A model of soybean growth under competition for light with common cocklebur

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By Yecai Liu

A research project submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirement for the degree of
Master of Biomathematics

Department of Statistics

Raleigh

1994

ABSTRACT

Yecai Liu. A model of soybean growth under competition for light with common cocklebur (under the direction of Dr. G. G. Wilkerson).

Five treatments were considered in this study: 'Essex' soybeans alone, 'Young' soybeans alone, cocklebur alone, Essex + cocklebur, Young + cocklebur. A simple model of interspecies competition for light was developed. This model was based on radiation information under assumption of adequate water, nutrients and no extreme temperature during the growing season. Total weight above ground, stem weight and leaf weight were simulated.

Field data indicated soybean height, diameter and V-stage were not affected by competition for light with cocklebur of low density (0.83 plant/m^2). Dry matter growth of soybean was reduced by competition in the simulation. Competition for light with cocklebur could vary between soybean varieties. Growth of Young was reduced less than that of Essex when competition occurred. The model is sensitive to weed density. The simulation indicated that soybean dry matter growth was reduced only slightly when weed density was less than 1.0 plant/m^2, but was reduced dramatically when weed density was greater than 2.0 plant/m^2. Cocklebur dry matter growth was underestimated seriously when competition occurred, but it could be improved by allowing a larger extinction coefficient early in the growing season. A long period of low PAR could cause problem since respiration was not adjusted by temperature in this model.

ACKNOWLEDGEMENTS

The author wishes to express appreciation to his Advisory Committee: Drs. R. E. Stinner (chairman), G. G. Wilkerson and H. J. Gold. They provided valuable advice and encouragement throughout the degree program.

The author is grateful to Dr. Wilkerson for her guidance and assistance in completing this project. The author is also grateful to Mr. Gregory S. Buol. He and Dr. Wilkerson provided the weather and field data for this study. It would not have been completed without their help.

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Introduction

Common cocklebur is a short-day plant that flowers and sets seeds when the critical night length is reached. Most of the seeds germinate and emerge. Consequently, a given area may be continually reinfected unless long-term weed control is applied (Bloomberg *et al.*, 1982). A single common cocklebur may grow to a height of 1.52 meters, and occupy a space of 4.3 meters in radius and 2.9 meters soil depth. It often emerges simultaneously with soybean (Barrentine *et al.*, 1974). Common cocklebur grows taller than soybean later in the season. In addition to maintaining leaves above the soybean canopy, common cocklebur maintains actively growing leaves below the top of the soybean canopy throughout the growth season as a result of leaf development from axillary buds along the lower main stems (Regnier *et al.*, 1988). Common cocklebur is a strong competitor with soybean for available water, light, and nutrients (Bloomberg *et al.*, 1982), and it is one of the worst broadleaf weeds on soybean farms in the southeast (Barrentine *et al.*, 1974).

Soybean growth and yield are reduced when competition with weeds occurs. The reduction of soybean growth and yield depends on the density of weeds. Yield reduction is from 3% to 88%, depending on weed species and density (Barrentine *et al.*, 1974;

Haggood *et al.*, 1981; Bloomberg *et al.*, 1982; Beckett *et al.*, 1988; Wilkerson *et al.*, 1990; Wilkerson *et al.*, 1991). Common cocklebur has more leaves within the soybean canopy than jimsonweed or velvetleaf (Regnier *et al.*, 1989a), and it is a stronger competitor for soybean. In addition to affecting soybean yield, competition may have an effect on soybean height, diameter, dry weights and leaf area. When water is not a limiting factor, soybean yield is affected most by common cocklebur competition, otherwise, soybean vegetative growth is affected most by common cocklebur competition (Bloomberg *et al.*, 1982). The best indicators of competition effects are leaf area index, plant dry weights, and yield of soybean. Soybean height is not affected by competition (Cordes *et al.*, 1984). Common cocklebur has an average influence area of 0.5 square meters in soybean. When the area of interference from adjacent common cocklebur plants overlap, the cumulative influence is additive. Also, common cocklebur is reduced by 50% to 90% in size with soybean interference (Henry *et al.*, 1989).

Competition for light, water, and nutrients have a large effect on soybean and common cocklebur growth. When water and nutrient availability is not a limiting factor, competition for light is dominant. Light is one of the key factors in photosynthesis, therefore, it has a significant effect on dry matter production. Both the percent light interception and the rate of dry matter production increase with leaf area development until they reach maximum and remain constant; the rate of dry matter production is linearly related to the percent light interception for soybean (Schibles and Weber, 1965). Dry weight is linearly related to cumulative intercepted photosynthetically active radiation for four potato cultivars, and estimates of daily light interception can give a reasonable prediction of daily biomass growth of potatoes (Manrique *et al.*, 1991). Competition for light is one of the major factors causing soybean yield loss (Stoller & Woolley, 1985; Regnier *et al.*, 1989b; Wilkerson *et al.*, 1990). Some models of competition for light between weed and crop have been developed. A deterministic model (Spitters & Aerts, 1983) called Weed-Crop simulates the competition between crop and weed for light and water. The model indicates crop biomass and yield are reduced because of competition. Another model of interspecies competition for light (Rimmington, 1984) describes the interception of light by the component species, and calculates the rate of dry matter production of each component species. Therefore, the effect of competition for light among species can be determined. SOYWEED (Wilkerson *et al.*, 1990) is a simulation model of crop/weed competition which could be used to investigate the effect of competition for light and water between soybean and cocklebur. Competition for light only occurs within an 'area of influence' in this model. When LTCOMP (Wiles & Wilkerson, 1991) is incorporated into SOYWEED and vertical leaf distribution is considered, the result of simulation of weed and crop growth is improved.

The objectives of this model are:

1) To determine the effect of competition for light on soybean and common cocklebur vegetative growth.
2) To determine the effect of competition for light on dry matter production for soybean and common cocklebur.
3) To determine the difference in competition for light with common cocklebur for the two soybean varieties: Essex and Young.
4) To determine the effect of weed density on soybean dry matter growth.
5) To determine if a simple model can adequately describe competition for light between a crop and a low density weed population.

Materials and Methods

The field experiment was established in May, 1992 at Clayton, North Carolina by Dr. G. G. Wilkerson at Crop Science Department at NCSU. A completely randomized block design with four replications and five treatments was used. The five treatments were: Essex alone, Young alone, common cocklebur alone, Essex + common cocklebur, and Young + common cocklebur. Soybeans were planted in rows 0.90 meters apart. Common cocklebur alone were also planted in rows 0.90 meters apart. Common cocklebur grown with soybean were planted 1.25 meters apart within soybean rows. One border row was placed between sample rows. Plots were irrigated to minimize competition for water. Height, diameter, and V-stage of soybean and common cocklebur were measured every week after emergence. Destructive samples were taken four times during the growing season, and total dry weight above ground, leaf dry weight, stem dry weight, leaf area, and leaf specific weight were also determined. The initial values for soybeans and common cocklebur were calculated based on plant density, average seed weight and partitioning factors for each species (Table 1.).

Table 1. Initial values for soybean and common cocklebur.

Treatment	Density (plants/m^2)	Whole plant	Canopy (g/m2)	Stem	Leaf
Essex alone	16.16	2.200	1.144	0.198	0.946
Essex + Weed	13.57	1.850	0.962	0.166	0.796
Young alone	19.89	2.750	1.430	0.248	1.183
Young + Weed	17.61	2.430	1.264	0.219	1.045
Weed alone	9.84	0.492	0.271	0.049	0.221
Weed + Essex	0.83	0.041	0.023	0.004	0.019
Weed + Young	0.83	0.041	0.023	0.004	0.019

Table 2. Initial values for weed of different density with soybean competition.

Density (plants/m^2)	Whole plant	Canopy (g/m^2)	Stem	Leaf
0.345	0.0174	0.0096	0.0017	0.0078
0.414	0.0207	0.0114	0.0021	0.0093
0.518	0.0259	0.0142	0.0026	0.0116
0.691	0.0346	0.0190	0.0035	0.0156
1.036	0.0518	0.0285	0.0052	0.0233
2.072	0.1036	0.0570	0.0104	0.0466
4.144	0.2072	0.1140	0.0207	0.0932
9.840 *	0.4920	0.2710	0.0490	0.2210
10.36	0.5180	0.2849	0.0518	0.2331

* weed alone.

In order to determine the effect of weed density on soybean growth, the initial values for weed with different density were also determined (Table 2.).

Parameters used in this model were estimated from the 1992 data and obtained from the literature (Wilkerson *et al.*, 1983; Wilkerson *et al.*, 1990; Wiles & Wilkerson, 1990; Kiniry *et al*, 1992).

Description of the Model

Crop growth is a result of the interaction of its genetic constitution and its environment. The weather conditions of the growing season have a major effect on crop development. The quantitative relationship between weather information and crop development is an interesting subject to modelers (France and Thorny, 1984). Dry matter production of soybean can be predicted based on radiation information under assumption of no extreme temperature, adequate water and nutrients during the growing season (Jones and Boote, 1987).

1) Structure model equations:

Soybean plants consist of leaf, stem, shell, seed, and root components. Photosynthesis converts CO_2 to carbohydrate (CH_2O). Some CH_2O is converted to plant tissues and some is used in respiration to maintain existing tissues. Organ growth rates are described by partitioning carbohydrate (CH_2O) to each component and utilizing CH_2O in synthesis and respiration. Plant components are described as grams of dry matter per square meter of ground area. The growth model can be established by describing the rate changes of dry matter components resulting from photosynthesis, respiration, tissue synthesis and senescence. First order nonlinear differential equations are applied to describe the change of dry matter rates for the major components. These equations are from SOYGRO (Wilkerson *et al*, 1983).

The overall soybean dry matter in g/m^2 is described as:

$$dW/dt = E_i(P_g - R_m) - S_l - S_s$$

where dW/dt is the growth rate of overall plants, P_g is photosynthesis, R_m is the maintenance respiration, and E_i is the efficiency of conversion for CH_2O to dry matter.

In order to represent dry matter accumulation in vegetative plant parts, the following equations are used:

$$dW_l/dt = X_l * E_i (P_g - R_m) - S_l$$

$$dW_s/dt = X_s * E_i (P_g - R_m) - S_s$$

$$dW_r/dt = X_r * E_i (P_g - R_m) - S_r$$

where dW_l/dt, dW_s/dt, dW_r/dt are the growth rates for leaf, stem, and root respectively. X_l, X_s, X_r are the partitioning coefficients for leaf, stem, and roots respectively, they depend on the physiological development of the crop. Roots are considered as a sink for CH_2O and are not included in the calculation of maintenance respiration.

The model structures for common cocklebur are similar to those for soybean (Wilkerson *et al*, 1990):

$$dW'/dt = E'_i(P'_g - R'_m) - S'_l - S'_s$$

$$dW'_l/dt = X'_l * E'_i (P'_g - R'_m) - S'_l$$

$$dW'_s/dt = X'_s * E'_i (P'_g - R'_m) - S'_s$$

$$dW'_r/dt = X'_r * E'_i (P'_g - R'_m) - S'_r$$

where dW'/dt, dW'_l/dt, dW'_s/dt, dW'_r/dt are the overall dry matter, leaf, stem, and root growth rates respectively. X'_l, X'_s, X'_r are the partitioning coefficients for leaf, stem, and roots respectively. E'_i is the efficiency of conversion.

2) Photosynthesis:

The primary effect of light competition is its influence on photosynthesis. Photosynthesis is reduced as light interception decreases. The daily gross photosynthesis rate per unit ground area of soybean canopy or common cocklebur is calculated by the following formula:

$$P_g = P^{max}_g * F_l$$

where P^{max}_g is the maximum potential photosynthesis rate of soybean or common cocklebur. F_l is the proportion of the available light intercepted (Wilkerson *et al*, 1990). The relationship between P^{max}_g and PAR developed by Ingram and colleagues (1981) is used to calculate P^{max}_g:

$$P^{max}_g = 1.67*PAR - 0.0173*PAR^2 \qquad 0 <= PAR <= 48.27 \quad \text{and}$$

$$P^{max}_g = 40.3 \qquad PAR > 48.27$$

The percentage of direct light penetrating a layer of crop canopy, integrated over a day has been described by an exponential function (Schibles & Weber, 1965):

$$I/I_o = \exp(-K*L)$$

where I_o is the irradiance above the canopy, I is irradiance below the canopy, K is the extinction coefficient and L is the leaf area index of the canopy. Light interception by a canopy can be approximated as the difference between the light intensity below and above the canopy. Total interception is computed assuming independence in the probability that a light beam will strike either crop or common cocklebur (Wilkerson *et al.*, 1990):

$$1-I/I_o = 1-\exp(-K*L-K'*L')$$

where $1-I/I_o$ is the proportion of direct light intercepted by the mixed canopy (soybean and common cocklebur), K and K' are the extinction coefficients for soybean and common cocklebur, L and L' are the leaf area indices for soybean and common cocklebur respectively. The extinction coefficient for soybean is assumed as 0.61 (Wiles & Wilkerson, 1991). The coefficient for common cocklebur is assumed as 0.90 (Kiniry *et al*, 1992). Both are assumed to be the same for the entire growing season.

One of the major differences between LTCOMP and this model is the assumption of leaf distribution. Three-layer model and a triangular function were used to model the effects of the vertical leaf structure in LTCOMP, but uniform and identical leaf distribution for soybean and cocklebur within the mixed canopy is assumed in this model. Based on the above assumption, the proportion of light interception by soybean can be determined by the following formula:

$$F_l = (1-I/I_o)*K*L/(k*L+K'*L').$$

The percentage of light interception by common cocklebur is $F'_l = (1-I/I_o)*K'*L'/(k*L+K'*L')$.

During the early growth period, competition between common cocklebur and soybean for light is small since leaves are not thoroughly intermingled horizontally. To avoid underestimation of early growth, no interspecies competition for light is assumed until the total leaf area index of soybean and common cocklebur is greater than 1.0.

Competition for light occurs within an 'area of influence' around each weed in SOYWEED (Wilkerson *et al*, 1990). In order to simplify the model structure, it is assumed that competition occurs in the whole canopy area in this model.

Leaf area index is calculated by the following formulas:

$L = W_l*SLA$ and

$L' = W'_l *SLA'$

where SLA and SLA' are the specific leaf areas for soybean and common cocklebur respectively. They were estimated from the 1992 data; 0.0029 m^2/g for Essex, 0.0032 m^2/g for Young, and 0.0019 m^2/g for common cocklebur.

3) Respiration:

A two component model (McCree, 1974) is used to describe the respiration: $R_m = R_1*W + R_2*P_g$, where R_m is the integrated daily respiration, P_g is the total of daily gross photosynthesis, and W is the total dry mass of living tissue. R_1 and R_2 are functions of temperature (McCree, 1974):

$$R_1=24*R_{1,30}*(0.044+0.0019*T+0.001*T^2)$$

$$R_2=24*R_{2,30}*(0.044+0.0019*T+0.001*T^2)$$

where $R_{1,30}$ equals to $3.5*10^{-4}$, and $R_{2,30}$ equals to 0.004 (Wilkerson *et al* 1983), T is the daily temperature. The daily temperature in the growing season is assumed as 30°C to simplify the model structure.

4) Partitioning coefficients:

Only vegetative dry matter growth is considered in this model. The partitioning coefficients for dry matter accumulation are needed to estimate the dry matter growth for each part of soybean and cocklebur. They are changed during the growing season. These partitioning coefficients for soybean and common cocklebur were obtained from SOYWEED (Wilkerson *et al*, 1990). The partitioning coefficients for soybean leaf can be determined by their relationship with V-stage:

$$X_l = 0.43 \qquad 1.5 <= \text{V-stage}$$

$$X_l = 0.43-0.0114*\text{V-stage} \qquad 1.5 < \text{V-stage} < 10.5$$

$$X_l = 0.31 \qquad \text{V-stage} >= 10.5$$

where X_l is the partitioning coefficient for soybean leaf. The partitioning coefficients for soybean stem are determined by V-stage too: $X_s = 0.09+0.04*\text{V-stage} \qquad \text{V-stage} <= 10.5$

$X_s = 0.51$ V-stage > 10.5

where X_s is the partitioning coefficient for soybean stem. The partitioning coefficients for soybean total weight above ground can be determined as $X_t = X_l + X_s$, where X_t is the partitioning coefficient for soybean total weight above ground.

The partitioning coefficients for common cocklebur are obtained from SOYWEED and they are determined by days after emergence (Wilkerson *et al*, 1990):

$X'_l = 0.45$ Days => 36

$X'_l = 0.70 - 0.0068*Days$ 36 < Days <= 90

$X'_l = 0.08$ Days > 90

$X'_s = 0.10 + 0.0084*Days$ Days <= 90

$X'_s = 0.86$ Days > 90

$X'_t = X'_l + X'_s$

where X'_l, X'_s and X'_t are partitioning coefficients for weed leaf, stem and total weight above ground.

5) Senescence:

A lot of factors such as leaf aging, water stress, competition for light, and protein remobilization can have an effect on soybean and common cocklebur leaf senescence. Leaf senescence of soybeans is handled in this model as a function of V-stage. Leaf senescence starts when V-stage is equal to 5, and increases linearly to 6% of leaf weight when V-stage is equal to 15: $S_l = (-0.03+0.006*V\text{-stage})*W_l$, where S_l is leaf senescence for soybean, W_l is the leaf weight for soybean. The petiole senescence, S_p is assumed to 50% of S_l based on the assumption that a petiole weighs 0.5 times as much as the leaf attached (Hanway & Weber, 1971). Leaf senescence for common cocklebur S'_l, is estimated as a function of days after emergence. Leaf senescence begins at 136 days after common cocklebur emerges, and S'_l is assumed to be 15% of leaf weight later in the growing season (Wilkerson *et al*, 1990). The weather data used in this model does not reach 136 days and it is assumed that no senescence for cocklebur during this early period.

6) Efficiency of conversion:

The efficiencies of conversion for soybeans are different among components: 0.66 for leaf, 0.71 for stem, and 0.79 for root. The efficiency of conversion for common cocklebur is assumed to be 0.68 for all components for the whole growing season (Wilkerson *et al*, 1983; Wiles & Wilkerson, 1990).

Results and Discussion

1) Effect of competition for light with common cocklebur on vegetative growth of soybean.

Soybean height and diameter with and without common cocklebur competition for light were fitted by nonlinear functions. Soybean V-stages were fitted by linear functions (Table 3 & 4). These functions fitted the data well and all had a R^2 of greater than 0.91.

Competition for light with weed had little effect on height growth of Essex and Young varieties (Figure 1). In general, both Essex and Young were taller than common cocklebur early in the growing season (Figure 1), and competition for light with common cocklebur had little effect on them. Once Essex and Young reached mature status and height growth stopped, common cocklebur surpassed them. Therefore, competition for light with common cocklebur did not affect soybean height growth under moderate weed density (0.83 plants/m^2 in this study).

Canopy diameter of Essex and Young varieties was not affected by cocklebur competition (Figure 2). This was expected given a low weed density in this study (0.83 plant/m^2). When competition is strong (weed density is high), both soybean and common cocklebur have a relatively small diameter (Herry & Bauman, 1989).

Table 3. Fitted functions for height, diameter and V-stage growth of Essex.

	Function	R^2
Height/alone	$= 1/(0.01010+0.35140*e^{-0.065*Days})$	0.9899
Height/cocklebur	$= 1/(0.00997+0.37622*e^{-0.065*Days})$	0.9849
Diameter/alone	$= 1/(0.01149+0.42663*e^{-0.075*Days})$	0.9962
Diameter/cocklebur	$= 1/(0.01151+0.41138*e^{-0.075*Days})$	0.9929
V-stage/alone	= -2.3010 + 0.20269*Days	0.9122
V-stage/cocklebur	= -2.1033 + 0.20076*Days	0.9160

Table 4. Fitted functions for height, diameter, and V-stage growth of Young.

	Function	R^2
Height/alone	$= 1/(0.00817+0.38431*e^{-0.065*Days})$	0.9841
Height/cocklebur	$= 1/(0.00771+0.40633*e^{-0.065*Days})$	0.9902
Diameter/alone	$= 1/(0.01058+0.40912*e^{-0.075*Days})$	0.9950
Diameter/cocklebur	$= 1/(0.01077+0.38013*e^{-0.075*Days})$	0.9959
V-stage/alone	= -3.4244 + 0.2377*Days	0.9749
V-stage/cocklebur	= -4.3555 + 0.2565*Days	0.9732

Competition for light with common cocklebur did not have an obvious effect on soybean V-stages (Figure 3). The soybean

V-stage has been shown to be most affected by cumulative temperature (Jones and Boote, 1987). Competition for light with common cocklebur did not change the soybean growth pattern during the vegetative phase covered in this study.

2) Effect of competition for light with soybean on vegetative growth of common cocklebur.

The vegetative growth of common cocklebur was fitted by nonlinear functions and linear functions (Table 5). All of these functions had high R^2 and they appeared to fit the data well. Common cocklebur height growth was not affected very much by soybean competition except for the last two data points (Figure 4). Since the weed density for weed alone was larger than for weed grown with soybean (Table 1), the increase of height for common cocklebur alone in the late growing season might be due to intraspecies competition.

Early in the growing season, competition with soybean did not influence common cocklebur diameter growth since the competition was weak. Later in the season, cocklebur diameter growth was decreased. Diameter growth of cocklebur with Young appeared to be affected more by competition than was that of cocklebur with Essex (Figure 5).

The V-stages of common cocklebur were not affected by soybean competition (Figure 6). Since temperature is the primary factor affecting V-staging rate (Jones and Boote, 1987), competition for light with soybean should have little effect on it.

Table 5. Fitted functions of height, diameter and v-stage growth of common cocklebur.

Function	R^2
Height/Alone = $1/(0.00756+0.50722*e^{-0.05*Days})$	0.9843
Height/Essex = $1/(0.00913+0.45066*e^{-0.05*Days})$	0.9944
Height/Young = $1/(0.00829+0.39031*e^{-0.05*Days})$	0.9948
Diameter/Alone = $1/(0.00950+0.48676*e^{-0.075*Days})$	0.9853
Diameter/Essex = $1/(0.01009+0.51802*e^{-0.075*Days})$	0.9816
Diameter/Young = $1/(0.01064+0.45547*e^{-0.075*Days})$	0.9863
V-stage/Alone = -3.9846 + 0.2615*Days	0.9726
V-stage/Essex = -4.0122 + 0.2725*Days	0.9794
V-stage/Young = -4.0077 + 0.2764*Days	0.9687

The competition effects for light of the two soybean varieties on common cocklebur showed a little difference. In general, Young had a stronger effect both on common cocklebur height and diameter since Young was taller and wider than Essex.

3) Simulated results for dry matter growth of soybean and cocklebur.

Two weather datasets from two weather stations close to Clayton were used to estimate the PAR since the weather information for Clayton was not available for 1992. These two stations were located in Raleigh and Smithfield, North Carolina. They were about 20 miles from Clayton. The temperatures appeared to be similar (Figure 7), but some differences existed for rainfall (Figure 8). PAR was estimated based on temperature and rainfall. Actual PAR at Clayton could be different from the calculated PAR. Although the calculated PAR were similar, some differences were obvious. The calculated PAR for Smithfield appeared to be greater than for Raleigh, especially late in the period (Figure 9).

These two estimated PAR datasets were used to simulate soybean and common cocklebur dry matter growth. Total weight above ground, stem weight and leaf weight were simulated.

a) Simulated results using Raleigh data.

Total weight above ground, stem weight and leaf weight for Essex were reduced when competition for light with common cocklebur occurred. At the early stage, since there was no competition, or just weak competition, dry matter growth for Essex alone and Essex with common cocklebur were similar. The reduction for dry matter growth of Essex with common cocklebur competition increased late in the season. The simulated data corresponded closely to field data for total weight above ground and stem weight, but leaf weights were overestimated. The trend was obvious: competition for light with common cocklebur would reduce dry matter growth of Essex (Figure 10).

Total weight above ground, stem weight and leaf weight for Young were reduced when competition for light with common cocklebur was increased. The simulated data did not respond closely to the field data. Total weight above ground for Young alone was overestimated at the early stage, but underestimated alone at late stage. Total weight above ground for Young grown with weed was overestimated. Leaf weights for Young were over estimated for the whole period (Figures 11).

The simulated data fit the field data well for common cocklebur alone, but underestimated common cocklebur grown with soybean. The dry matter growth for weed alone and weed grown with soybean were different since their densities were not the same (Table 1). The field data also showed the differences. Weed grown with Essex and Young had the same density. Young reduced common cocklebur dry matter growth more than Essex did in the simulation, but the field data showed little differences (Figure 12).

This model is very sensitive to weed density on soybean dry matter growth. The simulated data showed that soybean dry matter growth was reduced only slightly when weed density was less than 1.0 plant/m^2, but was reduced dramatically when weed density was greater than 2.0 plant/m^2 (Figure 13 and 14).

The effects of competition with common cocklebur appeared to be different on soybean varieties. Young dry matter was reduced less than Essex when competition occurred (Figures 13 and 14). The result indicates that competition for light with common cocklebur can vary between varieties. In general, Young grew taller and wider than Essex in this experiment. Therefore, Young was a stronger competitor and could get more sunlight during the late vegetative growing period than Essex.

Dry matter growth of cocklebur of different densities with soybean competition was simulated. The simulated data indicated that weed dry matter growth was increased as weed density increased. However, dry matter growth for weed alone was greater than weed grown with soybeans. The effects of competition for light with Essex and Young on common cocklebur were different. Dry matter of weed grown with Young was less than weed grown with Essex since Young was taller and wider (Figure 15 and 16). Young also had more leaf area than Essex since specific leaf area (SLA) of Young was larger than that of Essex. Young appeared to be a stronger competitor for cocklebur.

The soybean had a negative dry matter growth during period of 85 to 88 days from planting. The negative growth was due to the low PAR value (below 8 E/m^2). When the photosynthesis rate was less than respiration rate, a negative growth would occur since the model was not adjusted by temperature and rainfall. If a long period of low PAR occurred, simulated data would be seriously biased from field data because of the negative growth.

b) Simulated results using Smithfield data.

In general, the simulated data were similar as from the Raleigh data since the calculated PAR were similar. The simulated data were greater in the late stage because Smithfield had a higher calculated PAR values than Raleigh (Figures 17 to 23).

Growth of Cocklebur with soybean was seriously underestimated. The simulation for cocklebur could be improved (Figure 26) by allowing a larger cocklebur extinction coefficient (K'=1.0 for cocklebur with Essex and K'=1.1 for cocklebur with Young), but the simulation for cocklebur alone was overestimated and soybean with weed was underestimated (Figures 24, 25 and 26). It appeared that allowing a larger extinction coefficient for cocklebur only during the early growing season would help to improve the simulation. Since different extinction coefficients for cocklebur under Essex and Young competition were needed in order to fit the field data, some other factors might have an effect on the output of this model. In SOYWEED (Wilkerson *et al* 1990), competition for light occurs only within an 'area of influence' around each weed. LTCOMP (Wilkerson *et al* 1990) incorporated into SOYWEED, a three-layer model is used to describe the main effects of vertical structure of the mixed canopy. Water supply and respiration adjusted by temperature are also considered in SOYWEED. The uniform and identical leaf distribution, competition for light occurring in the whole canopy area, no extreme temperature, and adequate water and nutrient supplies during the growing season are some of the basic assumptions in this model. The simulation indicates that they can be the major concerns.

Conclusion

Soybean height, diameter width and V-stage were not affected by competition for light with common cocklebur of low density (0.83 plant/m^2 in this study). Dry matter growth of soybean was reduced by competition. The simulated data responded closely to the field data for Essex and common cocklebur alone, but underestimated Young and common cocklebur grown with soybean. This result indicated that this simple model can reflect soybean growth under weed competition appropriately. The long period of low PAR have a effect on this model. The simulation showed that assumptions of competition for light in the whole canopy area and uniformly leaf distribution structure can cause bias from the field data.

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Figure 1. Height growth for Essex and Young varieties.

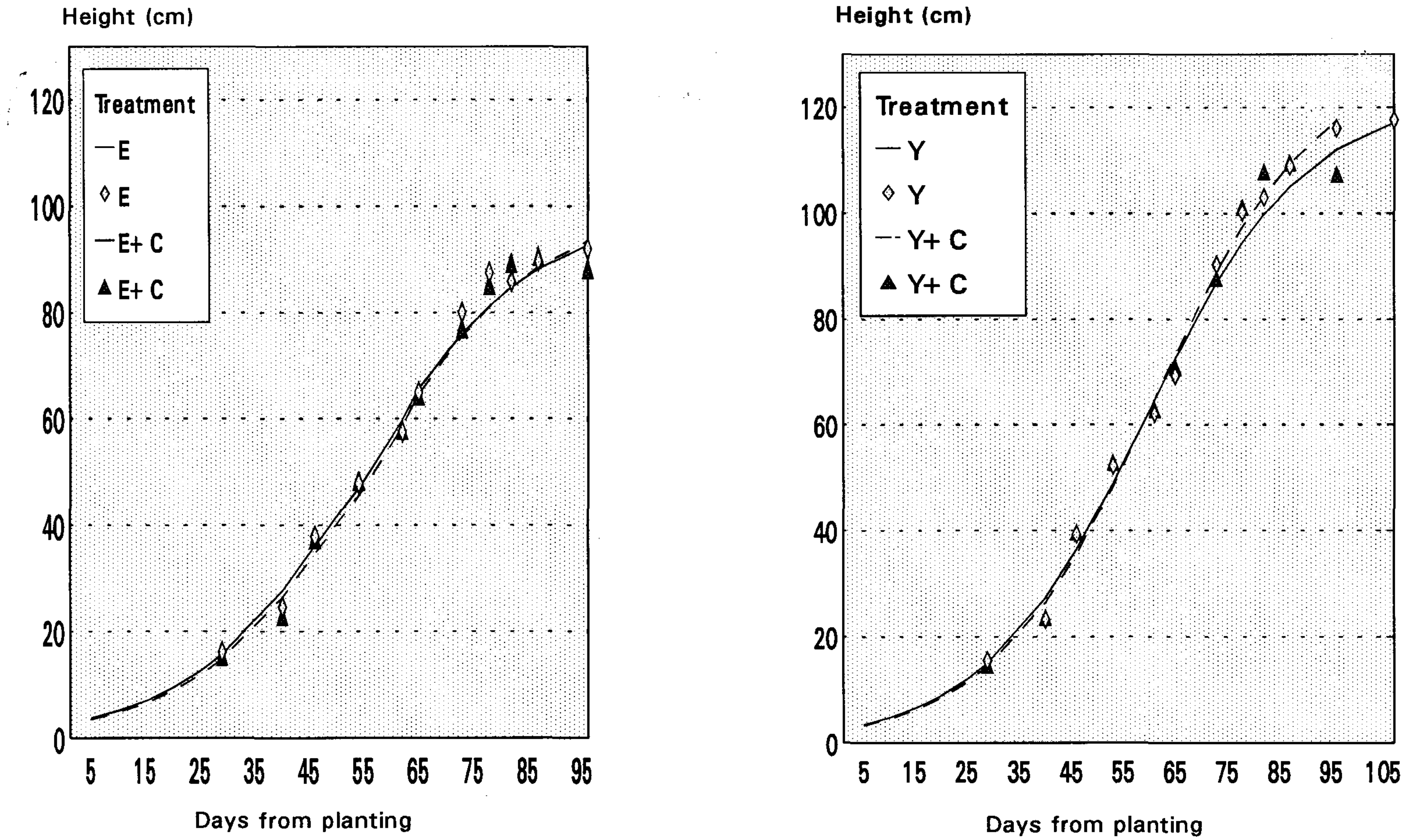

Figure 2. Diameter width growth for Essex and Young varieties.

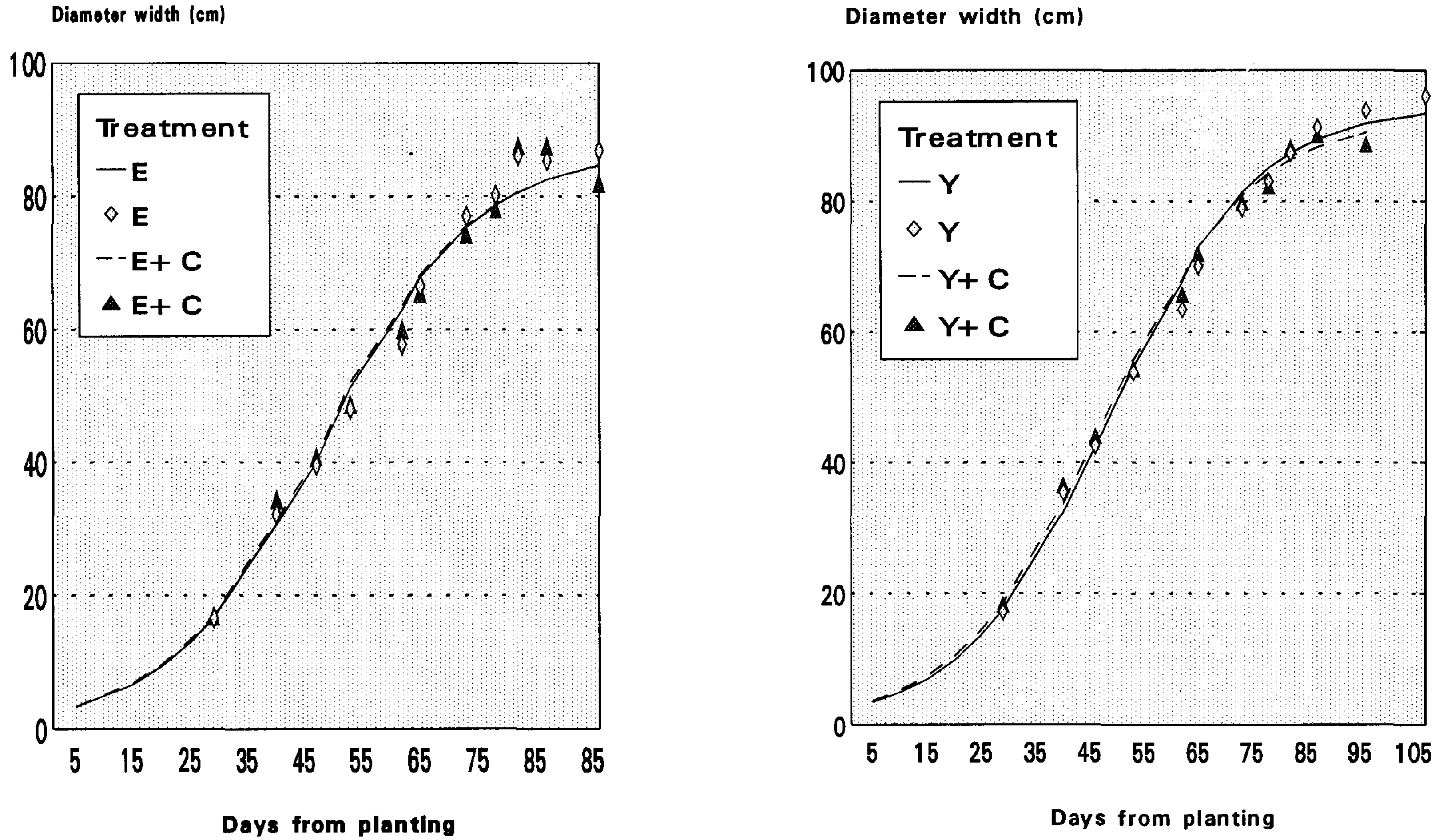

Figure 3. V-stage development of Essex and Young varieties.

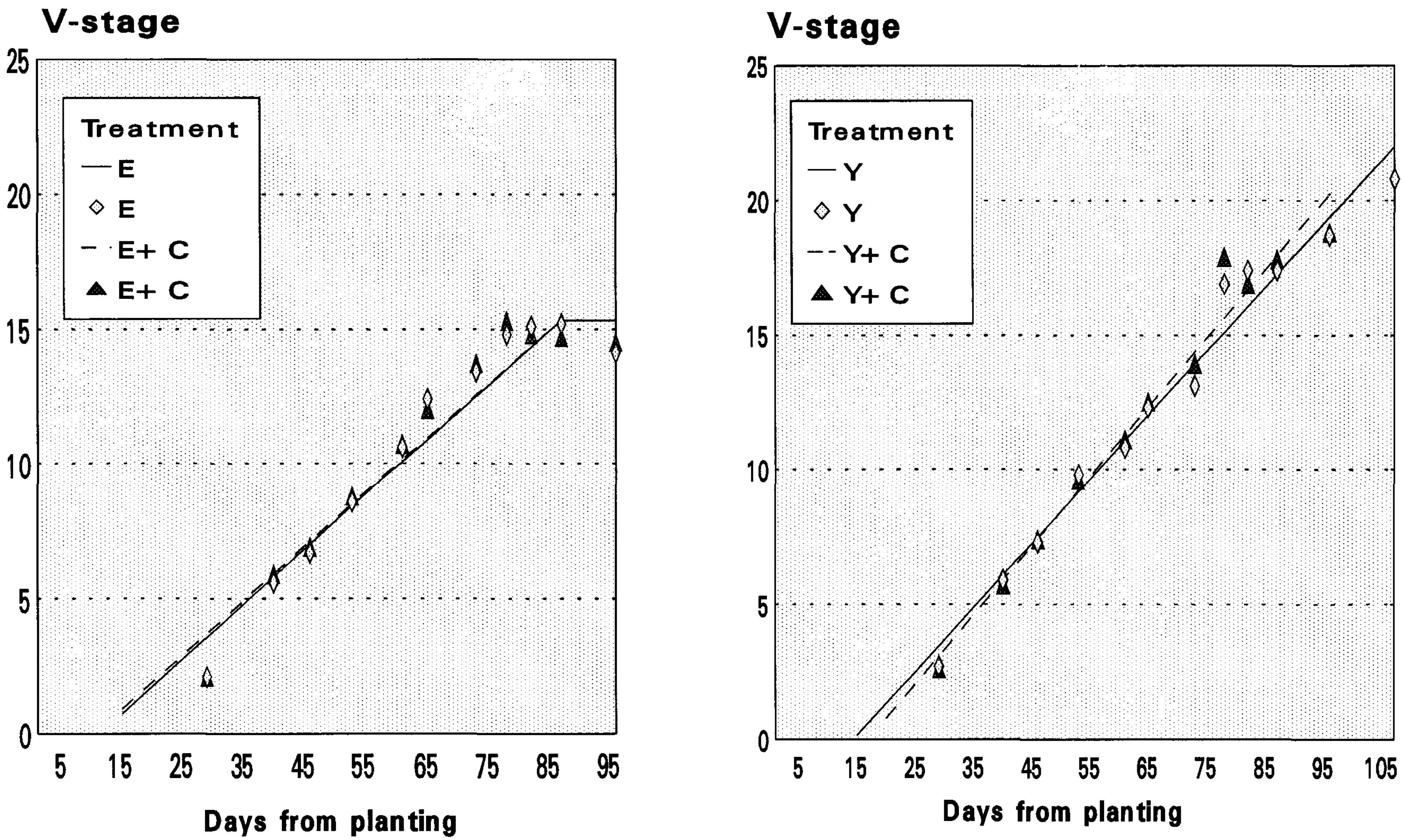

Figure 4. Height growth of cocklebur with Essex and Young competition.

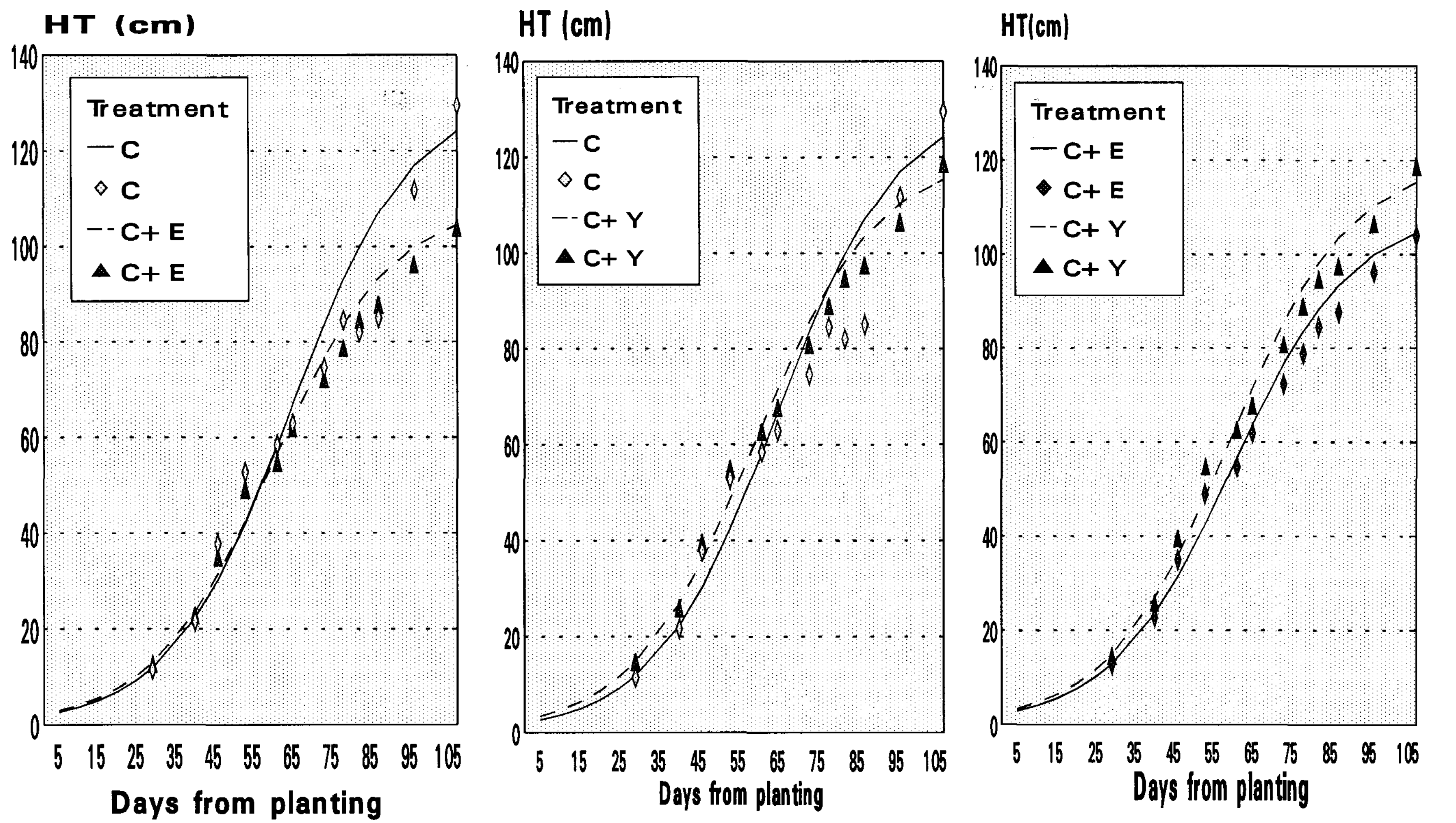

Figure 5. Diameter growth of cocklebur with Essex and Young competition.

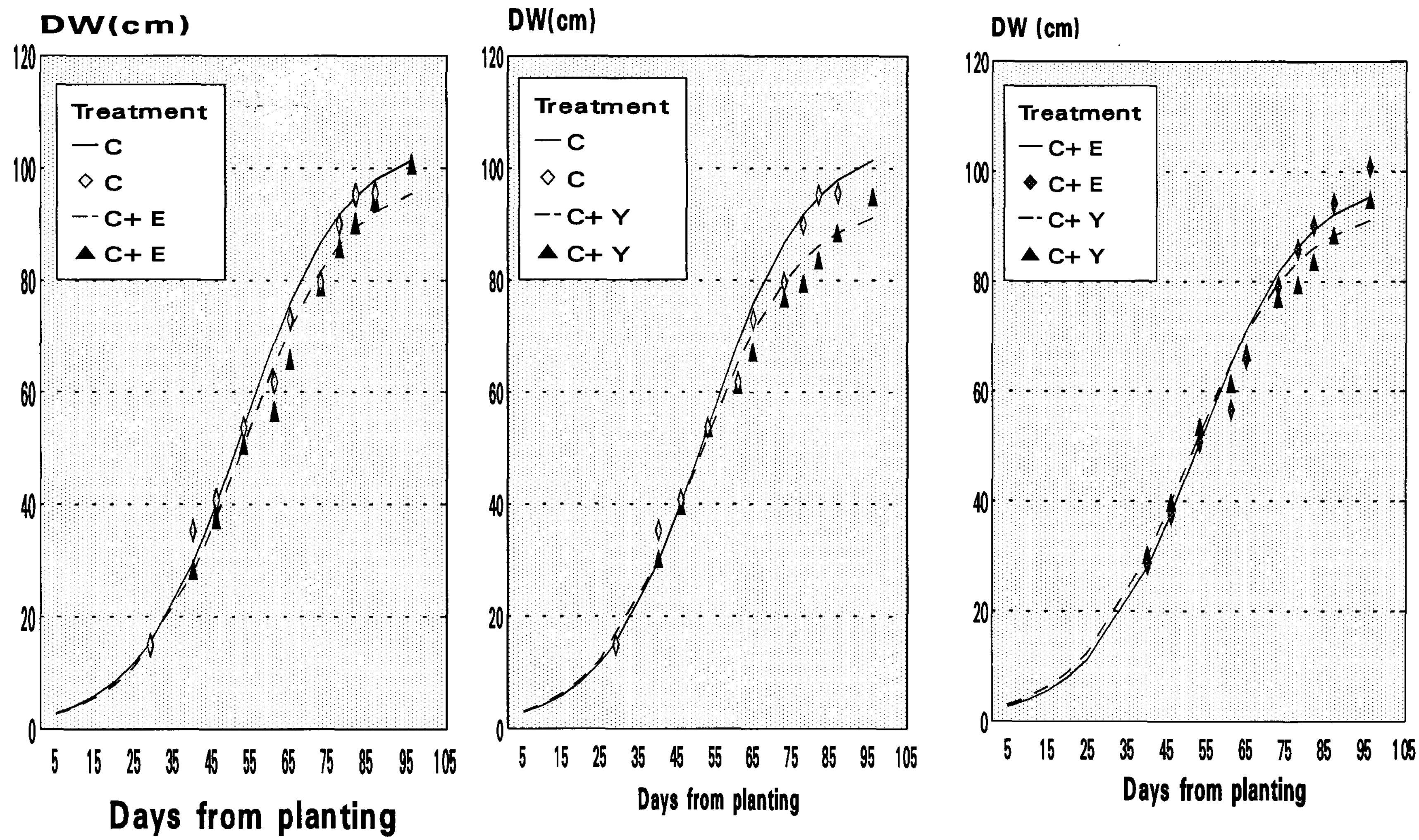

Figure 6. V-stage development of cocklebur with Essex and Young competition

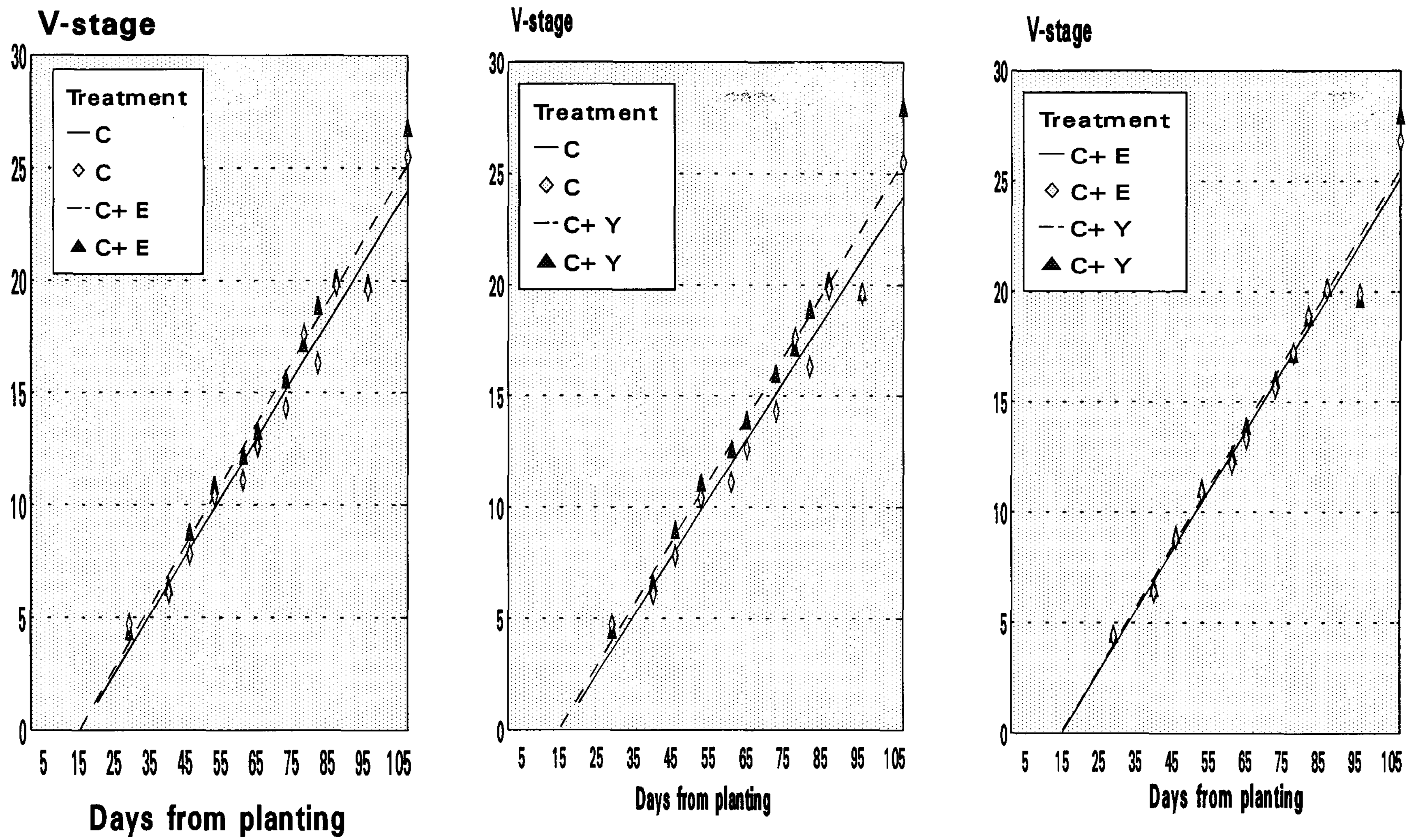

Figure 7. Comparision of maximax and minimum temperature for the two weather stations.

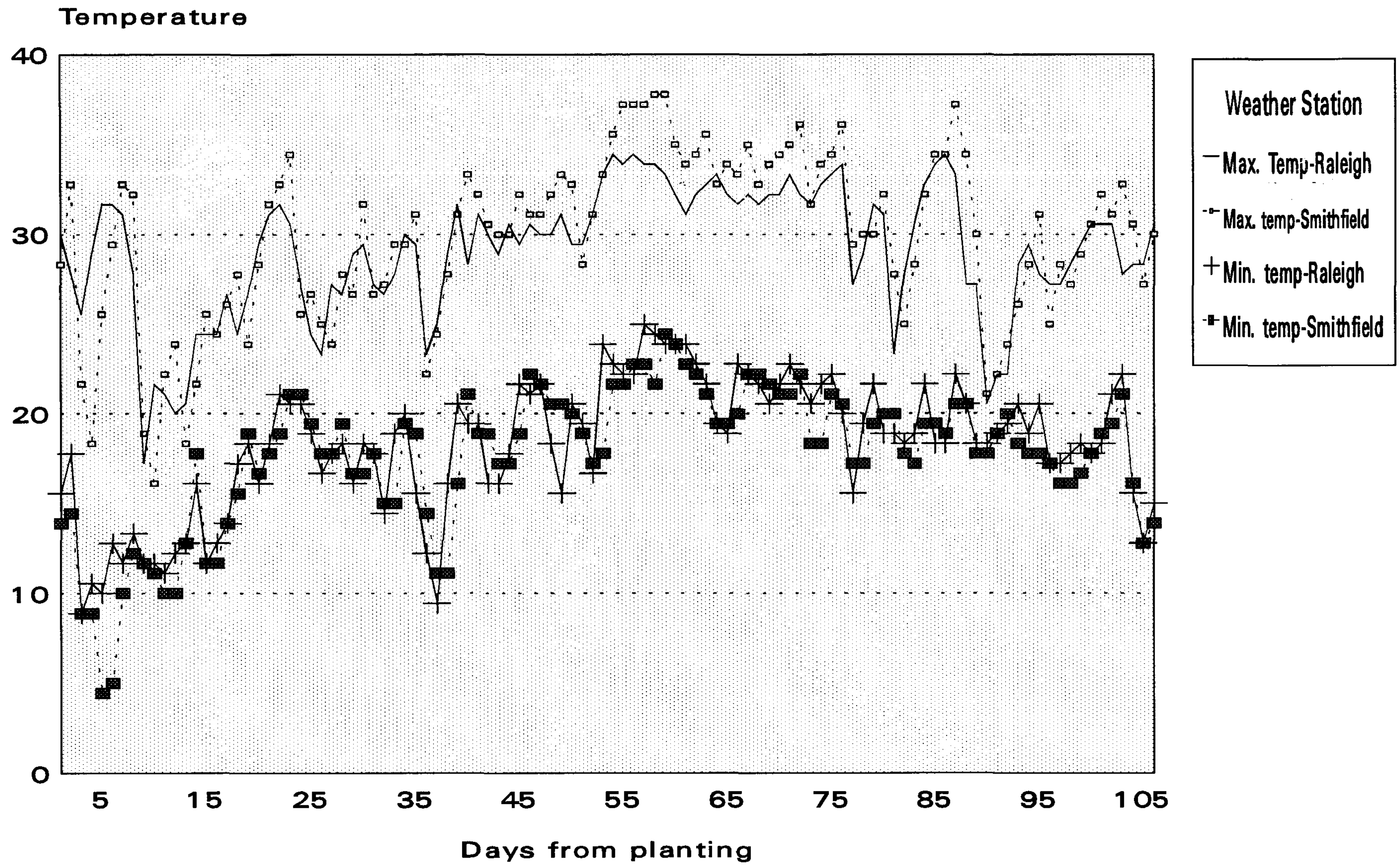

Figure 8. Comparision of rainfall for the two weather stations.

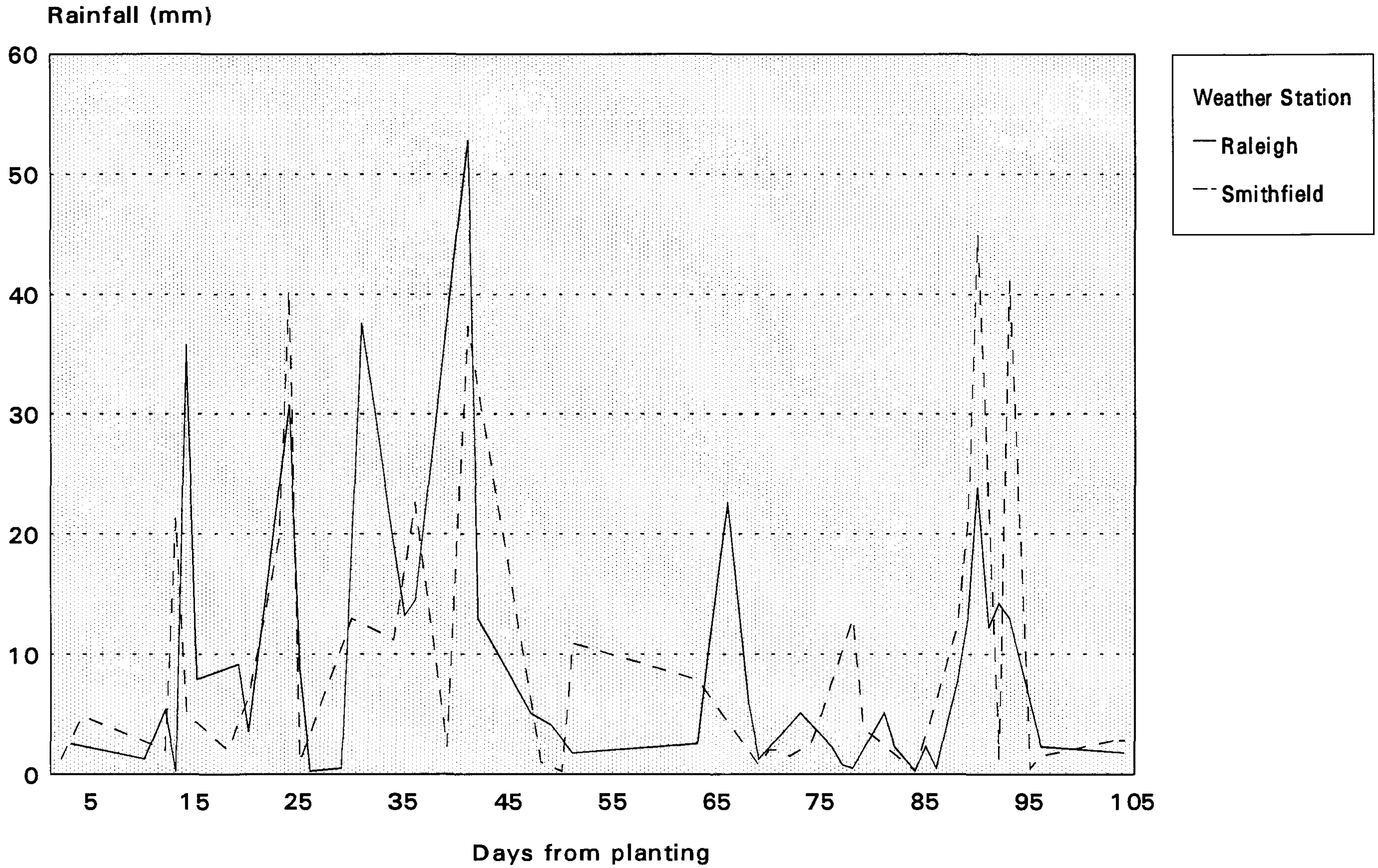

Figure 9. Comparision of calculated PAR for the two weather stations.

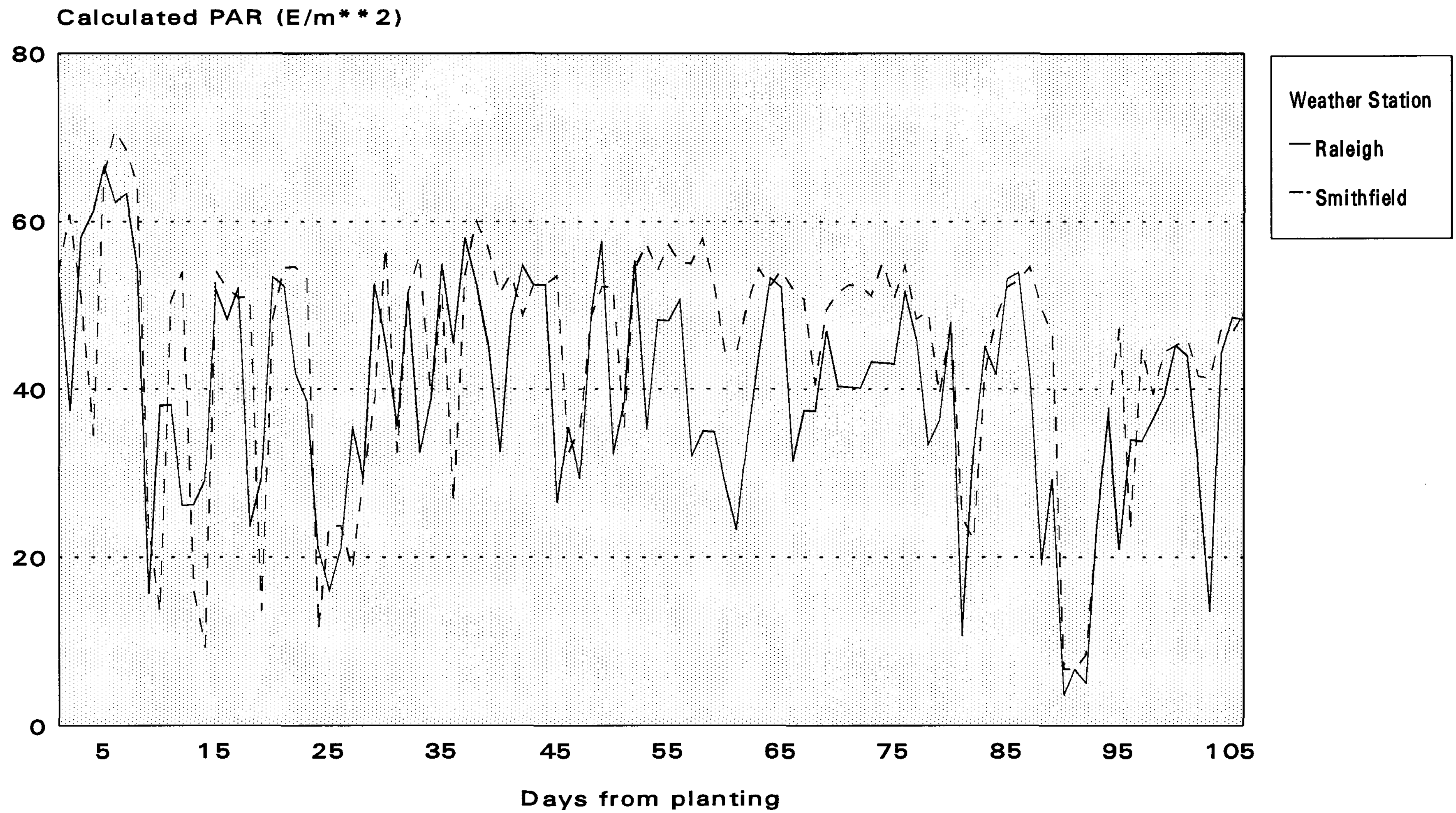

Figure 10. Simulated dry matter growth for Essex variety (Raleigh data).

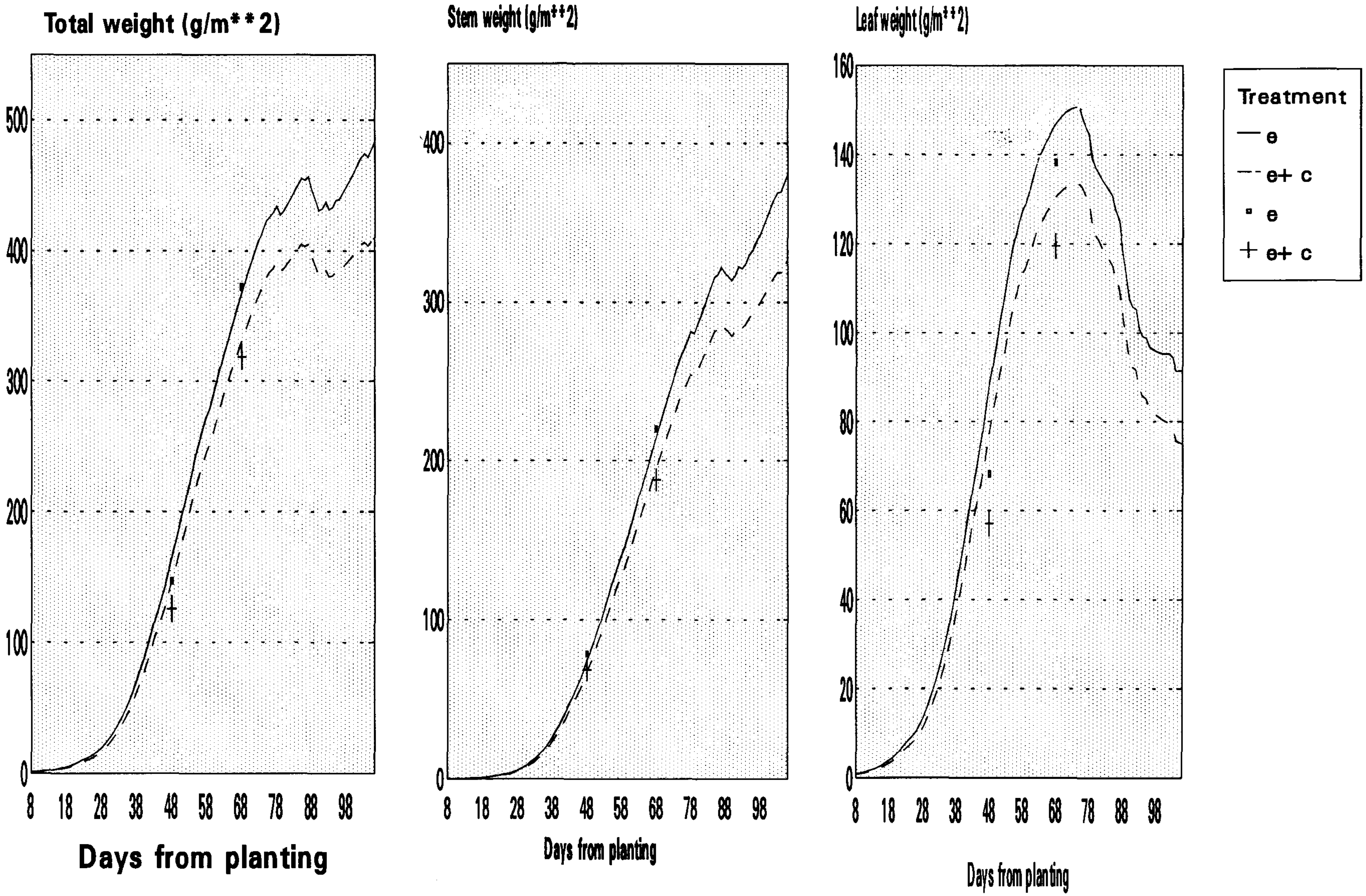

Figure 11. Simulated dry matter growth for Young variety (Raleigh data).

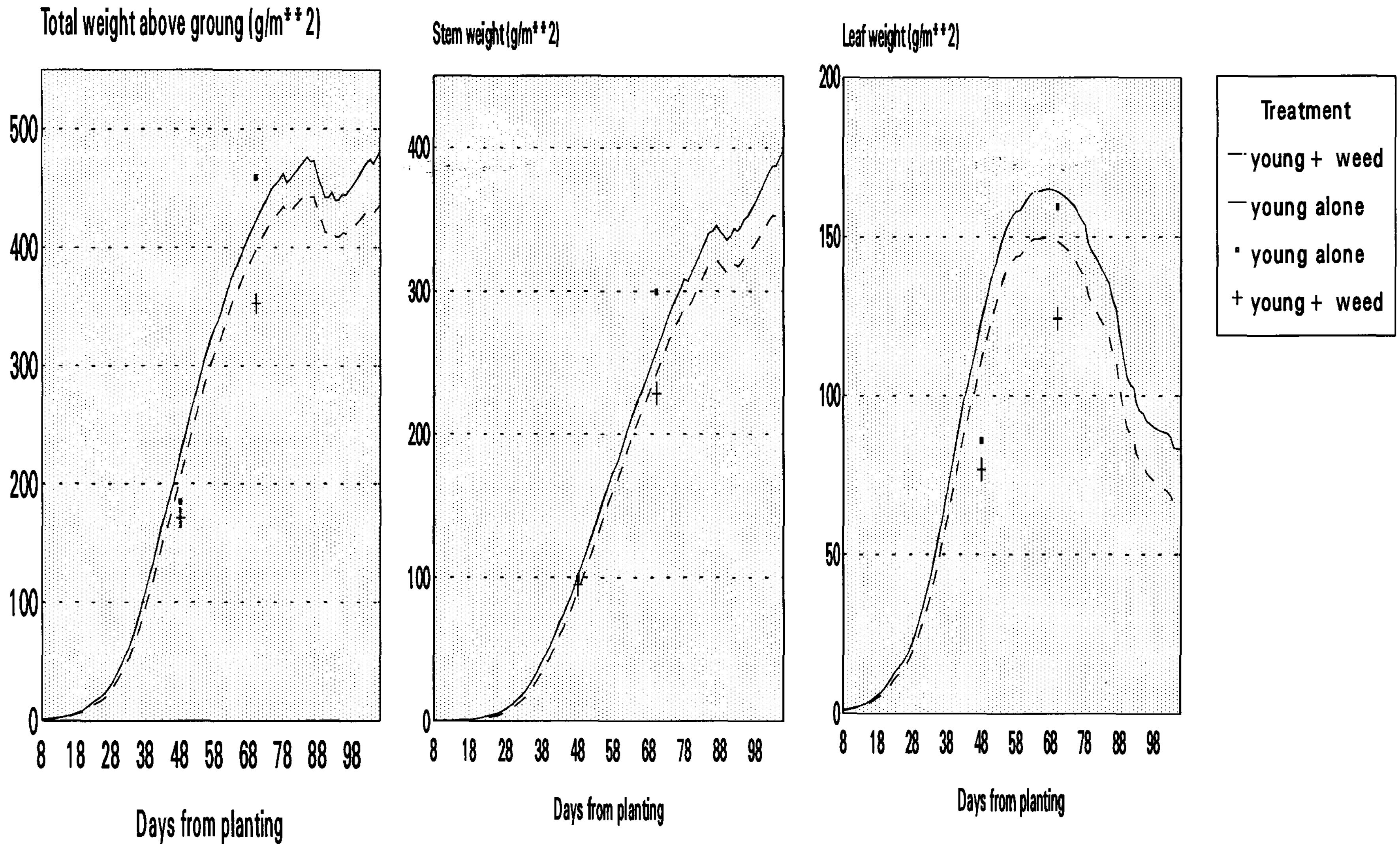

Figure 12. Simulated dry matter growth for common cocklebur (Raleigh data).

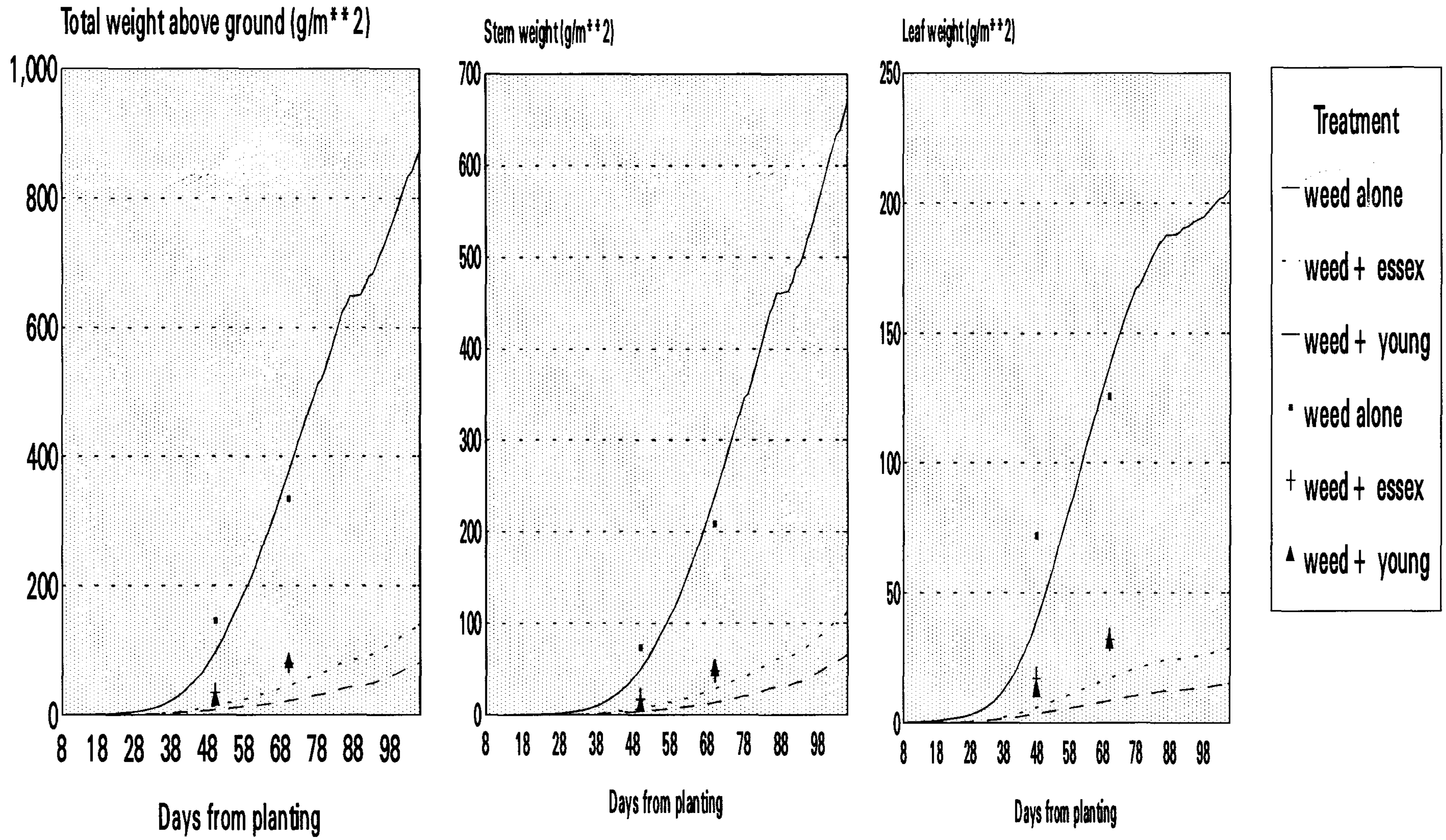

Figure 13. Simulated dry matter growth for Essex variety with weed competition (Raleigh data).

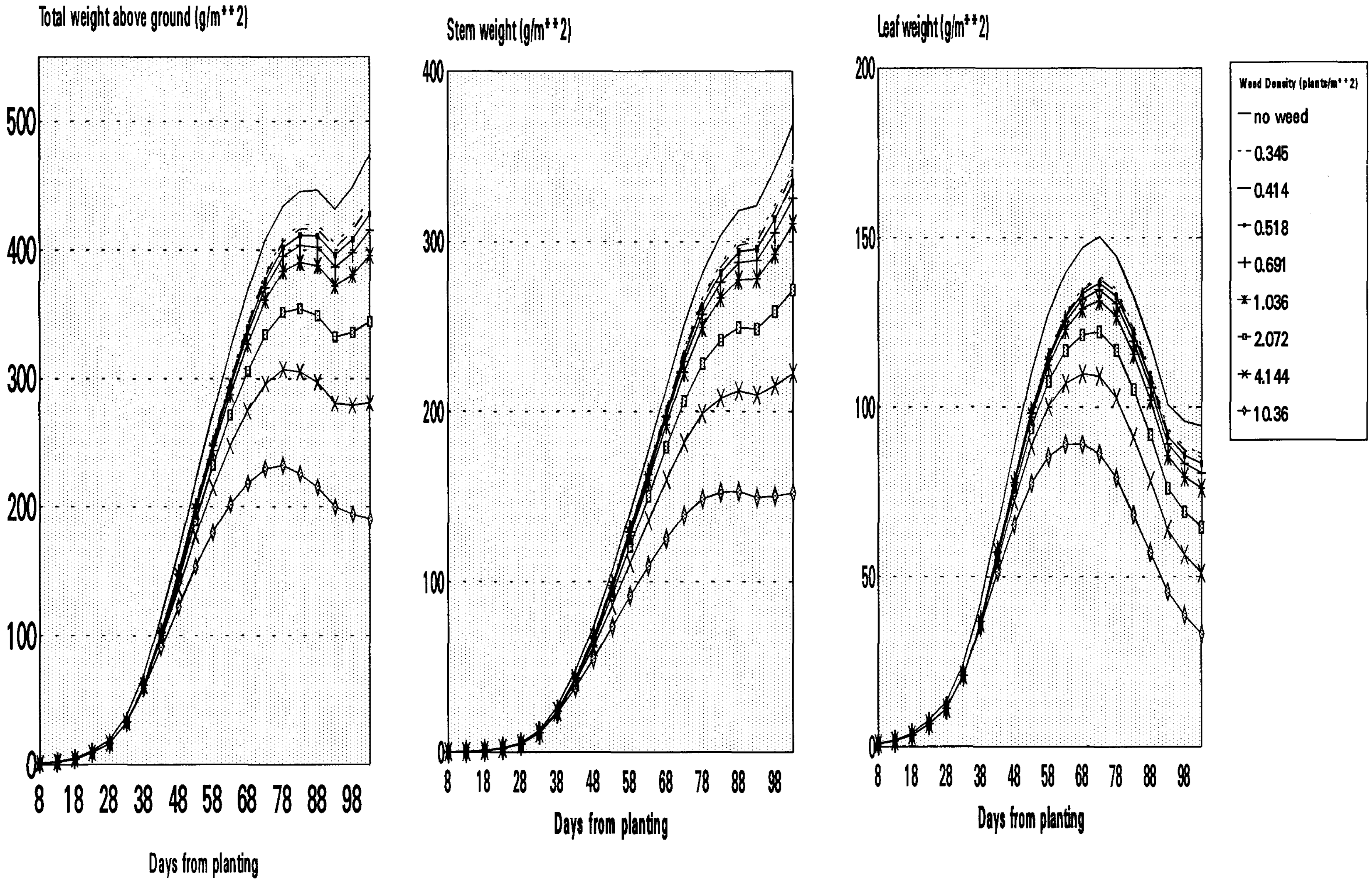

Figure 14. Simulated dry matter growth for Young variety with varied weed densities (Raleigh data).

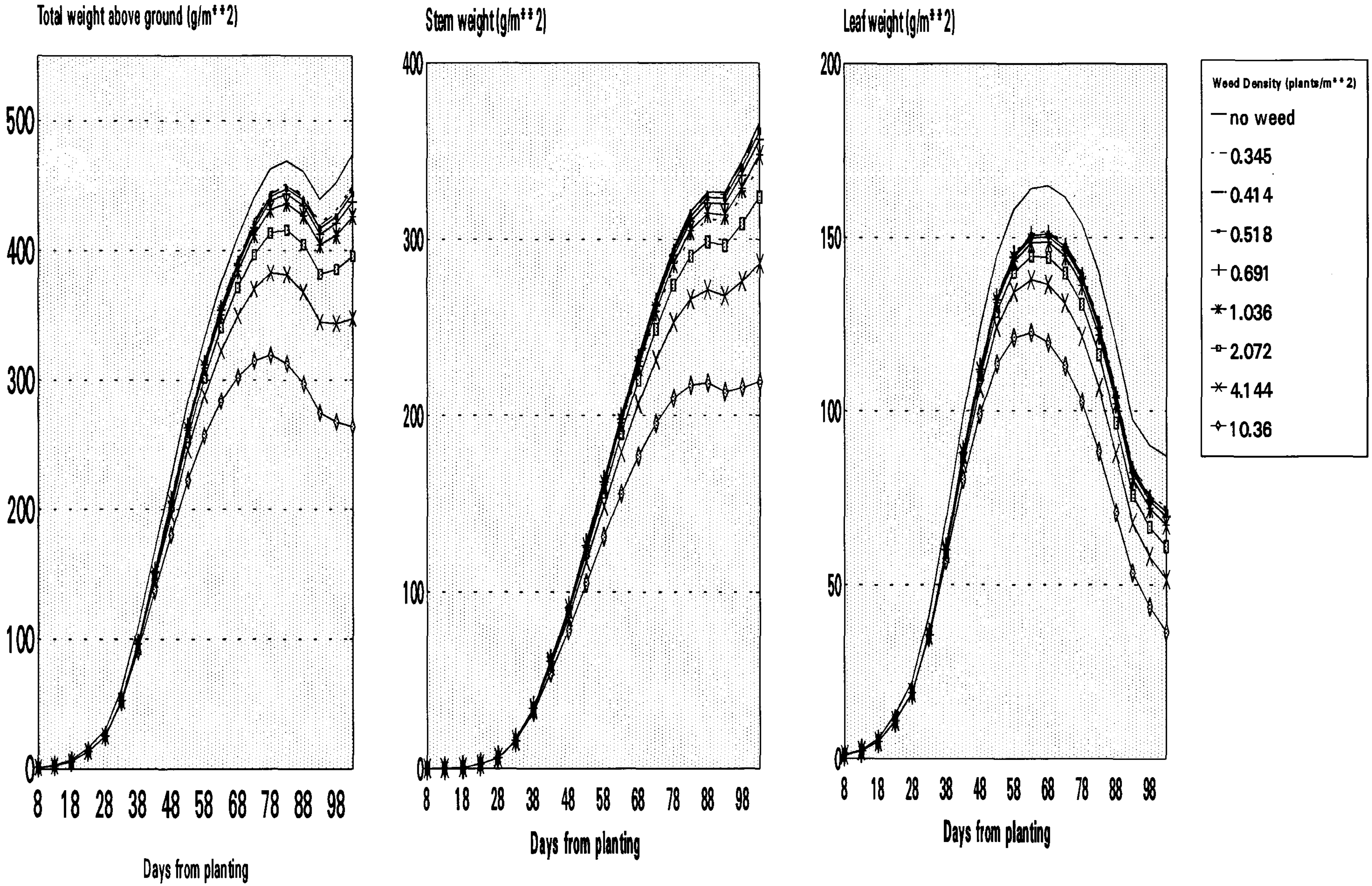

Figure 15. Simulated dry matter growth for commom cocklebur grown with Essex variety (Raleigh data).

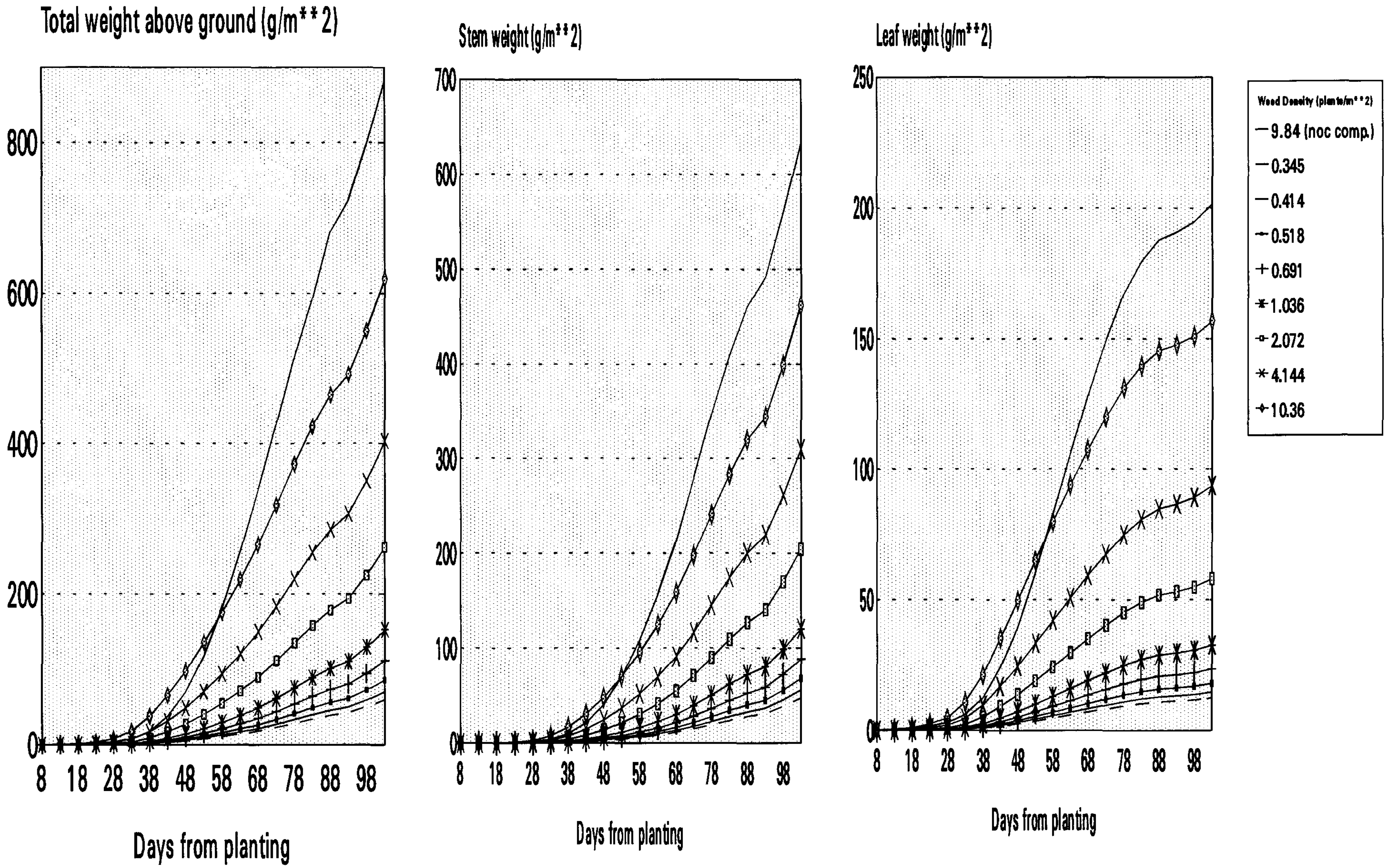

Figure 16. Simulated dry matter growth for commom cocklebur grown with Young variety (Raleigh data).

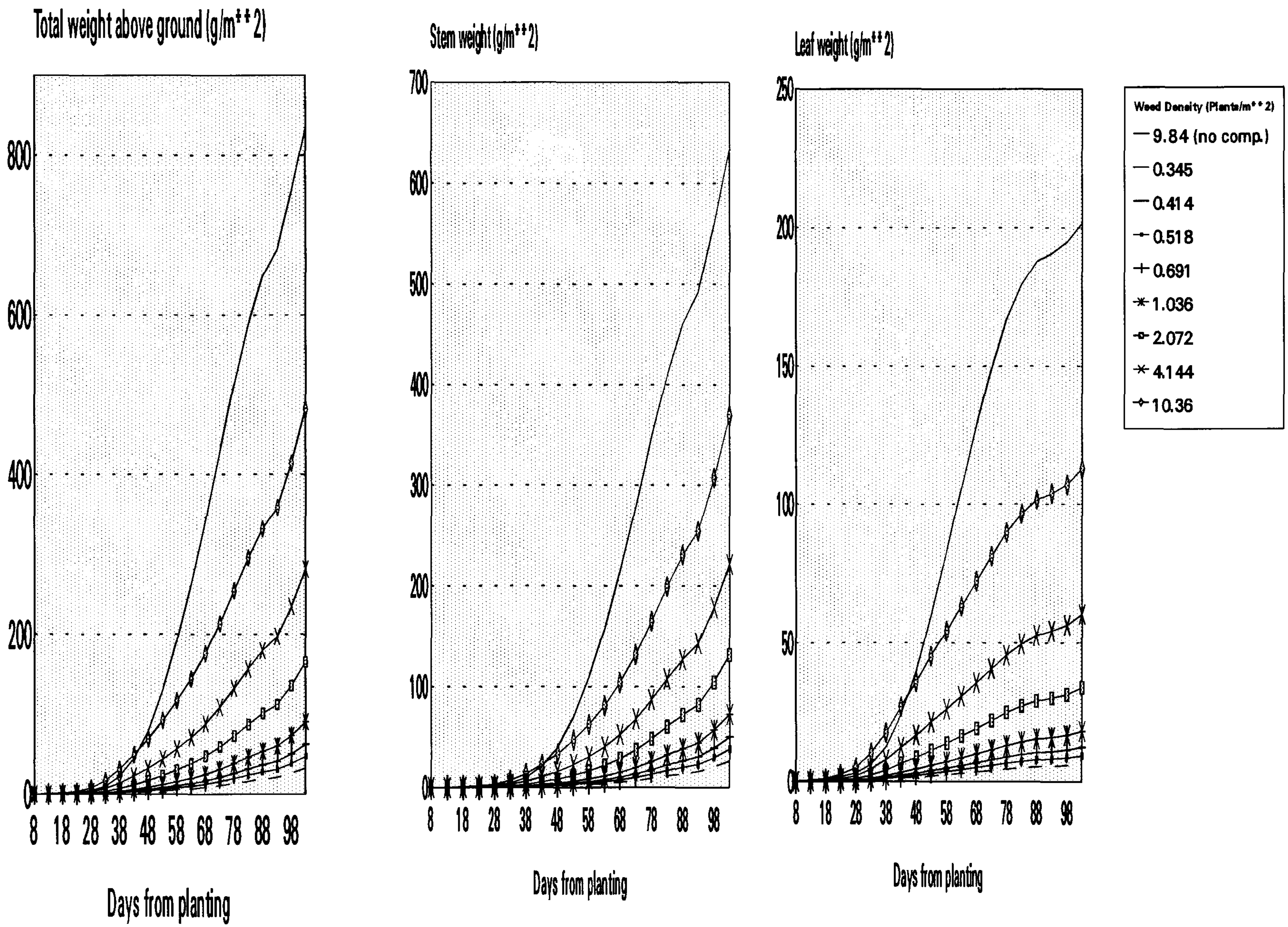

Figure 17. Simulated dry matter growth for Essex variety (Smithfield data).

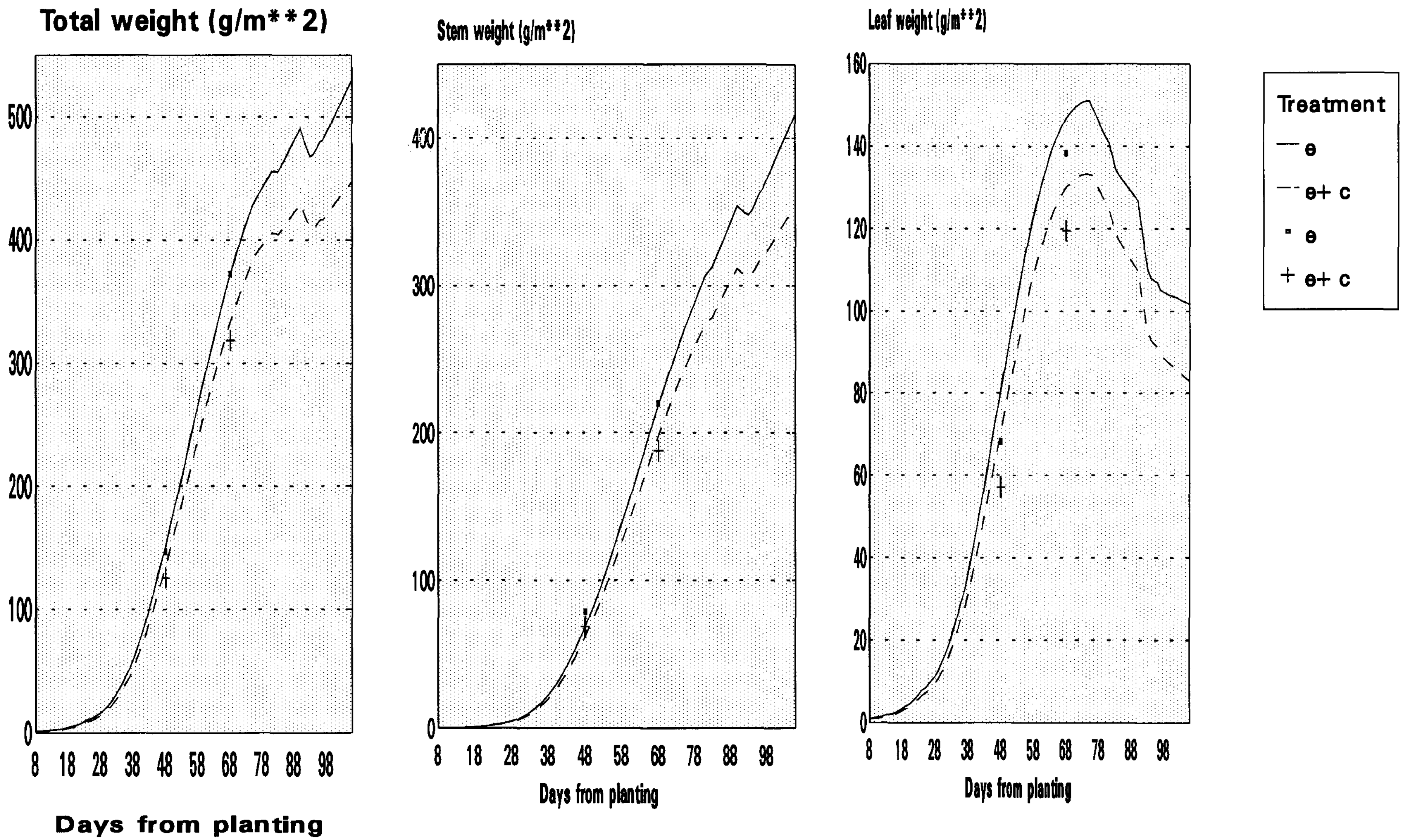

Figure 18. Simulated dry matter growth for Young variety (Smithfield data).

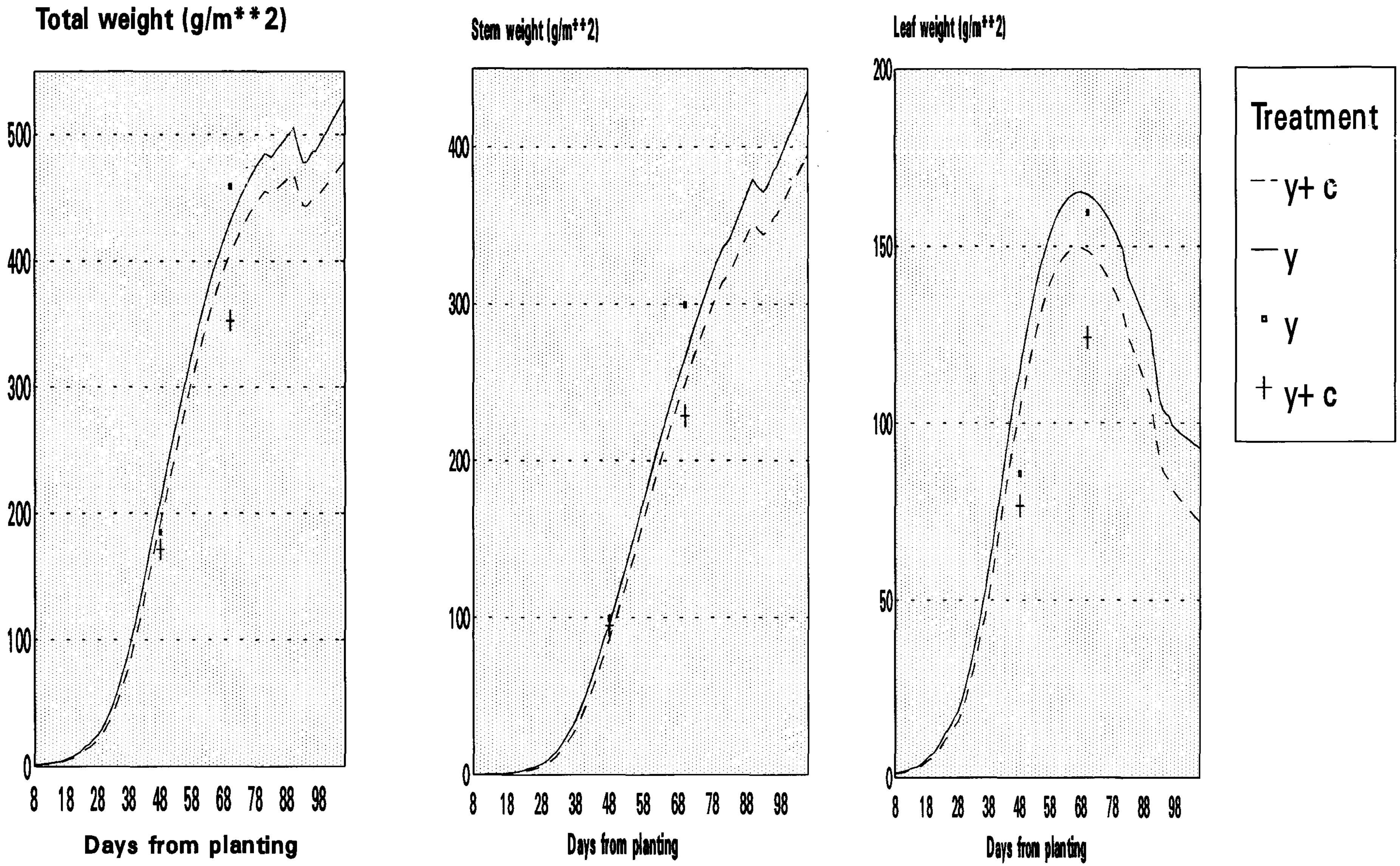

Figure 19. Simulated dry matter growth for common cocklebur with Essex and Young (Smithfield data).

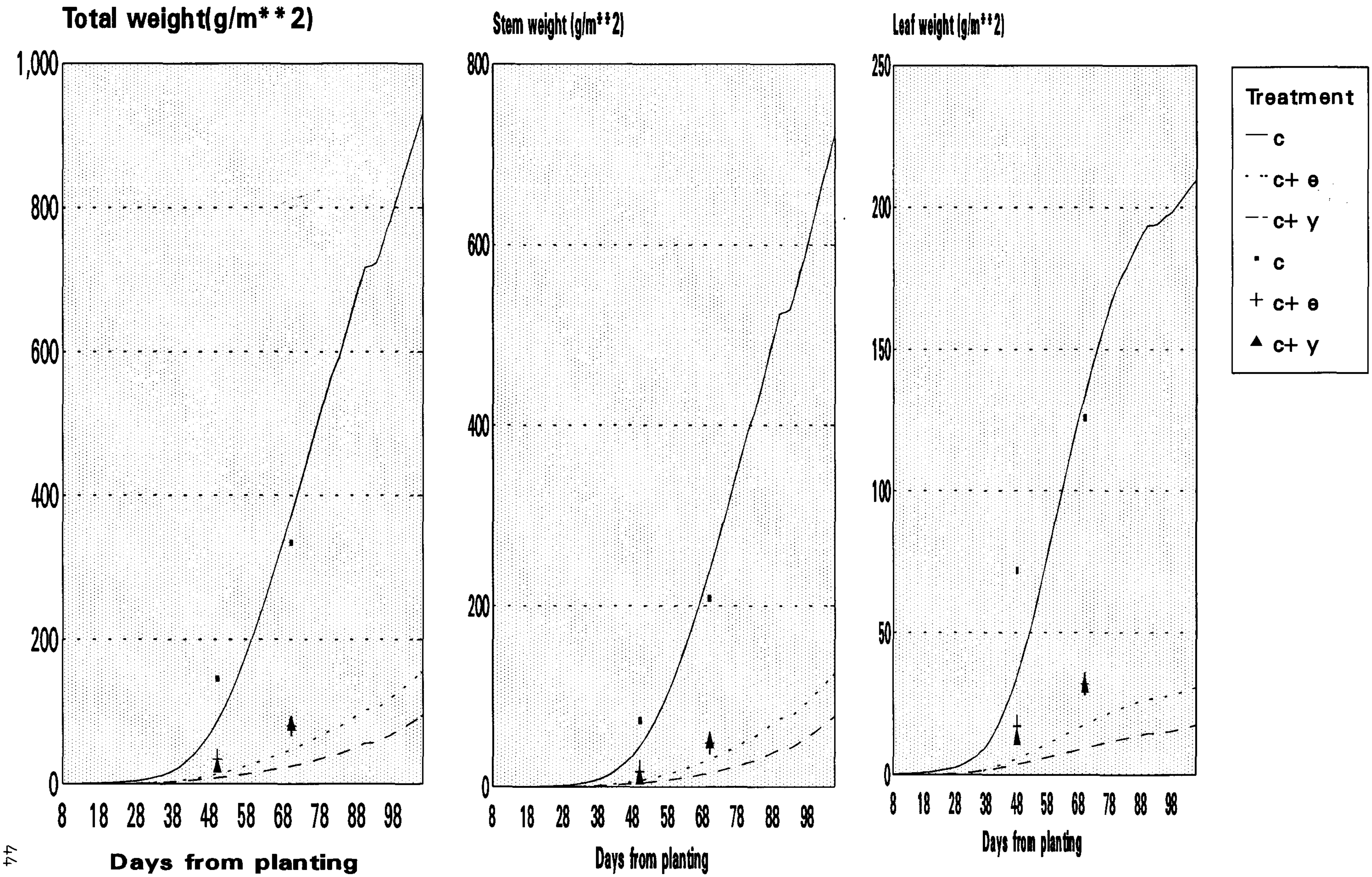

Figure 20. Simulated dry matter growth for Essex grown with varied weed density (Smithfield data).

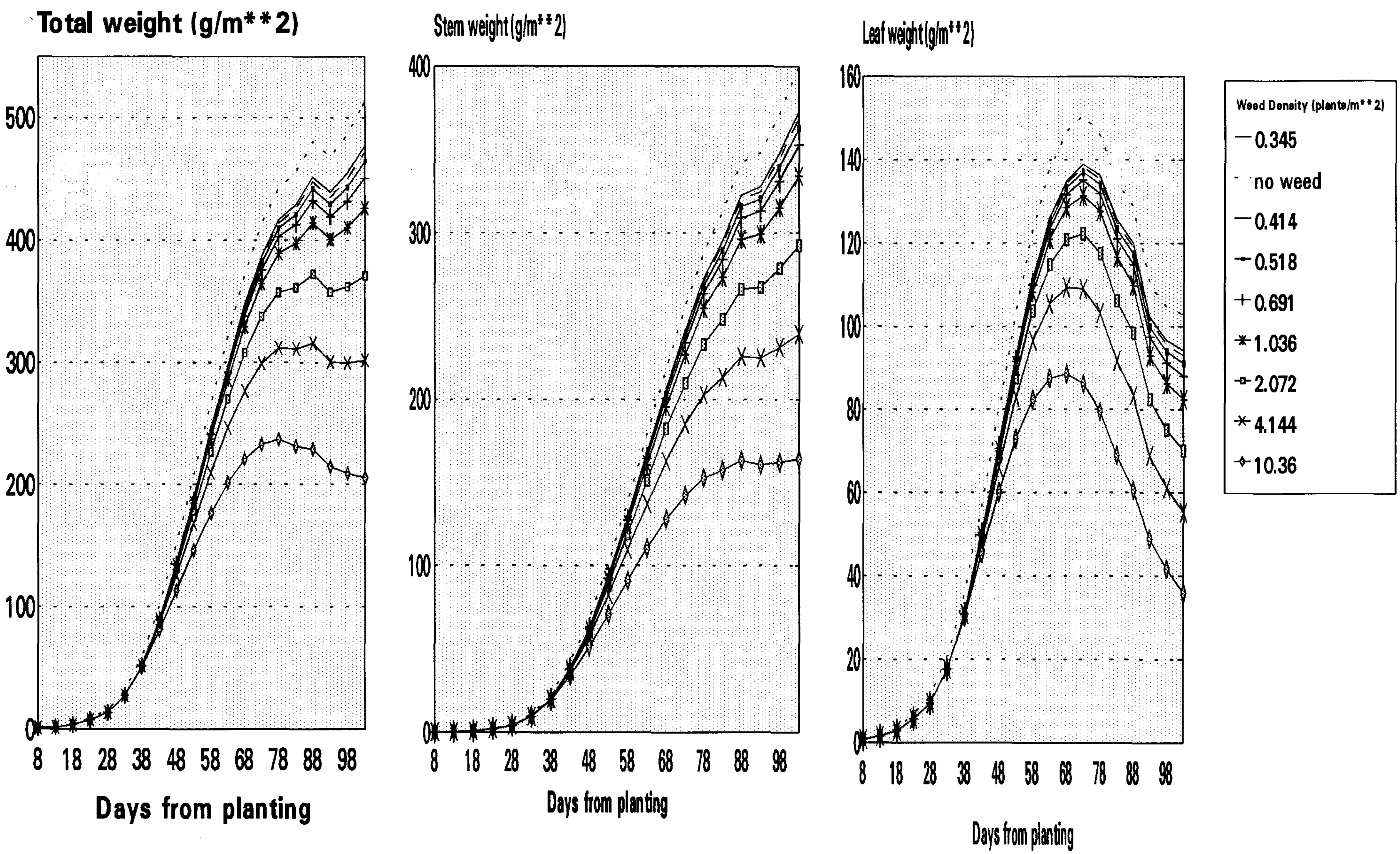

Figure 21. Simulated dry matter weight for Young grown with varied weed density (Smithfield data).

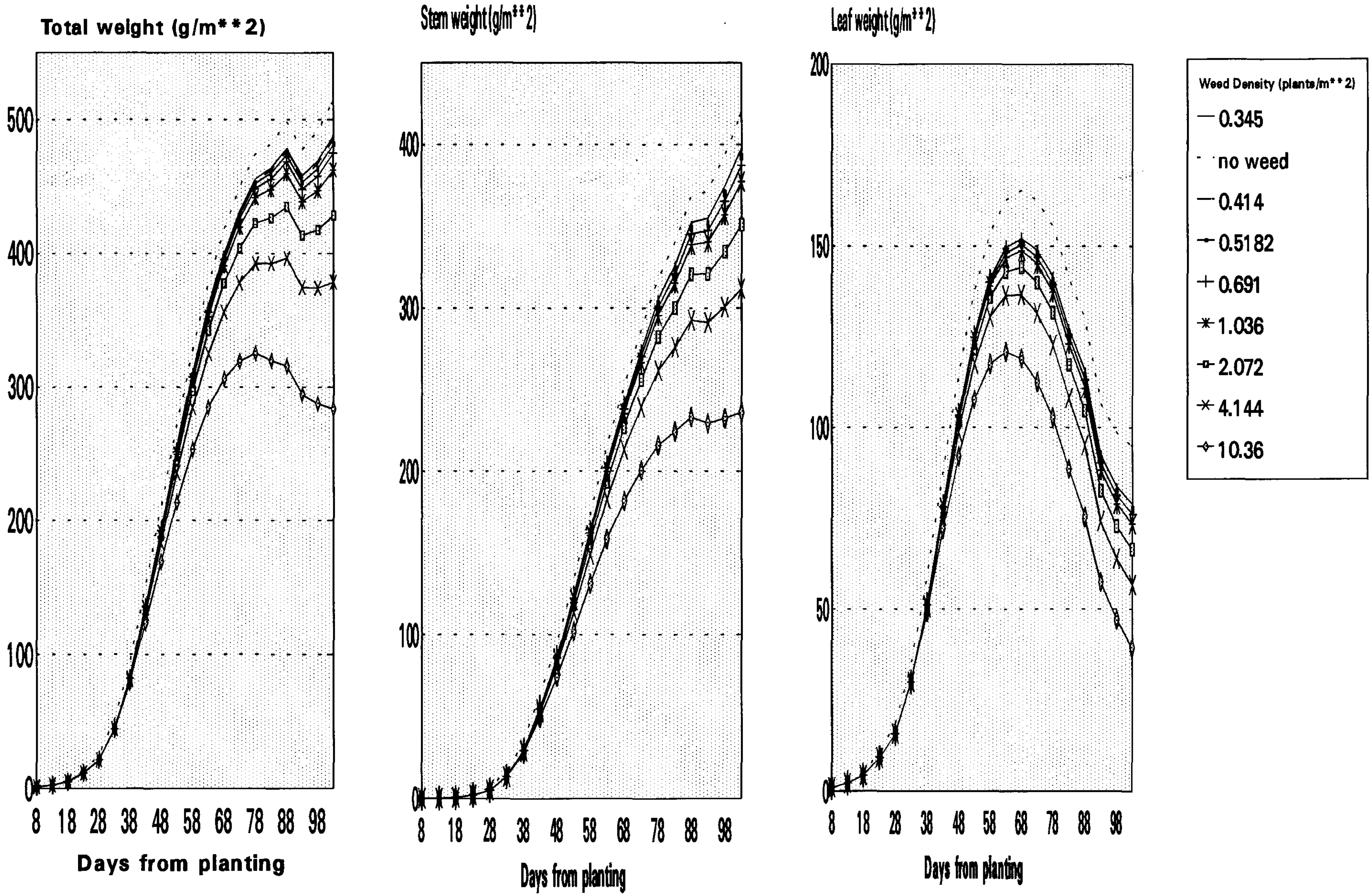

Figure 22. Simulated dry matter growth for commom cocklebur grown with Essex (Smithfield data).

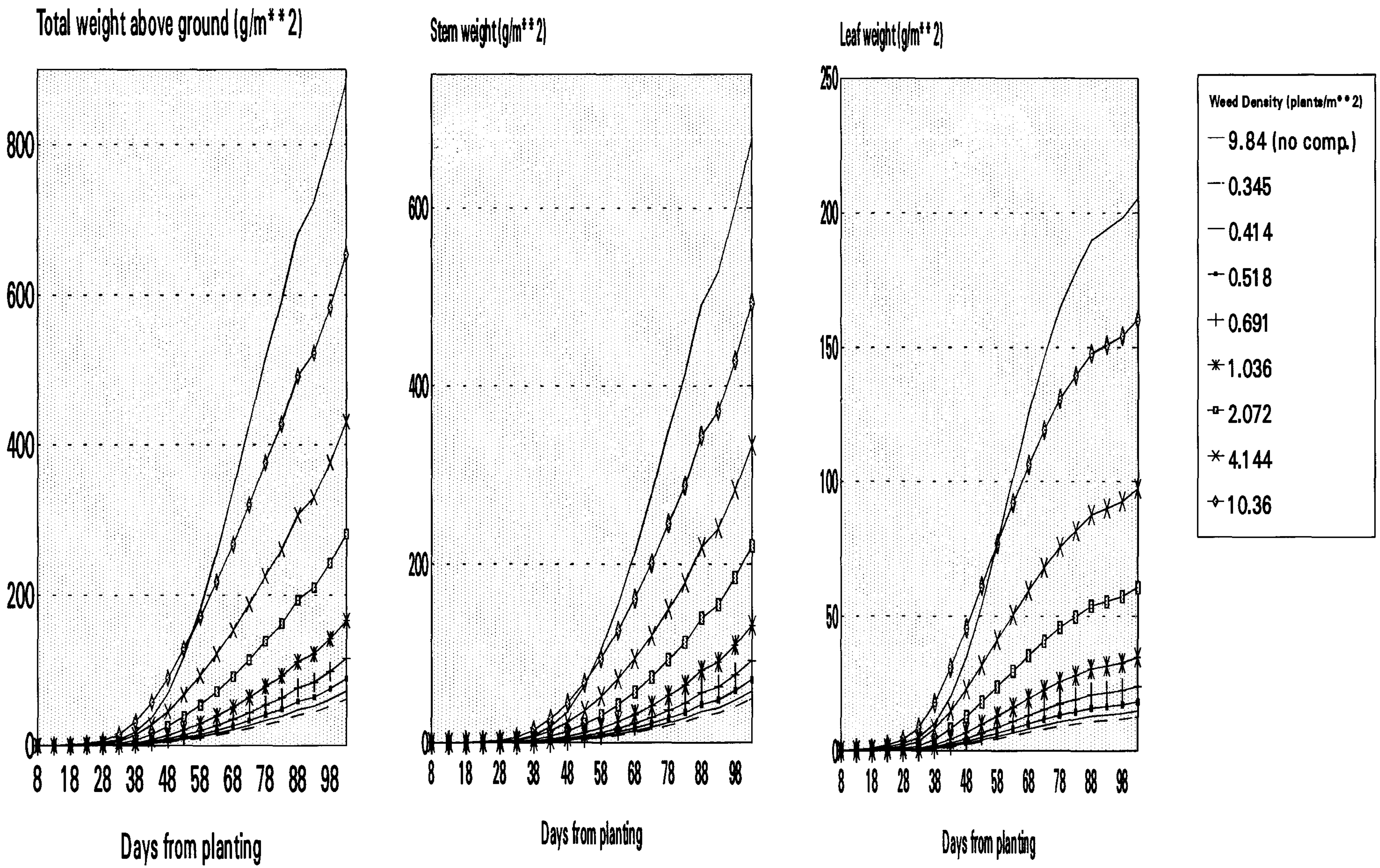

Figure 23. Simulated dry matter growth for commom cocklebur with Young variety (Smithfield data).

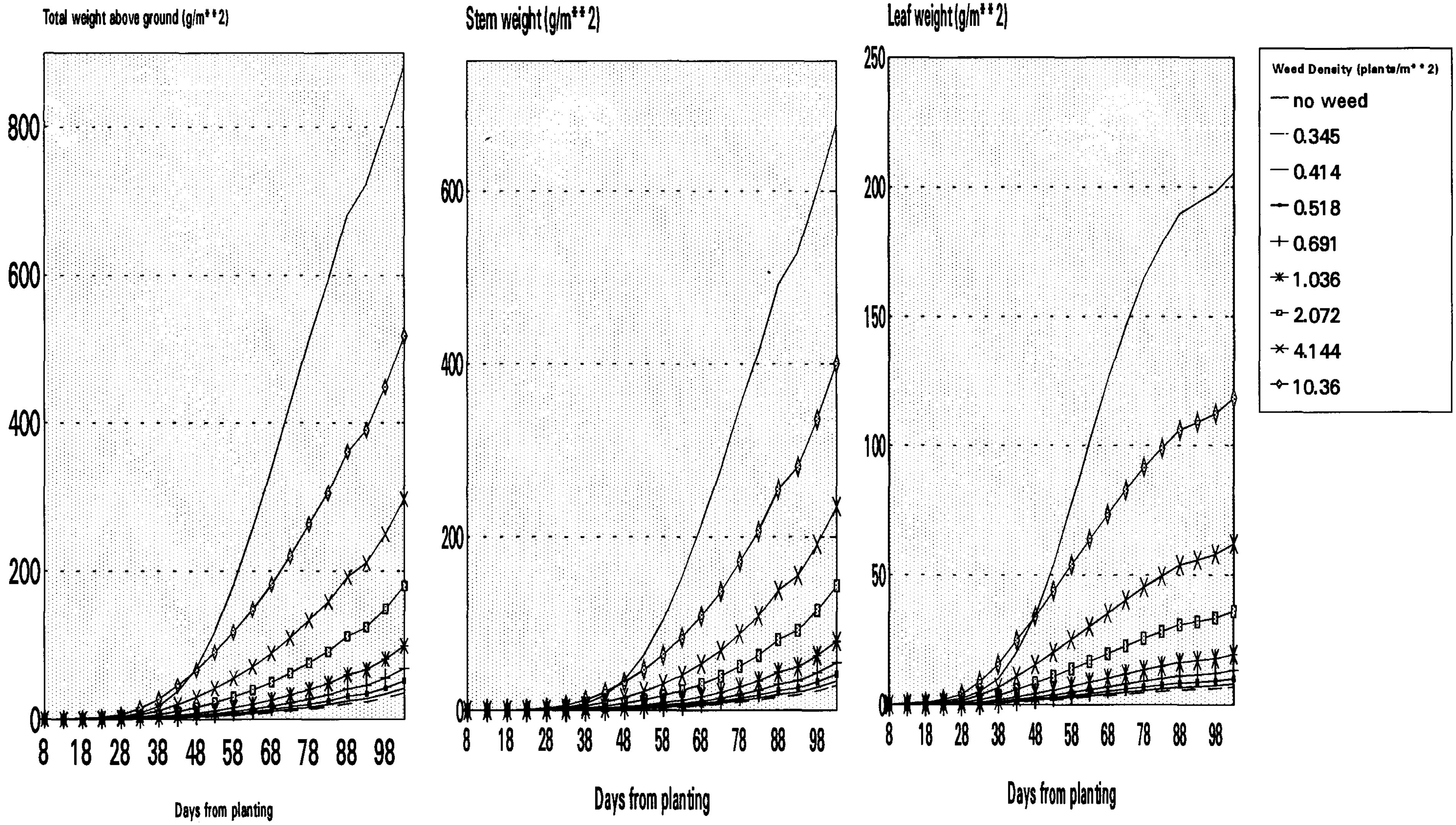

Figure 24. Dry matter growth for Essex (Raleigh data, k=1.0 for weed).

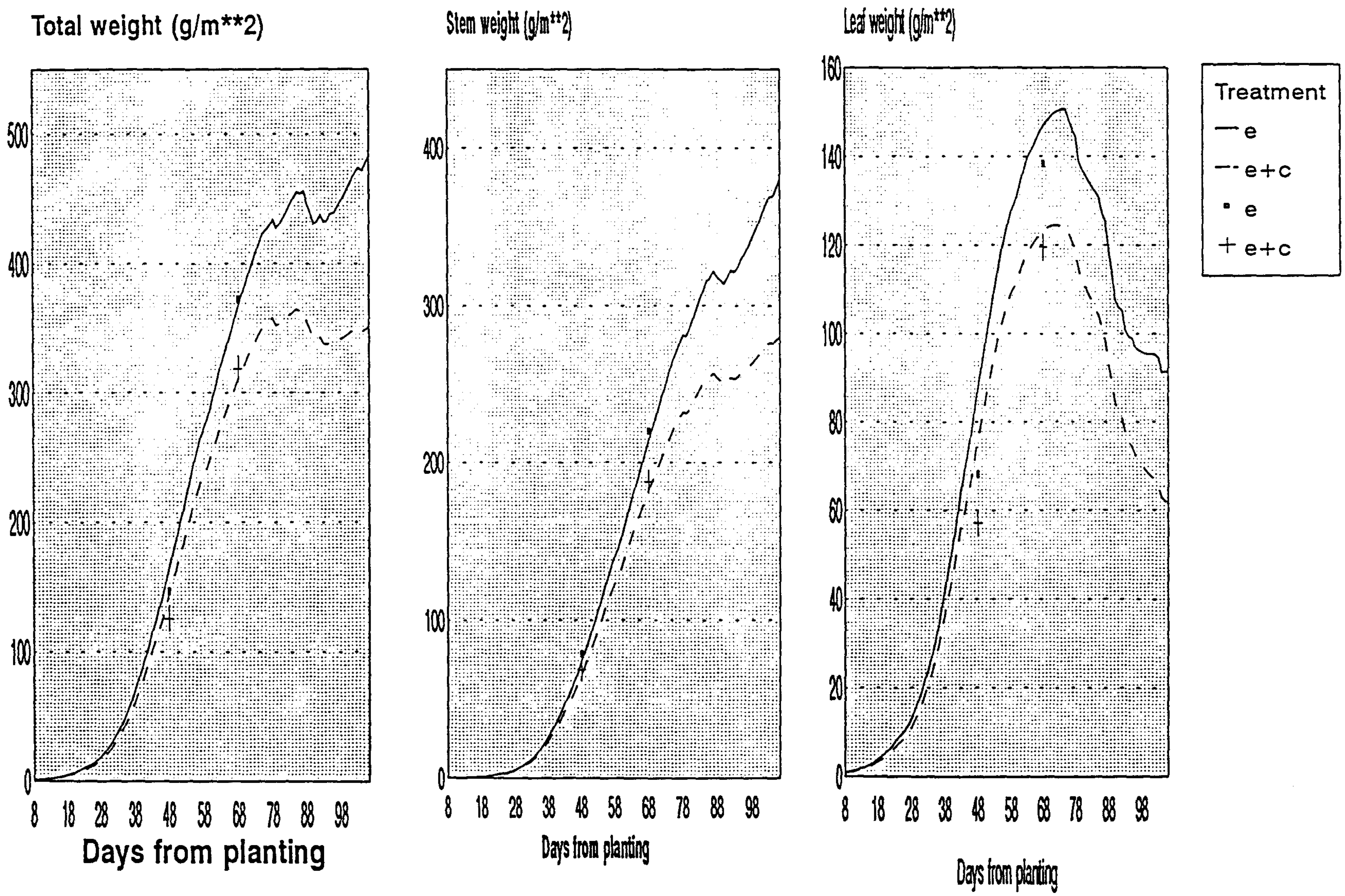

Figure 25. Dry matter growth for Young (Raleigh data, k=1.1 for weed).

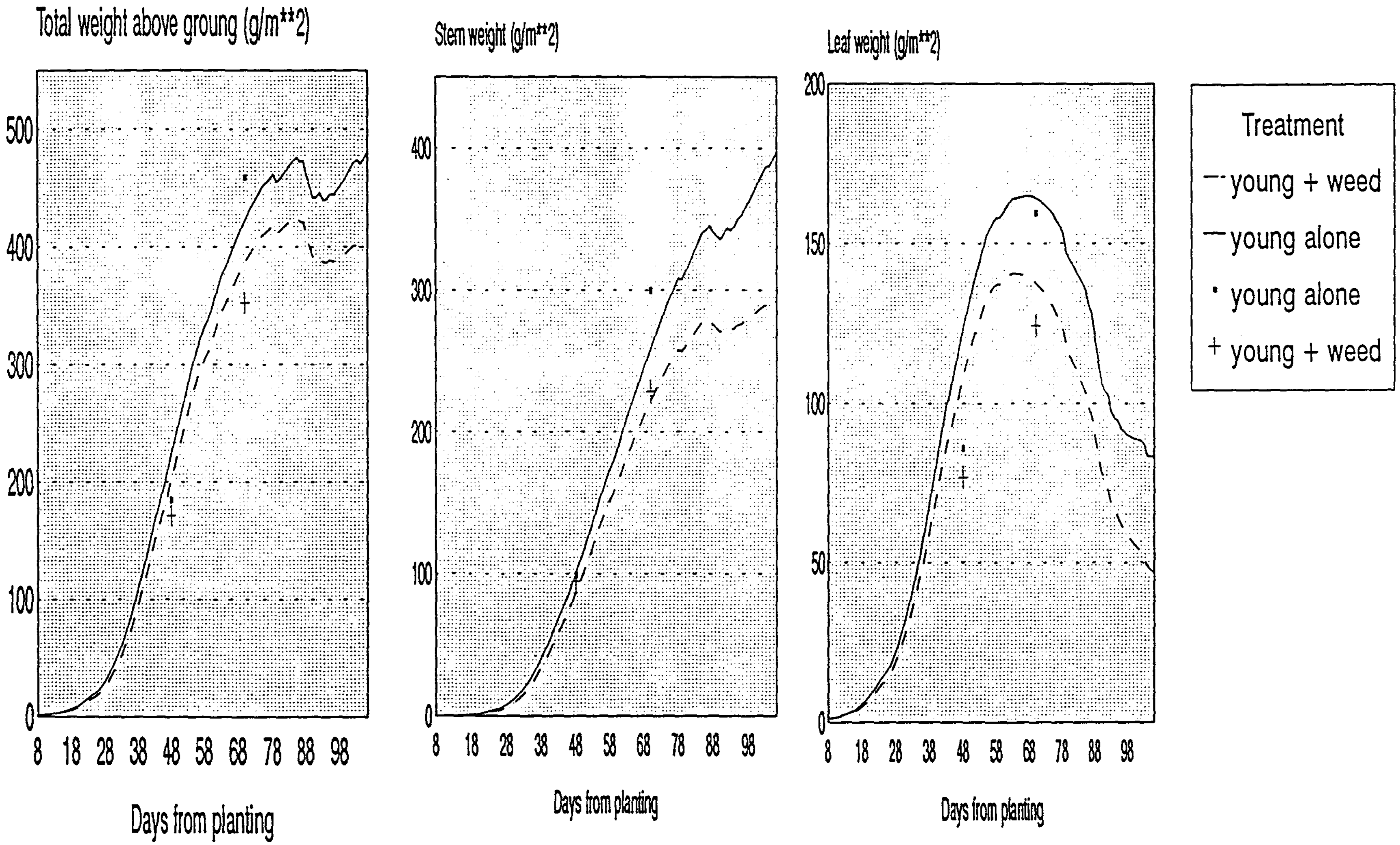

Figure 26. Dry matter growth for cocklebur (Raleigh data).
(k=1.0 for weed alone & grown with Essex, K=1.1 for weed grown with Young).

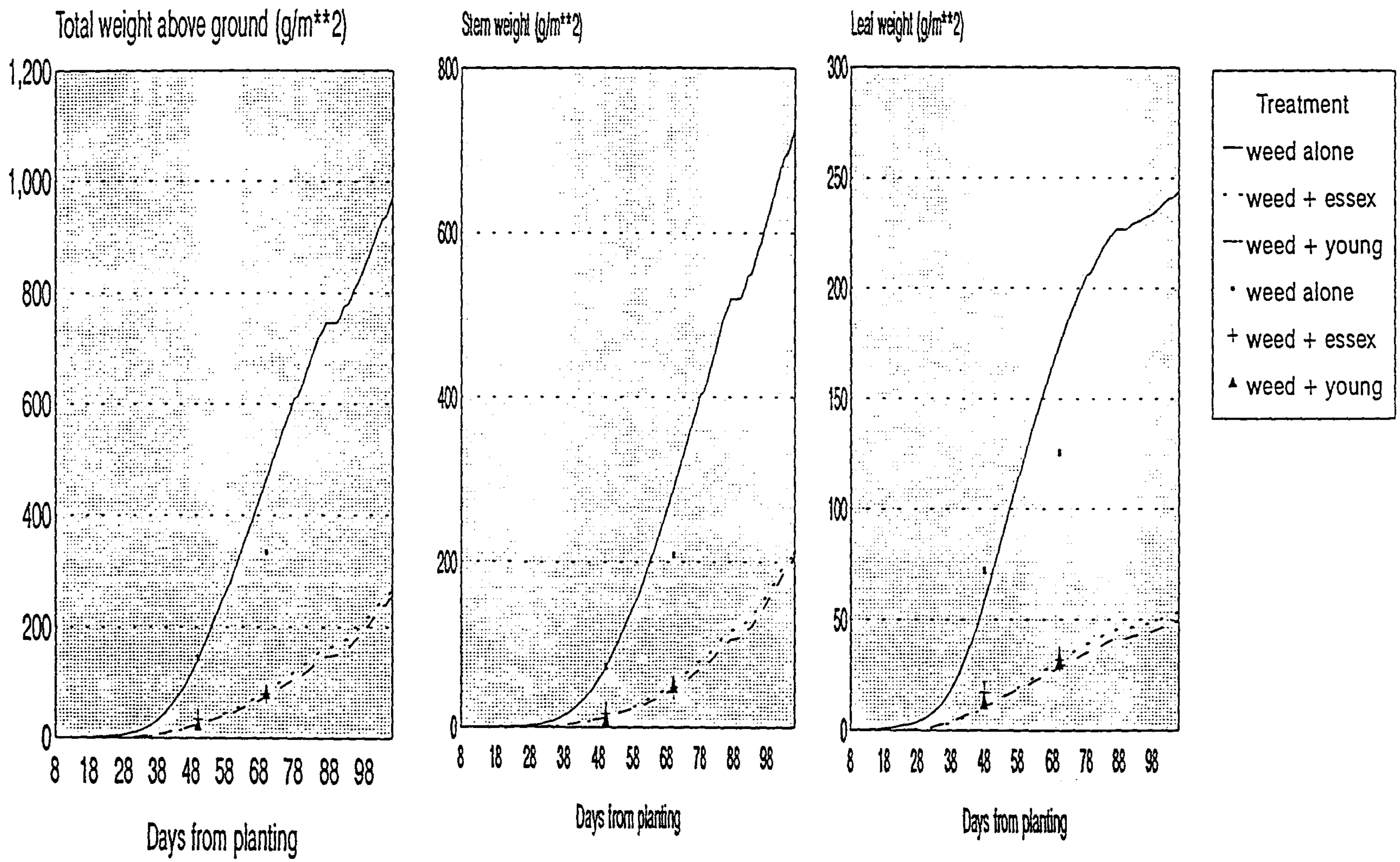

Table 6. Dry matter mesurement of soybean with and without common cocklebur competition.

Items	Mesurement Date	Essex Alone (g/m^2)			Essex + Cocklebur			Young Alone			Young + Cocklebur		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Leaf Weight	7/14/1992	33.24	95.13	68.18	49.70	66.03	57.08	79.95	92.19	85.75	69.74	91.60	76.65
Stem Weight	7/14/1992	35.02	121.60	78.72	58.13	83.48	68.58	87.62	114.50	99.24	83.00	103.26	94.81
Total Weigt	7/14/1992	68.26	216.73	146.90	107.82	149.51	125.66	171.79	206.69	184.99	152.75	194.86	171.46
Leaf Weight	8/4/1992	121.69	149.64	138.30	103.52	125.39	119.52	138.79	192.53	159.51	97.41	134.34	124.32
Stem Weight	8/4/1992	203.93	245.56	220.08	159.59	210.00	187.85	232.43	397.37	299.67	155.03	270.14	228.49
Total Weigt	8/4/1992	335.73	398.45	358.38	272.60	345.12	307.37	371.22	589.90	459.18	252.44	398.43	352.81

Table 7. Dry matter mesurement of common cocklebur with and without soybean competition.

Items	Mesurement Date	Cocklebur Alone			Cocklebur + Essex			Cocklebur + Young		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Leaf Weight	7/14/1992	26.20	139.13	72.03	8.29	22.92	17.18	7.88	19.03	13.45
Stem Weight	7/14/1992	18.98	147.46	73.54	5.73	24.72	17.03	6.66	19.49	12.43
Total Weigt	7/14/1992	45.18	286.58	145.57	14.02	47.64	34.21	14.55	38.52	25.88
Leaf Weight	8/4/1992	92.40	180.65	125.74	17.40	47.58	32.04	20.76	51.26	31.77
Stem Weight	8/4/1992	120.91	339.72	208.64	19.27	71.79	48.18	37.74	86.98	52.06
Total Weigt	8/4/1992	213.31	520.37	334.38	36.67	119.37	80.22	58.50	138.23	83.83