APPENDIX A

MODEL DATABASES

The following sections describe the source of input for databases included with the model and any assumptions used in compilation of the database. Also, a methodology for appending additional information to the various databases is summarized.

A.1 LAND COVER/PLANT GROWTH DATABASE

The land cover/plant growth database contains information needed by SWAT to simulate the growth of a particular land cover. The growth parameters in the plant growth database define plant growth under ideal conditions and quantify the impact of some stresses on plant growth.

Table A-1 lists all the default plant species and Table A-2 lists all the generic land covers included in the database. When adding a new plant/land cover to the database, a review of existing literature should provide most of the parameter values needed to simulate plant growth. For users that plan to collect the data directly, the following sections briefly describe the methods used to obtain the plant growth parameters needed by SWAT.

Table A-1: Plants included in plant growth database.

Common Name	**Plant Code**	**Taxonomic Name**	**Plant type**
Corn	CORN	*Zea mays* L.	warm season annual
Corn silage	CSIL	*Zea mays* L.	warm season annual
Sweet corn	SCRN	*Zea mays* L. *saccharata*	warm season annual
Eastern gamagrass	EGAM	*Tripsacum dactyloides* (L.) L.	perennial
Grain sorghum	GRSG	*Sorghum bicolor* L. (Moench)	warm season annual
Sorghum hay	SGHY	*Sorghum bicolor* L. (Moench)	warm season annual
Johnsongrass	JHGR	*Sorghum halepense* (L.) Pers.	perennial
Sugarcane	SUGC	*Saccharum officinarum* L.	perennial
Spring wheat	SWHT	*Triticum aestivum* L.	cool season annual
Winter wheat	WWHT	*Triticum aestivum* L.	cool season annual
Durum wheat	DWHT	*Triticum durum* Desf.	cool season annual
Rye	RYE	*Secale cereale* L.	cool season annual
Spring barley	BARL	*Hordeum vulgare* L.	cool season annual
Oats	OATS	*Avena sativa* L.	cool season annual
Rice	RICE	*Oryza sativa* L.	warm season annual
Pearl millet	PMIL	*Pennisetum glaucum* L.	warm season annual
Timothy	TIMO	*Phleum pratense* L.	perennial
Smooth bromegrass	BROS	*Bromus inermis* Leysser	perennial
Meadow bromegrass	BROM	*Bromus biebersteinii* Roemer & Schultes	perennial
Tall fescue	FESC	*Festuca arundinacea*	perennial
Kentucky bluegrass	BLUG	*Poa pratensis*	perennial
Bermudagrass	BERM	*Cynodon dactylon*	perennial
Crested wheatgrass	CWGR	*Agropyron cristatum* (L.) Gaertner	perennial
Western wheatgrass	WWGR	*Agropyron smithii* (Rydb.) Gould	perennial

Common Name	Plant Code	Taxonomic Name	Plant type
Slender wheatgrass	SWGR	*Agropyron trachycaulum* Malte	perennial
Italian (annual) ryegrass	RYEG	*Lolium multiflorum* Lam.	cool season annual
Russian wildrye	RYER	*Psathyrostachys juncea* (Fisch.) Nevski	perennial
Altai wildrye	RYEA	*Leymus angustus* (Trin.) Pilger	perennial
Sideoats grama	SIDE	*Bouteloua curtipendula* (Michaux) Torrey	perennial
Big bluestem	BBLS	*Andropogon gerardii* Vitman	perennial
Little bluestem	LBLS	*Schizachyrium scoparium* (Michaux) Nash	perennial
Alamo switchgrass	SWCH	*Panicum virgatum* L.	perennial
Indiangrass	INDN	*Sorghastrum nutans* (L.) Nash	perennial
Alfalfa	ALFA	*Medicago sativa* L.	perennial legume
Sweetclover	CLVS	*Melilotus alba* Med.	perennial legume
Red clover	CLVR	*Trifolium pratense* L.	cool season annual legume
Alsike clover	CLVA	*Trifolium hybridum* L.	perennial legume
Soybean	SOYB	*Glycine max* L., Merr.	warm season annual legume
Cowpeas	CWPS	*Vigna sinensis*	warm season annual legume
Mung bean	MUNG	*Phaseolus aureus* Roxb.	warm season annual legume
Lima beans	LIMA	*Phaseolus lunatus* L.	warm season annual legume
Lentils	LENT	*Lens esculenta* Moench J.	warm season annual legume
Peanut	PNUT	*Arachis hypogaea* L.	warm season annual legume
Field peas	FPEA	*Pisum arvense* L.	cool season annual legume
Garden or canning peas	PEAS	*Pisum sativum* L. ssp. *sativum*	cool season annual legume
Sesbania	SESB	*Sesbania macrocarpa* Muhl [*exaltata*]	warm season annual legume
Flax	FLAX	*Linum usitatissum* L.	cool season annual
Upland cotton (harvested with stripper)	COTS	*Gossypium hirsutum* L.	warm season annual
Upland cotton (harvested with picker)	COTP	*Gossypium hirsutum* L.	warm season annual
Tobacco	TOBC	*Nicotiana tabacum* L.	warm season annual
Sugarbeet	SGBT	*Beta vulgaris (saccharifera)* L.	warm season annual
Potato	POTA	*Solanum tuberosum* L.	cool season annual
Sweetpotato	SPOT	*Ipomoea batatas* Lam.	warm season annual
Carrot	CRRT	*Daucus carota* L. subsp. *sativus* (Hoffm.) Arcang.	cool season annual
Onion	ONIO	*Allium cepa* L. var *cepa*	cool season annual
Sunflower	SUNF	*Helianthus annuus* L.	warm season annual
Spring canola-Polish	CANP	*Brassica campestris*	cool season annual
Spring canola-Argentine	CANA	*Brassica napus*	cool season annual
Asparagus	ASPR	*Asparagus officinalis* L.	perennial
Broccoli	BROC	*Brassica oleracea* L. var *italica* Plenck.	cool season annual
Cabbage	CABG	*Brassica oleracea* L. var *capitata* L.	perennial
Cauliflower	CAUF	*Brassica oleracea* L. var *botrytis* L.	cool season annual
Celery	CELR	*Apium graveolens* L. var *dulce* (Mill.) Pers.	perennial
Head lettuce	LETT	*Lactuca sativa* L. var *capitata* L.	cool season annual
Spinach	SPIN	*Spinacia oleracea* L.	cool season annual

Common Name	Plant Code	Taxonomic Name	Plant Type
Green beans	GRBN	*Phaseolus vulgaris*	warm season annual legume
Cucumber	CUCM	*Cucumis sativus* L.	warm season annual
Eggplant	EGGP	*Solanum melongena* L.	warm season annual
Cantaloupe	CANT	*Cucumis melo* L. Cantaloupensis group	warm season annual
Honeydew melon	HMEL	*Cucumis melo* L. Inodorus group	warm season annual
Watermelon	WMEL	*Citrullus lanatus* (Thunb.) Matsum and Nakai	warm season annual
Bell pepper	PEPR	*Capsicum annuum* L. Grossum group	warm season annual
Strawberry	STRW	*Fragaria* X *Ananassa* Duchesne.	perennial
Tomato	TOMA	*Lycopersicon esculentum* Mill.	warm season annual
Apple	APPL	*Malus domestica* Borkh.	trees
Pine	PINE	*Pinus*	trees
Oak	OAK	*Quercus*	trees
Poplar	POPL	*Populus*	trees
Honey mesquite	MESQ	*Prosopis glandulosa* Torr. var. *glandulosa*	trees

Table A-2: Generic Land Covers included in database.

Name	Plant Code	Origin of Plant Growth Values	Plant Type
Agricultural Land-Generic	AGRL	use values for Grain Sorghum	warm season annual
Agricultural Land-Row Crops	AGRR	use values for Corn	warm season annual
Agricultual Land-Close-grown	AGRC	use values for Winter Wheat	cool season annual
Orchard	ORCD	use values for Apples	trees
Hay‡	HAY	use values for Bermudagrass	perennial
Forest-mixed	FRST	use values for Oak	trees
Forest-deciduous	FRSD	use values for Oak	trees
Forest-evergreen	FRSE	use values for Pine	trees
Wetlands	WETL	use values for Alamo Switchgrass	perennial
Wetlands-forested	WETF	use values for Oak	trees
Wetlands-nonforested	WETN	use values for Alamo Switchgrass	perennial
Pasture‡	PAST	use values for Bermudagrass	perennial
Summer pasture	SPAS	use values for Bermudagrass	perennial
Winter pasture	WPAS	use values for Fescue	perennial
Range-grasses	RNGE	use values for Little Bluestem (LAI_{max}=2.5)	perennial
Range-brush	RNGB	use values for Little Bluestem (LAI_{max}=2.0)	perennial
Range-southwestern US	SWRN	use values for Little Bluestem (LAI_{max}=1.5)	perennial
Water*	WATR		not applicable

‡ The Bermudagrass parameters input for Hay and Pasture are valid only in latitudes less than 35 to 37°. At higher latitudes, Fescue parameters should be used to model generic Hay and Pasture.

* Water was included in the plant growth database in order to process USGS map layers in the HUMUS project. This land cover should ***not*** be used as a land cover in an HRU. To model water bodies, create ponds, wetlands or reservoirs.

A.1.1 LAND COVER/PLANT TYPES IN DATABASE

When compiling the list of plants in the default database, we attempted to include the most economically important plants as well as those that are widely distributed in the landscape. This list is by no means exhaustive and users may need to add plants to the list. A number of generic land cover types were also compiled to facilitate linkage of land use/land cover maps to SWAT plant categories. Because of the broad nature of the some of the categories, a number of assumptions had to be made when compiling the plant growth parameter values. The user is strongly recommended to use parameters for a specific plant rather than those of the generic land covers any time information about plant types is available for the region being modeled.

Plant code (CPNM): 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. When adding a new plant species or land cover category, the four letter code for the new plant must be unique.

Land cover/plant classification (IDC): SWAT groups plants into seven categories: warm season annual legume, cold season annual legume, perennial legume, warm season annual, cold season annual, perennial and trees. (Biannual plants are classified as perennials.) The differences between the categories as modeled by SWAT are summarized in Chapter 5:1 in the theoretical documentation. Plant classifications can be easily found in horticulture books that summarize characteristics for different species. The classifications assigned to the plants in Table A-1 were obtained from Martin et al. (1976) and Bailey (1935).

A.1.2 TEMPERATURE RESPONSES

SWAT uses the base temperature (T_BASE) 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.

The optimal temperature (T_OPT) is used to calculate temperature stress for the plant during the growing season (temperature stress is the only calculation in which optimal temperature is used). Chapter 5:3 in the theoretical documentation reviews the influence of optimal temperature on plant growth.

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 A-1 plots data for corn. (Note that the line intersects the x-axis at 8°C.)

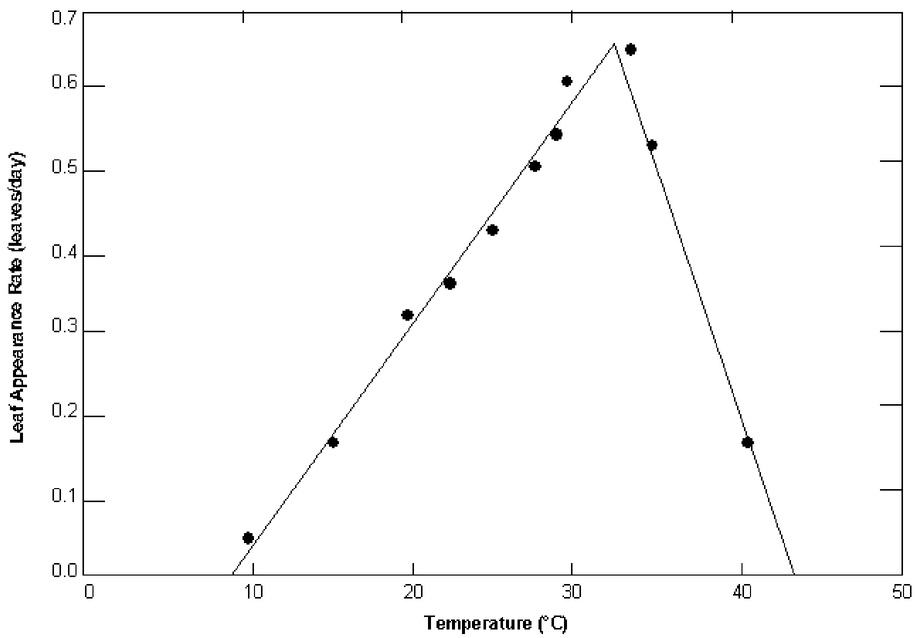

Figure A-1: Rate of leaf tip appearance as a function of temperature for corn.

Optimal temperature for plant growth is difficult to measure directly. Looking at Figure A-1, one might be tempted to select the temperature corresponding to the peak of the plot as the optimal temperature. This would not be correct. 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.

Base and optimal temperatures for the plants included in the database are listed in Table A-3.

Table A-3: Temperature parameters for plants included in plant growth database.

Common Name	Plant Code	T_{base}	T_{opt}	Reference
Corn	CORN	8	25	(Kiniry et al, 1995)
Corn silage	CSIL	8	25	(Kiniry et al, 1995)
Sweet corn	SCRN	12	24	(Hackett and Carolane, 1982)
Eastern gamagrass	EGAM	12	25	(Kiniry, personal comm., 2001)
Grain sorghum	GRSG	11	30	(Kiniry et al, 1992a)
Sorghum hay	SGHY	11	30	(Kiniry et al, 1992a)
Johnsongrass	JHGR	11	30	(Kiniry et al, 1992a)
Sugarcane	SUGC	11	25	(Kiniry and Williams, 1994)
Spring wheat	SWHT	0	18	(Kiniry et al, 1995)
Winter wheat	WWHT	0	18	(Kiniry et al, 1995)
Durum wheat	DWHT	0	15	estimated
Rye	RYE	0	12.5	estimated
Spring barley	BARL	0	25	(Kiniry et al, 1995)
Oats	OATS	0	15	(Kiniry, personal comm., 2001)
Rice	RICE	10	25	(Martin et al, 1976)
Pearl millet	PMIL	10	30	(Kiniry et al, 1991)
Timothy	TIMO	8	25	estimated
Smooth bromegrass	BROS	8	25	estimated
Meadow bromegrass	BROM	6	25	(Kiniry et al, 1995)
Tall fescue	FESC	0	15	estimated
Kentucky bluegrass	BLUG	12	25	(Kiniry, personal comm., 2001)
Bermudagrass	BERM	12	25	(Kiniry, personal comm., 2001)
Crested wheatgrass	CWGR	6	25	(Kiniry et al, 1995)
Western wheatgrass	WWGR	6	25	(Kiniry et al, 1995)
Slender wheatgrass	SWGR	8	25	estimated
Italian (annual) ryegrass	RYEG	0	18	estimated
Russian wildrye	RYER	0	15	(Kiniry et al, 1995)
Altai wildrye	RYEA	0	15	(Kiniry et al, 1995)
Sideoats grama	SIDE	12	25	(Kiniry, personal comm., 2001)
Big bluestem	BBLS	12	25	(Kiniry, personal comm., 2001)

Common Name	**Plant Code**	T_{base}	T_{opt}	**Reference**
Little bluestem	LBLS	12	25	(Kiniry, personal comm., 2001)
Alamo switchgrass	SWCH	12	25	(Kiniry et al, 1996)
Indiangrass	INDN	12	25	(Kiniry, personal comm., 2001)
Alfalfa	ALFA	4	20	(Kiniry, personal comm., 2001)
Sweetclover	CLVS	1	15	estimated
Red clover	CLVR	1	15	estimated
Alsike clover	CLVA	1	15	estimated
Soybean	SOYB	10	25	(Kiniry et al, 1992a)
Cowpeas	CWPS	14	28	(Kiniry et al, 1991; Hackett and Carolane, 1982)
Mung bean	MUNG	15	30	(Hackett and Carolane, 1982)
Lima beans	LIMA	18	26	(Hackett and Carolane, 1982)
Lentils	LENT	3	20	(Hackett and Carolane, 1982)
Peanut	PNUT	14	27	(Hackett and Carolane, 1982)
Field peas	FPEA	1	15	estimated
Garden or canning peas	PEAS	5	14	(Hackett and Carolane, 1982)
Sesbania	SESB	10	25	estimated
Flax	FLAX	5	22.5	estimated
Upland cotton (harvested with stripper)	COTS	15	30	(Martin et al, 1976)
Upland cotton (harvested with picker)	COTP	15	30	(Martin et al, 1976)
Tobacco	TOBC	10	25	(Martin et al, 1976)
Sugarbeet	SGBT	4	18	(Kiniry and Williams, 1994)
Potato	POTA	7	22	(Hackett and Carolane, 1982)
Sweetpotato	SPOT	14	24	(estimated; Hackett and Carolane, 1982)
Carrot	CRRT	7	24	(Kiniry and Williams, 1994)
Onion	ONIO	7	19	(Hackett and Carolane, 1982; Kiniry and Williams, 1994)
Sunflower	SUNF	6	25	(Kiniry et al, 1992b; Kiniry, personal communication, 2001)
Spring canola-Polish	CANP	5	21	(Kiniry et al, 1995)
Spring canola-Argentine	CANA	5	21	(Kiniry et al, 1995)
Asparagus	ASPR	10	24	(Hackett and Carolane, 1982)
Broccoli	BROC	4	18	(Hackett and Carolane, 1982)
Cabbage	CABG	1	18	(Hackett and Carolane, 1982)
Cauliflower	CAUF	5	18	(Hackett and Carolane, 1982)
Celery	CELR	4	22	(Hackett and Carolane, 1982)
Head lettuce	LETT	7	18	(Hackett and Carolane, 1982)
Spinach	SPIN	4	24	(Kiniry and Williams, 1994)
Green beans	GRBN	10	19	(Hackett and Carolane, 1982)
Cucumber	CUCM	16	32	(Kiniry and Williams, 1994)
Eggplant	EGGP	15	26	(Hackett and Carolane, 1982)
Cantaloupe	CANT	15	35	(Hackett and Carolane, 1982; Kiniry and Williams, 1994)

Common Name	Plant Code	T_{base}	T_{opt}	Reference
Honeydew melon	HMEL	16	36	(Kiniry and Williams, 1994)
Watermelon	WMEL	18	35	(Kiniry and Williams, 1994)
Bell pepper	PEPR	18	27	(Kiniry and Williams, 1994)
Strawberry	STRW	10	32	(Kiniry and Williams, 1994)
Tomato	TOMA	10	22	(Hackett and Carolane, 1982)
Apple	APPL	7	20	(Hackett and Carolane, 1982)
Pine	PINE	0	30	(Kiniry, personal comm., 2001)
Oak	OAK	10	30	(Kiniry, personal comm., 2001)
Poplar	POPL	10	30	(Kiniry, personal comm., 2001)
Honey mesquite	MESQ	10	30	(Kiniry, personal comm., 2001)

A.1.3 LEAF AREA DEVELOPMENT

Leaf area development is a function of the plant's growing season. Plant growth database variables used to quantify leaf area development are: BLAI, FRGRW1, LAIMX1, FRGRW2, LAIMX2, and DLAI. Figure A-2 illustrates the relationship of the database parameters to the leaf area development modeled by SWAT.

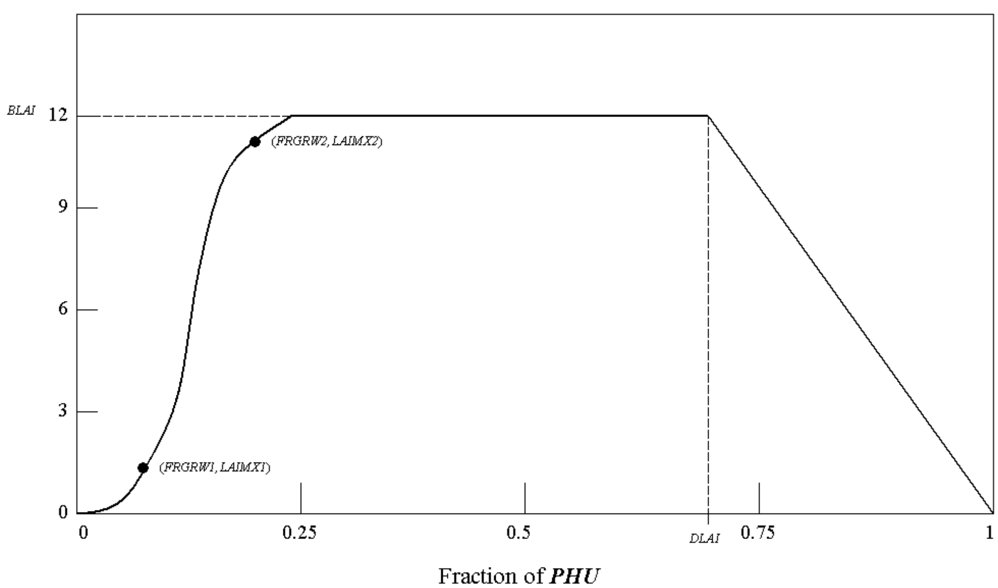

Figure A-2: Leaf area index as a function of fraction of growing season for Alamo switchgrass.

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.

Leaf area development parameter values for the plants included in the database are listed in Table A-4 (LAI_{mx} = BLAI; $fr_{PHU,1}$ = FRGRW1; $fr_{LAI,1}$ = LAIMX1; $fr_{PHU,2}$ = FRGRW2; $fr_{LAI,2}$ = LAIMX2; $fr_{PHU,sen}$ = DLAI).

Table A-4: Leaf area development parameters for plants included in plant growth database.

Common Name	Plant Code	LAI_{mx}	$fr_{PHU,1}$	$fr_{LAI,1}$	$fr_{PHU,2}$	$fr_{LAI,2}$	$fr_{PHU,sen}$	Reference
Corn	CORN	3	0.15	0.05	0.50	0.95	0.90	(Kiniry et al, 1995; Kiniry, personal comm., 2001)
Corn silage	CSIL	4	0.15	0.05	0.50	0.95	0.90	(Kiniry et al, 1995; Kiniry, personal comm., 2001)
Sweet corn	SCRN	2.5	0.15	0.05	0.50	0.95	0.90	(Kiniry, personal comm., 2001; Kiniry and Williams, 1994)
Eastern gamagrass	EGAM	2.5	0.05	0.18	0.25	0.90	0.80	(Kiniry, personal comm., 2001)
Grain sorghum	GRSG	3	0.15	0.05	0.50	0.95	0.90	(Kiniry, personal comm., 2001; Kiniry and Bockholt, 1998)
Sorghum hay	SGHY	4	0.15	0.05	0.50	0.95	0.80	(Kiniry, personal comm., 2001; Kiniry and Bockholt, 1998)
Johnsongrass	JHGR	2.5	0.15	0.05	0.57	0.95	0.80	(Kiniry, personal comm., 2001; Kiniry et al, 1992a)
Sugarcane	SUGC	6	0.15	0.01	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Spring wheat	SWHT	4	0.15	0.05	0.50	0.95	0.90	(Kiniry et al, 1995; Kiniry, personal comm., 2001)
Winter wheat	WWHT	4	0.05	0.05	0.45	0.95	0.90	(Kiniry et al, 1995; Kiniry, personal comm., 2001)
Durum wheat	DWHT	4	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal communication, 2001; estimated)
Rye	RYE	4	0.15	0.01	0.50	0.95	0.80	(Kiniry, personal communication, 2001; estimated)
Spring barley	BARL	4	0.15	0.01	0.45	0.95	0.90	(Kiniry et al, 1995; Kiniry, personal comm., 2001)
Oats	OATS	4	0.15	0.02	0.50	0.95	0.90	(Kiniry, personal comm., 2001)
Rice	RICE	5	0.30	0.01	0.70	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Pearl millet	PMIL	2.5	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Timothy	TIMO	4	0.15	0.01	0.50	0.95	0.85	(Kiniry, personal comm., 2001; estimated)
Smooth bromegrass	BROS	5	0.15	0.01	0.50	0.95	0.85	(Kiniry, personal comm., 2001; estimated)
Meadow bromegrass	BROM	3	0.45	0.02	0.80	0.95	0.85	(Kiniry et al, 1995; Kiniry, personal comm., 2001)
Tall fescue	FESC	4	0.15	0.01	0.50	0.95	0.80	(Kiniry, personal comm, 2001; estimated)
Kentucky bluegrass	BLUG	2	0.05	0.05	0.30	0.70	0.80	(Kiniry, personal comm., 2001)
Bermudagrass	BERM	4	0.05	0.05	0.49	0.95	0.99	(Kiniry, personal comm, 2001)
Crested wheatgrass	CWGR	4	0.35	0.02	0.62	0.95	0.85	(Kiniry et al, 1995; Kiniry, personal comm., 2001)
Western wheatgrass	WWGR	4	0.50	0.02	0.89	0.95	0.85	(Kiniry et al, 1995; Kiniry, personal comm., 2001)
Slender wheatgrass	SWGR	4	0.15	0.01	0.50	0.95	0.85	(Kiniry, personal comm., 2001; estimated)
Italian (annual) ryegrass	RYEG	4	0.20	0.32	0.45	0.95	0.80	(Kiniry, personal comm., 2001; estimated)
Russian wildrye	RYER	3	0.35	0.02	0.62	0.95	0.80	(Kiniry et al, 1995)
Altai wildrye	RYEA	3	0.35	0.02	0.62	0.95	0.80	(Kiniry et al, 1995)
Sideoats grama	SIDE	1.7	0.05	0.05	0.30	0.70	0.80	(Kiniry, personal comm., 2001)

Common Name	Plant Code	LAI_{mx}	$fr_{PHU,1}$	$fr_{LAI,1}$	$fr_{PHU,2}$	$fr_{LAI,2}$	$fr_{PHU,sen}$	Reference
Big bluestem	BBLS	3	0.05	0.10	0.25	0.70	0.80	(Kiniry, personal comm., 2001)
Little bluestem	LBLS	2.5	0.05	0.10	0.25	0.70	0.80	(Kiniry, personal comm., 2001)
Alamo switchgrass	SWCH	6	0.10	0.20	0.20	0.95	0.80	(Kiniry, personal comm., 2001; Kiniry et al, 1996)
Indiangrass	INDN	3	0.05	0.10	0.25	0.70	0.80	(Kiniry, personal comm., 2001)
Alfalfa	ALFA	4	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001)
Sweetclover	CLVS	4	0.15	0.01	0.50	0.95	0.80	(Kiniry, personal comm., 2001; estimated)
Red clover	CLVR	4	0.15	0.01	0.50	0.95	0.80	(Kiniry, personal comm., 2001; estimated)
Alsike clover	CLVA	4	0.15	0.01	0.50	0.95	0.80	(Kiniry, personal comm., 2001; estimated)
Soybean	SOYB	3	0.15	0.05	0.50	0.95	0.90	(Kiniry, personal comm., 2001; Kiniry et al, 1992a)
Cowpeas	CWPS	4	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Mung bean	MUNG	4	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Lima beans	LIMA	2.5	0.10	0.05	0.80	0.95	0.90	(Kiniry and Williams, 1994)
Lentils	LENT	4	0.15	0.02	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Peanut	PNUT	4	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Field peas	FPEA	4	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Garden or canning peas	PEAS	2.5	0.10	0.05	0.80	0.95	0.90	(Kiniry and Williams, 1994)
Sesbania	SESB	5	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Flax	FLAX	2.5	0.15	0.02	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Upland cotton (harvested with stripper)	COTS	4	0.15	0.01	0.50	0.95	0.95	(Kiniry, personal comm., 2001; estimated)
Upland cotton (harvested with picker)	COTP	4	0.15	0.01	0.50	0.95	0.95	(Kiniry, personal comm., 2001; estimated)
Tobacco	TOBC	4.5	0.15	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Sugarbeet	SGBT	5	0.05	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Potato	POTA	4	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; Kiniry and Williams, 1994)
Sweetpotato	SPOT	4	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; estimated)
Carrot	CRRT	3.5	0.15	0.01	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Onion	ONIO	1.5	0.15	0.01	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Sunflower	SUNF	3	0.15	0.01	0.50	0.95	0.90	(Kiniry, personal comm., 2001; Kiniry et al, 1992b)
Spring canola-Polish	CANP	3.5	0.15	0.02	0.45	0.95	0.90	(Kiniry et al, 1995)
Spring canola-Argentine	CANA	4.5	0.15	0.02	0.45	0.95	0.90	(Kiniry et al, 1995)
Asparagus	ASPR	4.2	0.25	0.23	0.40	0.86	1.00	(Kiniry and Williams, 1994)
Broccoli	BROC	4.2	0.25	0.23	0.40	0.86	1.00	(Kiniry and Williams, 1994)

Common Name	Plant Code	LAI_{mx}	$fr_{PHU,1}$	$fr_{LAI,1}$	$fr_{PHU,2}$	$fr_{LAI,2}$	$fr_{PHU,sen}$	Reference
Cabbage	CABG	3	0.25	0.23	0.40	0.86	1.00	(Kiniry and Williams, 1994)
Cauliflower	CAUF	2.5	0.25	0.23	0.40	0.86	1.00	(Kiniry and Williams, 1994)
Celery	CELR	2.5	0.25	0.23	0.40	0.86	1.00	(Kiniry and Williams, 1994)
Head lettuce	LETT	4.2	0.25	0.23	0.40	0.86	1.00	(Kiniry and Williams, 1994)
Spinach	SPIN	4.2	0.10	0.05	0.90	0.95	0.95	(Kiniry and Williams, 1994)
Green beans	GRBN	1.5	0.10	0.05	0.80	0.95	0.90	(Kiniry and Williams, 1994)
Cucumber	CUCM	1.5	0.15	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Eggplant	EGGP	3	0.15	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Cantaloupe	CANT	3	0.15	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Honeydew melon	HMEL	4	0.15	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Watermelon	WMEL	1.5	0.15	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Bell pepper	PEPR	5	0.15	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Strawberry	STRW	3	0.15	0.05	0.50	0.95	0.90	(Kiniry and Williams, 1994)
Tomato	TOMA	3	0.15	0.05	0.50	0.95	0.95	(Kiniry and Williams, 1994)
Apple	APPL	4	0.10	0.15	0.50	0.75	0.99	(Kiniry, personal comm., 2001; estimated)
Pine	PINE	5	0.15	0.70	0.25	0.99	0.99	(Kiniry, personal comm., 2001)
Oak	OAK	5	0.05	0.05	0.40	0.95	0.99	(Kiniry, personal comm., 2001)
Poplar	POPL	5	0.05	0.05	0.40	0.95	0.99	(Kiniry, personal comm., 2001)
Honey mesquite	MESQ	1.25	0.05	0.05	0.40	0.95	0.99	(Kiniry, 1998; Kiniry, personal communication, 2001)

A.1.4 ENERGY-BIOMASS CONVERSION

Radiation-use efficiency (RUE) quantifies the efficiency of a plant in converting light energy into biomass. Four variables in the plant growth database are used to define the RUE in ideal growing conditions (BIO_E), the impact of reduced vapor pressure on RUE (WAVP), and the impact of elevated CO_2 concentration on RUE (CO2HI, BIOEHI).

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.

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 A-4 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.)

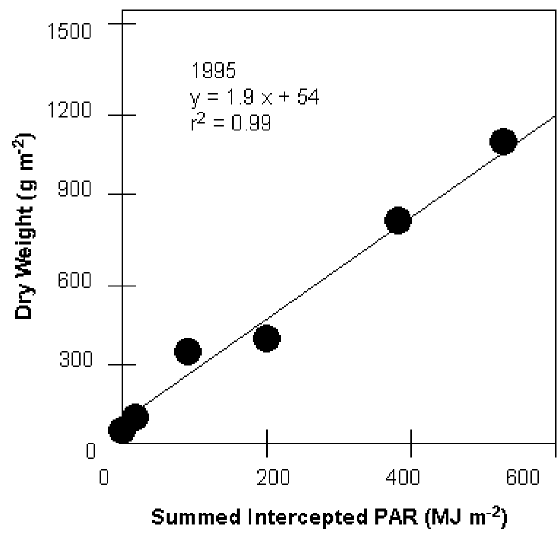

Figure A-4: Aboveground biomass and summed intercepted photosynthetically active radiation for Eastern gamagrass (from Kiniry et al.,1999).

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 the 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 A-5 shows a plot of RUE as a function of vapor pressure deficit for grain sorghum.

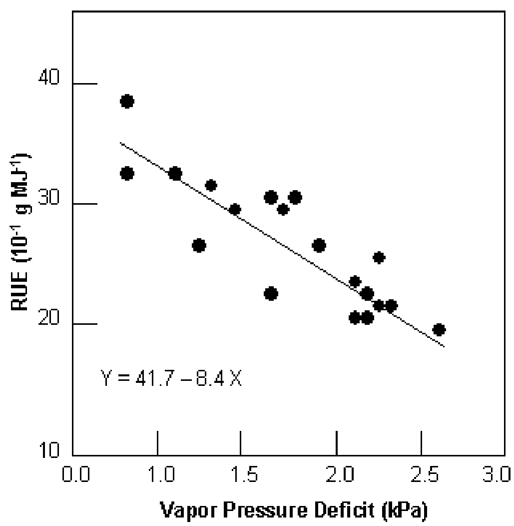

Figure A-5: Response of radiation-use efficiency to mean daily vapor pressure deficit for grain sorghum.

From Figure A-5, 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.

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 previously.

Radiation-use efficiency parameter values for the plants included in the database are listed in Table A-5 (RUE = BIO_E; Δrue_{dcl} = WAVP; RUE_{hi} = BIOEHI; CO_{2hi} = CO2HI).

Table A-5: Biomass production parameters for plants included in plant growth database.

Common Name	Plant Code	RUE	Δrue_{dcl}	RUE_{hi}	CO_{2hi}	Reference
Corn	CORN	39	7.2	45	660	(Kiniry et al, 1998; Kiniry et al, 1997; Kiniry, personal communication, 2001)
Corn silage	CSIL	39	7.2	45	660	(Kiniry et al, 1998; Kiniry et al, 1997; Kiniry, personal communication, 2001)
Sweet corn	SCRN	39	7.2	45	660	(Kiniry and Williams, 1994; Kiniry et al, 1997; Kiniry, personal communication, 2001)
Eastern gamagrass	EGAM	21	10	58	660	(Kiniry et al, 1999; Kiniry, personal communication, 2001)
Grain sorghum	GRSG	33.5	8.5	36	660	(Kiniry et al, 1998; Kiniry, personal communication, 2001)
Sorghum hay	SGHY	33.5	8.5	36	660	(Kiniry et al, 1998; Kiniry, personal communication, 2001)
Johnsongrass	JHGR	35	8.5	36	660	(Kiniry et al, 1992a; Kiniry, personal communication, 2001)
Sugarcane	SUGC	25	10	33	660	(Kiniry and Williams, 1994; Kiniry, personal communication, 2001)
Spring wheat	SWHT	35	8	46	660	(Kiniry et al, 1992a; Kiniry, personal communication, 2001; estimated)
Winter wheat	WWHT	30	6	39	660	(Kiniry et al, 1995; estimated)
Durum wheat	DWHT	30	7	45	660	(estimated)
Rye	RYE	35	7	45	660	(estimated)
Spring barley	BARL	35	7	45	660	(Kiniry et al, 1995; estimated)
Oats	OATS	35	10	45	660	(Kiniry, personal communication, 2001)

Common Name	Plant Code	RUE	Δrue_{dcl}	RUE_{hi}	CO_{2hi}	Reference
Rice	RICE	22	5	31	660	(Kiniry et al, 1989; estimated)
Pearl millet	PMIL	35	8	40	660	(estimated)
Timothy	TIMO	35	8	45	660	(estimated)
Smooth bromegrass	BROS	35	8	45	660	(estimated)
Meadow bromegrass	BROM	35	8	45	660	(Kiniry et al, 1995; estimated)
Tall fescue	FESC	30	8	39	660	(estimated)
Kentucky bluegrass	BLUG	18	10	31	660	(Kiniry, personal communication, 2001)
Bermudagrass	BERM	35	10	36	660	(Kiniry, personal communication, 2001)
Crested wheatgrass	CWGR	35	8	38	660	(Kiniry et al, 1995; Kiniry, personal communication, 2001)
Western wheatgrass	WWGR	35	8	45	660	(Kiniry et al, 1995; estimated)
Slender wheatgrass	SWGR	35	8	45	660	(estimated)
Italian (annual) ryegrass	RYEG	30	6	39	660	(estimated)
Russian wildrye	RYER	30	8	39	660	(Kiniry et al, 1995; estimated)
Altai wildrye	RYEA	30	8	46	660	(Kiniry et al, 1995; Kiniry, personal communication, 2001)
Sideoats grama	SIDE	11	10	21	660	(Kiniry et al, 1999; Kiniry, personal communication, 2001)
Big bluestem	BBLS	14	10	39	660	(Kiniry et al, 1999; Kiniry, personal communication, 2001)
Little bluestem	LBLS	34	10	39	660	(Kiniry, personal communication, 2001)
Alamo switchgrass	SWCH	47	8.5	54	660	(Kiniry et al, 1996; Kiniry, personal communication, 2001)
Indiangrass	INDN	34	10	39	660	(Kiniry, personal communication, 2001)
Alfalfa	ALFA	20	10	35	660	(Kiniry, personal communication, 2001)
Sweetclover	CLVS	25	10	30	660	(estimated)
Red clover	CLVR	25	10	30	660	(estimated)
Alsike clover	CLVA	25	10	30	660	(estimated)
Soybean	SOYB	25	8	34	660	(Kiniry et al, 1992a; Kiniry, personal communication, 2001)
Cowpeas	CWPS	35	8	39	660	(estimated)
Mung bean	MUNG	25	10	33	660	(estimated)
Lima beans	LIMA	25	5	34	660	(Kiniry and Williams, 1994; estimated)
Lentils	LENT	20	10	33	660	(estimated)
Peanut	PNUT	20	4	25	660	(estimated)
Field peas	FPEA	25	10	30	660	(estimated)
Garden or canning peas	PEAS	25	5	34	660	(Kiniry and Williams, 1994; estimated)
Sesbania	SESB	50	10	60	660	(estimated)
Flax	FLAX	25	10	33	660	(estimated)
Upland cotton (harvested with stripper)	COTS	15	3	19	660	(estimated)
Upland cotton (harvested with picker)	COTP	15	3	19	660	(estimated)
Tobacco	TOBC	39	8	44	660	(Kiniry and Williams, 1994; estimated)
Sugarbeet	SGBT	30	10	35	660	(Kiniry and Williams, 1994; estimated)

Common Name	Plant Code	*RUE*	Δrue_{dcl}	RUE_{hi}	CO_{2hi}	Reference
Potato	POTA	25	14.8	30	660	(Manrique et al, 1991; estimated)
Sweetpotato	SPOT	15	3	19	660	(estimated)
Carrot	CRRT	30	10	35	660	(Kiniry and Williams, 1994; estimated)
Onion	ONIO	30	10	35	660	(Kiniry and Williams, 1994; estimated)
Sunflower	SUNF	46	32.3	59	660	(Kiniry et al, 1992b; Kiniry, personal communication, 2001)
Spring canola-Polish	CANP	34	10	39	660	(Kiniry et al, 1995; estimated)
Spring canola-Argentine	CANA	34	10	40	660	(Kiniry et al, 1995; estimated)
Asparagus	ASPR	90	5	95	660	(Kiniry and Williams, 1994; estimated)
Broccoli	BROC	26	5	30	660	(Kiniry and Williams, 1994; estimated)
Cabbage	CABG	19	5	25	660	(Kiniry and Williams, 1994; estimated)
Cauliflower	CAUF	21	5	25	660	(Kiniry and Williams, 1994; estimated)
Celery	CELR	27	5	30	660	(Kiniry and Williams, 1994; estimated)
Head lettuce	LETT	23	8	25	660	(Kiniry and Williams, 1994; estimated)
Spinach	SPIN	30	5	35	660	(Kiniry and Williams, 1994; estimated)
Green beans	GRBN	25	5	34	660	(Kiniry and Williams, 1994; estimated)
Cucumber	CUCM	30	8	39	660	(Kiniry and Williams, 1994; estimated)
Eggplant	EGGP	30	8	39	660	(Kiniry and Williams, 1994; estimated)
Cantaloupe	CANT	30	3	39	660	(Kiniry and Williams, 1994; estimated)
Honeydew melon	HMEL	30	3	39	660	(Kiniry and Williams, 1994; estimated)
Watermelon	WMEL	30	3	39	660	(Kiniry and Williams, 1994; estimated)
Bell pepper	PEPR	30	8	39	660	(Kiniry and Williams, 1994; estimated)
Strawberry	STRW	30	8	39	660	(Kiniry and Williams, 1994; estimated)
Tomato	TOMA	30	8	39	660	(Kiniry and Williams, 1994; estimated)
Apple	APPL	15	3	20	660	(estimated)
Pine	PINE	15	8	16	660	(Kiniry, personal communication, 2001)
Oak	OAK	15	8	16	660	(Kiniry, personal communication, 2001)
Poplar	POPL	30	8	31	660	(Kiniry, personal communication, 2001)
Honey mesquite	MESQ	16.1	8	18	660	(Kiniry, 1998; Kiniry, personal comm., 2001)

A.1.5 LIGHT INTERCEPTION

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 A-3). A reduction in light intensity interception by an individual leaf favors a more complete conversion of total canopy-intercepted light energy into biomass.

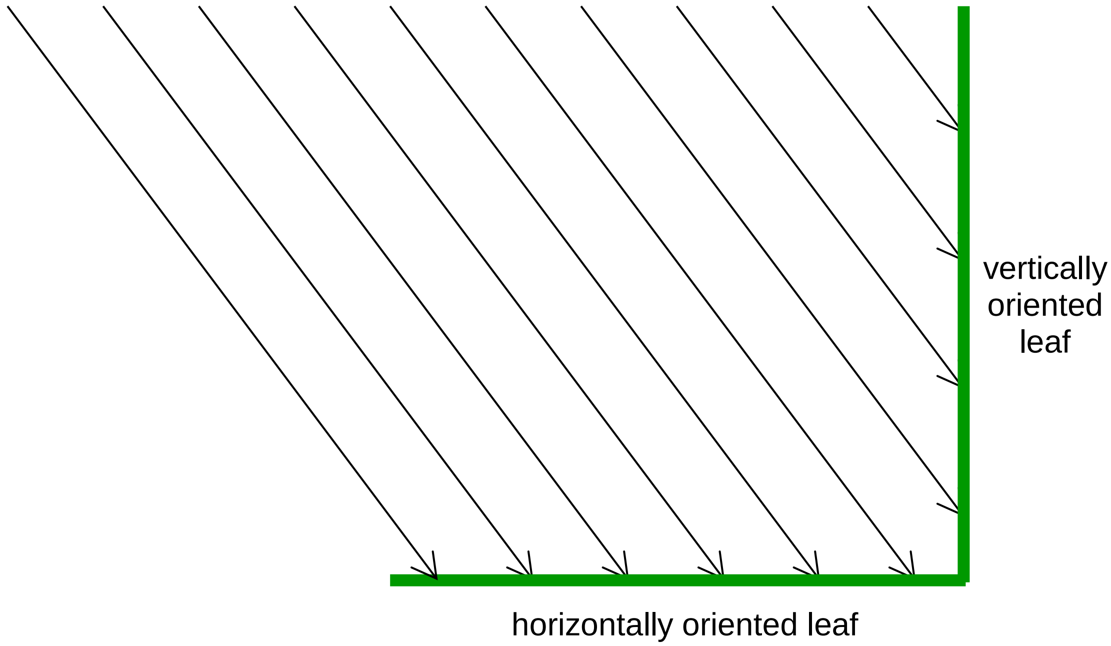

Figure A-3: Light intensity interception as a function of leaf orientation. The vertically oriented leaf intercepts 4 units of light while a horizontally oriented leaf of the same length intercepts 6 units of light.

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:

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

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

A.1.6 STOMATAL CONDUCTANCE

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 CO_2 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.

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.

Körner et al (1979) compiled maximum leaf diffusive conductance data for 246 plant species. The data for each individual species was presented as well as summarized by 13 morphologically and/or ecologically comparable plant groups. All maximum stomatal conductance values in the plant growth database were based on the data included in Körner et al (1979) (see Table A-6).

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.

A.1.7 CANOPY HEIGHT/ROOT DEPTH

Maximum canopy height (CHTMX) 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.

To determine maximum rooting depth (RDMX), 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 m 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. Table A-6 lists the maximum canopy height and maximum rooting depths for plants in the default database.

Table A-6: Maximum stomatal conductance ($g_{\ell,mx}$), maximum canopy height ($h_{c,mx}$), maximum root depth ($z_{root,mx}$), minimum USLE C factor for land cover ($C_{USLE,mn}$).

Common Name	Plant Code	$g_{\ell,mx}$	$h_{c,mx}$	$z_{root,mx}$	$C_{USLE,mn}$	Reference
Corn	CORN	.0071	2.5	2.0	.20	(Körner et al, 1979; Martin et al, 1976; Kiniry et al, 1995; Kiniry, personal comm., 2001)
Corn silage	CSIL	.0071	2.5	2.0	.20	(Körner et al, 1979; Martin et al, 1976; Kiniry et al, 1995; Kiniry, personal comm., 2001)
Sweet corn	SCRN	.0071	2.5	2.0	.20	(Körner et al, 1979, Kiniry and Williams, 1994; Kiniry, personal comm., 2001)
Eastern gamagrass	EGAM	.0055	1.7	2.0	.003	(Körner et al, 1979; Kiniry, personal comm., 2001)
Grain sorghum	GRSG	.0050	1.0	2.0	.20	(Körner et al, 1979; Kiniry, personal comm., 2001)
Sorghum hay	SGHY	.0050	1.5	2.0	.20	(Körner et al, 1979; Martin et al, 1976; Kiniry, personal comm., 2001)
Johnsongrass	JHGR	.0048	1.0	2.0	.20	(Körner et al, 1979; Kiniry et al, 1992a)
Sugarcane	SUGC	.0055	3.0	2.0	.001	(Körner et al, 1979; Kiniry and Williams, 1994)
Spring wheat	SWHT	.0056	0.9	2.0	.03	(Körner et al, 1979; Kiniry, personal comm., 2001)
Winter wheat	WWHT	.0056	0.9	1.3	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Kiniry et al, 1995)
Durum wheat	DWHT	.0056	1.0	2.0	.03	(Körner et al, 1979; estimated; Kiniry, personal comm., 2001)
Rye	RYE	.0100	1.0	1.8	.03	(Körner et al, 1979; estimated; Martin et al, 1976; Kiniry, personal comm., 2001)
Spring barley	BARL	.0083	1.2	1.3	.01	(Körner et al, 1979; Kiniry and Williams, 1994; Kiniry et al, 1995)
Oats	OATS	.0055	1.5	2.0	.03	(Körner et al, 1979; Martin et al, 1976; Kiniry, personal comm., 2001)
Rice	RICE	.0078	0.8	0.9	.03	(Körner et al, 1979; Martin et al, 1976; estimated)
Pearl millet	PMIL	.0143	3.0	2.0	.20	(Körner et al, 1979; Kiniry, personal comm., 2001; estimated)
Timothy	TIMO	.0055	0.8	2.0	.003	(Körner et al, 1979; estimated)
Smooth bromegrass	BROS	.0025	1.2	2.0	.003	(Körner et al, 1979; Martin et al, 1976; estimated)
Meadow bromegrass	BROM	.0055	0.8	1.3	.003	(Körner et al, 1979; estimated; Kiniry et al, 1995)
Tall fescue	FESC	.0055	1.5	2.0	.03	(Körner et al, 1979; Martin et al, 1976; estimated)
Kentucky bluegrass	BLUG	.0055	0.2	1.4	.003	(Körner et al, 1979; Kiniry, personal comm., 2001)
Bermudagrass	BERM	.0055	0.5	2.0	.003	(Körner et al, 1979; Kiniry, personal comm., 2001)
Crested wheatgrass	CWGR	.0055	0.9	1.3	.003	(Körner et al, 1979; Martin et al, 1976; Kiniry et al, 1995)
Western wheatgrass	WWGR	.0083	0.6	1.3	.003	(Körner et al, 1979; Martin et al, 1976; Kiniry et al, 1995; estimated)
Slender wheatgrass	SWGR	.0055	0.7	2.0	.003	(Körner et al, 1979; estimated)
Italian (annual) ryegrass	RYEG	.0055	0.8	1.3	.03	(Körner et al, 1979; estimated)
Russian wildrye	RYER	.0065	1.0	1.3	.03	(Körner et al, 1979; estimated; Kiniry et al, 1995)
Altai wildrye	RYEA	.0055	1.1	1.3	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Kiniry et al, 1995)

Common Name	Plant Code	$g_{\ell,mx}$	$h_{c,mx}$	$z_{root,mx}$	$C_{USLE,mn}$	Reference
Sideoats grama	SIDE	.0055	0.4	1.4	.003	(Körner et al, 1979; Kiniry, personal comm., 2001)
Big bluestem	BBLS	.0055	1.0	2.0	.003	(Körner et al, 1979; Kiniry, personal comm., 2001)
Little bluestem	LBLS	.0055	1.0	2.0	.003	(Körner et al, 1979; Kiniry, personal comm., 2001)
Alamo switchgrass	SWCH	.0055	2.5	2.2	.003	(Körner et al, 1979; Kiniry, personal comm., 2001; Kiniry et al, 1996)
Indiangrass	INDN	.0055	1.0	2.0	.003	(Körner et al, 1979; Kiniry, personal comm., 2001)
Alfalfa	ALFA	.0100	0.9	3.0	.01	(Jensen et al, 1990; Martin et al, 1976; Kiniry, personal comm., 2001)
Sweetclover	CLVS	.0055	1.5	2.4	.003	(Körner et al, 1979; Kiniry, personal comm., 2001; Martin et al, 1976; estimated)
Red clover	CLVR	.0065	0.75	1.5	.003	(Körner et al, 1979; Martin et al, 1976; estimated)
Alsike clover	CLVA	.0055	0.9	2.0	.003	(Körner et al, 1979; Martin et al, 1976; estimated)
Soybean	SOYB	.0071	0.8	1.7	.20	(Körner et al, 1979; Kiniry et al, 1992a)
Cowpeas	CWPS	.0055	1.2	2.0	.03	(Körner et al, 1979; estimated)
Mung bean	MUNG	.0055	1.5	2.0	.20	(Körner et al, 1979; estimated)
Lima beans	LIMA	.0055	0.6	2.0	.20	(Körner et al, 1979; Kiniry and Williams, 1994; Maynard and Hochmuth, 1997)
Lentils	LENT	.0055	0.55	1.2	.20	(Körner et al, 1979; Martin et al, 1976; Maynard and Hochmuth, 1997)
Peanut	PNUT	.0063	0.5	2.0	.20	(Körner et al, 1979; estimated)
Field peas	FPEA	.0055	1.2	1.2	.01	(Körner et al, 1979; Martin et al, 1976; Maynard and Hochmuth, 1997; estimated)
Garden or canning peas	PEAS	.0055	0.6	1.2	.20	(Körner et al, 1979; Kiniry and Williams, 1994; Maynard and Hochmuth, 1997)
Sesbania	SESB	.0055	2.0	2.0	.20	(Körner et al, 1979; Kiniry, personal comm., 2001; estimated)
Flax	FLAX	.0055	1.2	1.5	.20	(Körner et al, 1979; Martin et al, 1976; Jensen et al, 1990; estimated)
Upland cotton (harvested with stripper)	COTS	.0091	1.0	2.5	.20	(Monteith, 1965; Kiniry, personal comm., 2001; Martin et al, 1976)
Upland cotton (harvested with picker)	COTP	.0091	1.0	2.5	.20	(Monteith, 1965; Kiniry, personal comm., 2001; Martin et al, 1976)
Tobacco	TOBC	.0048	1.8	2.0	.20	(Körner et al, 1979; Martin et al, 1976; Kiniry and Williams, 1994)
Sugarbeet	SGBT	.0071	1.2	2.0	.20	(Körner et al, 1979; Kiniry and Williams, 1994)
Potato	POTA	.0050	0.6	0.6	.20	(Körner et al, 1979; Martin et al, 1976; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Sweetpotato	SPOT	.0065	0.8	2.0	.05	(Körner et al, 1979; estimated; Maynard and Hochmuth, 1997)
Carrot	CRRT	.0065	0.3	1.2	.20	(Körner et al, 1979; Kiniry and Williams, 1994; Maynard and Hochmuth, 1997)
Onion	ONIO	.0065	0.5	0.6	.20	(Körner et al, 1979; Kiniry and Williams, 1994; Maynard and Hochmuth, 1997)
Sunflower	SUNF	.0077	2.5	2.0	.20	(Körner et al, 1979; Kiniry, personal comm., 2001)

Common Name	Plant Code	$g_{\ell,mx}$	$h_{c,mx}$	$z_{root,mx}$	$C_{USLE,mn}$	Reference
Spring canola-Polish	CANP	.0065	0.9	0.9	.20	(Körner et al, 1979; estimated; Kiniry et al, 1995)
Spring canola-Argentine	CANA	.0065	1.3	1.4	.20	(Körner et al, 1979; estimated; Kiniry et al, 1995)
Asparagus	ASPR	.0065	0.5	2.0	.20	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Broccoli	BROC	.0065	0.5	0.6	.20	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Cabbage	CABG	.0065	0.5	0.6	.20	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Cauliflower	CAUF	.0065	0.5	0.6	.20	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Celery	CELR	.0065	0.5	0.6	.20	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Head lettuce	LETT	.0025	0.2	0.6	.01	(Körner et al, 1979; Kiniry and Williams, 1994; Maynard and Hochmuth, 1997)
Spinach	SPIN	.0065	0.5	0.6	.20	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Green beans	GRBN	.0077	0.6	1.2	.20	(Körner et al, 1979; Kiniry and Williams, 1994; Maynard and Hochmuth, 1997)
Cucumber	CUCM	.0033	0.5	1.2	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997)
Eggplant	EGGP	.0065	0.5	1.2	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Cantaloupe	CANT	.0065	0.5	1.2	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Honeydew melon	HMEL	.0065	0.5	1.2	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Watermelon	WMEL	.0065	0.5	2.0	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Bell pepper	PEPR	.0053	0.5	1.2	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Strawberry	STRW	.0065	0.5	0.6	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Tomato	TOMA	.0077	0.5	2.0	.03	(Körner et al, 1979; Kiniry, personal comm., 2001; Maynard and Hochmuth, 1997; Kiniry and Williams, 1994)
Apple	APPL	.0071	3.5	2.0	.001	(Körner et al, 1979; estimated; Jensen et al, 1990)
Pine	PINE	.0019	10.0	3.5	.001	(Körner et al, 1979; Kiniry, personal comm., 2001)
Oak	OAK	.0020	6.0	3.5	.001	(Körner et al, 1979; Kiniry, personal comm., 2001)

Common Name	Plant Code	$g_{\ell,mx}$	$h_{c,mx}$	$z_{root,mx}$	$C_{USLE,mn}$	Reference
Poplar	POPL	.0036	7.5	3.5	.001	(Körner et al, 1979; Kiniry, personal comm., 2001)
Honey mesquite	MESQ	.0036	6.0	3.5	.001	(Körner et al, 1979; Kiniry, personal comm., 2001)

A.1.8 PLANT NUTRIENT CONTENT

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 PLPPFR(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.

The fractions of nitrogen and phosphorus for the plants included in the default database are listed in Table A-7.

Table A-7: Nutrient parameters for plants included in plant growth database.

Common Name	Plant Code	$fr_{N,1}$	$fr_{N,2}$	$fr_{N,3}$	$fr_{P,1}$	$fr_{P,2}$	$fr_{P,3}$	Reference
Corn	CORN	.0470	.0177	.0138	.0048	.0018	.0014	(Kiniry et al., 1995)
Corn silage	CSIL	.0470	.0177	.0138	.0048	.0018	.0014	(Kiniry et al., 1995)
Sweet corn	SCRN	.0470	.0177	.0138	.0048	.0018	.0014	(Kiniry and Williams, 1994)
Eastern gamagrass	EGAM	.0200	.0100	.0070	.0014	.0010	.0007	(Kiniry, personal communication, 2001)
Grain sorghum	GRSG	.0440	.0164	.0128	.0060	.0022	.0018	(Kiniry, personal communication, 2001)
Sorghum hay	SGHY	.0440	.0164	.0128	.0060	.0022	.0018	(Kiniry, personal communication, 2001)
Johnsongrass	JHGR	.0440	.0164	.0128	.0060	.0022	.0018	(Kiniry et al., 1992a)
Sugarcane	SUGC	.0100	.0040	.0025	.0075	.0030	.0019	(Kiniry and Williams, 1994)
Spring wheat	SWHT	.0600	.0231	.0134	.0084	.0032	.0019	(Kiniry et al., 1992a)
Winter wheat	WWHT	.0663	.0255	.0148	.0053	.0020	.0012	(Kiniry et al., 1995)
Durum wheat	DWHT	.0600	.0231	.0130	.0084	.0032	.0019	estimated
Rye	RYE	.0600	.0231	.0130	.0084	.0032	.0019	estimated
Spring barley	BARL	.0590	.0226	.0131	.0057	.0022	.0013	(Kiniry et al., 1995)
Oats	OATS	.0600	.0231	.0134	.0084	.0032	.0019	(Kiniry, personal communication, 2001)
Rice	RICE	.0500	.0200	.0100	.0060	.0030	.0018	estimated
Pearl millet	PMIL	.0440	.0300	.0100	.0060	.0022	.0012	estimated
Timothy	TIMO	.0314	.0137	.0103	.0038	.0025	.0019	estimated
Smooth bromegrass	BROS	.0400	.0240	.0160	.0028	.0017	.0011	(Kiniry et al., 1995)
Meadow bromegrass	BROM	.0400	.0240	.0160	.0028	.0017	.0011	(Kiniry et al., 1995)
Tall fescue	FESC	.0560	.0210	.0120	.0099	.0022	.0019	estimated
Kentucky bluegrass	BLUG	.0200	.0100	.0060	.0014	.0010	.0007	(Kiniry, personal communication, 2001)
Bermudagrass	BERM	.0600	.0231	.0134	.0084	.0032	.0019	(Kiniry, personal communication, 2001)
Crested wheatgrass	CWGR	.0300	.0200	.0120	.0020	.0015	.0013	(Kiniry et al., 1995)
Western wheatgrass	WWGR	.0300	.0200	.0120	.0020	.0015	.0013	(Kiniry et al., 1995)

Common Name	Plant Code	$fr_{N,1}$	$fr_{N,2}$	$fr_{N,3}$	$fr_{P,1}$	$fr_{P,2}$	$fr_{P,3}$	Reference
Slender wheatgrass	SWGR	.0300	.0200	.0120	.0020	.0015	.0013	estimated
Italian (annual) ryegrass	RYEG	.0660	.0254	.0147	.0105	.0040	.0024	estimated
Russian wildrye	RYER	.0226	.0180	.0140	.0040	.0040	.0024	(Kiniry et al., 1995)
Altai wildrye	RYEA	.0226	.0180	.0140	.0040	.0040	.0024	(Kiniry et al., 1995)
Sideoats grama	SIDE	.0200	.0100	.0060	.0014	.0010	.0007	(Kiniry, personal communication, 2001)
Big bluestem	BBLS	.0200	.0120	.0050	.0014	.0010	.0007	(Kiniry, personal communication, 2001)
Little bluestem	LBLS	.0200	.0120	.0050	.0014	.0010	.0007	(Kiniry, personal communication, 2001)
Alamo switchgrass	SWCH	.0350	.0150	.0038	.0014	.0010	.0007	(Kiniry et al., 1996)
Indiangrass	INDN	.0200	.0120	.0050	.0014	.0010	.0007	(Kiniry, personal communication, 2001)
Alfalfa	ALFA	.0417	.0290	.0200	.0035	.0028	.0020	(Kiniry, personal communication, 2001)
Sweetclover	CLVS	.0650	.0280	.0243	.0060	.0024	.0024	estimated
Red clover	CLVR	.0650	.0280	.0243	.0060	.0024	.0024	estimated
Alsike clover	CLVA	.0600	.0280	.0240	.0060	.0025	.0025	estimated
Soybean	SOYB	.0524	.0265	.0258	.0074	.0037	.0035	(Kiniry et al., 1992a)
Cowpeas	CWPS	.0600	.0231	.0134	.0049	.0019	.0011	estimated
Mung bean	MUNG	.0524	.0265	.0258	.0074	.0037	.0035	estimated
Lima beans	LIMA	.0040	.0030	.0015	.0035	.0030	.0015	(Kiniry and Williams, 1994)
Lentils	LENT	.0440	.0164	.0128	.0074	.0037	.0023	estimated
Peanut	PNUT	.0524	.0265	.0258	.0074	.0037	.0035	estimated
Field peas	FPEA	.0515	.0335	.0296	.0033	.0019	.0014	estimated
Garden or canning peas	PEAS	.0040	.0030	.0015	.0030	.0020	.0015	(Kiniry and Williams, 1994)
Sesbania	SESB	.0500	.0200	.0150	.0074	.0037	.0035	estimated
Flax	FLAX	.0482	.0294	.0263	.0049	.0024	.0023	estimated
Upland cotton (harvested with stripper)	COTS	.0580	.0192	.0177	.0081	.0027	.0025	estimated
Upland cotton (harvested with picker)	COTP	.0580	.0192	.0177	.0081	.0027	.0025	estimated
Tobacco	TOBC	.0470	.0177	.0138	.0048	.0018	.0014	(Kiniry and Williams, 1994)
Sugarbeet	SGBT	.0550	.0200	.0120	.0060	.0025	.0019	(Kiniry and Williams, 1994)
Potato	POTA	.0550	.0200	.0120	.0060	.0025	.0019	(Kiniry and Williams, 1994)
Sweetpotato	SPOT	.0450	.0160	.0090	.0045	.0019	.0015	estimated
Carrot	CRRT	.0550	.0075	.0012	.0060	.0030	.0020	(Kiniry and Williams, 1994)
Onion	ONIO	.0400	.0300	.0020	.0021	.0020	.0019	(Kiniry and Williams, 1994)
Sunflower	SUNF	.0500	.0230	.0146	.0063	.0029	.0023	(Kiniry, personal communication, 2001)
Spring canola-Polish	CANP	.0440	.0164	.0128	.0074	.0037	.0023	(Kiniry et al., 1995)
Spring canola-Argentine	CANA	.0440	.0164	.0128	.0074	.0037	.0023	(Kiniry et al., 1995)
Asparagus	ASPR	.0620	.0500	.0400	.0050	.0040	.0020	(Kiniry and Williams, 1994)
Broccoli	BROC	.0620	.0090	.0070	.0050	.0040	.0030	(Kiniry and Williams, 1994)
Cabbage	CABG	.0620	.0070	.0040	.0050	.0035	.0020	(Kiniry and Williams, 1994)
Cauliflower	CAUF	.0620	.0070	.0040	.0050	.0035	.0020	(Kiniry and Williams, 1994)
Celery	CELR	.0620	.0150	.0100	.0060	.0050	.0030	(Kiniry and Williams, 1994)
Head lettuce	LETT	.0360	.0250	.0210	.0084	.0032	.0019	(Kiniry and Williams, 1994)
Spinach	SPIN	.0620	.0400	.0300	.0050	.0040	.0035	(Kiniry and Williams, 1994)

Common Name	Plant Code	$fr_{N,1}$	$fr_{N,2}$	$fr_{N,3}$	$fr_{P,1}$	$fr_{P,2}$	$fr_{P,3}$	Reference
Green beans	GRBN	.0040	.0030	.0015	.0040	.0035	.0015	(Kiniry and Williams, 1994)
Cucumber	CUCM	.0663	.0075	.0048	.0053	.0025	.0012	(Kiniry and Williams, 1994)
Eggplant	EGGP	.0663	.0255	.0075	.0053	.0020	.0015	(Kiniry and Williams, 1994)
Cantaloupe	CANT	.0663	.0255	.0148	.0053	.0020	.0012	(Kiniry and Williams, 1994)
Honeydew melon	HMEL	.0070	.0040	.0020	.0026	.0020	.0017	(Kiniry and Williams, 1994)
Watermelon	WMEL	.0663	.0075	.0048	.0053	.0025	.0012	(Kiniry and Williams, 1994)
Bell pepper	PEPR	.0600	.0350	.0250	.0053	.0020	.0012	(Kiniry and Williams, 1994)
Strawberry	STRW	.0663	.0255	.0148	.0053	.0020	.0012	(Kiniry and Williams, 1994)
Tomato	TOMA	.0663	.0300	.0250	.0053	.0035	.0025	(Kiniry and Williams, 1994)
Apple	APPL	.0060	.0020	.0015	.0007	.0004	.0003	estimated
Pine	PINE	.0060	.0020	.0015	.0007	.0004	.0003	(Kiniry, personal communication, 2001)
Oak	OAK	.0060	.0020	.0015	.0007	.0004	.0003	(Kiniry, personal communication, 2001)
Poplar	POPL	.0060	.0020	.0015	.0007	.0004	.0003	(Kiniry, personal communication, 2001)
Honey mesquite	MESQ	.0200	.0100	.0080	.0007	.0004	.0003	(Kiniry, personal communication, 2001)

A.1.9 HARVEST

Harvest operations are performed on agricultural crops where the yield is sold for a profit. Four variables in the database provide information used by the model to harvest a crop: HVSTI, WSYF, CNYLD, and CPYLD.

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).

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.

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.

Table A-8 lists values for the optimal harvest index (HI_{opt}), the minimum harvest index (HI_{min}), the fraction of nitrogen in the harvested portion of biomass ($fr_{N,yld}$), and the fraction of phosphorus in the harvested portion of biomass ($fr_{P,yld}$).

Table A-8: Harvest parameters for plants included in the plant growth database.

Common Name	**Plant Code**	HI_{opt}	HI_{min}	$fr_{N,yld}$	$fr_{P,yld}$	**Reference**
Corn	CORN	0.50	0.30	.0140	.0016	(Kiniry, personal communication, 2001; Kiniry et al, 1995)
Corn silage	CSIL	0.90	0.90	.0140	.0016	(Kiniry, personal communication, 2001; Kiniry et al, 1995)
Sweet corn	SCRN	0.50	0.30	.0214	.0037	(Kiniry, personal communication, 2001; Nutrition Monitoring Division, 1984a)
Eastern gamagrass	EGAM	0.90	0.90	.0160	.0022	(Kiniry, personal communication, 2001)
Grain sorghum	GRSG	0.45	0.25	.0199	.0032	(Kiniry and Bockholt, 1998; Nutrition Monitoring Division, 1984b)
Sorghum hay	SGHY	0.90	0.90	.0199	.0032	(Kiniry, personal communication, 2001; Nutrition Monitoring Division, 1984b)
Johnsongrass	JHGR	0.90	0.90	.0200	.0028	(Kiniry, personal communication, 2001; Kiniry et al, 1992a)
Sugarcane	SUGC	0.50	0.01	.0000	.0000	(Kiniry and Williams, 1994)
Spring wheat	SWHT	0.42	0.20	.0234	.0033	(Kinry et al, 1995; Kiniry et al, 1992a)
Winter wheat	WWHT	0.40	0.20	.0250	.0022	(Kiniry et al, 1995)
Durum wheat	DWHT	0.40	0.20	.0263	.0057	(Kiniry, personal communication, 2001; Nutrition Monitoring Division, 1984b)
Rye	RYE	0.40	0.20	.0284	.0042	(Kiniry, personal communication, 2001; Nutrition Monitoring Division, 1984b)
Spring barley	BARL	0.54	0.20	.0210	.0017	(Kiniry et al, 1995)
Oats	OATS	0.42	0.175	.0316	.0057	(Kiniry, personal communication, 2001; Nutrition Monitoring Division, 1984b)
Rice	RICE	0.50	0.25	.0136	.0013	(Kiniry, personal communication, 2001; Nutrition Monitoring Division, 1984b)
Pearl millet	PMIL	0.25	0.10	.0200	.0028	(Kiniry, personal communication, 2001; estimated)

Common Name	Plant Code	HI_{opt}	HI_{min}	$fr_{N,yld}$	$fr_{P,yld}$	Reference
Timothy	TIMO	0.90	0.90	.0234	.0033	(Kiniry, personal communication, 2001; estimated)
Smooth bromegrass	BROS	0.90	0.90	.0234	.0033	(Kiniry, personal communication, 2001; Kiniry et al, 1995)
Meadow bromegrass	BROM	0.90	0.90	.0234	.0033	(Kiniry, personal communication, 2001; Kiniry et al, 1995)
Tall fescue	FESC	0.90	0.90	.0234	.0033	(Kiniry, personal communication, 2001; estimated)
Kentucky bluegrass	BLUG	0.90	0.90	.0160	.0022	(Kiniry, personal communication, 2001)
Bermudagrass	BERM	0.90	0.90	.0234	.0033	(Kiniry, personal communication, 2001)
Crested wheatgrass	CWGR	0.90	0.90	.0500	.0040	(Kiniry, personal communication, 2001; Kiniry et al, 1995)
Western wheatgrass	WWGR	0.90	0.90	.0500	.0040	(Kiniry, personal communication, 2001; Kiniry et al, 1995)
Slender wheatgrass	SWGR	0.90	0.90	.0500	.0040	(Kiniry, personal communication, 2001; estimated)
Italian (annual) ryegrass	RYEG	0.90	0.90	.0220	.0028	(Kiniry, personal communication, 2001; estimated)
Russian wildrye	RYER	0.90	0.90	.0230	.0037	(Kiniry, personal communication, 2001; Kiniry et al, 1995)
Altai wildrye	RYEA	0.90	0.90	.0230	.0037	(Kiniry, personal communication, 2001; Kiniry et al, 1995)
Sideoats grama	SIDE	0.90	0.90	.0160	.0022	(Kiniry, personal communication, 2001)
Big bluestem	BBLS	0.90	0.90	.0160	.0022	(Kiniry, personal communication, 2001)
Little bluestem	LBLS	0.90	0.90	.0160	.0022	(Kiniry, personal communication, 2001)
Alamo switchgrass	SWCH	0.90	0.90	.0160	.0022	(Kiniry et al, 1996)
Indiangrass	INDN	0.90	0.90	.0160	.0022	(Kiniry, personal communication, 2001)
Alfalfa	ALFA	0.90	0.90	.0250	.0035	(Kiniry, personal communication, 2001)
Sweetclover	CLVS	0.90	0.90	.0650	.0040	(Kiniry, personal communication, 2001; estimated)
Red clover	CLVR	0.90	0.90	.0650	.0040	(Kiniry, personal communication, 2001; estimated)
Alsike clover	CLVA	0.90	0.90	.0600	.0040	(Kiniry, personal communication, 2001; estimated)
Soybean	SOYB	0.31	0.01	.0650	.0091	(Kiniry et al, 1992a)
Cowpeas	CWPS	0.42	0.05	.0427	.0048	(estimated; Nutrition Monitoring Division, 1984c)
Mung bean	MUNG	0.31	0.01	.0420	.0040	(estimated; Nutrition Monitoring Division, 1984c)
Lima beans	LIMA	0.30	0.22	.0368	.0046	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Lentils	LENT	0.61	0.01	.0506	.0051	(estimated; Nutrition Monitoring Division, 1984c)
Peanut	PNUT	0.40	0.30	.0505	.0040	(estimated; Nutrition Monitoring Division, 1984c)
Field peas	FPEA	0.45	0.10	.0370	.0021	estimated
Garden or canning peas	PEAS	0.30	0.22	.0410	.0051	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Sesbania	SESB	0.31	0.01	.0650	.0091	estimated

Common Name	Plant Code	HI_{opt}	HI_{min}	$fr_{N,yld}$	$fr_{P,yld}$	Reference
Flax	FLAX	0.54	0.40	.0400	.0033	estimated
Upland cotton (harvested with stripper)	COTS	0.50	0.40	.0140	.0020	(Kiniry, personal communication, 2001; estimated)
Upland cotton (harvested with picker)	COTP	0.40	0.30	.0190	.0029	(Kiniry, personal communication, 2001; estimated)
Tobacco	TOBC	0.55	0.55	.0140	.0016	(Kiniry and Williams, 1994)
Sugarbeet	SGBT	2.00	1.10	.0130	.0020	(Kiniry and Williams, 1994)
Potato	POTA	0.95	0.95	.0246	.0023	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Sweetpotato	SPOT	0.60	0.40	.0097	.0010	(estimated; Nutrition Monitoring Division, 1984a)
Carrot	CRRT	1.12	0.90	.0135	.0036	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Onion	ONIO	1.25	0.95	.0206	.0032	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Sunflower	SUNF	0.30	0.18	.0454	.0074	(Kiniry et al, 1992b; Nutrition Monitoring Division, 1984d)
Spring canola-Polish	CANP	0.23	0.01	.0380	.0079	(Kiniry et al, 1995)
Spring canola-Argentine	CANA	0.30	0.01	.0380	.0079	(Kiniry et al, 1995)
Asparagus	ASPR	0.80	0.95	.0630	.0067	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Broccoli	BROC	0.80	0.95	.0512	.0071	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Cabbage	CABG	0.80	0.95	.0259	.0031	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Cauliflower	CAUF	0.80	0.95	.0411	.0059	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Celery	CELR	0.80	0.95	.0199	.0049	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Head lettuce	LETT	0.80	0.01	.0393	.0049	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Spinach	SPIN	0.95	0.95	.0543	.0058	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Green beans	GRBN	0.10	0.10	.0299	.0039	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Cucumber	CUCM	0.27	0.25	.0219	.0043	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Eggplant	EGGP	0.59	0.25	.0218	.0041	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Cantaloupe	CANT	0.50	0.25	.0138	.0017	(Kiniry and Williams, 1994; Consumer Nutrition Center, 1982)
Honeydew melon	HMEL	0.55	0.25	.0071	.0010	(Kiniry and Williams, 1994; Consumer Nutrition Center, 1982)
Watermelon	WMEL	0.50	0.25	.0117	.0011	(Kiniry and Williams, 1994; Consumer Nutrition Center, 1982)
Bell pepper	PEPR	0.60	0.25	.0188	.0030	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)
Strawberry	STRW	0.45	0.25	.0116	.0023	(Kiniry and Williams, 1994; Consumer Nutrition Center, 1982)
Tomato	TOMA	0.33	0.15	.0235	.0048	(Kiniry and Williams, 1994; Nutrition Monitoring Division, 1984a)

Common Name	Plant Code	HI_{opt}	HI_{min}	$fr_{N,yld}$	$fr_{P,yld}$	Reference
Apple	APPL	0.10	0.05	.0019	.0004	(estimated; Consumer Nutrition Center, 1982)
Pine	PINE	0.76	0.60	.0015	.0003	(Kiniry, personal communication, 2001)
Oak	OAK	0.76	0.01	.0015	.0003	(Kiniry, personal communication, 2001)
Poplar	POPL	0.76	0.01	.0015	.0003	(Kiniry, personal communication, 2001)
Honey mesquite	MESQ	0.05	0.01	.0015	.0003	(Kiniry, personal communication, 2001)

A.1.10 USLE C FACTOR

The USLE C factor is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow. This factor measures the combined effect of all the interrelated cover and management variables. SWAT calculates the actual C factor based on the amount of soil cover and the minimum C factor defined for the plant/land cover. The minimum C factor quantifies the maximum decrease in erosion possible for the plant/land cover. Because the USLE C factor is influenced by management, this variable may be adjusted by the user to reflect management conditions in the watershed of interest.

The minimum C factor can be estimated from a known average annual C factor using the following equation (Arnold and Williams, 1995):

$$C_{USLE,mn} = 1.463 \ln\left[C_{USLE,aa}\right] + 0.1034$$

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. The minimum C factor for plants in the database are listed in Table A-6.

A.1.11 RESIDUE DECOMPOSITION

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 land cover. A default value of 0.05 is used for all plant species in the database.

A.1.12 MINIMUM LAI/BIOMASS DURING DORMANCY

Minimum leaf area index for plants (perennials and trees) during dormancy was set by SWAT to 0.75 in versions prior to SWAT2009. Because this minimum leaf area index did not work well for trees, the variable was added to the plant growth database. Users may now adjust the value to any desired value. A default value of 0.75 is used for trees and perennials and 0.0 for all other plants.

The fraction of tree leaf biomass that drops during dormancy was originally set to 0.30 within SWAT. To allow users more control over the tree growth cycle, this variable was added to the plant database. A default value of 0.30 is assigned to all trees in the database.

A.2 TILLAGE DATABASE

The tillage database contains information needed by SWAT to simulate the redistribution of nutrients and pesticide that occurs in a tillage operation. Table A-9 lists all the default tillage implements. This list was summarized from a farm machinery database maintained by the USDA Economic Research Service. Depth of tillage for each implement was also obtained from the USDA Economic Research Service. The fraction of residue mixed into the soil was estimated for each implement from a 'Residue Scorecard' provided by NACD's (National Association of Conservation Districts) Conservation Technology Information Center.

Table A-9: Implements included in the tillage database.

Implement	Tillage Code	Mixing Depth	Mixing Efficiency
Duckfoot Cultivator	DUCKFTC	100 mm	0.55
Field Cultivator	FLDCULT	100 mm	0.30
Furrow-out Cultivator	FUROWOUT	25 mm	0.75
Marker (Cultivator)	MARKER	100 mm	0.45
Rolling Cultivator	ROLLCULT	25 mm	0.50
Row Cultivator	ROWCULT	25 mm	0.25
Discovator	DISCOVAT	25 mm	0.50
Leveler	LEVELER	25 mm	0.50
Harrow (Tines)	HARROW	25 mm	0.20
Culti-mulch Roller	CULMULCH	25 mm	0.25
Culti-packer Pulverizer	CULPKPUL	40 mm	0.35
Land Plane-Leveler	LANDLEVL	75 mm	0.50
Landall, Do-All	LANDALL	150 mm	0.30
Laser Planer	LASRPLAN	150 mm	0.30
Levee-Plow-Disc	LEVPLDIS	25 mm	0.75
Float	FLOAT	60 mm	0.10
Field Conditioner (Scratcher)	FLDCDSCR	60 mm	0.10
Lister (Middle-Buster)	LISTRMID	40 mm	0.15
Roller Groover	ROLLGROV	60 mm	0.25
Roller Packer Attachment	ROLPKRAT	40 mm	0.05
Roller Packer Flat Roller	ROLPKRFT	40 mm	0.35
Sand-Fighter	SANDFIGT	100 mm	0.70
Seedbed Roller	SEEDROLL	100 mm	0.70
Crust Buster	CRUSTBST	60 mm	0.10
Roller Harrow	ROLLHRRW	60 mm	0.40
Triple K	TRIPLE K	100 mm	0.40
Finishing Harrow	FINHARRW	100 mm	0.55
Flex-Tine Harrow CL	FLEXHARW	25 mm	0.20
Powered Spike Tooth Harrow	SPIKETTH	75 mm	0.40
Spike Tooth Harrow	SPIKTOTH	25 mm	0.25
Springtooth Harrow	SPRGTOTH	25 mm	0.35

Implement	Tillage Code	Mixing Depth	Mixing Efficiency
Soil Finisher	SOILFINS	75 mm	0.55
Rotary Hoe	ROTHOE	5 mm	0.10
Roterra	ROTERRA	5 mm	0.80
Roto-Tiller	ROTOTILL	5 mm	0.80
Rotovator-Bedder	ROTBEDDR	100 mm	0.80
Rowbuck	ROWBUCK	100 mm	0.70
Ripper	RIPPER	350 mm	0.25
Middle Buster	MIDBST1R	100 mm	0.70
Rod Weeder	RODWEEDR	25 mm	0.30
Rubber-Wheel Weed Puller	RUBWHWPL	5 mm	0.35
Multi-Weeder	MULTIWDR	25 mm	0.30
Moldboard Plow Reg	MLDBOARD	150 mm	0.95
Chisel Plow	CHISPLOW	150 mm	0.30
Coulter-Chisel	CCHPLOW	150 mm	0.50
Disk Plow	DISKPLOW	100 mm	0.85
Stubble-mulch Plow	STUBMLCH	75 mm	0.15
Subsoil Chisel Plow	SUBCHPLW	350 mm	0.45
Row Conditioner	ROWCOND	25 mm	0.50
Hipper	HIPPER	100 mm	0.50
Rice Roller	RICEROLL	50 mm	0.10
Paraplow	PARAPLOW	350 mm	0.15
Subsoiler-Bedder Hip-Rip	SBEDHIPR	350 mm	0.70
Deep Ripper-Subsoiler	RIPRSUBS	350 mm	0.25
V-Ripper	VRIPPER	350 mm	0.25
Bed Roller	BEDROLLR	50 mm	0.25
Bedder (Disk)	BEDDER D	150 mm	0.55
Bedder Disk-Hipper	BEDDHIPR	150 mm	0.65
Bedder Disk-Row	BEDDKROW	100 mm	0.85
Bedder Shaper	BEDDER S	150 mm	0.55
Disk Border Maker	DSKBRMKR	150 mm	0.55
Disk Chisel (Mulch Tiller)	DKCHMTIL	150 mm	0.55
Offset Disk-Heavy Duty	OFFSETHV	100 mm	0.70
Offset Disk-Light Duty	OFFSETLT	100 mm	0.55
One-Way (Disk Tiller)	ONE-WAYT	100 mm	0.60
Tandem Disk Plow	TANDEMPL	75 mm	0.55
Tandem Disk Reg	TANDEMRG	75 mm	0.60
Single Disk	SINGLDIS	100 mm	0.45
Power Mulcher	PWRMULCH	50 mm	0.70
Blade 10 ft	BLADE 10	75 mm	0.25
Furrow Diker	FURWDIKE	100 mm	0.70
Beet Cultivator	BEETCULT	25 mm	0.25
Cultiweeder	CLTIWEED	100 mm	0.30
Packer	PACKER	40 mm	0.35

In addition to information about specific implements, the tillage database includes default information for the different crop residue management categories. Table A-10 summarizes the information in the database on the different residue management categories.

Table A-10: Generic management scenarios included in the tillage database.

Implement	Tillage Code	Mixing Depth	Mixing Efficiency
Generic Fall Plowing Operation	FALLPLOW	150 mm	0.95
Generic Spring Plowing Operation	SPRGPLOW	125 mm	0.50
Generic Conservation Tillage	CONSTILL	100 mm	0.25
Generic No-Till Mixing	ZEROTILL	25 mm	0.05

ASAE (1998b) categorizes tillage implements into five different categories—primary tillage, secondary tillage, cultivating tillage, combination primary tillage, and combination secondary tillage. The definitions for the categories are (ASAE, 1998b):

Primary tillage: the implements displace and shatter soil to reduce soil strength and bury or mix plant materials, pesticides, and fertilizers in the tillage layer. This type of tillage is more aggressive, deeper, and leaves a rougher soil surface relative to secondary tillage. Examples include plows—moldboard, chisel, disk, bedder; moldboard listers; disk bedders; subsoilers; disk harrows—offset disk, heavy tandem disk; and powered rotary tillers.

Secondary tillage: the implements till the soil to a shallower depth than primary tillage implements, provide additional pulverization, mix pesticides and fertilizers into the soil, level and firm the soil, close air pockets, and eradicate weeds. Seedbed preparation is the final secondary tillage operation. Examples include harrows—disk, spring, spike, coil, tine-tooth, knife, packer, ridger, leveler, rotary ground driven; field or field conditioner cultivators; rod weeders; rollers; powered rotary tillers; bed shapers; and rotary hoes.

Cultivating tillage: the implements perform shallow post-plant tillage to aid the crop by loosening the soil and/or by mechanical eradication of undesired vegetation. Examples include row crop cultivators—rotary ground-driven, spring tooth, shank tooth; rotary hoes; and rotary tillers.

Combination primary tillage: the implements perform primary tillage functions and utilize two or more dissimilar tillage components as integral parts of the implement.

Combination secondary tillage: the implements perform secondary tillage functions and utilize two or more dissimilar tillage components as integral parts of the implement.

ASAE (1998b) provides detailed descriptions and illustrations for the major implements. These are very helpful for those who are not familiar with farm implements.

A.3 PESTICIDE DATABASE

The pesticide database file (pest.dat) summarizes pesticide attribute information for various pesticides. The pesticide data included in the database was originally compiled for the GLEAMS model in the early nineties (Knisel, 1993). The following table lists the pesticides included in the pesticide database.

Table A-11: SWAT Pesticide Database

Trade Name	Common Name	Koc (ml/g)	Wash-off Fraction	Half-Life (days) Foliar	Half-Life (days) Soil	Water Solubility (mg/L)
2,4,5-TP	Silvex	2600	0.40	5.0	20.0	2.5
2 Plus 2	Mecoprop Amine	20	0.95	10.0	21.0	660000
Aatrex	Atrazine	100	0.45	5.0	60.0	33
Abate	Temephos	100000	0.65	5.0	30.0	0.001
Acaraben	Chlorobenzilate	2000	0.05	10.0	20.0	13
Accelerate	Endothall Salt	20	0.90	7.0	7.0	100000
Acclaim	Fenoxaprop-Ethyl	9490	0.20	5.0	9.0	0.8
Alanap	Naptalam Sodium Salt	20	0.95	7.0	14.0	231000
Alar	Daminozide	10	0.95	4.0	7.0	100000
Aldrin	Aldrin	300	0.05	2.0	28.0	0.1
Aliette	Fosetyl-Aluminum	20	0.95	0.1	0.1	120000
Ally	Metsulfuron-Methyl	35	0.80	30.0	120.0	9500
Amiben	Chloramben Salts	15	0.95	7.0	14.0	900000
Amid-Thin W	NAA Amide	100	0.60	5.0	10.0	100
Amitrol T	Amitrole	100	0.95	5.0	14.0	360000
Ammo	Cypermethrin	100000	0.40	5.0	30.0	0.004
Antor	Diethatyl-Ethyl	1400	0.40	10.0	21.0	105
A-Rest	Ancymidol	120	0.50	30.0	120.0	650
Arsenal	Imazapyr Acid	100	0.90	30.0	90.0	11000
Arsonate	MSMA	10000	0.95	30.0	100.0	1000000
Asana	Esfenvalerate	5300	0.40	8.0	35.0	0.002
Assert (m)	Imazamethabenz-m	66	0.65	18.0	35.0	1370
Assert (p)	Imazamethabenz-p	35	0.65	18.0	35.0	875
Assure	Quizalofop-Ethyl	510	0.20	15.0	60.0	0.31
Asulox	Asulam Sodium Salt	40	0.95	3.0	7.0	550000
Avenge	Difenzoquat	54500	0.95	30.0	100.0	817000
Azodrin	Monocrotophos	1	0.95	2.0	30.0	1000000
Balan	Benefin	9000	0.20	10.0	30.0	0.1
Banol	Propamocarb	1000000	0.95	15.0	30.0	1000000
Banvel	Dicamba	2	0.65	9.0	14.0	400000
Basagran	Bentazon	34	0.60	2.0	20.0	2300000

Trade Name	Common Name	Koc (ml/g)	Wash-off Fraction	Half-Life Foliar (days)	Half-Life Soil (days)	Water Solubility (mg/L)
Basta	Glufosinate Ammonia	100	0.95	4.0	7.0	1370000
Bayleton	Triadimefon	300	0.30	8.0	26.0	71.5
Baytex	Fenthion	1500	0.65	2.0	34.0	4.2
Baythroid	Cyfluthrin	100000	0.40	5.0	30.0	0.002
Benlate	Benomyl	1900	0.25	6.0	240.0	2
Benzex	BHC	55000	0.05	3.0	600.0	0.1
Betamix	Phenmedipham	2400	0.70	5.0	30.0	4.7
Betanex	Desmedipham	1500	0.70	5.0	30.0	8
Bidrin	Dicrotophos	75	0.70	20.0	28.0	1000000
Bladex	Cyanazine	190	0.60	5.0	14.0	170
Bolero	Thiobencarb	900	0.70	7.0	21.0	28
Bolstar	Sulprofos	12000	0.55	0.5	140.0	0.31
Bordermaster	MCPA Ester	1000	0.50	8.0	25.0	5
Botran	DCNA (Dicloran)	1000	0.50	4.0	10.0	7
Bravo	Chlorothalonil	1380	0.50	5.0	30.0	0.6
Buctril	Bromoxynil Octan. Ester	10000	0.20	3.0	7.0	0.08
Butyrac Ester	2,4-DB Ester	500	0.45	7.0	7.0	8
Caparol	Prometryn	400	0.50	10.0	60.0	33
Carbamate	Ferbam	300	0.90	3.0	17.0	120
Carsoron	Dichlobenil	400	0.45	5.0	60.0	21.2
Carzol	Formetanate Hydrochlor	1000000	0.95	30.0	100.0	500000
Cerone	Ethephon	100000	0.95	5.0	10.0	1239000
Chem-Hoe	Propham (IPC)	200	0.50	2.0	10.0	250
Chlordane	Chlordane	100000	0.05	2.5	100.0	0.1
Chopper	Imazapyr Amine	100	0.80	30.0	90.0	500000
Classic	Chlorimuron-ethyl	110	0.90	15.0	40.0	1200
Cobra	Lactofen	100000	0.20	2.0	3.0	0.1
Comite	Propargite	4000	0.20	5.0	56.0	0.5
Command	Clomazone	300	0.80	3.0	24.0	1000
Cotoran	Fluometuron	100	0.50	30.0	85.0	110
Counter	Terbufos	500	0.60	2.5	5.0	5
Crossbow	Triclopyr Amine	20	0.95	15.0	46.0	2100000
Curacron	Profenofos	2000	0.90	3.0	8.0	28
Cygon	Dimethoate	20	0.95	3.0	7.0	39800
Cyprex	Dodine Acetate	100000	0.50	10.0	20.0	700
Cythion	Malathion	1800	0.90	1.0	1.0	130
Dacamine	2,4-D Acid	20	0.45	5.0	10.0	890
Dacthal	DCPA	5000	0.30	10.0	100.0	0.5
Dalapon	Dalapon Sodium Salt	1	0.95	37.0	30.0	900000
Dasanit	Fensulfothion	10000	0.90	4.0	24.0	0.01
DDT	DDT	240000	0.05	10.0	120.0	0.1

Trade Name	Common Name	Koc (ml/g)	Wash-off Fraction.	Half-Life Foliar (days)	Half-Life Soil (days)	Water Solubility (mg/L)
Dedweed	MCPA Amine	20	0.95	7.0	25.0	866000
DEF	Tribufos	5000	0.25	7.0	30.0	2.3
Dessicant L-10	Arsenic Acid	100000	0.95	10000.0	10000.0	17000
Devrinol	Napropamide	400	0.60	15.0	70.0	74
Di-Syston	Disulfoton	600	0.50	3.0	30.0	25
Dibrom	Naled	180	0.90	5.0	1.0	2000
Dieldrin	Dieldrin	50000	0.05	5.0	1400.0	0.1
Dimilin	Diflubenzuron	10000	0.05	27.0	10.0	0.08
Dinitro	Dinoseb Phenol	500	0.60	3.0	20.0	50
Diquat	Diquat Dibromide	1000000	0.95	30.0	1000.0	718000
Dithane	Mancozeb	2000	0.25	10.0	70.0	6
Dowpon	Dalapon	4	0.95	37.0	30.0	1000
Dropp	Thidiazuron	110	0.40	3.0	10.0	20
DSMA	Methanearsonic Acid Na	100000	0.95	30.0	1000.0	1400000
Du-ter	Triphenyltin Hydroxide	23000	0.40	18.0	75.0	1
Dual	Metolachlor	200	0.60	5.0	90.0	530
Dyfonate	Fonofos	870	0.60	2.5	40.0	16.9
Dylox	Trichlorfon	10	0.95	3.0	10.0	120000
Dymid	Diphenamid	210	0.80	5.0	30.0	260
Dyrene	Anilazine	3000	0.50	5.0	1.0	8
Elgetol	DNOC Sodium Salt	20	0.95	8.0	20.0	100000
EPN	EPN	13000	0.60	5.0	5.0	0.5
Eradicane	EPTC	200	0.75	3.0	6.0	344
Ethanox	Ethion	10000	0.65	7.0	150.0	1.1
Evik	Ametryn	300	0.65	5.0	60.0	185
Evital	Norflurazon	600	0.50	15.0	90.0	28
Far-Go	Triallate	2400	0.40	15.0	82.0	4
Fenatrol	Fenac	20	0.95	30.0	180.0	500000
Fenitox	Fenitrothion	2000	0.90	3.0	8.0	30
Fruitone CPA	3-CPA Sodium Salt	20	0.95	3.0	10.0	200000
Fundal	Chlordimeform Hydroclo.	100000	0.90	1.0	60.0	500000
Funginex	Triforine	540	0.80	5.0	21.0	30
Furadan	Carbofuran	22	0.55	2.0	50.0	351
Fusilade	Fluazifop-P-Butyl	5700	0.40	4.0	15.0	2
Glean	Chlorsulfuron	40	0.75	30.0	160.0	7000
Goal	Oxyfluorfen	100000	0.40	8.0	35.0	0.1
Guthion	Azinphos-Methyl	1000	0.65	2.0	10.0	29
Harmony	Thifensulfuron-Methyl	45	0.80	3.0	12.0	2400
Harvade	Dimethipin	10	0.80	3.0	10.0	3000
Hoelon	Diclofop-Methyl	16000	0.45	8.0	37.0	0.8
Hyvar	Bromacil	32	0.75	20.0	60.0	700

Trade Name	Common Name	Koc (ml/g)	Wash-off Fraction	Half-Life Foliar (days)	Half-Life Soil (days)	Water Solubility (mg/L)
Imidan	Phosmet	820	0.90	3.0	19.0	20
Isotox	Lindane	1100	0.05	2.5	400.0	7.3
Karate	Lambda-Cyhalothrin	180000	0.40	5.0	30.0	0.005
Karathane	Dinocap	550	0.30	8.0	20.0	4
Karmex	Diuron	480	0.45	30.0	90.0	42
Kelthane	Dicofol	180000	0.05	4.0	60.0	1
Kerb	Pronamide	200	0.30	20.0	60.0	15
Krenite	Fosamine Ammon. Salt	150	0.95	4.0	8.0	1790000
Lannate	Methomyl	72	0.55	0.5	30.0	58000
Larvadex	Cyromazine	200	0.95	30.0	150.0	136000
Larvin	Thiodicarb	350	0.70	4.0	7.0	19.1
Lasso	Alachlor	170	0.40	3.0	15.0	240
Limit	Amidochlor	1000	0.70	8.0	20.0	10
Lontrel	Clopyralid	6	0.95	2.0	30.0	300000
Lorox	Linuron	400	0.60	15.0	60.0	75
Lorsban	Clorpyrifos	6070	0.65	3.3	30.0	0.4
Manzate	Maneb	1000	0.65	3.0	12.0	6
Marlate	Methoxychlor	80000	0.05	6.0	120.0	0.1
Matacil	Aminocarb	100	0.90	4.0	6.0	915
Mavrik	Fluvalinate	1000000	0.40	7.0	30.0	0.005
Metasystox	Oxydemeton-Methyl	10	0.95	3.0	10.0	1000000
Milogard	Propazine	154	0.45	5.0	135.0	8.6
Miral	Isazofos	100	0.65	5.0	34.0	69
Mitac	Amitraz	1000	0.45	1.0	2.0	1
Modown	Bifenox	10000	0.40	3.0	7.0	0.4
Monitor	Methamidophos	5	0.95	4.0	6.0	1000000
Morestan	Oxythioquinox	2300	0.50	10.0	30.0	1
Nemacur	Fenamiphos	240	0.70	5.0	5.0	400
Nemacur Sulfone	Fenamiphos Sulfone	45	0.70	18.0	18.0	400
Nemacur Sulfoxide	Fenamiphos Sulfoxide	40	0.70	42.0	42.0	400
Norton	Ethofumesate	340	0.65	10.0	30.0	50
Octave	Prochloraz	500	0.50	30.0	120.0	34
Oftanol	Isofenphos	600	0.65	30.0	150.0	24
Orthene	Acephate	2	0.70	2.5	3.0	818000
Orthocide	Captan	200	0.65	9.0	2.5	5.1
Oust	Sulfometuron-Methyl	78	0.65	10.0	20.0	70
Pay-Off	Flucythrinate	100000	0.40	5.0	21.0	0.06
Penncap-M	Methyl Parathion	5100	0.90	3.0	5.0	60
Phenatox	Toxaphene	100000	0.05	2.0	9.0	3
Phosdrin	Mevinphos	44	0.95	0.6	3.0	600000
Phoskil	Parathion (Ethyl)	5000	0.70	4.0	14.0	24

Trade Name	Common Name	Koc (ml/g)	Wash-off Fraction	Half-Life Foliar (days)	Half-Life Soil (days)	Water Solubility (mg/L)
Pipron	Piperalin	5000	0.60	10.0	30.0	20
Pix	Mepiquat Chlor. Salt	1000000	0.95	30.0	1000.0	1000000
Plantvax	Oxycarboxin	95	0.70	10.0	20.0	1000
Poast	Sethoxydim	100	0.70	3.0	5.0	4390
Polyram	Metiram	500000	0.40	7.0	20.0	0.1
Pounce	Permethrin	100000	0.30	8.0	30.0	0.006
Pramitol	Prometon	150	0.75	30.0	500.0	720
Prefar	Bensulide	1000	0.40	30.0	120.0	5.6
Prelude	Paraquat	1000000	0.60	30.0	1000.0	620000
Prime	Flumetralin	10000	0.40	7.0	20.0	0.1
Princep	Simazine	130	0.40	5.0	60.0	6.2
Probe	Methazole	3000	0.40	5.0	14.0	1.5
Prowl	Pendimethalin	5000	0.40	30.0	90.0	0.275
Pursuit	AC 263,499	10	0.90	20.0	90.0	200000
Pydrin	Fenvalerate	5300	0.25	10.0	35.0	0.002
Pyramin	Pyrazon	120	0.85	5.0	21.0	400
Ramrod	Propaclor	80	0.40	3.0	6.0	613
Reflex	Fomesafen Salt	60	0.95	30.0	100.0	700000
Rescue	2,4-DB Sodium Amine	20	0.45	9.0	10.0	709000
Ridomil	Metalaxyl	50	0.70	30.0	70.0	8400
Ro-Neet	Cycloate	430	0.50	2.0	30.0	95
Ronstar	Oxadiazon	3200	0.50	20.0	60.0	0.7
Roundup	Glyphosate Amine	24000	0.60	2.5	47.0	900000
Rovral	Iprodione	700	0.40	5.0	14.0	13.9
Royal Slo-Gro	Maleic Hydrazide	20	0.95	10.0	30.0	400000
Rubigan	Fenarimol	600	0.40	30.0	360.0	14
Sancap	Dipropetryn	900	0.40	5.0	30.0	16
Savey	Hexythiazox	6200	0.40	5.0	30.0	0.5
Scepter	Imazaquin Ammonium	20	0.95	20.0	60.0	160000
Sencor	Metribuzin	60	0.80	5.0	40.0	1220
Sevin	Carbaryl	300	0.55	7.0	10.0	120
Sinbar	Terbacil	55	0.70	30.0	120.0	710
Slug-Geta	Methiocarb	300	0.70	10.0	30.0	24
Sonalan	Ethalfluralin	4000	0.40	4.0	60.0	0.3
Spectracide	Diazinon	1000	0.90	4.0	40.0	60
Spike	Tebuthiuron	80	0.90	30.0	360.0	2500
Sprout Nip	Chlorpropham	400	0.90	8.0	30.0	89
Stam	Propanil	149	0.70	1.0	1.0	200
Supracide	Methidathion	400	0.90	3.0	7.0	220
Surflan	Oryzalin	600	0.40	5.0	20.0	2.5
Sutan	Butylate	400	0.30	1.0	13.0	44

Trade Name	Common Name	Koc (ml/g)	Wash-off Fraction	Half-Life Foliar (days)	Half-Life Soil (days)	Water Solubility (mg/L)
Swat	Phosphamidon	7	0.95	5.0	17.0	1000000
Tackle	Acifluorfen	113	0.95	5.0	14.0	250000
Talstar	Bifenthrin	240000	0.40	7.0	26.0	0.1
Tandem	Tridiphane	5600	0.40	8.0	28.0	1.8
Tanone	Phenthoate	250	0.65	2.0	40.0	200
Tattoo	Bendiocarb	570	0.85	3.0	5.0	40
TBZ	Thiabendazole	2500	0.60	30.0	403.0	50
Temik	Aldicarb	40	0.70	7.0	7.0	6000
Temik Sulfone	Aldicarb Sulfone	10	0.70	20.0	20.0	6000
Temik Sulfoxide	Aldicarb Sulfoxide	30	0.70	30.0	30.0	6000
Tenoran	Chloroxuron	3000	0.40	15.0	60.0	2.5
Terbutrex	Terbutryn	2000	0.50	5.0	42.0	22
Terrachlor	PCNB	5000	0.40	4.0	21.0	0.44
Terraneb	Chloroneb	1650	0.50	30.0	130.0	8
Terrazole	Etridiazole	1000	0.60	3.0	20.0	50
Thimet	Phorate	1000	0.60	2.0	60.0	22
Thiodan	Endosulfan	12400	0.05	3.0	50.0	0.32
Thiram	Thiram	670	0.50	8.0	15.0	30
Thistrol	MCPB Sodium Salt	20	0.95	7.0	14.0	200000
Tillam	Pebulate	430	0.70	4.0	14.0	100
Tilt	Propiconazole	1000	0.70	30.0	110.0	110
Tolban	Profluralin	2240	0.35	1.0	140.0	0.1
Topsin	Thiophanate-Methyl	1830	0.40	5.0	10.0	3.5
Tordon	Picloram	16	0.60	8.0	90.0	200000
Tralomethrin	Tralomethrin	100000	0.40	1.0	27.0	0.001
Treflan	Trifluralin	8000	0.40	3.0	60.0	0.3
Tre-Hold	NAA Ethyl Ester	300	0.40	5.0	10.0	105
Tupersan	Siduron	420	0.70	30.0	90.0	18
Turflon	Triclopyr Ester	780	0.70	15.0	46.0	23
Velpar	Hexazinone	54	0.90	30.0	90.0	3300
Vendex	Fenbutatin Oxide	2300	0.20	30.0	90.0	0.013
Vernam	Vernolate	260	0.80	2.0	12.0	108
Volck oils	Petroleum oil	1000	0.50	2.0	10.0	100
Vydate	Oxamyl	25	0.95	4.0	4.0	282000
Weedar	2,4-D amine	20	0.45	9.0	10.0	796000
Weed-B-Gon	2,4,5-T Amine	80	0.45	10.0	24.0	500000
Wedone	Dichlorprop Ester	1000	0.45	9.0	10.0	50
Zolone	Phosalone	1800	0.65	8.0	21.0	3

Knisel (1993) cites Wauchope et al. (1992) as the source for water solubility, soil half-life and K_{oc} values. Wash-off fraction and foliar half-life were obtained from Willis et al. (1980) and Willis and McDowell (1987).

A.3.1 WATER SOLUBILITY

The water solubility value defines the highest concentration of pesticide that can be reached in the runoff and soil pore water. While this is an important characteristic, researchers have found that the soil adsorption coefficient, K_{oc}, tends to limit the amount of pesticide entering solution so that the maximum possible concentration of pesticide in solution is seldom reached (Leonard and Knisel, 1988).

Reported solubility values are determined under laboratory conditions at a constant temperature, typically between 20°C and 30°C.

A.3.2 SOIL ADSORPTION COEFFICIENT

The pesticide adsorption coefficient reported in the pesticide database can usually be obtained from a search through existing literature on the pesticide.

A.3.3 SOIL HALF-LIFE

The half-life for a pesticide defines the number of days required for a given pesticide concentration to be reduced by one-half. The soil half-life entered for a pesticide is a lumped parameter that includes the net effect of volatilization, photolysis, hydrolysis, biological degradation and chemical reactions.

The pesticide half-life for a chemical will vary with a change in soil environment (e.g. change in soil temperature, water content, etc.). Soil half-life values provided in the database are “average” or representative values. Half-life values reported for a chemical commonly vary by a factor of 2 to 3 and sometimes by as much as a factor of 10. For example, the soil half-life for atrazine can range from 120 to 12 days when comparing values reported in cool, dry regions to those from warm, humid areas. Another significant factor is soil treatment history. Repeated soil treatment by the same or a chemically similar pesticide commonly results in a reduction in half-life for the pesticide. This reduction is attributed to the preferential build-up of microbial populations adapted to degrading the compound. Users are encouraged to replace the default soil half-life value with a site-specific or region-specific value whenever the information is available.

A.3.4 FOLIAR HALF-LIFE

As with the soil half-life, the foliar half-life entered for a pesticide is a lumped parameter describing the loss rate of pesticides on the plant canopy. For most pesticides, the foliar half-life is much less than the soil half-life due to enhanced volatilization and photodecomposition. While values for foliar half-life were available for some pesticides in the database, the majority of foliar half-life values were calculated using the following rules:

1) Foliar half-life was assumed to be less than the soil half-life by a factor of 0.5 to 0.25, depending on vapor pressure and sensitivity to photodegradation.
2) Foliar half-life was adjusted downward for pesticides with vapor pressures less than 10^{-5} mm Hg.
3) The maximum foliar half-life assigned was 30 days.

A.3.5 WASH-OFF FRACTION

The wash-off fraction quantifies the fraction of pesticide on the plant canopy that may be dislodged. The wash-off fraction is a function of the nature of the leaf surface, plant morphology, pesticide solubility, polarity of the pesticide molecule, formulation of the commercial product and timing and volume of the rainfall event. Some wash-off fraction values were obtained from Willis et al. (1980). For the remaining pesticides, solubility was used as a guide for estimating the wash-off fraction.

A.3.6 APPLICATION EFFICIENCY

The application efficiency for all pesticides listed in the database is defaulted to 0.75. This variable is a calibration parameter.

A.4 FERTILIZER DATABASE

The fertilizer database file (fert.dat) summarizes nutrient fractions for various fertilizers and types of manure. The following table lists the fertilizers and types of manure in the fertilizer database.

Table A-12: SWAT Fertilizer Database

Name	Name Code	Min-N	Min-P	Org-N	Org-P	NH_3-N/ Min N
Elemental Nitrogen	Elem-N	1.000	0.000	0.000	0.000	0.000
Elemental Phosphorous	Elem-P	0.000	1.000	0.000	0.000	0.000
Anhydrous Ammonia	ANH-NH3	0.820	0.000	0.000	0.000	1.000
Urea	UREA	0.460	0.000	0.000	0.000	1.000
46-00-00	46-00-00	0.460	0.000	0.000	0.000	0.000
33-00-00	33-00-00	0.330	0.000	0.000	0.000	0.000
31-13-00	31-13-00	0.310	0.057	0.000	0.000	0.000
30-80-00	30-80-00	0.300	0.352	0.000	0.000	0.000
30-15-00	30-15-00	0.300	0.066	0.000	0.000	0.000
28-10-10	28-10-10	0.280	0.044	0.000	0.000	0.000
28-03-00	28-03-00	0.280	0.013	0.000	0.000	0.000
26-13-00	26-13-00	0.260	0.057	0.000	0.000	0.000
25-05-00	25-05-00	0.250	0.022	0.000	0.000	0.000
25-03-00	25-03-00	0.250	0.013	0.000	0.000	0.000
24-06-00	24-06-00	0.240	0.026	0.000	0.000	0.000
22-14-00	22-14-00	0.220	0.062	0.000	0.000	0.000
20-20-00	20-20-00	0.200	0.088	0.000	0.000	0.000
18-46-00	18-46-00	0.180	0.202	0.000	0.000	0.000
18-04-00	18-04-00	0.180	0.018	0.000	0.000	0.000
16-20-20	16-20-20	0.160	0.088	0.000	0.000	0.000
15-15-15	15-15-15	0.150	0.066	0.000	0.000	0.000
15-15-00	15-15-00	0.150	0.066	0.000	0.000	0.000
13-13-13	13-13-13	0.130	0.057	0.000	0.000	0.000
12-20-00	12-20-00	0.120	0.088	0.000	0.000	0.000
11-52-00	11-52-00	0.110	0.229	0.000	0.000	0.000
11-15-00	11-15-00	0.110	0.066	0.000	0.000	0.000
10-34-00	10-34-00	0.100	0.150	0.000	0.000	0.000
10-28-00	10-28-00	0.100	0.123	0.000	0.000	0.000
10-20-20	10-20-20	0.100	0.088	0.000	0.000	0.000
10-10-10	10-10-10	0.100	0.044	0.000	0.000	0.000
08-15-00	08-15-00	0.080	0.066	0.000	0.000	0.000
08-08-00	08-08-00	0.080	0.035	0.000	0.000	0.000
07-07-00	07-07-00	0.070	0.031	0.000	0.000	0.000
07-00-00	07-00-00	0.070	0.000	0.000	0.000	0.000
06-24-24	06-24-24	0.060	0.106	0.000	0.000	0.000

Name	Name Code	Min-N	Min-P	Org-N	Org-P	NH_3-N/ Min N
05-10-15	05-10-15	0.050	0.044	0.000	0.000	0.000
05-10-10	05-10-10	0.050	0.044	0.000	0.000	0.000
05-10-05	05-10-05	0.050	0.044	0.000	0.000	0.000
04-08-00	04-08-00	0.040	0.035	0.000	0.000	0.000
03-06-00	03-06-00	0.030	0.026	0.000	0.000	0.000
02-09-00	02-09-00	0.020	0.040	0.000	0.000	0.000
00-15-00	00-15-00	0.000	0.066	0.000	0.000	0.000
00-06-00	00-06-00	0.000	0.026	0.000	0.000	0.000
Dairy-Fresh Manure	DAIRY-FR	0.007	0.005	0.031	0.003	0.990
Beef-Fresh Manure	BEEF-FR	0.010	0.004	0.030	0.007	0.990
Veal-Fresh Manure	VEAL-FR	0.023	***0.006***	0.029	***0.007***	0.990
Swine-Fresh Manure	SWINE-FR	0.026	0.011	0.021	0.005	0.990
Sheep-Fresh Manure	SHEEP-FR	***0.014***	0.003	***0.024***	0.005	0.990
Goat-Fresh Manure	GOAT-FR	***0.013***	***0.003***	***0.022***	***0.005***	0.990
Horse-Fresh Manure	HORSE-FR	***0.006***	0.001	***0.014***	0.003	0.990
Layer-Fresh Manure	LAYER-FR	0.013	0.006	0.040	0.013	0.990
Broiler-Fresh Manure	BROIL-FR	***0.010***	***0.004***	***0.040***	***0.010***	0.990
Turkey-Fresh Manure	TURK-FR	0.007	***0.003***	0.045	***0.016***	0.990
Duck-Fresh Manure	DUCK-FR	***0.023***	0.008	***0.025***	0.009	0.990

Values in bold italics are estimated (see section A.4.2)

A.4.1 COMMERCIAL FERTILIZERS

In compiling the list of commercial fertilizers in the database, we tried to identify and include commonly used fertilizers. This list is not comprehensive, so users may need to append the database with information for other fertilizers used in their watersheds.

When calculating the fractions of N and P for the database, it is important to remember that the percentages reported for a fertilizer are %N-%P_2O_5-%K_2O. The fraction of mineral N in the fertilizer is equal to %N divided by 100. To calculate the fraction of mineral P in the fertilizer, the fraction of P in P_2O_5 must be known. The atomic weight of phosphorus is 31 and the atomic weight of oxygen is 16, making the molecular weight of P_2O_5 equal to 142. The fraction of P in P_2O_5 is 62/142 = 0.44 and the fraction of mineral P in the fertilizer is equal to 0.44 (%P_2O_5 / 100).

A.4.2 MANURE

The values in the database for manure types were derived from manure production and characteristics compiled by the ASAE (1998a). Table A-13 summarizes the levels of nitrogen and phosphorus in manure reported by the ASAE. The data summarized by ASAE is combined from a wide range of published and unpublished information. The mean values for each parameter are determined by an arithmetic average consisting of one data point per reference source per year and represent fresh (as voided) feces and urine.

Table A-13: Fresh manure production and characteristics per 1000 kg live animal mass per day (from ASAE, 1998a)

			Animal Type‡										
Parameter			Dairy	Beef	Veal	Swine	Sheep	Goat	Horse	Layer	Broiler	Turkey	Duck
Total Manure	kg†	mean	86	58	62	84	40	41	51	64	85	47	110
		std dev	17	17	24	24	11	8.6	7.2	19	13	13	**
Total Solids	kg	mean	**12**	**8.5**	**5.2**	**11**	**11**	**13**	**15**	**16**	**22**	**12**	**31**
		std dev	2.7	2.6	2.1	6.3	3.5	1.0	4.4	4.3	1.4	3.4	15
Total Kjeldahl	kg	mean	**0.45**	**0.34**	**0.27**	**0.52**	**0.42**	**0.45**	**0.30**	**0.84**	**1.1**	**0.62**	**1.5**
nitrogen‖		std dev	0.096	0.073	0.045	0.21	0.11	0.12	0.063	0.22	0.24	0.13	0.54
Ammonia	kg	mean	**0.079**	**0.086**	**0.12**	**0.29**	**	**	**	**0.21**	**	**0.080**	**
nitrogen		std dev	0.083	0.052	0.016	0.10	**	**	**	0.18	**	0.018	**
Total	kg	mean	**0.094**	**0.092**	**0.066**	**0.18**	**0.087**	**0.11**	**0.071**	**0.30**	**0.30**	**0.23**	**0.54**
phosphorus		std dev	0.024	0.027	0.011	0.10	0.030	0.016	0.026	0.081	0.053	0.093	0.21
Ortho-	kg	mean	**0.061**	**0.030**	**	**0.12**	**0.032**	**	**0.019**	**0.092**	**	**	**0.25**
phosphorus		std dev	0.0058	**	**	**	0.014	**	0.0071	0.016	**	**	**

** Data not found.
† All values wet basis.
‡ Typical live animal masses for which manure values represent are: dairy, 640 kg; beef, 360 kg; veal, 91 kg; swine, 61 kg; sheep, 27 kg; goat, 64 kg; horse, 450 kg; layer, 1.8 kg; broiler, 0.9 kg; turkey, 6.8 kg; and duck, 1.4 kg.
‖ All nutrient values are given in elemental form.

The fractions of the nutrient pools were calculated on a Total Solids basis, i.e. the water content of the manure was ignored. Assumptions used in the calculations are: 1) the mineral nitrogen pool is assumed to be entirely composed of NH_3/NH_4^+, 2) the organic nitrogen pool is equal to total Kjeldahl nitrogen minus ammonia nitrogen, 3) the mineral phosphorus pool is equal to the value given for orthophosphorus, and 4) the organic phosphorus pool is equal to total phosphorus minus orthophosphorus.

Total amounts of nitrogen and phosphorus were available for all manure types. For manure types with either the ammonia nitrogen or orthophosphorus value missing, the ratio of organic to mineral forms of the provided element were used to partition the total amount of the other element. For example, in Table A-13 amounts of total Kjeldahl N, ammonia N, and total P are provided for veal but data for orthophosphorus is missing. To partition the total P into organic and mineral pools, the ratio of organic to mineral N for veal was used. If both ammonia nitrogen and orthophosphorus data are missing, the ratio of the organic to mineral pool for a similar animal was used to partition the total amounts of element into different fractions. This was required for goat and broiler manure calculations. The ratio of organic to mineral pools for sheep was used to partition the goat manure nutrient pools while layer manure nutrient ratios were used to partition the broiler manure nutrient pools.

As can be seen from the standard deviations in Table A-13, values for nutrients in manure can vary widely. If site specific data are available for the region or watershed of interest, those values should be used in lieu of the default fractions provided in the database.

A.5 URBAN DATABASE

The urban database file (urban.dat) summarizes urban landscape attributes needed to model urban areas. These attributes tend to vary greatly from region to region and the user is recommended to use values specific to the area being modeled. The following tables list the urban land types and attributes that are provided in the urban database.

Numerous urban land type classifications exist. For the default urban land types included in the database, an urban land use classification system created by Palmstrom and Walker (1990) was simplified slightly. Table A-14 lists the land type classifications used by Palmstrom and Walker and those provided in the database.

Table A-14: Urban land type classification systems

Palmstrom and Walker (1990)	**SWAT Urban Database**
Residential-High Density	Residential-High Density
Residential-Med/High Density	Residential-Medium Density
Residential-Med/Low Density	Residential-Med/Low Density
Residential-Low Density	Residential-Low Density
Residential-Rural Density	Commercial
Commercial	Industrial
Industrial-Heavy	Transportation
Industrial-Medium	Institutional
Transportation	
Institutional	

The urban database includes the following information for each urban land type: 1) fraction of urban land area that is impervious (total and directly connected); 2) curb length density; 3) wash-off coefficient; 4) maximum accumulated solids; 5) number of days for solid load to build from 0 kg/curb km to half of the maximum possible load; 6) concentration of total N in solid loading; 7) concentration of total P in solid loading; and 8) concentration of total NO_3-N in solid loading. The fraction of total and directly connected impervious areas is needed for urban surface runoff calculations. The remaining information is used only when the urban build up/wash off algorithm is chosen to model sediment and nutrient loading from the urban impervious area.

A.5.1 DRAINAGE SYSTEM CONNECTEDNESS

When modeling urban areas the connectedness of the drainage system must be quantified. The best methods for determining the fraction total and directly connected impervious areas is to conduct a field survey or analyze aerial photographs. However these methods are not always feasible. An alternative approach is to use data from other inventoried watersheds with similar land types. Table A-15 contains ranges and average values calculated from a number of different individual surveys (the average values from Table A-15 are the values included in the database). Table A-16 contains data collected from the cities of Madison and Milwaukee, Wisconsin and Marquett, Michigan.

Table A-15: Range and average impervious fractions for different urban land types.

Urban Land Type	Average total impervious	Range total impervious	Average connected impervious	Range connected impervious
Residential-High Density (> 8 unit/acre or unit/2.5 ha)	.60	.44 - .82	.44	.32 - .60
Residential-Medium Density (1-4 unit/acre or unit/2.5 ha)	.38	.23 - .46	.30	.18 - .36
Residential-Med/Low Density (> 0.5-1 unit/acre or unit/2.5 ha)	.20	.14 - .26	.17	.12 - .22
Residential-Low Density (< 0.5 unit/acre or unit/2.5 ha)	.12	.07 - .18	.10	.06 - .14
Commercial	.67	.48 - .99	.62	.44 - .92
Industrial	.84	.63 - .99	.79	.59 - .93
Transportation	.98	.88 - 1.00	.95	.85 – 1.00
Institutional	.51	.33 - .84	.47	.30 - .77

Table A-16: Impervious fractions for different urban land types in Madison and Milwaukee, WI and Marquett, MI.

Urban Land Type	Directly connected impervious	Indirectly connected impervious	Pervious
Residential-High Density	.51	.00	.49
Residential-Medium Density	.24	.13	.63
Residential-Low Density	.06	.10	.84
Regional Mall	.86	.00	.14
Strip Mall	.75	.00	.25
Industrial-Heavy	.80	.02	.18
Industrial-Light	.69	.00	.31
Airport	.09	.25	.66
Institutional	.41	.00	.59
Park	.08	.06	.86

A.5.2 CURB LENGTH DENSITY

Curb length may be measured directly by scaling the total length of streets off of maps and multiplying by two. To calculate the density the curb length is divided by the area represented by the map.

The curb length densities assigned to the different land uses in the database were calculated by averaging measured curb length densities reported in studies by Heaney et al. (1977) and Sullivan et al. (1978). Table A-17 lists the reported values and the averages used in the database.

Table A-17: Measured curb length density for various land types

Location: Land type	Tulsa, OK km/ha	10 Ontario Cities km/ha	Average of two values km/ha	SWAT database categories using average value:
Residential	0.30	0.17	0.24	All Residential
Commercial	0.32	0.23	0.28	Commercial
Industrial	0.17	0.099	0.14	Industrial
Park	0.17	--	0.17	
Open	0.063	0.059	0.06	
Institutional	--	0.12	0.12	Transportation, Institutional

A.5.3 WASH-OFF COEFFICENT

The database assigns the original default value, 0.18 mm^{-1}, to the wash-off coefficient for all land types in the database (Huber and Heaney, 1982). This value was calculated assuming that 13 mm of total runoff in one hour would wash off 90% of the initial surface load. Using sediment transport theory, Sonnen (1980) estimated values for the wash-off coefficient ranging from 0.002-0.26 mm^{-1}. Huber and Dickinson (1988) noted that values between 0.039 and 0.390 mm^{-1} for the wash-off coefficient give sediment concentrations in the range of most observed values. This variable is used to calibrate the model to observed data.

A.5.4 MAXIMUM SOLID ACCUMULATION AND RATE OF ACCUMULATION

The shape of the solid build-up equation is defined by two variables: the maximum solid accumulation for the land type and the amount of time it takes to build up from 0 kg/curb km to one-half the maximum value. The values assigned to the default land types in the database were extrapolated from a study performed by Sartor and Boyd (1972) in ten U.S. cities. They summarized the build-up of solids over time for residential, commercial, and industrial land types as well as providing results for all land types combined (Figure A-6).

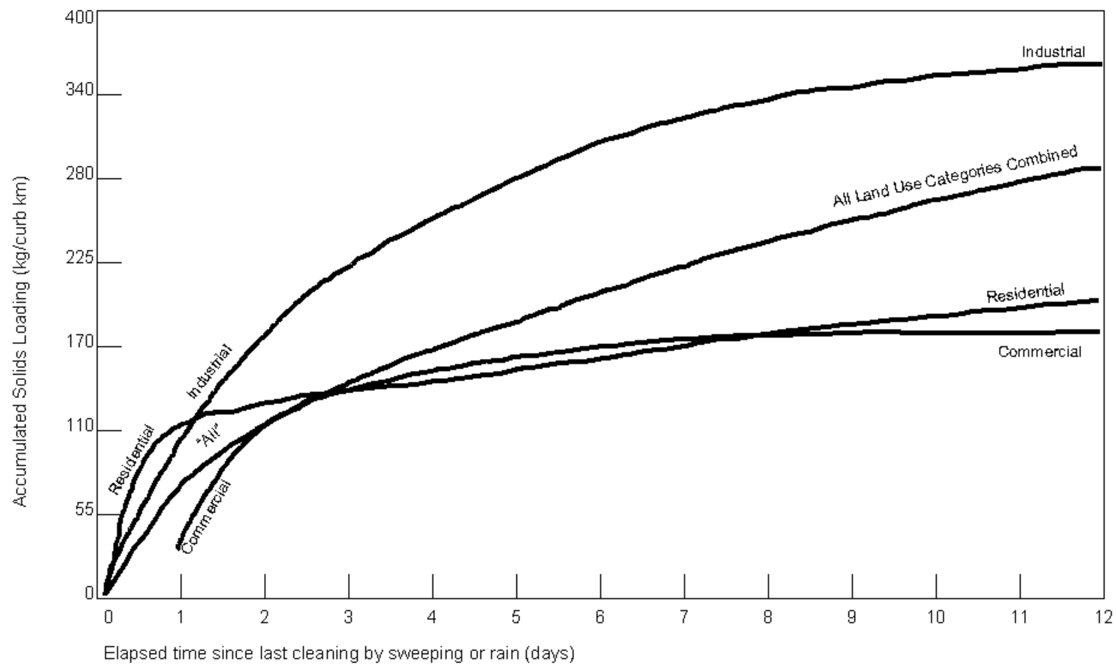

Figure A-6: Solid loading as a function of time (Sartor and Boyd, 1972)

The lines plotted in Figure A-6 were adapted for use in the database. Table A-18 lists maximum load values and time to accumulate half the maximum load that were derived from the graph. The assignment of values to the different land types is provided in the table also.

Table A-18: Maximum solid load and accumulation time (from Sartor and Boyd, 1972).

Land type	**Maximum loading kg/curb km**	**time to accumulate ½ maximum load days**	**SWAT database categories using value:**
Residential	225	0.75	All Residential
Commercial	200	1.60	Commercial
Industrial	400	2.35	Industrial
All land types	340	3.90	Transportation/Institutional

A.5.5 NUTRIENT CONCENTRATION IN SOLIDS

For the default land types in the database, nutrient concentrations in the solids were extrapolated from a nationwide study by Manning et al. (1977). The data published by Manning is summarized in Table A-19.

Three concentration values are required: total nitrogen (mg N/kg), nitrate nitrogen (mg NO_3-N/kg), and total phosphorus (mg P/kg). Manning provided total nitrogen values for all of his land use categories, nitrate values for one land use category and mineral phosphorus values for all the land use categories. To obtain nitrate concentrations for the other land use categories, the ratio of NO_3-N to total N for commercial areas was assumed to be representative for all the categories. The nitrate to total N ratio for commercial land was multiplied by the total N concentrations for the other categories to obtain a nitrate concentration. The total phosphorus concentration was estimated by using the ratio of organic phosphorus to orthophosphate provided by the Northern Virginia Planning District Commission (1979). Total phosphorus loads from impervious areas are assumed to be 75 percent organic and 25 percent mineral. Table A-20 summarizes the assignment of values to the default land types in the urban database.

Table A-19: Nationwide dust and dirt build-up rates and pollutant fractions (Manning et al., 1977)

Pollutant		**Land Use Category**				
		Single Family Residential	Mult. Family Residential	Commercial	Industrial	All Data
Dust & Dirt Accumulation	mean	17	32	47	90	45
(kg/curb km/day)	range	1-268	2-217	1-103	1-423	1-423
	# obs.	74	101	158	67	400
Total N-N	mean	460	550	420	430	480
(mg/kg)	range	325-525	356-961	323-480	410-431	323-480
	# obs.	59	93	80	38	270
NO_3	mean	--	--	24	--	24
(mg/kg)	range	--	--	10-35	--	10-35
	# obs.	--	--	21	--	21
PO_4-P	mean	49	58	60	26	53
(mg/kg)	range	20-109	20-73	0-142	14-30	0-142
	# obs.	59	93	101	38	291

Table A-20: Nutrient concentration assignments for default land types

	Manning et al (1977)	Modifications:	Final Value:	SWAT database categories using value:
Total Nitrogen-N				
Single Fam Res.	460 ppm	--	460 ppm	Residential: Med/Low & Low
Mult. Fam. Res.	550 ppm	--	550 ppm	Residential: Med. & High
Commercial	420 ppm	--	420 ppm	Commercial
Industrial	430 ppm	--	430 ppm	Industrial
All Data	480 ppm	--	480 ppm	Transportation/Institutional
Nitrate-N: multiply reported value by fraction of weight that is nitrogen to get NO_3-N				
Single Fam Res.		(5.5/420) x 460	6.0 ppm	Residential: Med/Low & Low
Mult. Fam. Res.		(5.5/420) x 550	7.2 ppm	Residential: Med. & High
Commercial	5.5 ppm	--	5.5 ppm	Commercial
Industrial		(5.5/420) x 430	5.6 ppm	Industrial
All Data		(5.5/420) x 480	6.3 ppm	Transportation/Institutional
Total Phosphorus-P: assume PO_4-P is 25% of total P				
Single Fam Res.	49 ppm PO_4-P	49/(.25)	196 ppm	Residential: Med/Low & Low
Mult. Fam. Res.	58 ppm PO_4-P	58/(.25)	232 ppm	Residential: Med. & High
Commercial	60 ppm PO_4-P	60/(.25)	240 ppm	Commercial
Industrial	26 ppm PO_4-P	26/(.25)	104 ppm	Industrial
All Data	53 ppm PO_4-P	53/(.25)	212 ppm	Transportation/Institutional

A.5.6 CURVE NUMBER

The database includes an entry for the SCS curve number value for moisture condition II to be used for impervious areas. This variable was added to the database to allow the user more control. The impervious area curve number is set to a default value of 98 for all urban land types.

REFERENCES

American Society of Agricultural Engineers, 1998a. Manure production and characteristics, p. 646-648. *In* ASAE Standards 1998, 45th edition, Section D384.1. ASAE, St. Joseph.

American Society of Agricultural Engineers, 1998b. Terminology and definitions for agricultural tillage implements, p. 261-272. *In* ASAE Standards 1998, 45th edition, Section S414.1. ASAE, St. Joseph.

Arnold, J.G. and J.R. Williams. 1995. SWRRB—A watershed scale model for soil and water resources management. p. 847-908. *In* V.P. Singh (ed) Computer models of watershed hydrology. Water Resources Publications.

Bailey, L.H. 1935. The Standard cyclopedia of horticulture. The Macmillan Publishing Co., New York, N.Y.

Consumer Nutrition Center. 1982. Composition of foods: Fruit and fruit juices. USDA Human Nutrition Information Service. Agricultural Handbook 8-9.

Diaz, R.A. and G.S. Campbell. 1988. Assessment of vapor density deficit from available air temperature information. ASA Annual Meetings, Anaheim, CA, Agron. Abstr., 1988, 16.

Duncan, W.G. and Hesketh, J.D. 1968. Net photosynthesis rates, relative leaf growth rates and leaf numbers of 22 races of maize grown at eight temperatures. Crop Sci. 8:670-674.

Hackett, C. and J. Carolane. 1982. Edible horticultural crops, a compendium of information on fruit, vegetable, spice and nut species, Part II: Attribute data. Division of Land Use Research, CSIRO, Canberra.

Heaney, J.P., W.C. Huber, M.A. Medina, Jr., M.P. Murphy, S.J. Nix, and S.M. Haasan. 1977. Nationwide evaluation of combined sewer overflows and urban stormwater discharges—Vol. II: Cost assessment and impacts. EPA-600/2-77-064b (NTIS PB-266005), U.S. Environmental Protection Agency, Cincinnati, OH.

Huber, W.C. and R.E. Dickinson. 1988. Storm water management model, version 4: user's manual. U.S. Environmental Protection Agency, Athens, GA.

Huber, W.C. and J.P. Heaney. 1982. Chapter 3: Analyzing residual discharge and generation from urban and non-urban land surfaces. p. 121-243. *In* D.J. Basta and B.T. Bower (eds). Analyzing natural systems, analysis for regional residuals—environmental quality management. John Hopkins University Press, Baltimore, MD.

Jensen, M.E., R.D. Burman, and R.G. Allen. 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70. ASCE, New York, N.Y.

Kiniry, J.R. 1998. Biomass accumulation and radiation use efficiency of honey mesquite and eastern red cedar. Biomass and Bioenergy 15:467-473.

Kiniry, J.R. 1999. Response to questions raised by Sinclair and Muchow. Field Crops Research 62:245-247.

Kiniry, J.R., R. Blanchet, J.R. Williams, V. Texier, C.A. Jones, and M. Cabelguenne. 1992b. Sunflower simulation using EPIC and ALMANAC models. Field Crops Res., 30:403-423.

Kiniry, J.R. and A.J. Bockholt. 1998. Maize and sorghum simulation in diverse Texas environments. Agron. J. 90:682-687.

Kiniry, J.R. C.A. Jones, J.C. O'Toole, R. Blanchet, M. Cabelguenne and D.A. Spanel. 1989. Radiation-use efficiency in biomass accumulationprior to grain-filling for five grain-crop species. Field Crops Research 20:51-64.

Kiniry, J.R., J.A. Landivar, M. Witt, T.J. Gerik, J. Cavero, L.J. Wade. 1998. Radiation-use efficiency response to vapor pressure deficit for maize and sorghum. Field Crops Research 56:265-270.

Kiniry, J.R., D.J. Major, R.C. Izaurralde, J.R. Williams, P.W. Gassman, M. Morrison, R. Bergentine, and R.P. Zentner. 1995. EPIC model parameters for cereal, oilseed, and forage crops in the northern Great Plains region. Can. J. Plant Sci. 75: 679-688.

Kiniry, J.R., W.D. Rosenthal, B.S. Jackson, and G. Hoogenboom. 1991. Chapter 5: Predicting leaf development of crop plants. p. 30-42. *In* Hodges (ed.) Predicted crop phenology. CRC Press, Boca Raton, FL.

Kiniry, J.R., M.A. Sanderson, J.R. Williams, C.R. Tischler, M.A. Hussey, W.R. Ocumpaugh, J.C. Read, G.V. Esbroeck, and R.L. Reed. 1996. Simulating Alamo switchgrass with the Almanac model. Agron. J. 88:602-606.

Kiniry, J.R., C.R. Tischler and G.A. Van Esbroeck. 1999. Radiation use efficiency and leaf CO_2 exchange for diverse C_4 grasses. Biomass and Bioenergy 17:95-112.

Kiniry, J.R. and J.R. Williams. 1994. EPIC Crop Parameters for Vegetables for the Nitrogen and Phosphorus Portions of the RCA Analysis. Memorandum.

Kiniry, J.R., J.R. Williams, P.W. Gassman, P. Debaeke. 1992a. A general, process-oriented model for two competing plant species. Transactions of the ASAE 35:801-810.

Kiniry, J.R., J.R. Williams, R.L. Vanderlip, J.D. Atwood, D.C. Reicosky, J. Mulliken, W.J. Cox, H.J. Mascagni, Jr., S.E. Hollinger and W.J. Wiebold. 1997. Evaluation of two maize models for nine U.S. locations. Agron. J. 89:421-426.

Knisel, W.G. (ed). 1993. GLEAMS: Groundwater loading effects of agricultural management systems, Version 2.10. UGA-CPES-BAED Publication No. 5. University of Georgia, Tifton, GA.

Körner, Ch. 1977. Blattdiffusionswiderstände verschiedener Pflanzen in der zentralalpinen Grasheide der Hohen Tauren. p. 69-81. *In* Cernusca, A. (ed.) Alpine Grasheide Hohe Tauern. Ergebnisse der Ökosystemstudie 1976. Veröff. Österr. MaB-Hochgebirgsprogr. „Hohe Tauern“. Vol 1. Universitätsverlag Wagner, Innsbruck.

Körner, Ch., J.A. Scheel and H. Bauer. 1979. Maximum leaf diffusive conductance in vascular plants. Photosynthetica 13:45-82.

Leonard, R.A. and W.G. Knisel. 1988. Evaluating groundwater contamination potential from herbicide use. Weed Tech. 2:207-216.

Manning, M.J., R.H. Sullivan, and T.M. Kipp. 1977. Nationwide evaluation of combined sewer overflows and urban stormwater discharges—Vol. III:

Characterization of discharges. EPA-600/2-77-064c (NTIS PB-272107) U.S. Environmental Protection Agency, Cincinnati, OH.

Manrique, L.A., J.R. Kiniry, T. Hodges, and D.S. Axness. 1991. Dry matter production and radiation interception of potato. Crop Sci. 31: 1044-1049.

Martin, J.H., W.H. Leonard and D.L. Stamp. 1976. Principles of field crop production, 3rd edition. Macmillan Publishing Co., Inc., New York.

Maynard, D.N. and Hochmuth. 1997. Knott's handbook for vegetable growers, 4th edition. John Wiley & Sons, Inc., New York.

Monteith, J.L. 1965. Evaporation and the environment. p. 205-234. *In* The state and movement of water in living organisms, XIXth Symposium. Soc. for Exp. Biol., Swansea. Cambridge University Press.

Northern Virginia Planning District Commission. 1979. Guidebook for screening urban nonpoint pollution management strategies: a final report prepared for Metropolitan Washington Council of Governments. Northern Virginia Planning District Commission, Falls Church, VA.

Nutrition Monitoring Division. 1984b. Composition of food: Cereal grains and pasta. USDA Human Nutrition Information Service. Agricultural Handbook 8-20.

Nutrition Monitoring Division. 1984c. Composition of food: Legumes and legume products. USDA Human Nutrition Information Service. AgriculturalHandbook 8-16.

Nutrition Monitoring Division. 1984d. Composition of food: Nut and seed products. USDA Human Nutrition Information Service. AgriculturalHandbook 8-12.

Nutrition Monitoring Division. 1984a. Composition of food: Vegetables and vegetable products. USDA Human Nutrition Information Service. Agricultural Handbook 8-11.

Palmstrom, N. and W.W. Walker, Jr. 1990. P8 Urban Catchment Model: User’s guide, program documentation, and evaluation of existing models, design concepts and Hunt-Potowomut data inventory. The Narragansett Bay Project Report No. NBP-90-50.

Sartor, J.D. and G.B. Boyd. 1972. Water pollution aspects of street surface contaminants. EPA-R2-72-081 (NTIS PB-214408) U.S. Environmental Protection Agency, Washington, DC.

Sonnen, M.B. 1980. Urban runoff quality: information needs. ASCE Journal of the Technical Councils 106(TC1): 29-40.

Stockle, C.O. and J.R. Kiniry. 1990. Variability in crop radiation-use efficiency associated with vapor pressure deficit. Field Crops Research 25:171-181.

Stockle, C.O., J.R. Williams, N.J. Rosenberg, and C.A. Jones. 1992. A method for estimating the direct and climatic effects of rising atmospheric carbon dioxide on growth and yield of crops: Part 1—Modification of the EPIC model for climate change analysis. Agricultural Systems 38:225-238.

Sullivan, R.H., W.D. Hurst, T.M. Kipp, J.P. Heaney, W.C. Huber, and S.J. Nix. 1978. Evaluation of the magnitude and significance of pollution from urban storm water runoff in Ontario. Research Report No. 81, Canada-Ontario Research Program, Environmental Protection Service, Environment Canada, Ottawa, Ontario.

Watson, D.J. 1958. The dependence of net assimilation rate on leaf area index. Ann. Bot. N.S. 22:37-54.

Wauchope, R.D., T.M. Buttler, A.G. Hornsby, P.W.M. Augustijn-Beckers, and J.P. Burt. 1992. The SCS/ARS/CES pesticide properties database for environmental decision-making. Environ. Contam. Toxicol. Reviews 123:1-164.

Willis, G.H. and L.L. McDowell. 1987. Pesticide persistence on foliage. Environ. Contam. Toxicol. Reviews 100:23-73.

Willis, G.H., W.F. Spencer, and L.L. McDowell. 1980. Chapter 18: The interception of applied pesticides by foliage and their persistence and washoff potential. p. 595-606. *In* W.G. Knisel (ed). CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems, Vol. 3. U.S. Dept. of Agri., Sci., and Education Adm., Conservation Research Report No. 26. U.S. Government Printing Office, Washington, D.C.