PARTITIONING OF BIOMASS IN THE CROP SUBMODEL OF WEPS (WIND EROSION PREDICTION SYSTEM)

A. Retta, D. V. Armbrust, L. J. Hagen

ABSTRACT. *A crop growth submodel (dubbed CROP) is being developed for the wind erosion prediction system (WEPS). One of the requirements of CROP is to estimate leaf and stem growth on a daily mass basis and supply these values to the appropriate subroutines. The separate effects of leaves and stems on the processes of wind erosion then can be taken into account in the model. We developed a procedure for calculating leaf and stem growth separately for six crops: corn (*Zea mays *L.), grain sorghum [*Sorghum bicolor *(L.) Moench)], soybean [*Glycine max *(L.) Merr.], winter wheat (*Triticum aestivum *L.), oat (*Avena sativa *L.), and rice (*Oryza sativa *L.). Above ground biomass was regressed on relative growing degree days (which is a ratio of the growing degree days from planting to any day, to the growing degree days from planting to physiological maturity), or relative growing days where temperature data were not available. Stem mass was regressed on above ground biomass. In both cases, the logistic (sigmoid) model was used. Differentiation of the stem mass equation in conjunction with the biomass equation enabled us to calculate the partitioning ratios of leaf, stem, and reproductive plant parts, as functions of relative growing degree days (or relative growing days). The partitioning equations were incorporated into CROP. Overall, CROP predicted leaf, stem, reproductive, and above ground masses agreed fairly well with measured data (r^2 ranged from 0.60 to 0.92, slopes from 0.65 to 1.18 and intercepts from –0.15 to 0.96 t ha^{-1}).* **Keywords.** *WEPS, Modeling, Biomass, Partioning of biomass.*

A new wind erosion prediction system (WEPS), intended to replace the wind erosion equation of Woodruff and Siddoway (1965), is being developed (Hagen, 1991). WEPS consists of submodels that simulate important processes related to wind erosion that occur in nature. The cover provided by crop residue and the silhouette area of growing crops and their residues are important factors that determine the amount of soil that may be eroded by wind. However, not all plant parts provide equal protection. It is estimated that on a per-unit-area basis, stems of young seedlings are about 10 to 20 times more effective than leaves in depleting wind energy, but the effectiveness of leaves increases as the crop develops (Hagen, 1991; Armbrust and Bilbro, 1995). Damage caused by wind and wind-blown soil particles affects leaves and stems differently (Armbrust, 1982; Fryrear, 1971). Additionally, future improvements in the WEPS residue decomposition submodel will include calculation of decomposition rates of leaves and stems. In order to account for the separate effects of leaves and stems of growing plants on the processes of wind erosion, the WEPS crop growth submodel (CROP) is required to estimate leaf, stem, and reproductive growth state variables and supply these values to the EROSION and other submodels. Thus, the CROP submodel needs to have the capability to partition aboveground biomass into leaf, stem, and reproductive masses.

Partitioning of aboveground biomass into leaf, stem, and reproductive parts is one of the areas in crop modeling that is least understood (Whisler et al., 1986). The influences of environmental factors such as soil temperature, water stress, excess nitrogen supply, source-sink imbalances, etc., on partitioning of newly formed assimilates is difficult to account in a direct and simple way. Consequently, many crop models use empirical methods to perform partitioning of aboveground biomass into the different plant parts. In a number of models, leaf area is calculated independently of biomass [CERES-Maize: Jones and Kiniry, 1986; SORKAM: Rosenthal et al., 1989 (except in periods of stress): EPIC: Williams et al., 1989]. In CERES-Maize, leaf mass is calculated as a function of leaf area, and stem mass as a function of leaf mass. Other models use partitioning fractions that remain constant during a given stage of growth, but may change at other stages of growth, to partition aboveground biomass into different plant parts (Vanderlip and Arkin, 1977; Wilkerson et al., 1983). The method of using constant [within a given stage(s) of growth] partitioning ratios is simple and convenient for single crop models. However, for multicrop models, such as CROP, partitioning fractions are needed for a wide range of crop and noncrop plants. Data to evaluate such parameters may not be readily available.

Where experimental data of leaf, stem, and other plant component masses, measured over sufficiently short intervals of time (usually once a week) during the entire growing season, are available, relationships can be derived that can be used to implement partitioning of biomass into

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different plant parts. The change in dry weight of a plant part between successive harvests is related to cumulative time of growth. However, the variability of such data can be so high that obtaining relationships that are reasonably reliable (have acceptable levels of correlation) may be difficult (van Keulen, 1986). Even if reasonably good fits can be obtained, different crops or different organs for the same crop may fit different types of models, which increases program complexity and unreliability. Ideally, a single model that fits partitioning data of different plant parts and all crops would greatly simplify coding of partitioning algorithms for a variety of crop and noncrop plants that have to be dealt with by the CROP submodel of WEPS. The parameters for such a model, of course, would be crop and organ dependent.

The logistic (sigmoid or S-curve) function has been used widely in modeling plant growth (Richards, 1969; Hunt, 1981). This function is well suited to mimic growth of plant components, which is characterized by periods of slow, rapid, declining, and zero rates of growth. The objective of this study was to develop regression parameters of the logistic model for partitioning of aboveground biomass into leaf, stem, and reproductive parts for soybean, corn, grain sorghum, winter wheat, and oats.

Materials and Methods

Field Data

Field plots for corn (1988 dryland, and 1990 under irrigation), sorghum (1987 dryland), soybean (1988 and 1990, dryland), winter wheat (1988 and 1989, dryland), and oat (1989 and 1990, dryland) were established in Manhattan, Kansas. Each crop was grown in a plot (15 × 65 m) that was divided into three sampling sites. Each crop was grown separately, and no statistical design was used. Ten adjacent plants were sampled destructively every week from randomly selected strips within a plant row. Leaf, stem, and reproductive masses were determined for each plant. Detailed descriptions of site and growth conditions for each crop are reported elsewhere (Retta and Armbrust, 1995). Data for all plants (up to 30) were averaged by sampling date and the means were used to derive partitioning parameters for each crop. Where data from multiple years for a crop were available, partitioning parameters were obtained using data from the year that had the most rainfall during the growing season (i.e., suffered the least water stress). This was done to minimize the influence of water stress on partitioning ratios.

Our grain sorghum data were limited to one year. We used this data to derive partitioning ratios for grain sorghum. For validation we obtained Reeves' (1971) grain sorghum growth data, which consisted of dry weights of

Table 1. Base temperatures used for calculating GDD (left part of table); and linear regression parameters of simulated on measured plant component masses (right side of table)

Crop	T_{bas} (°C)	Plant Part	Slope	Intercept (t/ha)	r^2	n
Soybean	10	Leaf mass	1.18	–0.15	0.62	192
Corn	8	Stem mass	0.65	0.61	0.73	192
Sorghum	10	Rep. mass	0.74	0.74	0.74	103
Wheat	0	Abg. mass	0.86	0.70	0.92	192
Oat	0					

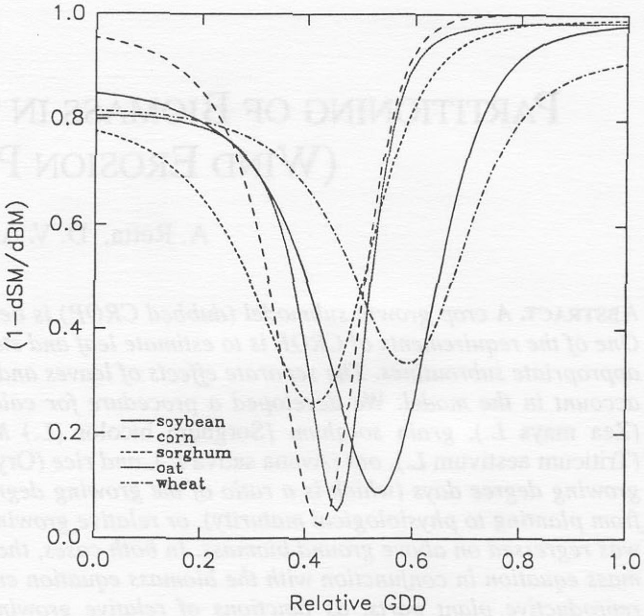

Figure 1–Values of (1 – dSM/dBM) for several crops.

leaves, stems, reproductive organs, and total aboveground biomass, sampled every five days from emergence to physiological maturity. Data were obtained for three grain sorghum hybrids (representing three maturity groups) over a two-year period.

In order to test the applicability of the hypothesized method on other crops and climatic conditions, Erdman's (1972) rice data as reported by van Keulen (1986) were included in the analysis. Because that report did not include data after anthesis, an estimated data pair for biomass and stem mass were added for that period (aboveground biomass at 0.8 RGD was assumed to be twice the amount measured at anthesis).

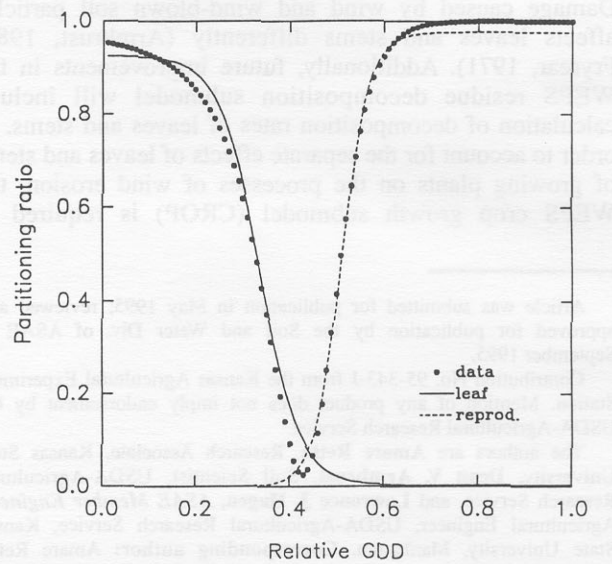

Figure 2–An example illustrating how partitioning ratios for leaf (solid line) and reproductive (dashed line) parts were obtained from "data" calculated using equations 2 and 4.

PARTITIONING METHOD

For each crop (except rice) the relative growing degree day (GDD_r) was calculated as a ratio of the growing degree day (GDD) accumulation at any time to the total GDD needed to grow the crop to physiological maturity (eq. 1):

$$GDD_r = \frac{\sum_{i=1}^{k} \left(T_{av} - T_{bas}\right)}{GDD_p} \quad (1)$$

where

T_{av} = daily average air temperature (°C)

T_{bas} = base temperature (°C)

GDD_p = total GDD from planting to physiological maturity (°C d)

GDD_r = ratio of GDD from planting to any day during the growing season, to the GDD at physiological maturity

k = number of days since planting

Growing degree days will accumulate if $T_{av} > T_{bas}$. In the case of the rice data relative growing days (RGD), which is the ratio of days from transplanting to an estimated number of days to physiological maturity, were used instead of GDD_r because no temperature data were available to calculate GDD. Base temperature data for each

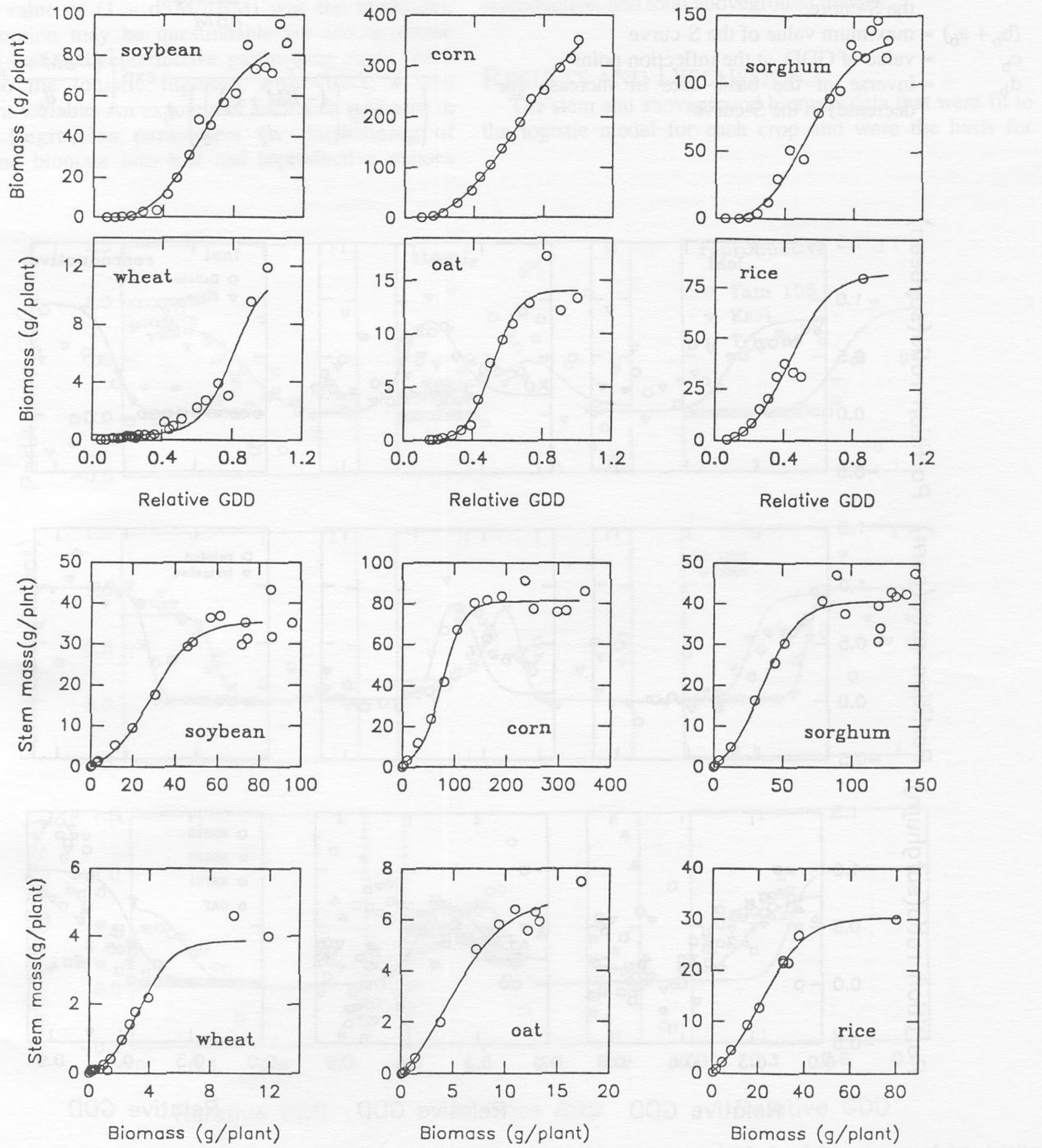

Figure 3–Logistic model fit (curve) for biomass and stem mass data of several crops. For rice the last data pair for both stem and biomass were estimated.

crop were obtained from EPIC (Williams et al., 1990b) (table 1).

Aboveground biomass data during the season were fitted to the logistic function for each crop (eq. 2). The independent variable was GDD_r:

$$BM = a_b + \frac{b_b}{1 + \exp\left[-\frac{(GDD_r - c_b)}{d_b}\right]} \quad (2)$$

where

BM = aboveground biomass (g/plant)

a_b = the line which is asymptotic to one side of the S-curve

$(b_b + a_b)$ = maximum value of the S-curve

c_b = value of GDD_r at the inflection point

d_b = inverse of the basic rate of increase (or decrease) in the S-curve

Stem dry weight data were fit to the logistic function (eq. 3) with aboveground biomass as the independent variable:

$$SM = a_s + \frac{b_s}{1 + \exp\left[-\frac{(BM - c_s)}{d_s}\right]} \quad (3)$$

where SM is the stem mass (g/plant) and a_s, b_s, c_s, d_s are regression coefficients.

Equation 3 is differentiated to yield equation 4:

$$\frac{dSM}{dBM} = \frac{b_s}{\left\{1 + \exp\left[\frac{(-BM + c_s)}{d_s}\right]\right\}^2 d_s} \exp\left[\frac{(-BM + c_s)}{d_s}\right] \quad (4)$$

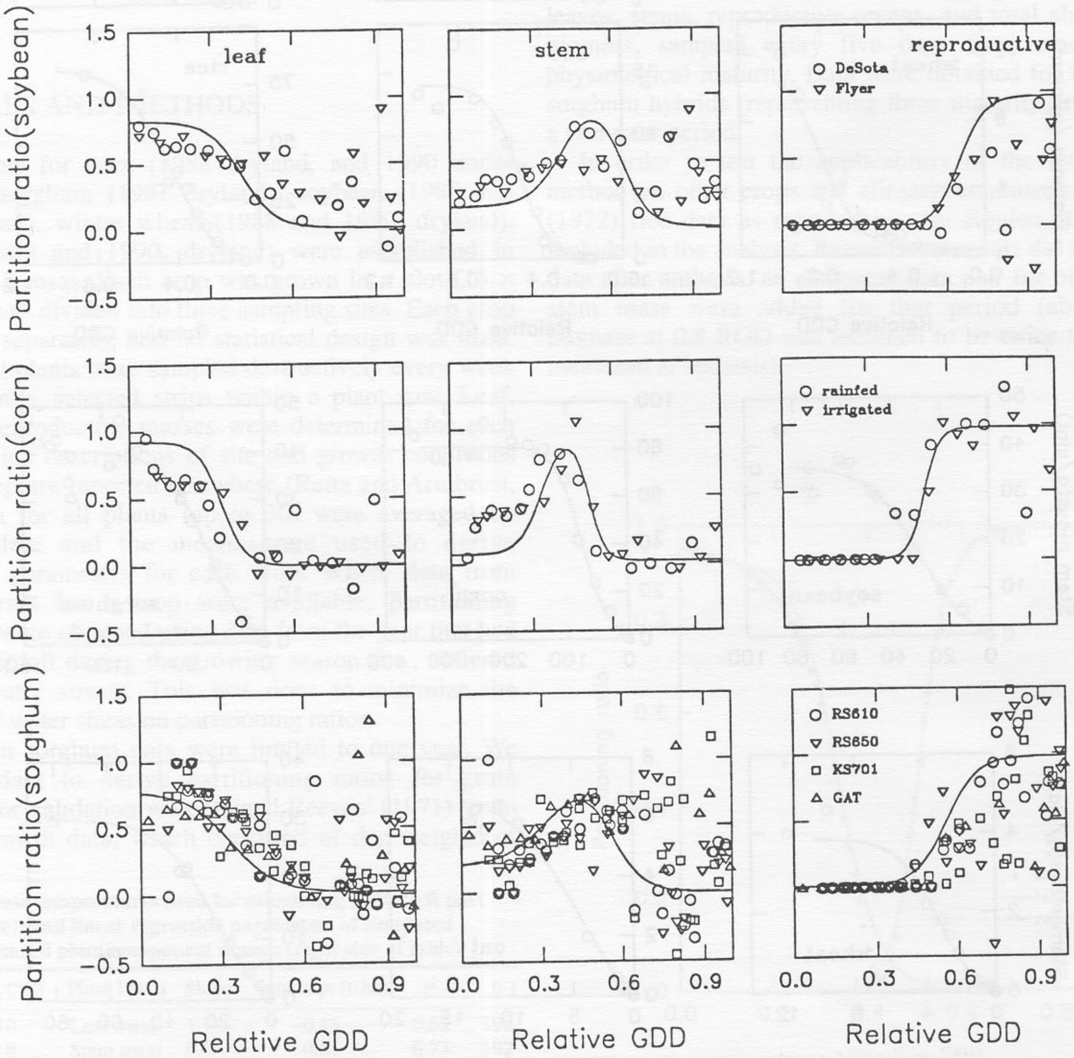

Figure 4–Comparison among partitioning ratios calculated using the regression models (curves), and calculated from measured data (scatter points). Top to bottom: soybean, corn, and sorghum; left to right: leaf, stem, and reproductive masses. Measured ratios greater than 1.5 or less than −0.5 are not shown in the graphs.

where dSM and dBM are increments in stem and aboveground biomass.

Regression equations 2 and 4 were used to calculate the stem partitioning ratio (dSM/dBM) over small increments in GDD_r. The values of (1 – dSM/dBM) then were calculated for each crop. The results are shown in figure 1. The values of (1 – dSM/dBM) from 0 GDD_r to about the time when the minimum value is reached were assigned as leaf partitioning ratios, and the values of (1 – dSM/dBM) after the minimum were assigned as reproductive partitioning ratios. This procedure assumes that during the leaf growth period, all newly produced aboveground biomass was allocated to stems and leaves and after the end of the leaf growth period, to stems and reproductive organs. It was also assumed that leaf growth essentially ended where the value of (1 – dSM/dBM) was the minimum. This assumption may be questionable for indeterminate crops. The leaf and reproductive partitioning ratios were then fit to the logistic function with GDD_r as the independent variable. An example of such a fit is shown in figure 2. Regression parameters for partitioning of aboveground biomass into leaf and reproductive masses were calculated for different crops using the mathematical software "TableCurve" (Jandel Scientific, 1991). The resulting equations can be used to estimate partitioning of newly formed aboveground biomass into leaf, stem, and reproductive parts at any time (expressed as GDD_r or RGD) during the growing season.

The CROP submodel calculates daily biomass production as a function of absorbed photosynthetically active radiation, crop radiation use efficiency, leaf area index, and an environmental stress factor. Parameters developed for the logistic curve were incorporated into CROP to partition simulated aboveground biomass into leaf, stem, and reproductive masses. Validation data sets not involved in deriving the partitioning parameters were then used to compare simulated and measured leaf, stem, reproductive, and total aboveground masses.

Results and Discussion

The stem and aboveground biomass data that were fit to the logistic model for each crop and were the basis for

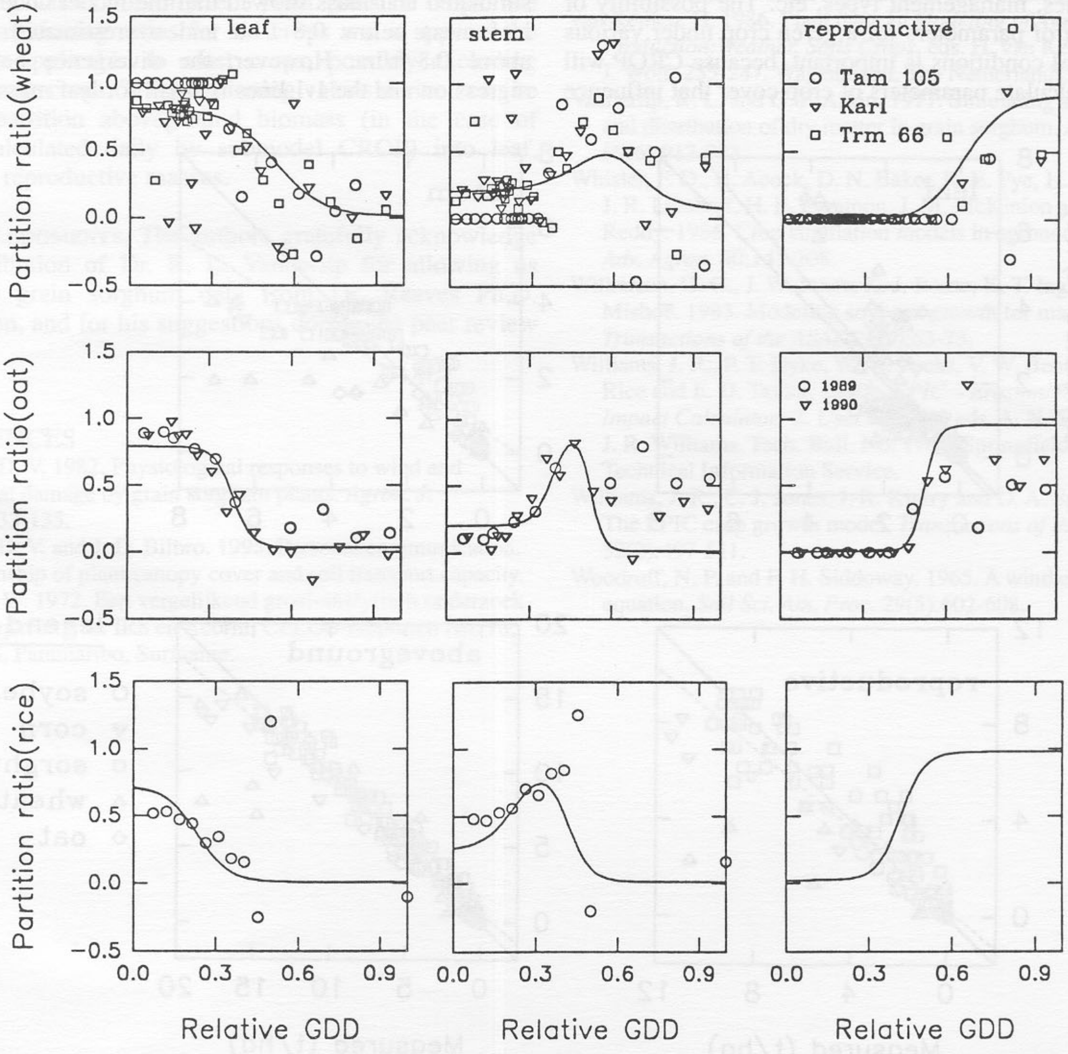

Figure 5–Comparison among partitioning ratios calculated using the regression models (curves), and calculated from measured data (scatter points). Top to bottom: winter wheat, oat, and rice; left to right: leaf, stem, and reproductive masses. Measured ratios greater than 1.5 or less than –0.5 are not shown in the graphs.

deriving partitioning functions are shown in figure 3. In all cases, the fit is good with r^2 ranging from 0.947 to 0.996.

The partitioning ratios obtained using the logistic regression equations were compared to ratios calculated from all measured data. The variability in the partitioning ratios derived from measured data was high, with some of the ratios being greater than 1.0 or less than 0.0 (figs. 4 and 5). Although, by definition, partitioning ratios can not be greater than 1 or less than 0, the y-axis was plotted with a range of –0.5 to 1.5 to show the relative number of data points outside of 1 and 0. This illustrates the difficulty in calculating partitioning ratios from measured data, Thus it was necessary to resort to indirect methods to get partitioning equations that are useable, yet general enough to apply to different plant parts and different crops.

Visual examination of figures 4 and 5 indicates that, overall, agreement between partitioning ratios derived from measured data and calculated from the logistic model is generally good. The logistic model represents the measured data that were not used in the development of the regression model with about the same accuracy as the data that were used to derive the regression model. This implies that the regression parameters are relatively stable and do not have to be changed to fit data from different years, soil types, varieties, management types, etc. The possibility of using one set of parameters for a given crop under various environmental conditions is important, because CROP will be used to calculate parameters of crop cover that influence soil loss by wind erosion for disparate regions of the United States, and eventually the world.

The potential for soil loss by wind erosion decreases as the amount of plant cover increases. At full canopy cover soil loss by wind erosion is negligible. To obtain accurate estimates of the protective value of growing plants, the model should estimate as accurately as possible leaf and stem mass growth during the early vegetative growth period. However, it is also necessary for the model to adequately estimate aboveground biomass growth throughout the growing period, because the accuracy of WEPS routines that model processes such as conversion of standing biomass to flat biomass, burying flat biomass, and decomposing new (and old) biomass, etc., will be dependent on the accuracy of biomass estimates made by the crop submodel. To test model accuracy, linear regressions of simulated on measured leaf, stem, reproductive, and aboveground masses were performed for five crops. No simulation was made for rice, because of lack of data on weather, soils, and management.

There were statistically significant linear correlations between simulated and measured leaf, stem, and reproductive masses, with r^2 ranging from 0.62 to 0.92 (table 1). Calculations using the regression of measured on simulated leaf mass showed that the model underestimated leaf mass below 0.8 t/ha and overestimated leaf mass above 0.8 t/ha. However, the divergence between the regression and the 1:1 lines is small for leaf mass values up

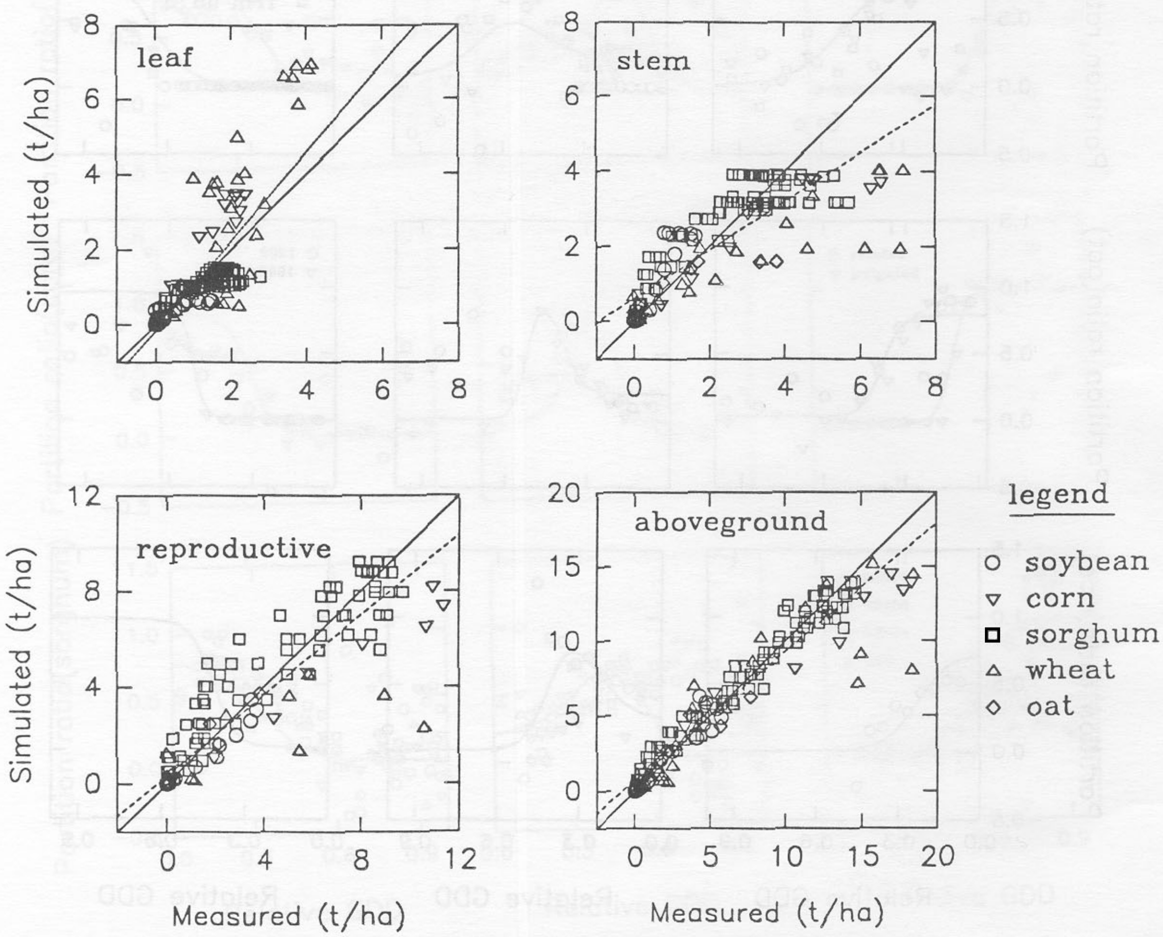

Figure 6–Comparison among measured and simulated leaf, stem, reproductive, and aboveground masses. The 1:1 (solid) and the regression (dashed) lines are included to help in comparing the data.

to about 2 t/ha which indicated that model estimates of leaf mass during the earlier part of the vegetative period was relatively good while leaf mass during the later part of the vegetative growing period was overestimated, particularly for wheat. Stem mass was overestimated early and underestimated during the later part of the vegetative growth period. As in the leaf mass, the divergence between the regression and the 1:1 lines was small during the earlier growth period. Again the overestimation of stem mass during the later part of the growing season was more severe for wheat than for other crops. Agreement among model estimated and measured aboveground and reproductive masses was good throughout the growing season (fig. 6). The above analysis indicates that overall, reasonably accurate estimates of leaf, stem, reproductive, and aboveground masses could be obtained for most crops using the ratio method, we derived, for partitioning aboveground biomass into its components.

CONCLUSIONS

Partitioning ratios derived using the logistic model with GDD_r (or RGD if GDD data is lacking) as the independent variable can be used to obtain reasonable estimates of daily partitioning values for different plant parts of crops. We derived partitioning ratios for six crops and it appears the method is applicable to most crops, possibly excluding indeterminate crops. The partitioning values derived can be used to partition aboveground biomass (in the case of WEPS calculated daily by submodel CROP) into leaf, stem, and reproductive masses.

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