass harvest. To determine biomass production, aboveground biomass is harvested from a known area of land within the plot. The plant material should be dried at least 2 days at 65°C and then weighed. RUE is determined by fitting a linear regression for aboveground biomass as a function of intercepted PAR. The slope of the line is the RUE. Figure 14-1 shows the plots of aboveground biomass and summed intercepted photosynthetically active radiation for Eastern gamagrass. (Note that the units for RUE values in the graph, as well as values typically reported in literature, are different from those used by SWAT. To obtain the value used in SWAT, multiply by 10.) This parameter can greatly change the rate of growth, incidence of stress during the season and the resultant yield. This parameter should be one of the last to be adjusted. Adjustments should be based on research results. Care should be taken to make adjustments based only on data with no drought, nutrient or temperature stress. Required.

Variable name	Definition
	 Figure 14-1: Aboveground biomass and summed intercepted photosynthetically active radiation for Eastern gamagrass (after Kiniry et al.,1999).
HVSTI	Harvest index for optimal growing conditions. The harvest index defines the fraction of the aboveground biomass that is removed in a harvest operation. This value defines the fraction of plant biomass that is "lost" from the system and unavailable for conversion to residue and subsequent decomposition. For crops where the harvested portion of the plant is aboveground, the harvest index is always a fraction less than 1. For crops where the harvested portion is belowground, the harvest index may be greater than 1. Two harvest indices are provided in the database, the harvest index for optimal growing conditions (HVSTI) and the harvest index under highly stressed growing conditions (WSYF).

Variable name	Definition
HVSTI, cont.	To determine the harvest index, the plant biomass removed during the harvest operation is dried at least 2 days at 65°C and weighed. The total aboveground plant biomass in the field should also be dried and weighed. The harvest index is then calculated by dividing the weight of the harvested portion of the plant biomass by the weight of the total aboveground plant biomass. Plants will need to be grown in two different plots where optimal climatic conditions and stressed conditions are produced to obtain values for both harvest indices. Required.
BLAI	Maximum potential leaf area index. BLAI is one of six parameters use to quantify leaf area development of a plant species during the growing season. Figure 14-2 illustrates the relationship of the database parameters to the leaf area development modeled by SWAT.

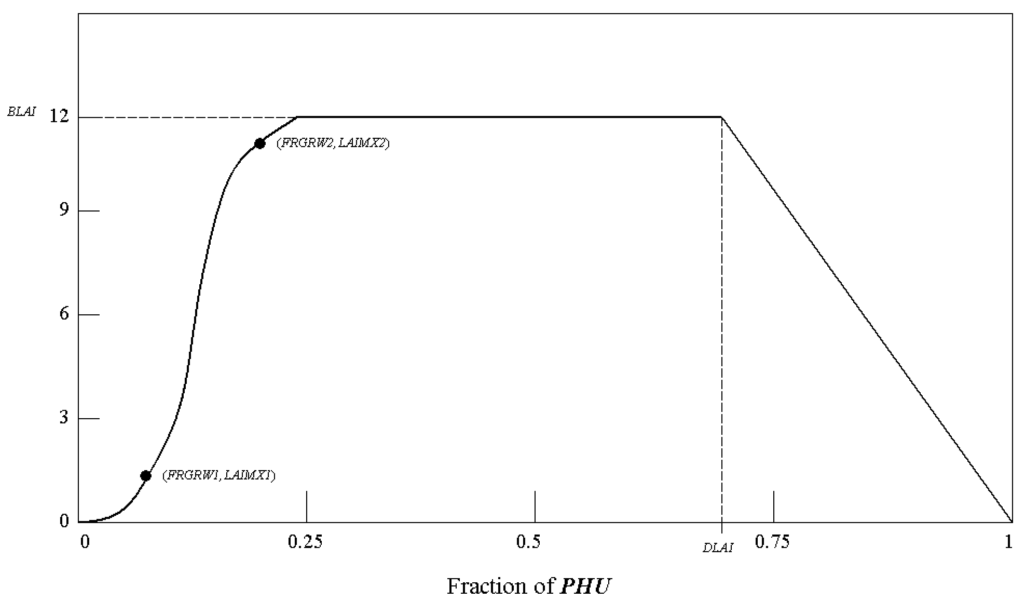


Figure 14-2: Leaf area index as a function of fraction of growing season for Alamo switchgrass

Variable name	Definition
BLAI, cont.	To identify the leaf area development parameters, record the leaf area index and number of accumulated heat units for the plant species throughout the growing season and then plot the results. For best results, several years worth of field data should be collected. At the very minimum, data for two years is recommended. It is important that the plants undergo no water or nutrient stress during the years in which data is collected. The leaf area index incorporates information about the plant density, so field experiments should either be set up to reproduce actual plant densities or the maximum LAI value for the plant determined from field experiments should be adjusted to reflect plant densities desired in the simulation. Maximum LAI values in the default database correspond to plant densities associated with rainfed agriculture. The leaf area index is calculated by dividing the green leaf area by the land area. Because the entire plant must be harvested to determine the leaf area, the field experiment needs to be designed to include enough plants to accommodate all leaf area measurements made during the year. Although measuring leaf area can be laborious for large samples, there is no intrinsic difficulty in the process. The most common method is to obtain an electronic scanner and feed the harvested green leaves and stems into the scanner. Older methods for estimating leaf area include tracing of the leaves (or weighed subsamples) onto paper, the use of planimeters, the punch disk method of Watson (1958) and the linear dimension method of Duncan and Hesketh (1968). Chapter 5:1 in the Theoretical Documentation reviews the methodology used to calculate accumulated heat units for a plant at different times of the year as well as determination of the fraction of total, or potential, heat units that is required for the plant database.

Variable name	Definition
BLAI, cont.	The values for BLAI in the plant growth database are based on average plant densities in dryland (rainfed) agriculture. BLAI may need to be adjusted for drought-prone regions where planting densities are much smaller or irrigated conditions where densities are much greater. Required.
FRGRW1	Fraction of the plant growing season or fraction of total potential heat units corresponding to the 1st point on the optimal leaf area development curve. Please see Figure 14-2 and the explanation given for parameter BLAI to obtain additional information about this parameter and methods used to measure it. Required.
LAIMX1	Fraction of the maximum leaf area index corresponding to the 1st point on the optimal leaf area development curve. Please see Figure 14-2 and the explanation given for parameter BLAI to obtain additional information about this parameter and methods used to measure it. Required.
FRGRW2	Fraction of the plant growing season or fraction of total potential heat units corresponding to the 2nd point on the optimal leaf area development curve. Please see Figure 14-2 and the explanation given for parameter BLAI to obtain additional information about this parameter and methods used to measure it. Required.
LAIMX2	Fraction of the maximum leaf area index corresponding to the 2nd point on the optimal leaf area development curve. Please see Figure 14-2 and the explanation given for parameter BLAI to obtain additional information about this parameter and methods used to measure it. Required.

Variable name	Definition
DLAI	Fraction of growing season when leaf area begins to decline. Please see Figure 14-2 and the explanation given for parameter BLAI to obtain additional information about this parameter and methods used to measure it. Required.
CHTMX	Maximum canopy height (m). Maximum canopy height is a straightforward measurement. The canopy height of non-stressed plants should be recorded at intervals throughout the growing season. The maximum value recorded is used in the database. Required.
RDMX	Maximum root depth (m). To determine maximum rooting depth, plant samples need to be grown on soils without an impermeable layer. Once the plants have reached maturity, soil cores are taken for the entire depth of the soil. Each 0.25 meter increment is washed and the live plant material collected. Live roots can be differentiated from dead roots by the fact that live roots are whiter and more elastic and have an intact cortex. The deepest increment of the soil core in which live roots are found defines the maximum rooting depth. Required.
T_OPT	Optimal temperature for plant growth (ºC). Both optimal and base temperatures are very stable for cultivars within a species. Optimal temperature for plant growth is difficult to measure directly. Looking at Figure 14-3, one might be tempted to select the temperature corresponding to the peak of the plot as the optimal temperature. This would not be correct.

Variable name	Definition
T_OPT, cont.	The peak of the plot defines the optimal temperature for leaf development—not for plant growth. If an optimal temperature cannot be obtained through a review of literature, use the optimal temperature listed for a plant already in the database with similar growth habits. Review of temperatures for many different plants have provided generic values for base and optimal temperatures as a function of growing season. In situations, where temperature information is unavailable, these values may be used. For warm season plants, the generic base temperature is ~8ºC and the generic optimal temperature is ~25ºC. For cool season plants, the generic base temperature is ~0ºC and the generic optimal temperature is ~13ºC. Required.
T_BASE	Minimum (base) temperature for plant growth (ºC). SWAT uses the base temperature to calculate the number of heat units accrued every day. The minimum or base temperature for plant growth varies with growth stage of the plant. However, this variation is ignored by the model—SWAT uses the same base temperature throughout the growing season. Base temperature is measured by growing plants in growth chambers at several different temperatures. The rate of leaf tip appearance as a function of temperature is plotted. Extrapolating the line to the leaf tip appearance rate of 0.0 leaves/day gives the base or minimum temperature for plant growth. Figure 14-3 plots data for corn. (Note that the line intersects the x-axis at 8°C.) Required.

Variable name	Definition
T_BASE, cont.	

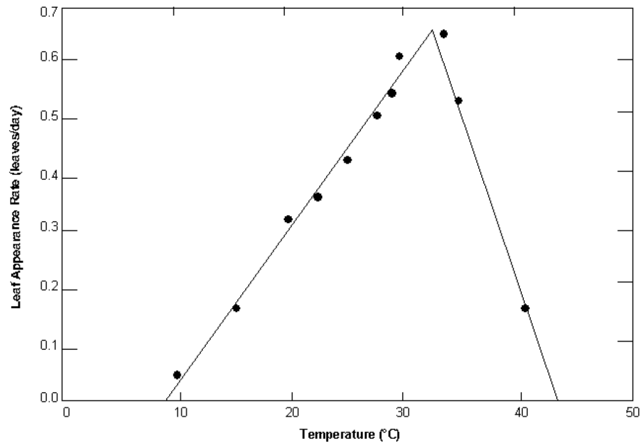


Figure 14-3: Rate of leaf tip appearance as a function of temperature for corn (after Kiniry et al, 1991)

CNYLD	Normal fraction of nitrogen in yield (kg N/kg yield). In addition to the amount of plant biomass removed in the yield, SWAT needs to know the amount of nitrogen and phosphorus removed in the yield. The harvested portion of the plant biomass is sent to a testing laboratory to determine the fraction of nitrogen and phosphorus in the biomass. This value is estimated on a dry weight basis. Required.
CPYLD	Normal fraction of phosphorus in yield (kg P/kg yield). In addition to the amount of plant biomass removed in the yield, SWAT needs to know the amount of nitrogen and phosphorus removed in the yield. The harvested portion of the plant biomass is sent to a testing laboratory to determine the fraction of nitrogen and phosphorus in the biomass. This value is estimated on a dry weight basis. Required.

Variable name	Definition
PLTNFR(1)	Nitrogen uptake parameter #1: normal fraction of nitrogen in plant biomass at emergence (kg N/kg biomass) In order to calculate the plant nutrient demand throughout a plant's growing cycle, SWAT needs to know the fraction of nutrient in the total plant biomass (on a dry weight basis) at different stages of crop growth. Six variables in the plant database provide this information: PLTNFR(1), PLTNFR(2), PLTNFR(3), PLTPFR(1), PLTPFR(2), and PLTPFR(3). Plant samples are analyzed for nitrogen and phosphorus content at three times during the growing season: shortly after emergence, near the middle of the season, and at maturity. The plant samples can be sent to testing laboratories to obtain the fraction of nitrogen and phosphorus in the biomass. Ideally, the plant samples tested for nutrient content should include the roots as well as the aboveground biomass. Differences in partitioning of nutrients to roots and shoots can cause erroneous conclusions when comparing productivity among species if only the aboveground biomass is measured. Required.
PLTNFR(2)	Nitrogen uptake parameter #2: normal fraction of nitrogen in plant biomass at 50% maturity (kg N/kg biomass) Please read the explanation for parameter PLTNFR(1) to obtain additional information about this parameter and methods used to measure it. Required.
PLTNFR(3)	Nitrogen uptake parameter #3: normal fraction of nitrogen in plant biomass at maturity (kg N/kg biomass) Please read the explanation for parameter PLTNFR(1) to obtain additional information about this parameter and methods used to measure it. Required.

Variable name	Definition
PLTPFR(1)	Phosphorus uptake parameter #1: normal fraction of phosphorus in plant biomass at emergence (kg P/kg biomass) Please read the explanation for parameter PLTNFR(1) to obtain additional information about this parameter and methods used to measure it. Required.
PLTPFR(2)	Phosphorus uptake parameter #2: normal fraction of phosphorus in plant biomass at 50% maturity (kg P/kg biomass) Please read the explanation for parameter PLTNFR(1) to obtain additional information about this parameter and methods used to measure it. Required.
PLTPFR(3)	Phosphorus uptake parameter #3: normal fraction of phosphorus in plant biomass at maturity (kg P/kg biomass) Please read the explanation for parameter PLTNFR(1) to obtain additional information about this parameter and methods used to measure it. Required.
WSYF	Lower limit of harvest index ((kg/ha)/(kg/ha)). The value between 0.0 and HVSTI which represents the lowest harvest index expected due to water stress. Please read the explanation for parameter HVSTI to obtain additional information about this parameter and methods used to measure it. Required.

Variable name	Definition
USLE_C	Minimum value of USLE C factor for water erosion applicable to the land cover/plant. The minimum C factor can be estimated from a known average annual C factor using the following equation (Arnold and Williams, 1995): $C_{USLE,mn} = 1.463 \ln[C_{USLE,aa}] + 0.1034$ where $C_{USLE,mn}$ is the minimum C factor for the land cover and $C_{USLE,aa}$ is the average annual C factor for the land cover. Required.
GSI	Maximum stomatal conductance at high solar radiation and low vapor pressure deficit (m·s-1). Stomatal conductance of water vapor is used in the Penman-Monteith calculations of maximum plant evapotranspiration. The plant database contains three variables pertaining to stomatal conductance that are required only if the Penman-Monteith equations are chosen to model evapotranspiration: maximum stomatal conductance (GSI), and two variables that define the impact of vapor pressure deficit on stomatal conductance (FRGMAX, VPDFR). Körner et al (1979) defines maximum leaf diffusive conductance as the largest value of conductance observed in fully developed leaves of well-watered plants under optimal climatic conditions, natural outdoor CO2 concentrations and sufficient nutrient supply. Leaf diffusive conductance of water vapor cannot be measured directly but can be calculated from measurements of transpiration under known climatic conditions. A number of different methods are used to determine diffusive conductance: transpiration measurements in photosynthesis cuvettes, energy balance measurements or weighing experiments, ventilated diffusion porometers and non-ventilated porometers. Körner (1977) measured diffusive conductance using a ventilated diffusion porometer.

Variable name	Definition
GSI, cont.	To obtain maximum leaf conductance values, leaf conductance is determined between sunrise and late morning until a clear decline or no further increase is observed. Depending on phenology, measurements are taken on at least three bright days in late spring and summer, preferably just after a rainy period. The means of maximum leaf conductance of 5 to 10 samples each day are averaged, yielding the maximum diffusive conductance for the species. Due to the variation of the location of stomata on plant leaves for different plant species, conductance values should be calculated for the total leaf surface area. Required.
VPDFR	Vapor pressure deficit (kPa) corresponding to the second point on the stomatal conductance curve. (The first point on the stomatal conductance curve is comprised of a vapor pressure deficit of 1 kPa and the fraction of maximum stomatal conductance equal to 1.00.) As with radiation-use efficiency, stomatal conductance is sensitive to vapor pressure deficit. Stockle et al (1992) compiled a short list of stomatal conductance response to vapor pressure deficit for a few plant species. Due to the paucity of data, default values for the second point on the stomatal conductance vs. vapor pressure deficit curve are used for all plant species in the database. The fraction of maximum stomatal conductance (FRGMAX) is set to 0.75 and the vapor pressure deficit corresponding to the fraction given by FRGMAX (VPDFR) is set to 4.00 kPa. If the user has actual data, they should use those values, otherwise the default values are adequate. Required.

Variable name	Definition
FRGMAX	Fraction of maximum stomatal conductance corresponding to the second point on the stomatal conductance curve. (The first point on the stomatal conductance curve is comprised of a vapor pressure deficit of 1 kPa and the fraction of maximum stomatal conductance equal to 1.00.) Please read the explanation for parameter VPDFR to obtain additional information about this parameter and methods used to measure it. Required.
WAVP	Rate of decline in radiation use efficiency per unit increase in vapor pressure deficit. Stockle and Kiniry (1990) first noticed a relationship between RUE and vapor pressure deficit and were able to explain a large portion of within-species variability in RUE values for sorghum and corn by plotting RUE values as a function of average daily vapor pressure deficit values. Since this first article, a number of other studies have been conducted that support the dependence of RUE on vapor pressure deficit. However, there is still some debate in the scientific community on the validity of this relationship. If the user does not wish to simulate a change in RUE with vapor pressure deficit, the variable WAVP can be set to 0.0 for the plant. To define the impact of vapor pressure deficit on RUE, vapor pressure deficit values must be recorded during the growing seasons that RUE determinations are being made. It is important that the plants are exposed to no other stress than vapor pressure deficit, i.e. plant growth should not be limited by lack of soil water and nutrients. Vapor pressure deficits can be calculated from relative humidity (see Chapter 1:2 in Theoretical Documentation) or from daily maximum and minimum temperatures using the technique of Diaz and Campbell (1988) as described by Stockle and Kiniry (1990). The change in RUE with vapor pressure deficit is determined by fitting a linear regression for RUE as a function of vapor pressure deficit. Figure 14-4 shows a plot of RUE as a function of vapor pressure deficit for grain sorghum.

Variable name	Definition
WAVP, cont.	

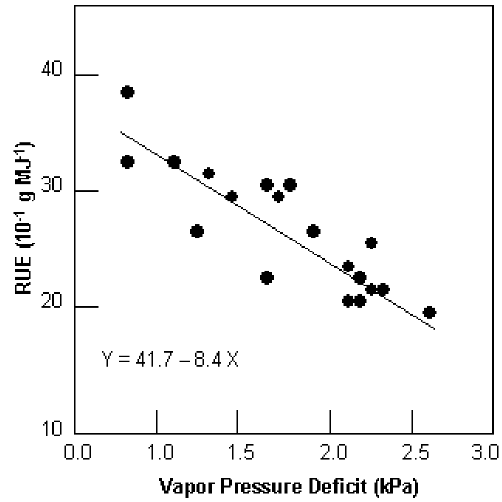


Figure 14-4: Response of radiation-use efficiency to mean daily vapor pressure deficit for grain sorghum (after Kiniry, 1999).

From Figure 14-4, the rate of decline in radiation-use efficiency per unit increase in vapor pressure deficit, Δrue_{dcl}, for sorghum is 8.4×10^{-1} g·MJ^{-1}·kPa^{-1}. When RUE is adjusted for vapor pressure deficit, the model assumes the RUE value reported for BIO_E is the radiation-use efficiency at a vapor pressure deficit of 1 kPa.

The value of WAVP varies among species, but a value of 6 to 8 is suggested as an approximation for most plants.

Required.

Variable name	Definition
CO2HI	Elevated CO_2 atmospheric concentration (μL CO_2/L air) corresponding the 2nd point on the radiation use efficiency curve. (The 1st point on the radiation use efficiency curve is comprised of the ambient CO_2 concentration, 330 μL CO_2/L air, and the biomass-energy ratio reported for BIO_E)

Variable name	Definition
CO2HI, cont.	In order to assess the impact of climate change on agricultural productivity, SWAT incorporates equations that adjust RUE for elevated atmospheric CO_2 concentrations. Values must be entered for CO2HI and BIOEHI in the plant database whether or not the user plans to simulate climate change. For simulations in which elevated CO_2 levels are not modeled, CO2HI should be set to some number greater than 330 ppmv and BIOEHI should be set to some number greater than BIO_E. To obtain radiation-use efficiency values at elevated CO_2 levels for plant species not currently in the database, plants should be established in growth chambers set up in the field or laboratory where CO_2 levels can be controlled. RUE values are determined using the same methodology described in the explanation of BIO_E. Required.
BIOEHI	Biomass-energy ratio corresponding to the 2^{nd} point on the radiation use efficiency curve. (The 1^{st} point on the radiation use efficiency curve is comprised of the ambient CO_2 concentration, 330 μL CO_2/L air, and the biomass-energy ratio reported for BIO_E.) Please read the explanation for parameter CO2HI and BIO_E to obtain additional information about this parameter and methods used to measure it. Required.
RSDCO_PL	Plant residue decomposition coefficient. The plant residue decomposition coefficient is the fraction of residue that will decompose in a day assuming optimal moisture, temperature, C:N ratio, and C:P ratio. This variable was originally in the basin input file (.bsn), but was added to the crop database so that users could vary decomposition by plant species. A default value of 0.05 is used for all plant species in the database. Required.

Variable name	Definition
ALAI_MIN	Minimum leaf area index for plant during dormant period (m^2/m^2). This variable pertains to perennials and trees only. (The value is never used for other types of plants.) In versions of SWAT prior to SWAT2012, the minimum leaf area index for plants during the dormant period was always set to 0.75. Because this value was not ideal for all plants (trees in particular), users are now allowed to vary the minimum LAI for dormancy. Please see the explanation given for parameter BLAI to obtain additional information about this parameter and methods used to measure it. Required.
BIO_LEAF	Fraction of tree biomass accumulated each year that is converted to residue during dormancy. This variable pertains to trees only. (The value is never used for other types of plants.) BIO_LEAF governs the amount of biomass that falls off the tree and is converted to residue when the plant goes dormant in the winter. In versions of SWAT prior to SWAT2012, the fraction of biomass converted to residue at the beginning of dormancy was always defined as 0.30. Required if land cover is classified as a tree (see IDC).
MAT_YRS	Number of years required for tree species to reach full development (years). This variable pertains to trees only. (The value is never used for other types of plants.) Required if land cover is classified as a tree (see IDC).
BMX_TREES	Maximum biomass for a forest (metric tons/ha). This variable pertains to trees only. (The value is never used for other types of plants.) The maximum biomass for a mature forest stand generally falls in the range of 30-50 metric tons/ha. Required if land cover is classified as a tree (see IDC).
BMDIEOFF	Biomass dieoff fraction. This coefficient is the fraction above ground biomass that dies off at dormancy. Default value = 0.10.

RSR1C	Initial root to shoot ration at the beginning of the growing season. Default = 0.40.
RSR2C	Root to shoot ration at the end of the growing season. Default = 0.20.
EXT_COEF	Light extinction coefficient. This coefficient is used to calculate the amount of intercepted photosynthetically active radiation. In versions of SWAT prior to SWAT2012, the light extinction coefficient was always defined as 0.65.

EXT_COEF

Differences in canopy structure for a species are described by the number of leaves present (leaf area index) and the leaf orientation. Leaf orientation has a significant impact on light interception and consequently on radiation-use efficiency. More erect leaf types spread the incoming light over a greater leaf area, decreasing the average light intensity intercepted by individual leaves (Figure 14-5). A reduction in light intensity interception by an individual leaf favors a more complete conversion of total canopy-intercepted light energy into biomass.

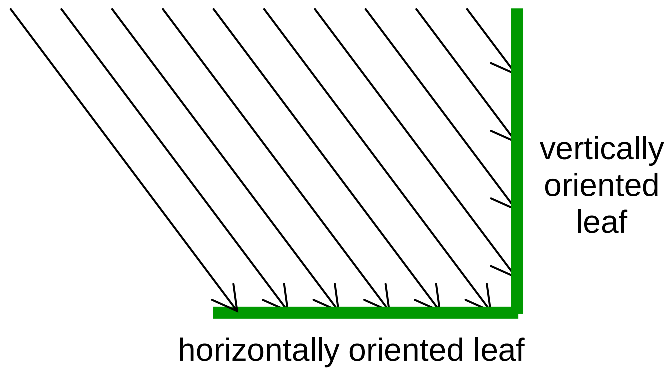


Figure 14-5: Light intensity interception as a function of leaf orientation. The vertically oriented leaf intercepts 4 units of light while a horizontally oriented leaf of the same length intercepts 6 units of light.

Using the light extinction coefficient value (k_ℓ) in the Beer-Lambert formula (equation 5:2.1.1) to quantify efficiency of light interception per unit leaf area index, more erect leaf types have a smaller k_ℓ.

To calculate the light extinction coefficient, the amount of photosynthetically active radiation (PAR) intercepted and the mass of aboveground biomass (LAI) is measured several times throughout a plant's growing season using the methodology described in the previous sections. The light extinction coefficient is then calculated using the Beer-Lambert equation:

$$\frac{TPAR}{PAR} = \left(1 - \exp\left(-k_\ell \cdot LAI\right)\right) \quad \text{or} \quad k_\ell = -\ln\left(\frac{TPAR}{PAR}\right) \cdot \frac{1}{LAI}$$

where *TPAR* is the transmitted photosynthetically active radiation, and *PAR* is the incoming photosynthetically active radiation.

Five lines are required to store the plant growth parameters for a land cover/plant in the database (plant.dat) file. The plant growth database file is a free format file. The variables may be placed in any position the user wishes on the line. Values for variables classified as integers *should not* include a decimal while values for variables classified as reals *must* contain a decimal. A blank space denotes the end of an input value and the beginning of the next value if there is another on the line.

Variable name	Line #	Format	F90 Format
ICNUM	1	integer	free
CPNM	1	character	a4
IDC	1	integer	free
BIO_E	2	real	free
HVSTI	2	real	free
BLAI	2	real	Free
FRGRW1	2	real	Free
LAIMX1	2	real	Free
FRGRW2	2	real	Free
LAIMX2	2	real	Free
DLAI	2	real	Free
CHTMX	2	real	free
RDMX	2	real	free
T_OPT	3	real	free
T_BASE	3	real	free
CNYLD	3	real	free
CPYLD	3	real	free
PLTNFR(1)	3	real	free
PLTNFR(2)	3	real	free
PLTNFR(3)	3	real	free
PLTPFR(1)	3	real	free
PLTPFR(2)	3	real	free
PLTPFR(3)	3	real	free
WSYF	4	real	free
USLE_C	4	real	free
GSI	4	real	free
VPDFR	4	real	free
FRGMAX	4	real	free
WAVP	4	real	free

Variable name	Line #	Format	F90 Format
CO2HI	4	real	free
BIOEHI	4	real	free
RSDCO_PL	4	real	free
ALAI_MIN	4	real	free
BIO_LEAF	5	real	free
MAT_YRS	5	integer	free
BMX_TREES	5	real	free
EXT_COEF	5	real	free
BMDIEOFF	5	real	free
RSR1C	5	real	free
RSR2C	5	real	free

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