THE EFFECTS OF DENSITY AND HARVEST TIME ON GROWTH AND YIELD OF FORAGE CORN (Zea mays L.)

by

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ABSTRACT

A field experiment was undertaken to investigate the effects of planting density on growth and yield of forage corn (Zea mays L., cv. DK 24) using modern methods of plant growth analysis and yield component analysis. A complete randomized block design was used with four planting densities and five harvests. The four planting densities were 49383, 67204, 87796 and 111111 plants per hectare. Replicate plants were harvested at 21 days after emergence (DAE), 42 DAE, 63 DAE, 85 DAE and 115 DAE. At each harvest, data were recorded of several primary growth characteristics, including plant height, stem diameter leaf areas and dry weights of stems, leaves, leaf sheaths, tillers and reproductive structures. The recorded data, and indices and ratios derived from recorded data, were analyzed by the analysis of variance, cubic spline regressions and the two-dimensional partitioning technique of yield component analysis.

Yield per hectare varied significantly among densities from the second harvest (42 DAE) until maturity. At the crop maturity stage (30.8% crop dry matter content), the yield per hectare increased with increasing number of plants per hectare. The mean yields were: 15.1, 15.9 and 17.1 MT per hectare from the lowest planting density to the highest planting density, respectively. Conversely, yield per plant decreased linearly with increasing number of plants per hectare from 306.4 to 154.1 g/plant.

All the primary plant growth characteristics were highly affected

by the planting density treatment, and these effects increased with plant age. Thus, the variability in yield per plant among planting densities was accounted for by the variability of those growth characteristics.

The plant growth indices showed that crop growth rate, leaf area index and biomass density were major contributors to yield variability per hectare among planting densities. Yield component analysis showed sporadic contributions by yield components depending on age and the direction of the two-dimensional partitioning technique of yield component analysis. The relative growth rates of yield and yield components did not clearly show the effects of planting density but strongly showed the time course trends of the relative growth rates within stand densities. All of the techniques used in this study complemented each other in the analysis of corn growth and productivity.

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LIST OF SYMBOLS

A	-	Land area.
ANOVA	-	Analysis of variance.
C	-	Yield component variable.
CGR	-	Crop growth rate.
D	-	Average plant diameter.
DAE	-	Days after emergence.
DM	-	Dry matter.
E_F	-	Ear fresh weight.
ENT	-	Total number of ears/plant.
FNT	-	Total number of ears and tassels/plant.
H	-	Harvest index.
ha	-	Hectare.
L_A	-	Leaf area/plant.
LAI	-	Leaf area index.
LAR	-	Leaf area ratio.
L_F	-	Leaf blade fresh weight/plant.
L_N	-	Number of leaves/plant.
Log_e	-	Natural logarithm.
LWR	-	Leaf weight ratio.
MT	-	Metric tonne.
N	-	Number of plants.
R_C	-	Relative growth rate of yield component variable.
R_F	-	Remaining fresh weight.

R_G	-	Relative growth rate of growth characteristics.
RGR	-	Relative growth rate.
R_{LA}	-	Relative growth rate of leaf area/plant.
R_W	-	Relative growth rate of shoot biomass/plant.
R_{WL}	-	Relative growth rate of leaf dry weight/plant.
R_{WST}	-	Relative growth rate of stem dry weight.
R_Y	-	Relative growth rate of shoot yield/plant.
SLA	-	Specific leaf area/plant.
T	-	Plant height.
TDP	-	Two-dimensional partitioning.
ULR	-	Unit leaf rate.
W	-	Total shoot dry weight/plant.
W_C	-	Dry weight of cobs/plant.
W_G	-	Dry weight of grains/plant.
W_H	-	Dry weight of husks/plant.
W_L	-	Dry weight of leaves/plant.
W_{LS}	-	Dry weight of leaf sheaths/plant.
W_{ST}	-	Dry weight of stem/plant.
W_{TA}	-	Dry weight of tassels/plant.
W_{TL}	-	Dry weight of tillers/plant.
W_{rep}	-	Total reproductive dry weight/plant.
W_V	-	Total vegetative dry weight/plant.
Y	-	Yield of shoot dry matter per plant.
YCA		Yield Component analysis.

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1. INTRODUCTION

Variations in planting density can affect vegetative and reproductive productivity of crop plants. Both yield per hectare and yield per plant can be influenced by the number of plants per unit land area. In most instances, yield per land area increases with increased number of plants per unit land area, while the yield per plant is reduced, until a limit is reached. The analysis of plant response to different planting densities can provide some insight into the biology of plant growth and can contribute to improved agricultural practices.

Corn (*Zea mays* L.) was used in the present research because it is a valuable crop, not only for animal feed, but also more directly for human food. The present study, however, is focused on silage corn production for the beef industry. Secondarily, corn grows well in the experimental area available for my research (at the University of British Columbia, Vancouver, B.C.) and corn has growth characteristics which can be studied effectively throughout the growing season.

Several approaches to plant growth and yield analysis have been developed and refined in recent years. Such approaches include yield component analysis (Fraser and Eaton, 1983), which has been applied widely in agricultural research, and which subdivides productivity into a set of morphological components whose product is yield. Demographic analysis, a central method in population biology, has been extended to the sub-organismal level in plants to follow the appearance, presence and loss of morphological characteristics (e.g., Bazzaz and Harper, 1977; Lovett Doust and Eaton, 1982). Plant growth analysis (Causton and Venus, 1981; Evans, 1972; Hunt, 1982a) includes indices of both the presence and assimilatory performance of morphological characteristics. The chief value of yield component analysis, demographic analysis or plant growth analysis, however, may be that each provides a framework for defining long term relationships among components and overall growth (Jolliffe _et al_. 1983 (in preparation)).

While considerable research has been carried out on the effects of planting density on plant performance, much remains to be learned about this interaction. My research had two main objectives:

1. To investigate the time course of forage corn productivity at four different planting densitites using modern techniques of plant growth analysis.
2. To define when and how some morphological and physiological components of forage corn yield respond to different planting densities, and how variation in those components is associated with variation in yield.

In addition, two secondary objectives of the research were:

3. To evaluate the seeding rates currently recommended for forage corn production in this locality.
4. To evaluate the effectiveness of the different approaches to plant growth analysis.

2. LITERATURE REVIEW

2.1 The Corn Plant and its Cultivation

The corn plant is a tall annual grass, with thick, solid stems usually supported by proproots. It is thought to have originated in Central America, although this has not been completely proven. The origin of the plant is more obscure because apparently it does not occur in the wild form. However, in Mexico there occurs a closely related grass, teosinte (*Euchlena mexicana* L.), which hybridises freely with *Zea*. Thus, it has been suggested that modern corn is either of hybrid origin, or in some other way it is a derivative of teosinte (Janick, *et al*. 1981; Langer and Hill, 1982).

Modern cultivars of corn resemble the primordial form only remotely. Moreover modern corn is wholly a ward of humanity since it is unable to survive and perpetuate itself without human care in harvesting and planting (Gill and Vear, 1980; Janick *et al*. 1981).

The corn plant does not normally branch. However, a few tillers do occur. It bears broad, smooth leaves with a conspicuous midrib. The plant is monoecious. It bears the male flowers on the terminal panicle (tassel), and the female flowers are borne on the axils of the middle leaves. Pollen is shed and carried by wind to the female inflorescences (Langer and Hill, 1982). The cob bears rows of naked caryopses which are protected by the husks. On the other hand, a mass of elongated styles protrude at the end of the husks ready to receive pollen shed from the terminal male inflorescences to effect fertilization of the ovules. One characteristic of effective pollination of the female flower is the immediate death of the extruded ends of the silk (styles). Grain development and growth then follows and grains mature inside the husks. Unlike other grasses, there is no seed dispersal, which accounts for the fact that corn is not known as a wild plant (Langer and Hill, 1982).

Although predominantly a grain crop, corn is also used as a forage crop. Forage corn is grown in areas where the climate is marginal for grain ripening but where advantage can be taken of the rapid growth of the plant. Forage corn is cut at an immature reproductive stage and is either fed to animals in the fresh state or after having been ensiled (Langer and Hill, 1982).

In a normal silage crop, the ears contribute some 40 to 45% of the dry weight (Gill and Vear, 1980), with a digestible dry matter content of about 80%; the remainder comes from the stem and leaves (Stover), in which digestible dry matter content is about 65%.

The productivity of forage corn varies with prevailing climatic conditions. In most temperate countries, regions of corn production are limited by low temperature since the corn crop does not grow well under temperatures below about 10°C. Good yields are also very much dependent on the availability of sunshine (Lockhart and Wiseman, 1978). Exposed windy situations are generally not suitable. The corn crop thrives in rich, deep, well drained loam soils. Light soils are reasonably suitable for corn if they do not dry out. Thin chalky soils are not suitable, nor are heavy soils which are usually very slow to warm up in spring (Lockhart and Wiseman, 1978).

Corn seed should be planted on a well prepared seedbed. Thorough ploughing should be done before planting to ensure a good seedbed, and seed should be sown 4-6 cm deep in a level, moist, friable soil. Organic manures and fertilizers are required wherever the soil fertility is otherwise insufficient for vigorous growth and high productivity.

In order to ensure vigorous growth and high productivity, weeds and pests must be controlled throughout the growing period of the crop. In early crop growth, weeds can smother corn seedlings and impair normal growth. Arrested growth of corn in the early vegetative growth stage is the main cause of poor yields later in the season. Chemical weed control is commonly used in forage corn fields because high corn plant populations restrict the use of mechanized weed control.

When, corn is grown for silage, the whole above ground shoot is harvested (Lockhart and Wiseman, 1978). In practise, forage corn makes a highly palatable silage, but it is better suited for beef than dairy production systems (Lockhart and Wiseman, 1978). The protein content of silage can be improved by addition of non-protein nitrogen compounds, usually when the crop is being ensiled. The ensiled corn should be harvested with a dry matter content of between 25% and 35%. The digestibility value for such silage would be about 68%. Plant maturity at harvest is assessed by observing the kernel development. Plants are normally cut for silage when the kernels become "cheesy" and "doughy" in the early dent stage. The yields realized at this stage of growth depend on the effects of various climatic and agronomic factors during the cropping season. Such factors include: the amount and distribution of precipitation, amount and duration of solar radiation, temperature, soil characteristics planting density per hill and per hectare, weed and pest controls and exposure to wind and air pollution.

2.2 Effects of Planting Density on the Growth and Yield of Forage Corn

As noted above, forage corn yields may depend on the planting density used during the establishment of the crop. The general effects of planting density on the growth and yield of herbacious species were reviewed by Donald (1963) and Holliday (1960). The commonly observed trends of density effects on yield are lower yields per unit land area in lower densities and higher yields per unit land area in higher densities until an optimum or plateau is reached. When high yield/plant is desirable, the reverse holds true. Yield per unit land area is, however, the most commonly used agronomic basis for recommending a certain planting density for crop species. Optimum planting density may be influenced by environmental hazards. Plants grown at low density could yield lower than otherwise expected due to greater exposure to wind, pests and diseases (Donald, 1963).

Corn cultivars have been shown to differ significantly in the ways they react to increasing planting density. For example, Buren *et al.* (1974) observed that high density-tolerant genotypes were free from the apparent density effects of barrenness. Such cultivars were characterized by rapid completion of silk extrusion, coincidence of silk extrusion and pollen shed, rapid growth in the first ear and first ear silk, prolificacy, reduced tassel size and efficient production of grain per unit land area. Higher planting densitites have also been found to increase plant quality through increased soluble sugar content and also may advance maturity of silage (McAllan and Phipps, 1977).

Some plant morphological characteristics have been found to be more susceptible to density effects than others. Stems are highly susceptible to the effects of planting density (McAllan and Phipps, 1977), mainly being reduced in weight in response to increasing number of plants per unit land area. Corn plants grown at a low planting density produce larger ears, and show slower leaf senescence and more robust stems than corn grown at a high planting density. Stem elongation responds to increased number of plants per unit land area by increased plant height (Lopes and Maestri, 1981). Planting density does not influence the maximum number of leaves per plant. Both plant height and number of leaves per plant reach their maximum values at the time of ear initiation, regardless of planting density.

Dry matter partitioning within a corn plant varies with stage of plant growth and development (Lopes and Maestri, 1981). Leaves and roots are the common sinks in the early stages of growth. At ear initiation, the ear becomes the preferential sink. Such trends have not been shown to be affected by planting density.

Higher dry matter yields/ha in plants grown at a density of 8 plants/m^2 were found to be due mainly to increased leaf area index (Remison and Lucas, 1982). Silage yield in corn depends on dry matter accumulation in the shoots (Iremiren and Milbourn, 1978). Increasing number of plants/m^2 reduces dry matter accumulation in individual plants but increases dry matter yields/ha asymptotically until a plateau is reached. Plants grown at a higher density, however, have increased risks of lodging which may interfere with the total recoverable yield at harvest.

Time for harvesting forage corn depends on the kernel maturity (Gonske and Keeney, 1969). Such forage will be of better quality when harvested at late dent of kernels than early dent because late dent corn has higher dry matter and protein yields, and lower nitrate nitrogen and soluble nitrogen contents, than does corn harvested at early dent (Gonske and Keeney, 1969). Kernel dry weight accummulation rate is not affected by planting density, but the effective filling period may be shortened at high planting density (Poneleit and Egli, 1979). This effect can also reduce yield per plant to some extent.

2.3 Growth and Yield Analyses

Several different approaches have been developed during this century for the quantitative analysis of plant growth and yield. Recent studies have refined many of the main concepts and have provided improved procedures for understanding and analyzing experiments related to crop productivity. Recent reviews and major contributions in this general subject area include publications on plant growth analysis (Causton and Venus, 1981; Evans, 1972; Jolliffe *et al*. 1983 (in preparation); Hunt, 1982a, 1982b), yield components analysis (Eaton *et al*., 1983; Fraser and Eaton, 1983; Jolliffe *et al*. 1982, 1983 (in preparation)) and demographic analysis (Bazzaz and Harper, 1977; Lovett Doust and Eaton, 1982; Jolliffe *et al*. 1983 (in preparation)). In this thesis, the two approaches used to analyze the response of forage corn productivity to planting density were plant growth analysis and yield component analysis.

Plant growth analysis (i.e. the so-called British School of plant growth analysis) includes indices of both the presence and assmilatory performance of morphological growth characteristics (Evans, 1972). Modern plant growth analysis is facilitated by the use of fitted curves (Causton and Venus, 1981; Hunt, 1982a; Parsons and Hunt, 1981). The fitted curves describe the quantitative performance of plants or plant parts, integrated both throughout the system under study and across ecologically or agronomically-meaningful intervals of time (Hunt, 1982b) Ratios, rates, compounded rates and integral durations are its stock-in-trade and they can all be effectively described by cubic spline regressions (Hunt, 1982b).

Yield component analysis has been applied in agricultural research to analyze crop productivity in single harvests or in a sequence of harvests during the course of crop growth. In yield component analysis, plant morphological characteristics are selected in a rationalized sequence (e.g., following the chronological development of plant growth), and are included as a series of ratios (yield components) in a model predicting yield. Yield component models may be analyzed in several ways including simple or multiple regressions of the components in relation to yield. Other analytical procedures involve the use of ordered stepwise multiple regressions (Eaton and Kyte, 1978), analysis of variance (Bowen, 1983) and two-dimensional positioning-yield component analysis (TDP-YCA; Eaton et al. 1983).

3. MATERIALS AND METHODS

3.1 Generation of the Primary data

The experiment was conducted at the Totem Field Laboratory of the University of British Columbia during the summer of 1982. The land was ploughed early in April and was frequently harrowed before the planting date, which was the 26th of May, 1982. Before planting, the field plots were laid out in a randomized complete block design (RCBD) with 9 blocks and 4 different planting density plots in each block. Five sample sub-plots were randomly marked out within each density plot for the five harvests done in the growing season. Sampled plots were separated by at least one row of unsampled plants to ensure that early harvested plots would not influence the subsequent growth in remaining sample plots. Four plants were sampled from each planting density plot at each harvest. A complete layout of the experimental plots is shown in Appendix (I). Within the plots, forage corn (*Zea mays* L.) seed cr. DK 24 was sown in a square planting pattern with the dimensions of the square varying according to the planting density. The square dimensions were 45 cm x 45 cm, 39 cm x 39 cm, 34 cm x 34 cm and 30 cm x 30 cm, representing the following number of plants per hectare: 49383, 67204, 87796 and 111111, for d_1 to d_4 (Appendix I), respectively.

Bird and weed damage to seedlings and the established crop were kept to a minimum throughout the growing season. Birds were controlled by stretching large pieces of fishnet about 60 cm above the plots immediately after sowing. These nets were removed after the seedlings were fully established. Weeds were constantly eradicated from the plots by hand-pulling or by use of a hand hoe.

Harvesting of the plots was done when the plants reached the following ages: 21 days after emergence (DAE), 42 DAE, 63 DAE, 85 DAE and 115 DAE, which correspond to growth stages designated as early vegetative growth, late vegetative growth, early reproductive growth, late reproductive growth and forage maturity, respectively. The four plants harvested from each plot were sampled for the following data before drying of samples:

Number of leaves per plant (L_N)

Plant height (T; cm)

Plant diameter (D; cm)

Leaf area per plant (L_A; cm)

Leaf blade fresh weight (L_F; g/plant)

Remaining fresh weight per plant (R_F; g/plant)

Total number of tassels and ears/plant (FNT/plant)

Total number of ears per plant (ENT/plant)

Ear fresh weight per plant (E_F; g/plant)

Total fresh weight (W_F; g/plant)

After drying the samples to a constant dry weight at 80°C in a forced air bulk drier, the following data were also recorded:

Leaf blade dry weight per plant (W_L; g/plant)

Leaf sheath dry weight per plant (W_{LS}; g/plant)

Stem dry weight per plant (W_{ST}; g/plant)

Tiller dry weight per plant (W_{TL}; g/plant)

Total vegetative dry weight per plant (W_V; g/plant)

Tassel dry weight per plant (W_{TA}; g/plant)

Husk dry weight per plant (W_H; g/plant)

Cob dry weight per plant (W_C; g/plant)

Grain dry weight per plant (W_G; g/plant)

Total reproductive dry weight per plant (W_{rep}; g/plant)

Total shoot biomass yield per plant (W; g/plant)

3.2 Growth and Yield Analyses

3.2.1 Growth Analysis

Growth trends and variability in growth characteristics among different planting densitites were developed from the primary plant growth characteristics listed above. Analysis of variance was used to study the variability of means of primary growth characteristics among densities and ages. Whole shoot biomass was also analyzed separately by the ANOVA method. In both cases the ANOVA model was set to partition variability according to blocks, density, harvest time, density x harvest time interaction and error. The respective degrees of freedom were 8, 3, 4, 12 and 696 for those sources of variability. A total of 720 data cases were therefore analyzed in the ANOVA model for each primary growth characteristic.

At each harvest, yield, which was defined to be total shoot biomass (W), was derived from the following equation:

$$W = W_L + W_{LS} + W_{ST} + W_{TL} + W_{rep} \quad (1)$$

Fitted curves, describing the time course of most of the primary values described above were generated using a cubic spline regression procedure. This procedure (Jolliffe et al. 1983 (in preparation)) involved the Fortran subroutines DSPLFT and DSPLN available through the University of British Columbia Computing Centre. The procedure also generated fitted curves for the first derivative (e.g. dW/dt) and the first derivative of the logarithm (i.e. the relative growth rate) of each characteristic. Smoothing of the spline regressions was determined entirely within the computer program according to the size of the standard deviations of the variates at each harvest.

Several derived plant growth indices were developed from the cubic spline regressions of the primary growth characteristics as follows:

$$R_W = \frac{1}{W}\left(\frac{dW}{dt}\right)$$

$$= \frac{1}{W}\left(\frac{dW_L}{dt}\right) + \frac{1}{W}\left(\frac{dW_{LS}}{dt}\right) + \frac{1}{W}\left(\frac{dW_{ST}}{dt}\right) + \frac{1}{W}\left(\frac{W_{TL}}{dt}\right) + \frac{1}{W}\left(\frac{dW_{rep}}{dt}\right) \qquad (2)$$

$$CGR = N\left(\frac{L_A}{A}\right) \cdot \frac{1}{L_A}\left(\frac{dW}{dt}\right) = \frac{N}{A}\left(\frac{dW}{dt}\right)$$

$$= LAI \times ULR \qquad (3)$$

Where CGR = crop growth rate ($g/m^2/day$)

LAI = leaf area index (m^2/m^2)

ULR = Unit leaf rate ($g/m^2/day$)

$$ULR = \frac{1}{W}\left(\frac{dW}{dt}\right) \cdot \frac{1}{L_A/W}$$

$$= R_W/LAR \qquad (4)$$

where R_W = relative growth rate of total shoot biomass (g/g/day).

$$LAR = \frac{L_A}{W} \qquad (5)$$

Where LAR = leaf area ratio (m^2/g)

$$SLA = L_A/W_L \qquad (6)$$

Where SLA = specific leaf area (m^2/g).

$$LWR = W_L/W \qquad (7)$$

Where LWR = leaf weight ratio (g/g).

3.2.2 Yield Component Analysis

Plant morphological characteristics were included in a yield component analysis model based on the following developmental order:

$$Y = T \times \frac{D}{T} \times \frac{L_N}{D} \times \frac{L_A}{L_N} \times \frac{W_L}{L_A} \times \frac{W}{W_L} \qquad (8)$$

where Y = W = yield.

Each term on the right hand side of Eqn. (8) will be called a yield component (C).

The yield components were also analyzed by the ANOVA model described above and their means were used to develop cubic spline regressions, using procedures similar to those described above, to trace their trends of growth over time.

In addition, the yield components were transformed into their natural logarithms. Thus Eqn. (8) was tranformed as follows:

$$\mathrm{Log}_e(Y) = \mathrm{Log}_e(T) + \mathrm{Log}_e(\frac{D}{T}) + \mathrm{Log}_e(\frac{L_N}{D}) + \mathrm{Log}_e(\frac{L_A}{L_N}) + \mathrm{Log}_e(\frac{W_L}{L_A}) + \mathrm{Log}_e(\frac{W}{W_L}) \qquad (9)$$

The logarithmically transformed data were orthogonalized and transformed according to the method of Eaton et al. (1983). The analysis then proceeded by the two-dimensional partitioning-yield component analysis (TDP-YCA) method described by these authors.

Both forward and backward TDP-YCA analyses were performed on the pooled data from all harvests and were also performed on data from individual harvests in order to identify significant yield components and examine the effects of density on yield and yield components.

The cubic spline regressions derived for yield components were also used to express the relative growth rate of yield (R_Y) according to the equation (Jolliffe et al., 1983 (in preparation)):

$$RY = \sum_{i=1}^{n} RCi \qquad (10)$$

where R_{Ci} = relative growth rate of each yield component variable (C).

n - 6 (the number of yield components).

These growth indices were also plotted in time course curves to study their trends at each planting density.

4. RESULTS

The results will be presented in four main parts; each part will consider the effects of planting density and harvest time on different aspects of growth and yield of forage corn. Primary characteristics of growth will be summarized in Section (4.1), some derived indices of growth and the analysis of those indices by plant growth analysis will be presented in Section (4.2). Section (4.3) will present and analyze the yield components derived from primary growth characteristics, and Section (4.4) will outline the analysis of relative growth rate of yield using the relative growth rates of yield componenets for each planting density.

4.1 Primary Characteristics of Growth

Primary growth characteristics are summarized in Tables (1a) and (1b). In general, the primary characteristics increased with plant age until full development was achieved, and they usually decreased with increased number of plants per square metre. An exception to this pattern was stem height (T) which increased with increased planting density.

Table (2) indicates that the effects of planting density and harvest time on all primary plant characteristics were highly significant ($p<.001$).

The responses of individual characteristics to treatments were further analysed by describing the time and density trends using cubic spline regressions (Figs. 1-7). Such analysis was applied to most of the individual characteristics listed in Tables (1a) and (1b). Several

Table 1a

Yield (per plant) of Primary Plant Growth characteristics of forage corn at four planting densities and five harvest times.

Planting Density (Plants/m²)	Age (days)	Plant Growth Characteristics T (cm)	D (cm)	L_N (#)	L_A (dm^2)	FNT (#)	ENT (#)
4.9	21	1.81	0.60	7.80	5.012	-[2]	-
		(0.61)[1]	(0.18)	(0.86)	(2.16)	-	-
	42	25.40	2.11	11.44	36.04	0.06	0.06
		(8.64)	(0.32)	(0.97)	(5.96)	(0.33)	(0.33)
	63	156.40	2.50	10.17	55.02	2.56	1.58
		(27.70)	(0.23)	(1.46)	(6.73)	(0.81)	(0.77)
	85	194.70	2.64	7.86	46.48	3.25	2.25
		(22.08)	(0.25)	(0.87)	(8.31)	(1.18)	(1.18)
	115	195.60	2.79	6.86	38.54	3.36	2.36
		(19.79)	(0.18)	(1.44)	(8.99)	(1.05)	(1.05)
6.7	21	1.62	0.55	7.28	4.16	-	-
		(0.42)	(0.11)	(0.66)	(1.20)	-	-
	42	33.00	2.16	11.11	38.37	-	-
		(9.48)	(0.30)	(1.45)	(5.73)	-	-
	63	168.30	2.36	9.75	49.64	2.08	1.11
		(17.21)	(0.25)	(1.27)	(8.00)	(0.77)	(0.71)
	85	201.80	2.50	7.69	42.94	3.00	2.00
		(27.14)	(0.25)	(1.39)	(8.39)	(0.89)	(0.89)
	115	196.40	2.63	6.44	36.20	2.58	1.58
		(21.97)	(0.20)	(1.23)	(7.96)	(0.77)	(0.77)
8.8	21	1.80	0.58	7.39	4.67	-	-
		(0.48)	(0.13)	(0.87)	(1.88)	-	-
	42	27.69	2.03	10.97	33.81	-	-
		(10.80)	(0.27)	(0.91)	(5.77)	-	-
	63	153.70	2.15	9.11	47.34	1.44	0.50
		(21.74)	(0.20)	(1.24)	(7.00)	(0.65)	(0.61)
	85	194.90	2.32	6.89	36.30	2.56	1.56
		(24.28)	(0.24)	(1.09)	(8.17)	(0.88)	(0.88)
	115	194.20	2.38	5.89	31.13	2.17	1.17
		(17.92)	(0.24)	(1.30)	(6.47)	(0.45)	(0.45)
11.1	21	1.98	0.58	7.22	4.84	-	-
		(0.56)	(0.14)	(0.80)	(2.12)	-	-
	42	30.00	1.90	11.19	33.50	-	-
		(9.98)	(0.26)	(1.19)	(6.85)	-	-
	63	163.10	2.05	8.75	44.30	1.50	0.50
		(25.29)	(0.21)	(0.97)	5.77)	(0.61)	(0.61)
	85	200.20	2.15	7.03	34.05	2.06	1.06
		(20.69)	(0.27)	(0.97)	(6.78)	(0.48)	(0.48)
	115	200.10	2.29	5.50	27.12	2.14	1.14
		(23.92)	(0.16)	(1.06)	(6.51)	(0.49)	(0.49)
Mean[3]		117.13	1.96	8.32	32.50	1.44	0.843
S.D.		86.57	0.76	(2.13)	(16.64)	(1.39)	(1.011)
Signif.		***	***	***	***	***	***

1. - values in brackets represent the standard deviations
2. - represent unrecorded data
3. - distributed throughout the five harvests
*** - significant at $P \leq .001$

Table 1b

Yield (g/plant) of Primary Plant Growth characteristics of forage corn at four planting densities and five harvests times.

Planting Density ($Plants/m^2$)	Age (days)	Plant Growth Characteristics W_L	W_{LS}	W_{ST}	W_{TL}	W_{TA}	W_H	W_C	W_G
4.9	21	1.55	0.37	0.12	-[2]	-	-	-	-
		(0.82)[1]	(0.23)	(0.11)	-	-	-	-	-
	42	16.38	5.47	5.52	1.56	-	-	-	-
		(4.32)	(1.72)	(3.24)	(1.92)	-	-	-	-
	63	30.99	18.53	43.63	3.70	8.48	4.41	-	-
		(5.39)	(4.69)	(14.12)	(6.61)	(2.23)	(4.47)	-	-
	85	31.56	20.34	82.91	2.91	5.73	16.00	30.29	-
		(5.68)	(3.67)	(19.62)	(6.38)	(1.10)	(9.57)	(14.50)	-
	115	31.92	18.17	73.46	-	5.52	26.91	42.81	107.80
		(5.73)	(3.43)	(19.02)	-	(1.29)	(7.46)	(18.93)	(25.79)
6.7	21	1.26	0.35	0.09	-	-	-	-	-
		(0.44)	(0.38)	(0.06)	-	-	-	-	-
	42	17.56	6.01	7.00	1.58	-	-	-	-
		(4.07)	(1.52)	(3.16)	(2.09)	-	-	-	-
	63	27.91	16.25	38.59	0.90	7.68	2.92	-	-
		(4.16)	(3.15)	(9.18)	(1.78)	(2.34)	(2.97)	-	-
	85	29.56	18.56	69.99	0.98	4.98	11.62	21.49	-
		(4.65)	(3.70)	(18.49)	(2.13)	(1.37)	(6.22)	(9.74)	-
	115	29.17	15.89	55.51	-	4.69	20.43	24.19	86.22
		(4.71)	(2.76)	(17.39)	-	(0.99)	(4.11)	(6.88)	(16.85)
8.8	21	1.44	0.32	0.17	-	-	-	-	-
		(0.75)	(0.17)	(0.22)	-	-	-	-	-
	42	14.89	4.97	5.19	0.28	-	-	-	-
		(3.46)	(1.42)	(2.75)	(0.68)	-	-	-	-
	63	25.24	14.06	30.62	0.24	7.04	0.69	-	-
		(3.61)	(2.57)	(8.23)	(0.61)	(1.77)	(1.11)	-	-
	85	26.32	16.23	58.85	0.05	4.35	7.94	12.75	-
		(5.02)	(3.30)	(14.49)	(0.20)	(1.03)	(6.51)	(8.19)	-
	115	25.21	14.14	43.17	-	3.93	15.40	16.75	62.17
		(3.35)	(2.31)	(10.12)	-	(1.07)	(4.76)	(5.71)	(27.03)
11.1	21	1.54	0.332	0.13	-	-	-	-	-
		(0.77)	(0.19)	(0.09)	-	-	-	-	-
	42	14.15	4.94	5.56	0.03	-	-	-	-
		(3.40)	(1.27)	(2.77)	(0.09)	-	-	-	-
	63	23.83	12.66	27.45	0.03	6.25	0.37	-	-
		(2.98)	(2.23)	7.42	(0.20)	(1.87)	(0.57)	-	-
	85	23.14	13.36	49.06	0.00	3.56	4.20	6.99	-
		(4.70)	(3.06)	(12.45)	0.02	(1.17	(3.63)	(5.28)	-
	115	24.01	12.93	42.50	-	3.58	11.03	14.89	45.17
		4.53	(2.17)	(10.50)	-	(0.60)	(4.66)	(6.20)	(25.17)
Mean[3]		19.88	10.69	31.98	0.61	3.28	6.10	8.51	15.07
S.D.		(11.26)	(7.32)	(29.10)	(2.45)	(3.15)	(8.90)	(14.00)	(33.72)
Signif.		***	***	***	***	***	***	***	***

1. - values in brackets represent the standard deviations
2. - represent unrecorded data
3. - distributed throughout the five harvests

*** - significant at $P \leq .001$

Table 2

Effects of Planting Density and harvest time on the Primary Growth Characteristics of Forage Corn.

Plant Growth Characteristic	Treatment Means					
	A. Planting Density (Plants/m^2)					
	(4.9)	(6.7)	(8.8)	(11.1)	Mean	Signif.
T (cm)	114.80	120.20	114.50	119.10	117.13	***
D (cm)	2.13	2.04	1.89	1.79	1.96	***
L_N	8.83	8.46	8.05	7.94	8.32	***
L_A (dm^2)	36.22	34.36	30.65	28.76	32.50	***
FNT	1.84	1.53	1.23	1.14	1.44	***
ENT	1.25	0.94	0.64	0.54	0.84	***
W_L (g)	22.48	21.09	18.62	17.34	11.26	***
W_{LS} (g)	12.57	11.41	9.94	8.85	7.32	***
W_{ST} (g)	41.13	34.24	27.60	24.94	31.98	***
W_{TL} (g)	1.63	0.69	0.11	0.01	0.61	***
W_{TA} (g)	3.91	3.47	3.06	2.68	3.28	***
W_H (g)	9.46	6.99	4.81	3.12	6.10	***
W_C (g)	14.62	9.14	5.90	4.38	8.51	***
W_G (g)	21.56	17.24	12.43	9.03	15.07	***

Table 2 (continued):

	B. (21)	(42)	Harvest Time (Age in days). (63)	(85)	(115)	Mean	
T (cm)	1.80	29.02	160.40	197.90	196.60	117.13	***
D (cm)	0.58	2.05	2.26	2.40	2.53	1.96	***
L_N	7.42	11.18	9.44	7.37	6.17	8.32	***
L_A (dm^2)	5.02	36.04	55.02	46.48	38.54	32.50	***
FNT	0.00	0.01	1.90	2.72	2.56	1.44	***
ENT	0.00	0.01	0.92	1.72	1.56	0.84	***
W_L (g)	1.45	15.75	27.00	27.65	27.58	11.26	***
W_{LS} (g)	0.34	5.35	15.37	17.12	15.28	7.32	***
W_{ST} (g)	0.13	5.82	35.07	65.20	53.66	31.98	***
W_{TL} (g)	0.00	0.86	1.22	0.99	0.00	0.61	***
W_{TA} (g)	-[1]	-	7.36	4.65	4.38	3.28	***
W_H (g)	-	-	2.10	9.94	18.44	6.10	***
W_C (g)	-	-	0.00	17.88	24.66	8.51	***
W_G (g)	-	-	-	-	75.34	15.07	***

1. - Values not recorded
*** - Significant at $P \leq .001$ according to F-test

of the dry weight components (W_{TL}, W_{TA}, W_H, W_C and W_G), however, are not shown individually but are pooled in the total shoot dry weight regressions (Fig. 8). Regressions were also not developed for total number of flowers/plant (FNT) and total number of ears/plant (ENT), since those characteristics were not determined at all harvests.

The effects of harvest time on primary plant characteristics were always large and for most of the characteristics, density effects were large at later harvests. However, the effects of density on the growth in height (T) of stems were not very large at any time during growth. Thus, while all primary characteristics were significantly affected by planting density (Table 2), the magnitude of the effects were variable among the characteristics (Figs. 1-7). Planting density did not greatly affect the early exponential phase of growth of the plant characteristics (Figs. 1-7).

The reproductive growth characteristics were not recorded until at the age of 42 days after emergence (DAE) (Table 1a). Early dry weights of the undeveloped ears were negligible and were not separately included in the table of dry weights of the ear characteristics (Table 1b) at the age of 42 DAE. Undeveloped tassels were also observed at the second harvest (42 DAE), but their separation for individual records was not feasible at that time. Their dry weight values were included with the dry weights for stems at 42 DAE. Also, undeveloped cobs were included in the husk dry weight (W_H) at the age of 63 DAE (Table 1b). Similarly, the undeveloped grains on the cob were not separated from the dry weights of the cobs (W_C) at the age of 85 DAE (Table 1b).

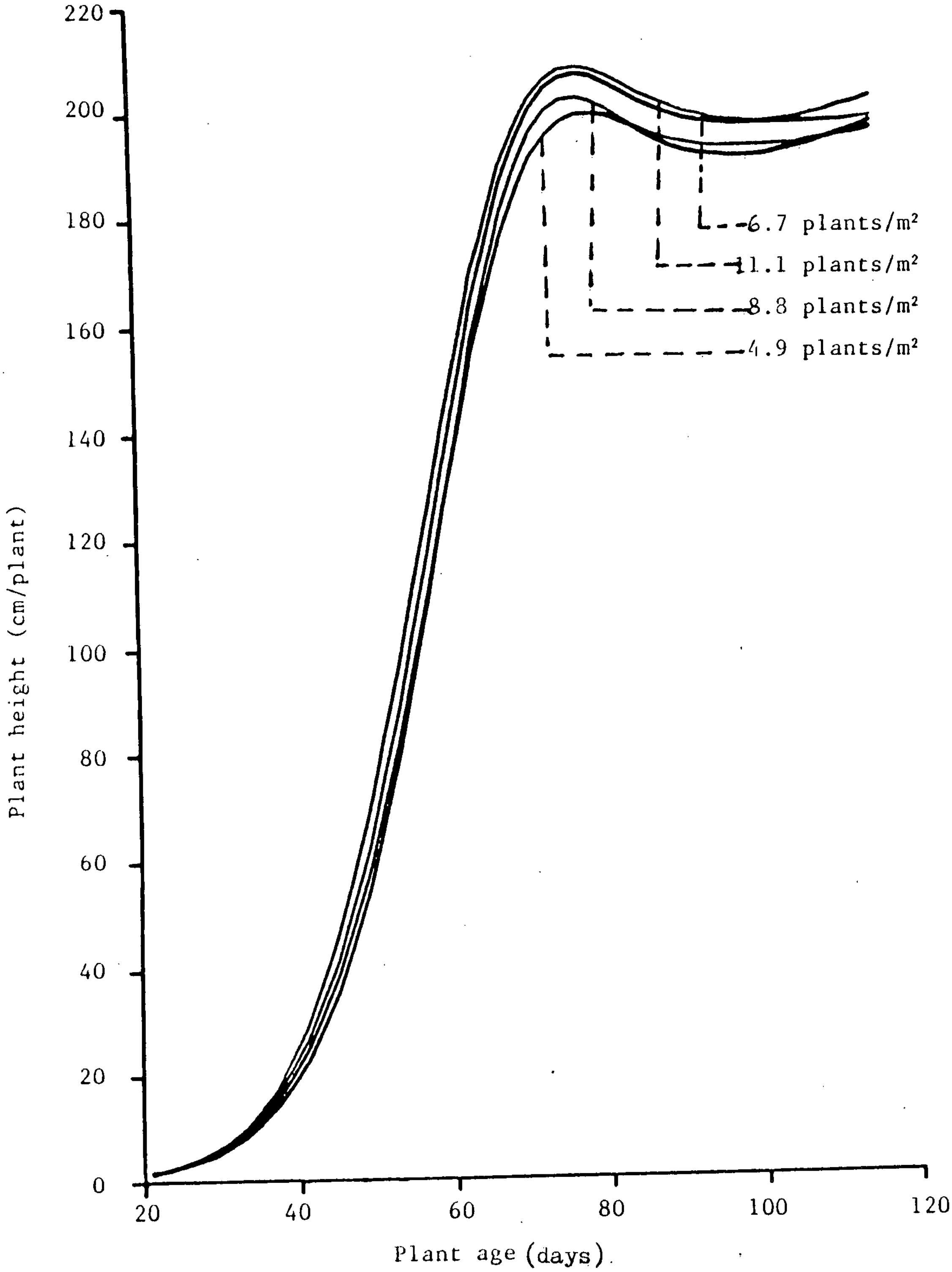

Figure 1 - Cubic spline regressions describing the time course of plant height (T) in corn at four planting densities.

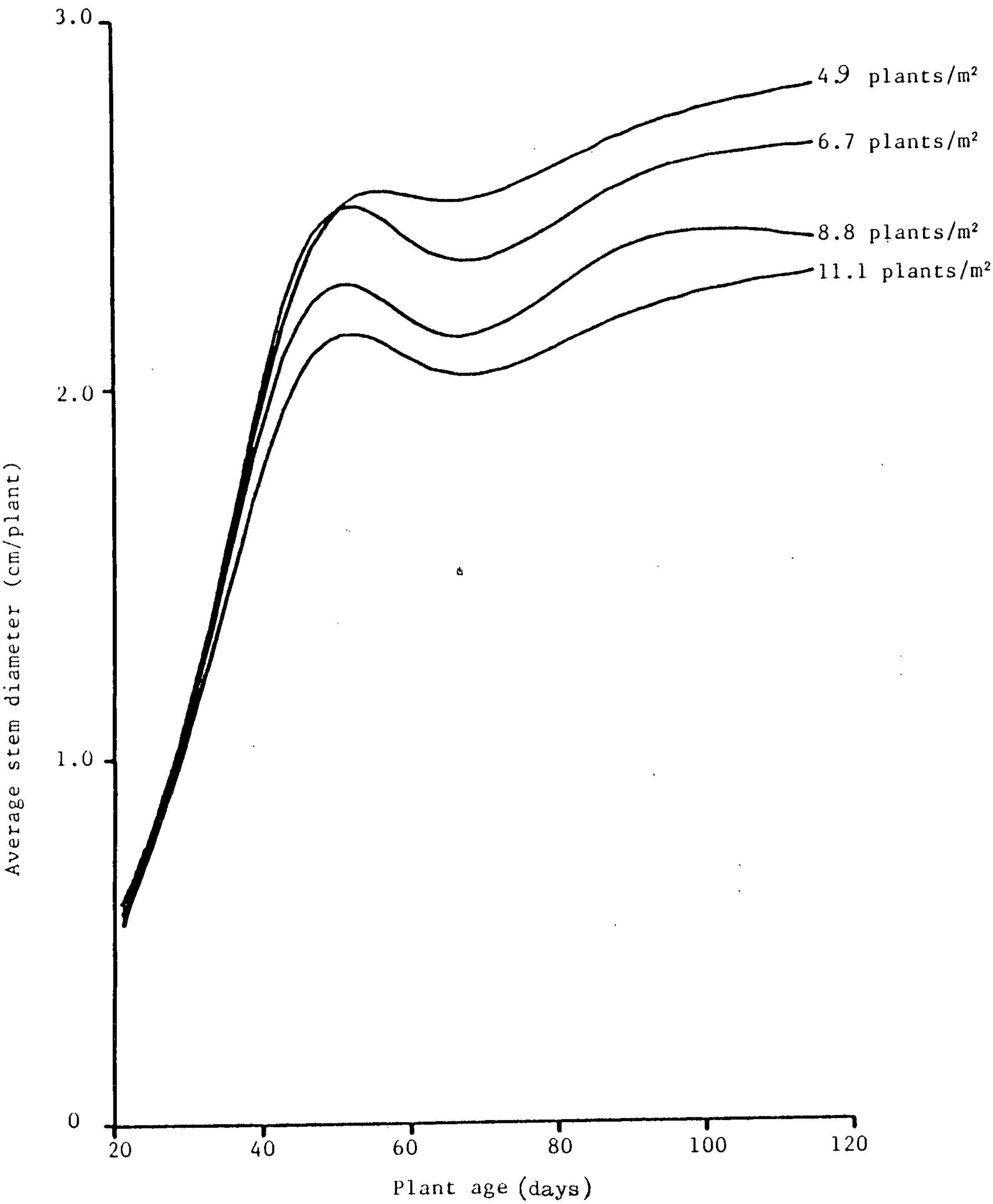

Figure 2 - Cubic spline regressions describing the time course of plant diameter (D) in corn at four planting densities.

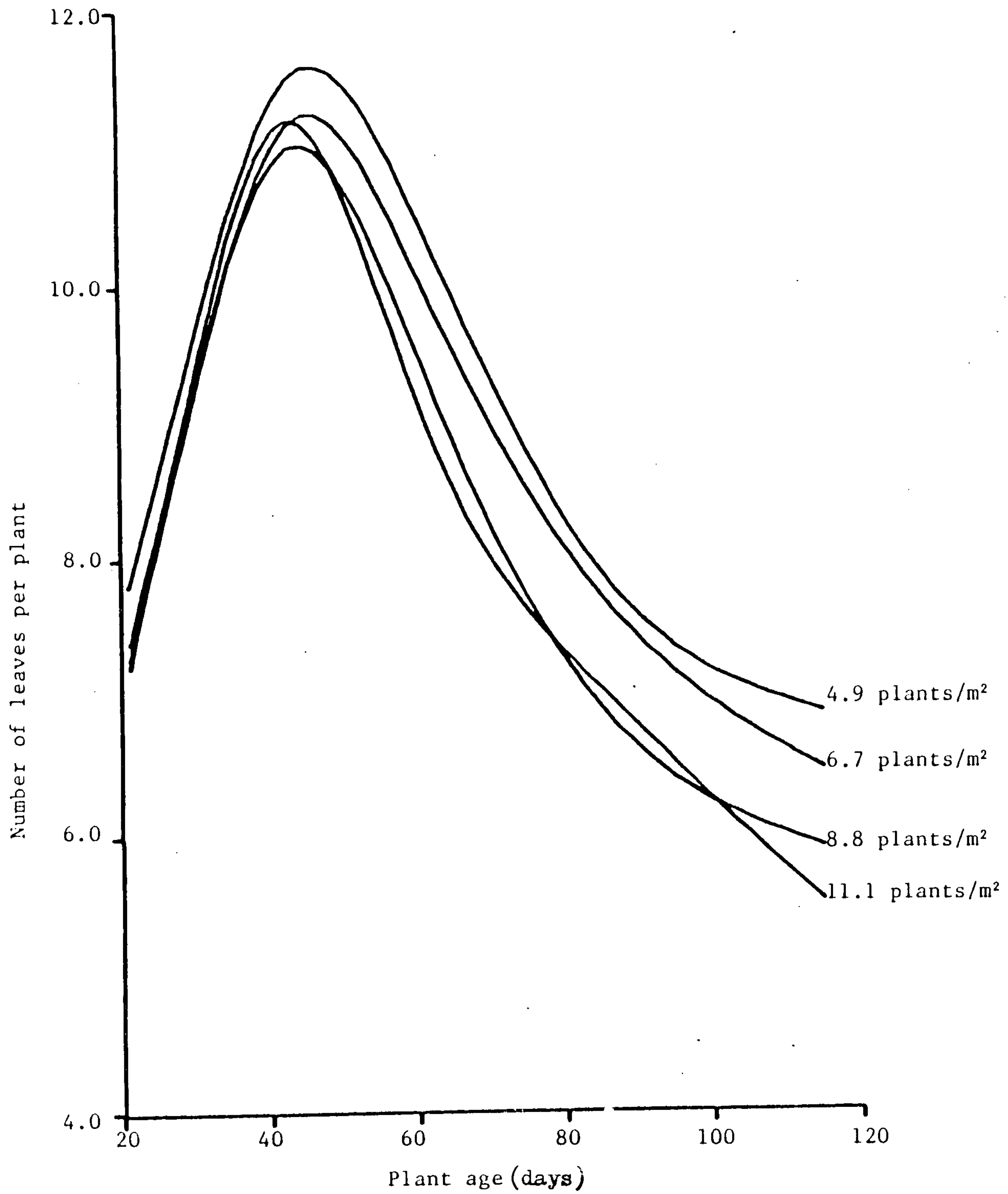

Figure 3 - Cubic spline regressions describing the time course of number of leaves/plant (L_N) in corn at four planting densities.

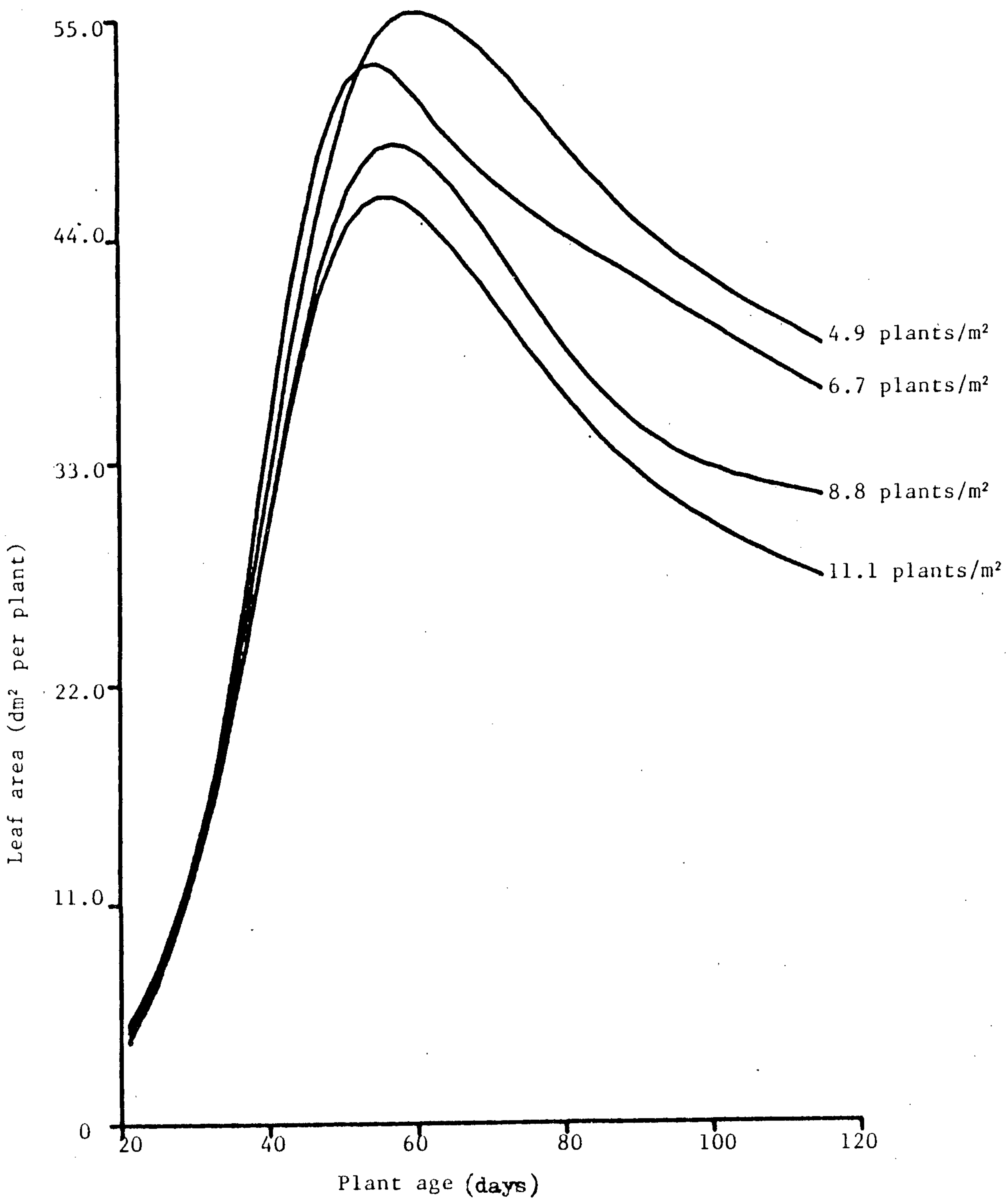

Figure 4 - Cubic spline regressions describing the time course of leaf area/plant (L_A) in corn at four planting densities.

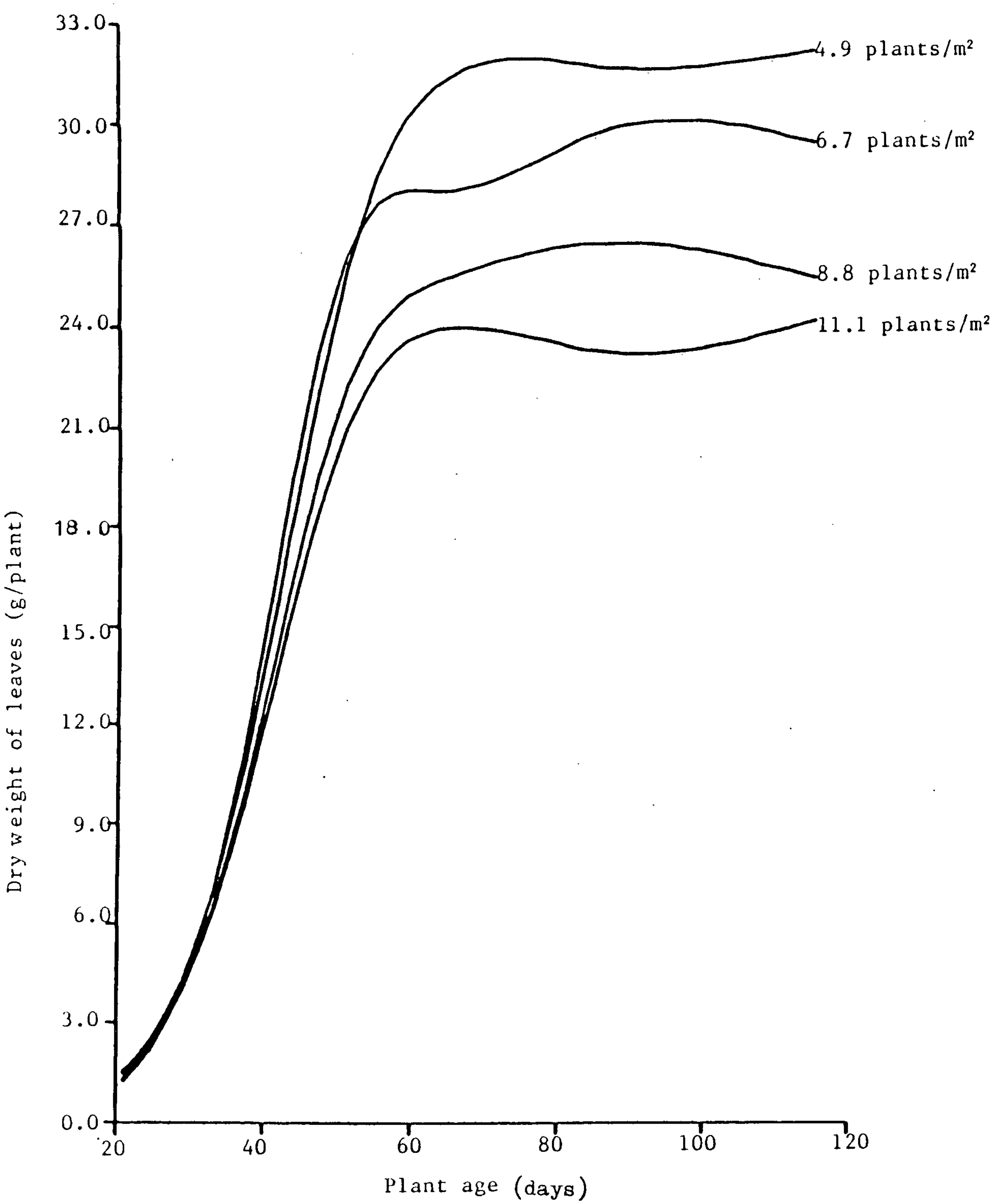

Figure 5 - Cubic spline regressions describing the time course of dry weight of leaves/plant (W_L) in corn at four planting densities.

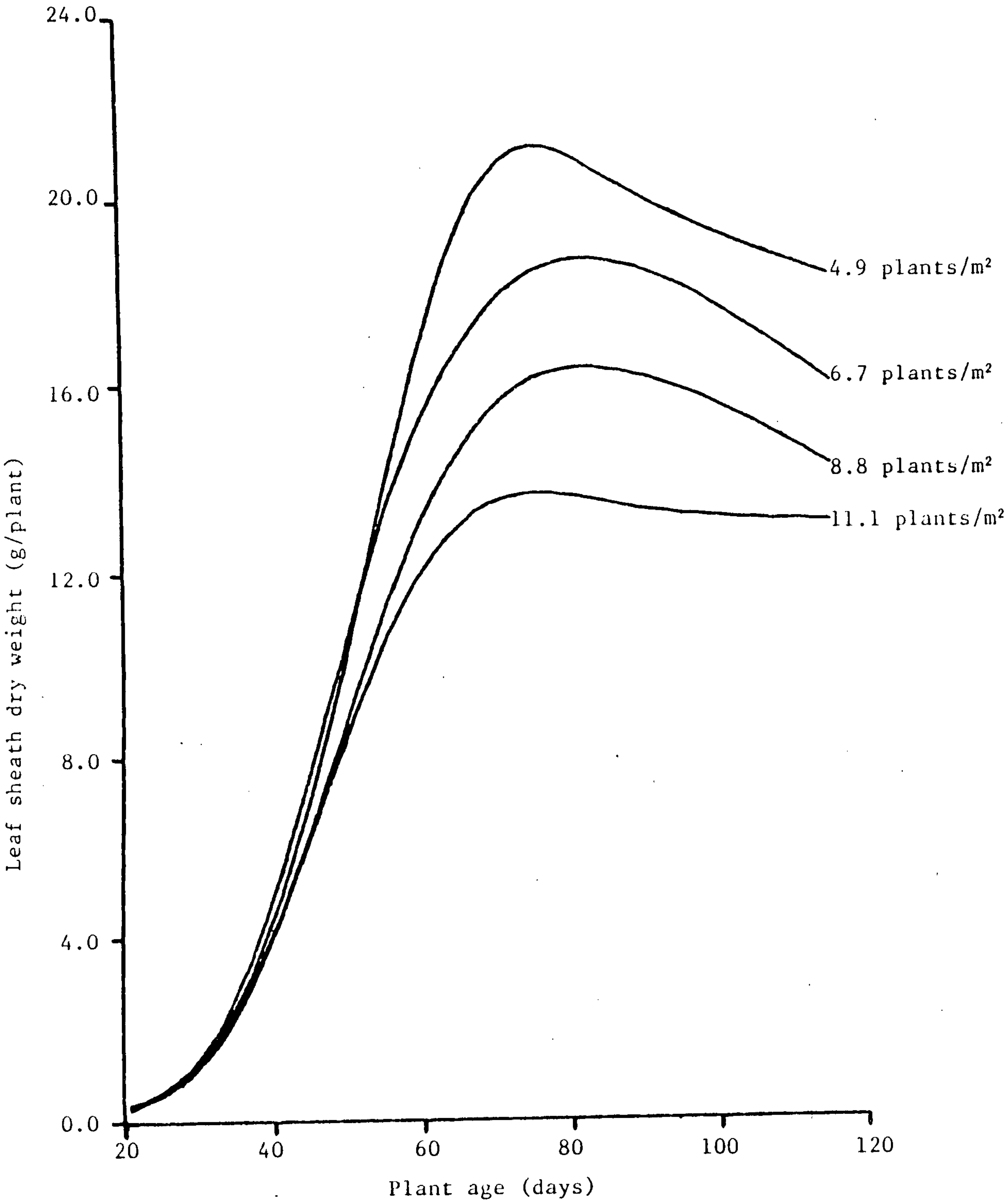

Figure 6 - Cubic spline regressions describing the time course of dry weight of leaf sheaths/plant (W_{LS}) in corn at four planting densities.

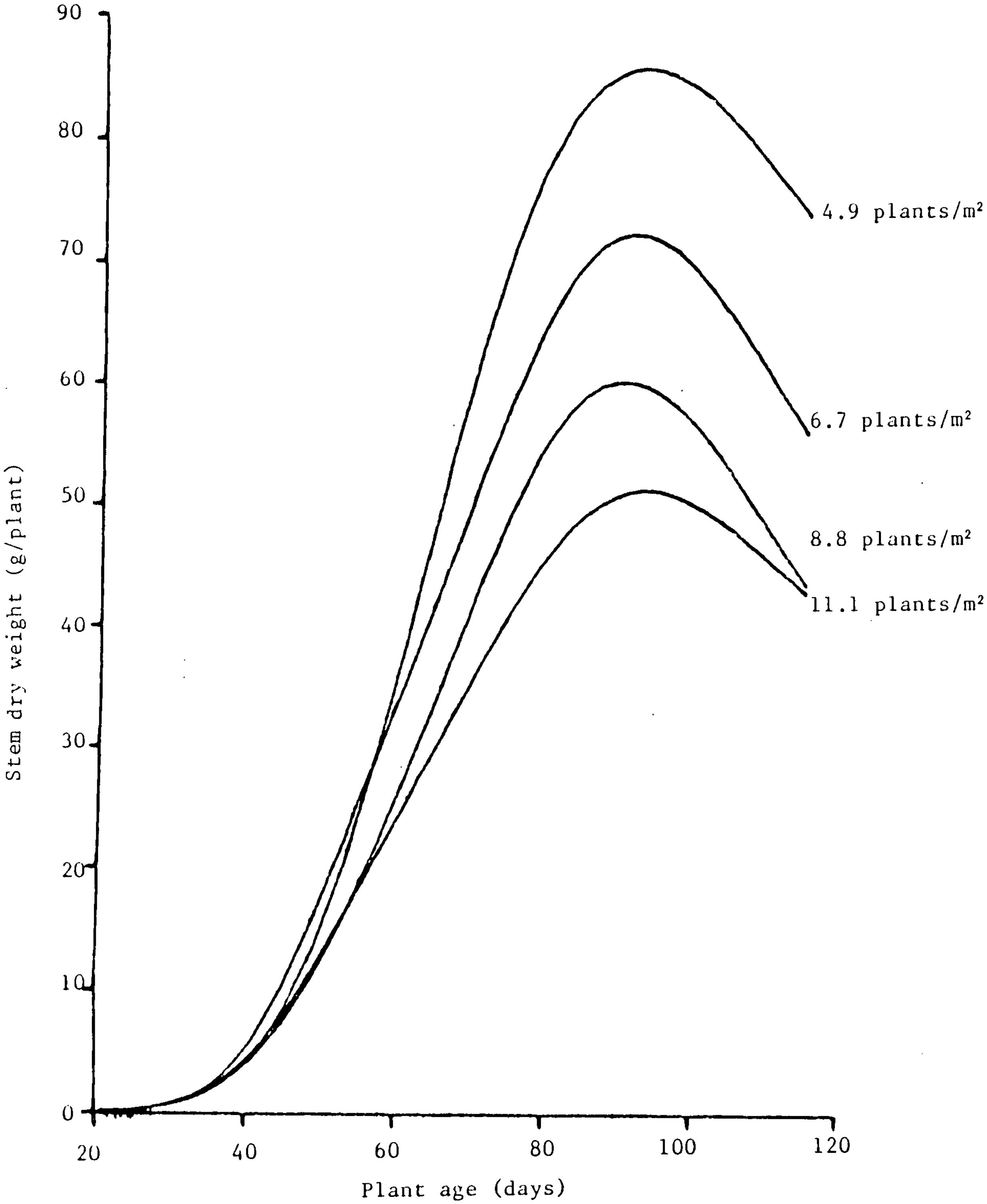

Figure 7 - Cubic spline regressions describing the time course of dry weight of stem/plant (W_{ST}) in corn at four planting densities.

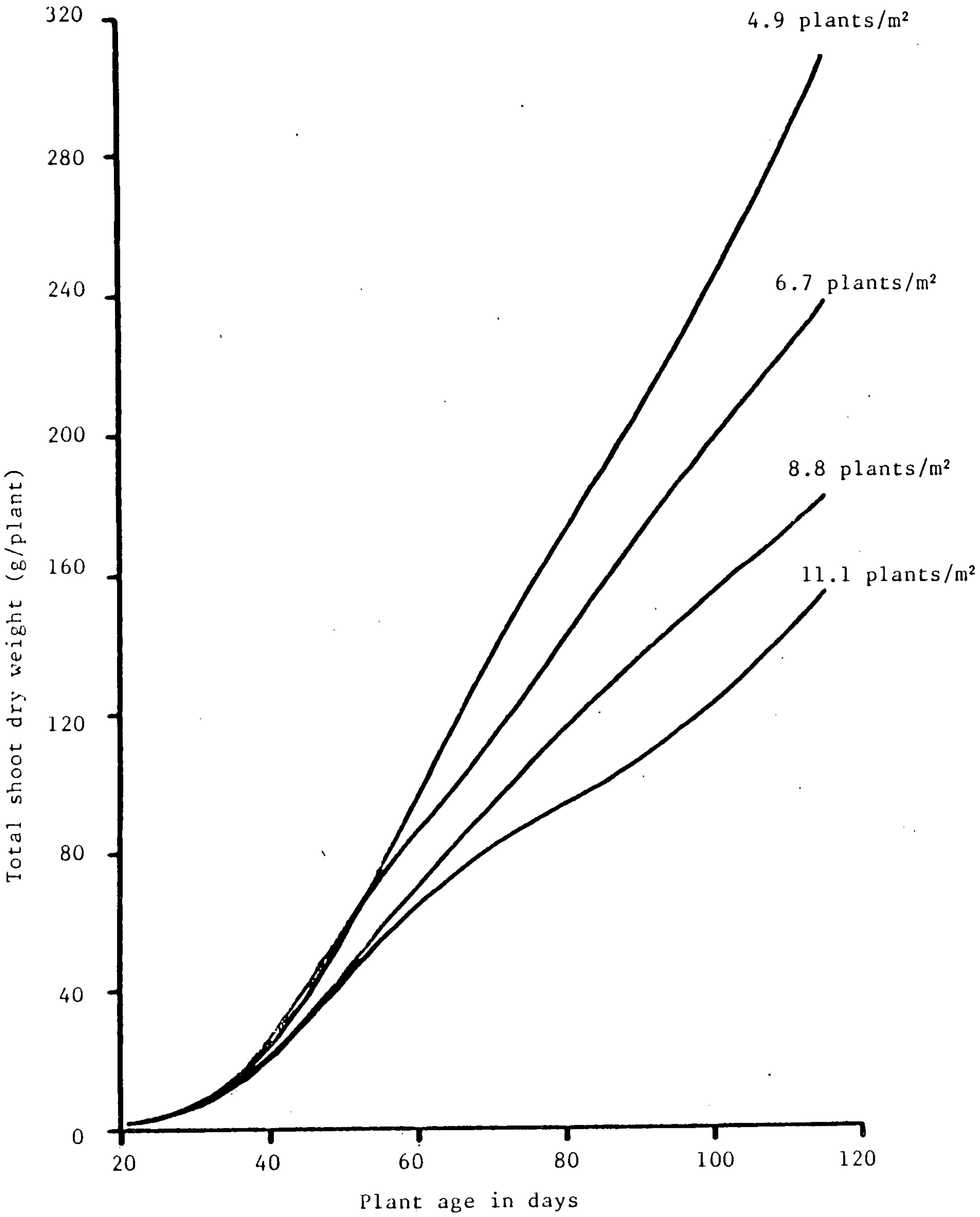

Figure 8 - Cubic spline regressions describing the time course of dry weight/plant (W) in corn grown at four planting densities.

Therefore, grain yields (W_G) were recorded only once, although the recorded grand mean was distributed throughout the harvests (Table 1b). It is evident that the reproductive characteristics were more strongly affected by planting density than were many of the vegetative characteristics (Table 2).

The curves in Figure (8) show nearly linear trends with age up to the final harvest, indicating that shoot growth continued throughout the study at all densities. Ear growth was a major contributor to overall shoot growth at the end of the season. High variability was observed among means recorded from each density, especially toward the reproductive growh period (Table 3).

Throughout plant growth total shoot DM production per hectare increased (Table 4). The maximum recorded shoot yield per hectare was 17.1 MT/ha, which was observed from the highest planting density (11.1 plants/m^2) at 115 DAE. Thus, despite the decreasing effects of density on many growth characteristics, yield per land area increased slightly with increasing planting density. The average yield/ha for the first 3 densities were very slightly different from each other (Table 4). These values remained virtually constant despite the observed decreasing trends of shoot dry matter per plant with increasing number of plants/m^2 (Table 4). Thus, increasing the number of plants/m^2 from 4.9 to 8.8 did not affect strongly the yield/ha but strongly reduced the performance of individual plants (Tables 3 and 4; Fig. 8).

4.2 Plant Growth Indices

Plant growth indices commonly used in plant growth analysis

Table 3

Shoot dry matter yield (g/plant) of forage corn at four planting densities and five harvest times.

Planting Density ($Plants/m^2$)	Harvest Time (days)						
	1 (21)	2 (42)	3 (63)	4 (85)	5 (115)	Mean	Signif.
1. (4.9)	2.04	28.93	109.70	189.70	306.40	127.40	***
	(1.11)[1]	(9.92)	(24.45)	(48.72)	(61.83)	(117.20)	
2. (6.7)	1.69	32.15	94.26	157.20	236.10	104.30	***
	(0.75)	(9.41)	(18.25)	(36.91)	(37.60)	(88.69)	
3. (8.8)	1.92	25.33	77.89	126.50	180.80	82.48	***
	(0.94)	(7.65)	(15.02)	(32.79)	(43.43)	(70.24)	
4. (11.1)	2.00	24.68	70.59	100.30	154.10	70.34	***
	(1.02)	(7.05)	(12.67)	(25.41)	(36.12)	(58.08)	
Mean	1.95	27.77	88.12	143.40	219.30	96.12	
S.D.	(0.96)	(9.02)	(23.52)	(49.63)	(74.07)	(89.01)	
Signif.	N.S.	***	***	***	***		

1. - values in brackets are the standard deviations
*** - significant at probability ($P \leq .001$)

Table 4

Shoot dry matter yield (MT/ha) of forage corn at four planting densities and five harvest times.

Planting Density (Plants/m^2)	Harvest Time (days) 1 (21)	2 (42)	3 (63)	4 (85)	5 (115)	Mean	Signif.
1. (4.9)	0.10 (0.05)[1]	1.43 (0.49)	5.42 (1.21)	9.37 (2.41)	15.13 (3.05)	6.29 (5.79)	***
2. (6.7)	0.11 (0.05)	2.16 (0.63)	6.34 (1.23)	10.54 (2.49)	15.87 (1.86)	7.00 (5.92)	***
3. (8.8)	0.17 (0.08)	2.22 (0.67)	6.84 (1.31)	11.11 (2.88)	15.87 (3.81)	7.24 (6.18)	***
4. (11.1)	0.22 (0.11)	2.74 (0.78)	7.84 (1.41)	11.15 (2.83)	17.12 (4.01)	7.82 (6.45)	***
Mean	0.15	4.28	6.61	10.54	16.00	9.39	
S.D.	(0.07)	(0.65)	(1.70)	(3.58)	(5.33)	(6.41)	
Signif.	N.S.	***	***	***	***		

1. - values in brackets represent the standard deviations
*** - significant at probability ($P<.001$)
N.S. - not significant

(Evans, 1972) which will be considered in this section include: crop growth rate (CGR), leaf area index (LAI), unit leaf rate (ULR), relative growth rate of shoot biomass (R_W), leaf area ratio (LAR), leaf weight ratio (LWR) and specific leaf area (SLA). Also, the relative growth rates of individual primary plant growth characteristics were calculated. However, only the relative growth rates of stem dry weights (R_{WST}), leaf dry weights (R_{WL}) and those of leaf area (R_{LA}) in each plant density will be considered in these results, since those characteristics exhibited large density responses (Section 4.1).

The effects of plant age and planting density on shoot biomass yield per unit land area (Table 4) must reflect changes in crop growth rate during this experiment. The variability of CGR throughout the growing season could be divided into 3 phases. Phase one, which covers the period between 21 DAE to about 55 DAE, showed increased CGR with increased number of plants/m^2. However, there was relatively little difference in the CGR between densities 2 (6.7 plants/m^2) and 3 (8.8 plants/m^2) during this growth period. The difference of CGR between the first density (4.9 plants/m^2) and the fourth density (11.1 plants/m^2) was very large (Fig. 9). During the second phase, which covers the period from about 56 DAE to 98 DAE, the trends in crop growth rate fluctuated and overlapped (Fig. 9). The third phase which covers the period from about 99 DAE to harvest time again showed well defined responses to planting density. In this phase, densities 1 and 4 had steadily increasing values of CGR. The CGR values in densities 2 and 3 were decreasing in most of this period, but exhibited slight increases

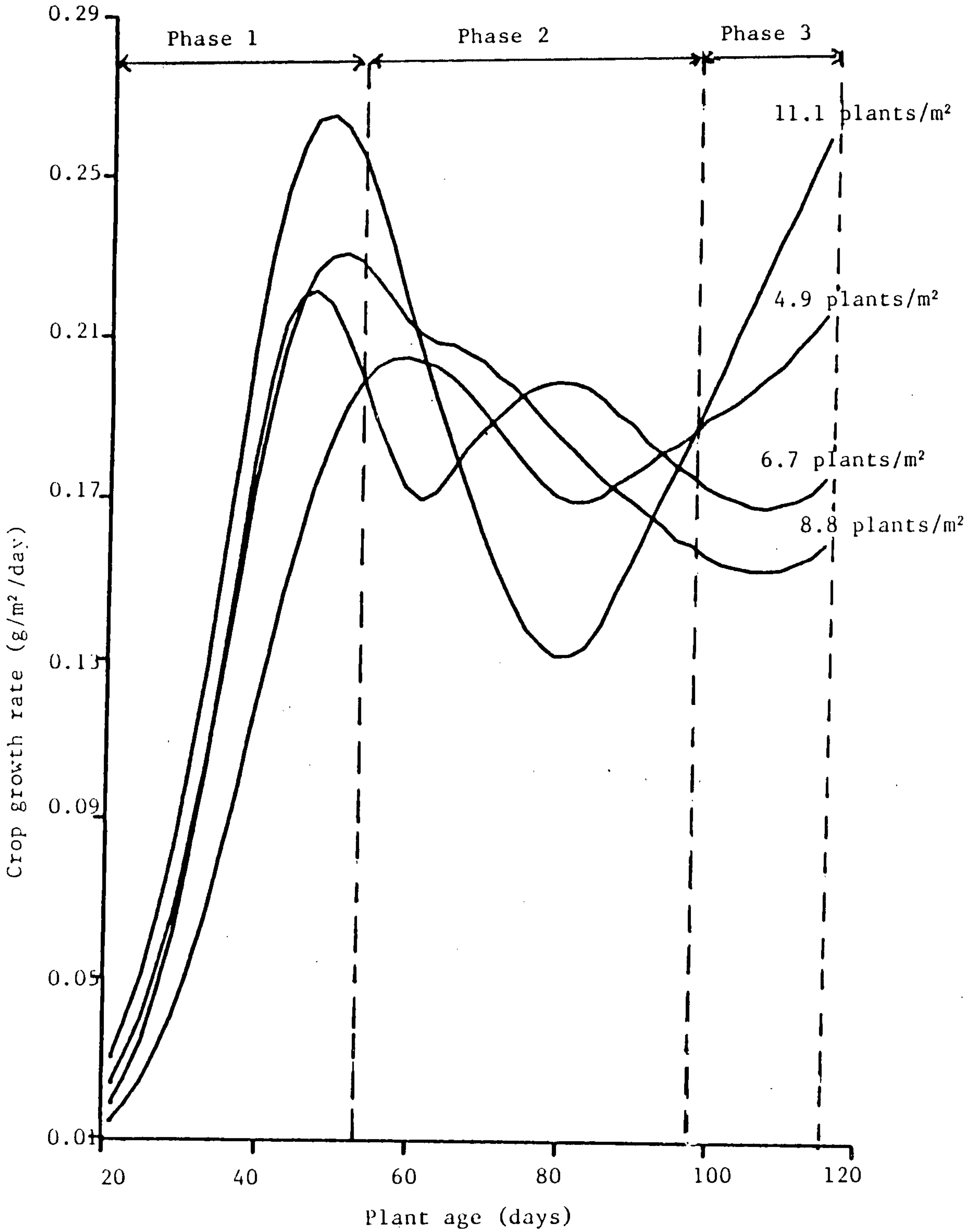

Figure 9 - Cubic spline regressions describing the time course of crop growth rate (CGR) in corn at four planting densities.

toward maturity (115 DAE; Fig. 9).

CGR is the product of leaf area index (LAI) and unit leaf rate (ULR), so the variability of CGR depends on the variability of LAI and ULR (Figs. 10 and 11). The relative variability of LAI over time and among densities was about six times the variability of ULR. Moreover, LAI increased steadily both between densities and age during phase 1 of CGR (Fig. 10) while ULR increased only slightly with plant age and decreased in both densities later in this phase (Fig. 11). As LAI was decreasing in the period above 55 DAE to 98 DAE, ULR values flactuated with age in the same period (Figs. 10 and 11). In this period the differences among densities were large for both LAI and ULR, but the increase in LAI with decreasing densities (Fig. 10) was counteracted by the decrease in ULR. The values of ULR were increasing in densities 1 and 4 at the end of phase 2, which might have caused the observed increases of CGR in those densities in phase 3. The pattern of variability of ULR among densities during this period resembled that of CGR. LAI steadily declined after the age of 55 DAE (Fig. 10) and thus could not have contributed to the observed increasing values of CGR in phase 3.

The relative growth rate of shoot biomass per plant (R_W) did not show large responses to the planting density (Fig. 12). While the 6.7 plants/m^2 density had the highest R_W in the early vegetative growth period, this difference did not persist in later growth periods. At all densities R_W declined rapidly during the first 70 days of growth.

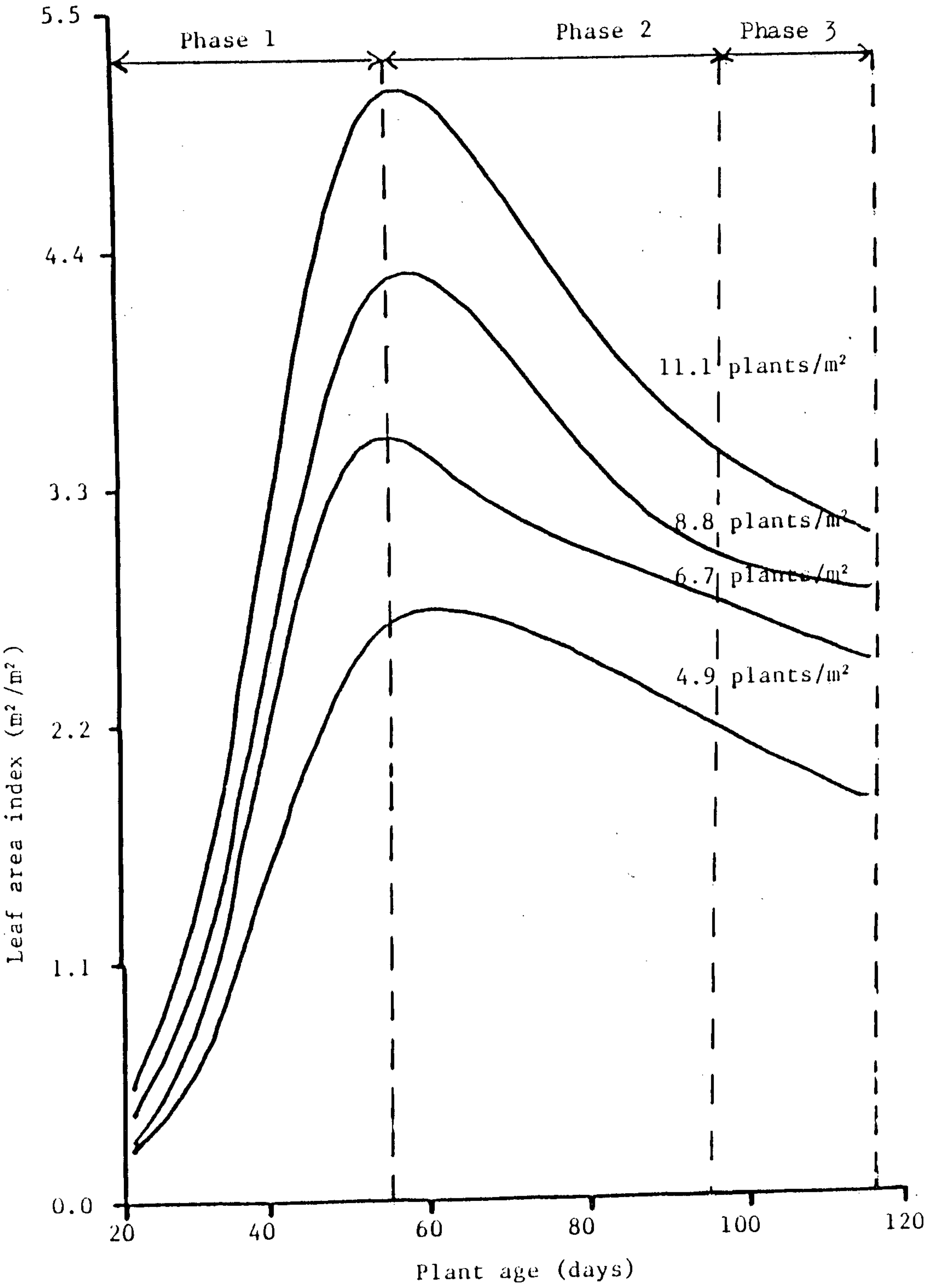

Figure 10 - Cubic spline regressions describing the time course of leaf area index (LAI) in corn at four planting densities.

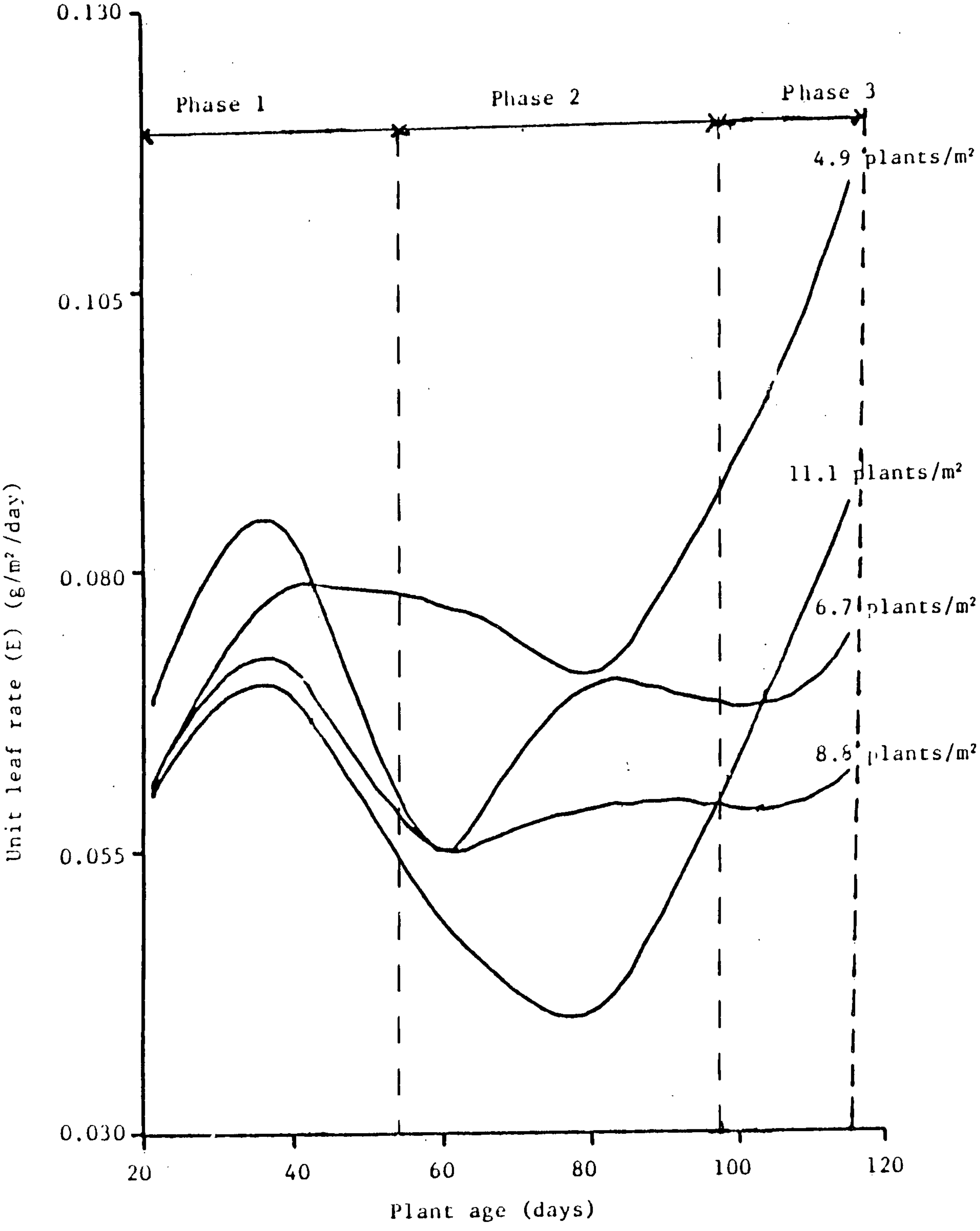

Figure 11 - Cubic spline regressions describing the time course of unit leaf rate (ULR) in corn grown at four planting densities.

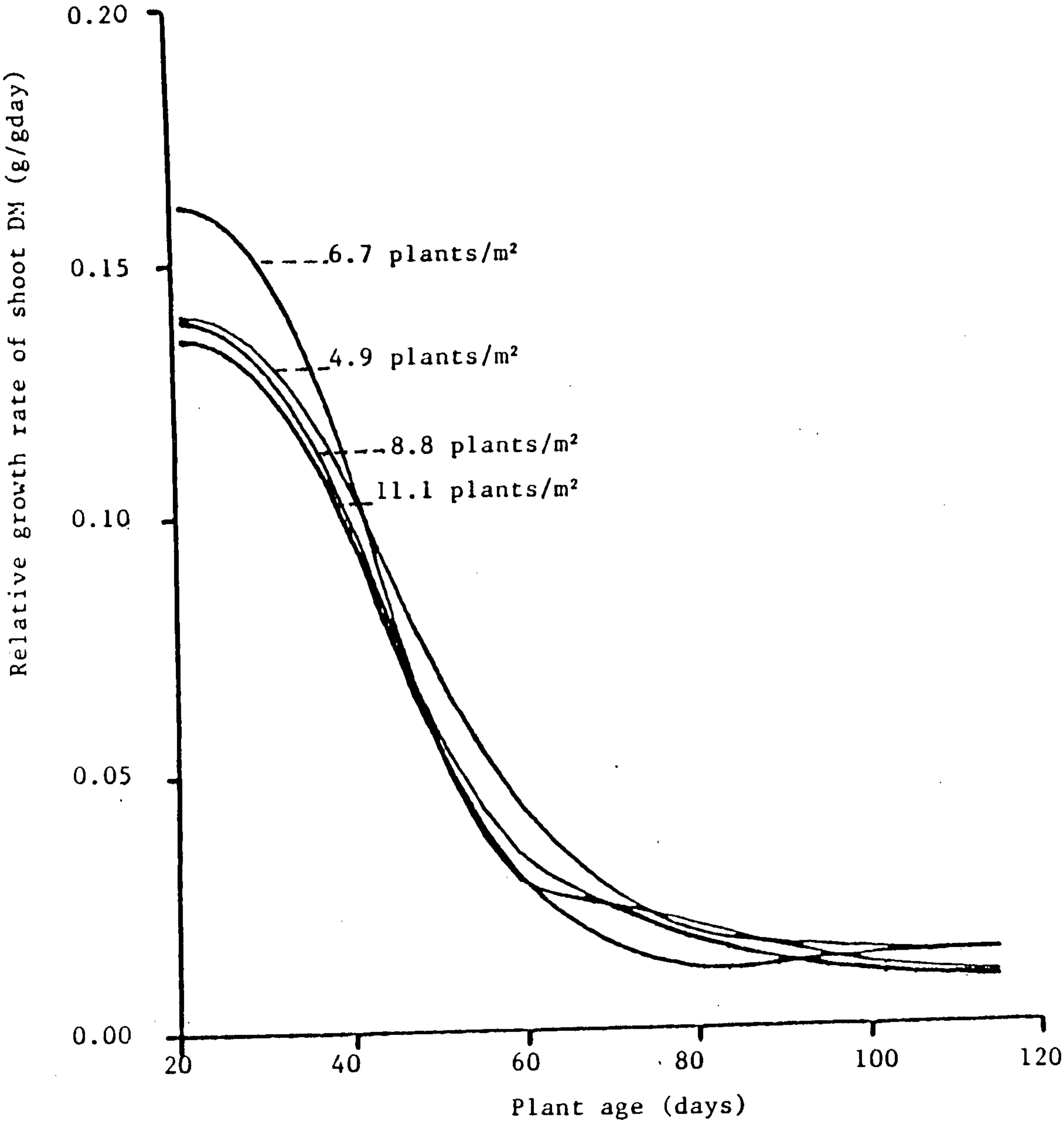

Figure 12 - Cubic spline regressions describing the time course of relative growth rate of plant dry weight (R_W) in corn at your planting densities.

The relative growth rate (R_W) is the product of LAR and ULR, so variability of R_W during growth at various densities depended upon the variability of LAR (Fig. 13) and ULR (Fig. 11). The overall relative variability in LAR in this study was about eight times the variability of ULR (Figs. 11 and 13). The relatively high initial value of R_W at a density of 6.7 plants/m^2 (Fig. 12) appears to have been caused by the relatively high initial ULR at that planting density (Fig. 11). Similarly, the high R_W value at 4.9 plants/m^2 from 40 to 70 days, and for 4.9 and 11.1 plants/m^2 at the end of growth (Fig. 12), also seem to have depended on high ULR values (Fig. 11). LAR varied greatly over the course of plant growth, but was not strongly affected by planting density (Fig. 13). However, it is clear that the declining values in R_W during the course of growth were strongly driven by corresponding declines in LAR.

The two components of LAR, leaf weight ratio (LWR; Fig. 14) and specific leaf area (SLA; Fig. 15) were also evaluated. LWR was more responsive to planting density than SLA, which did not seem to vary systematically with planting density throughout most of the plant growth (Fig. 15). LWR responded to increased number of plants/m^2 by exhibiting higher values in higher densities, especially during the late vegetative to maturity growth period (63 to 115 DAE; Fig. 14). Density effects, however, did not alter greatly the time course exhibited by the spline regressions for either LWR or SLA. Both SLA and LWR contribute to the decline in LAR during growth.

As with R_W, the relative growth rates of the other primary

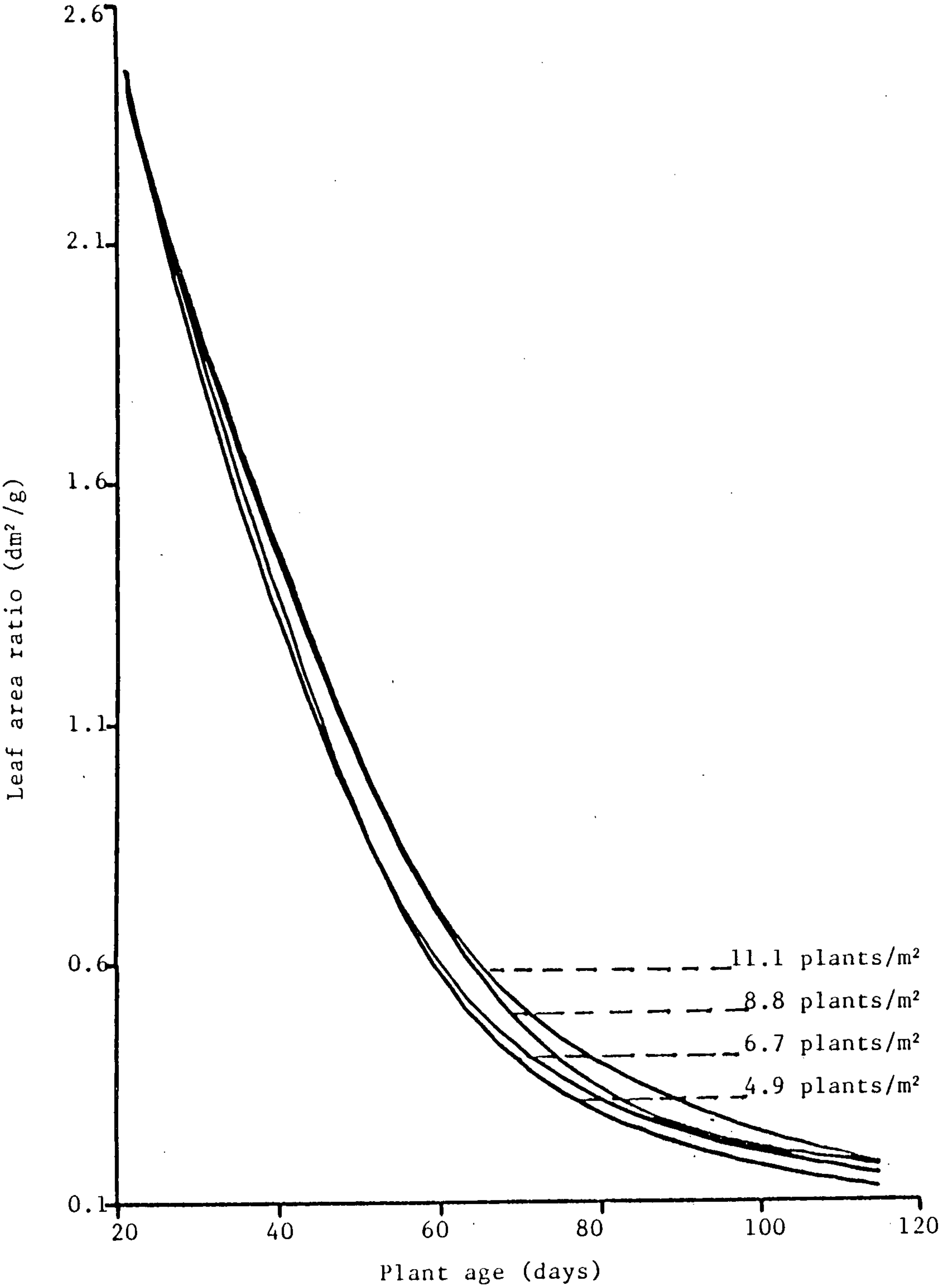

Figure 13 - Cubic spline regressions describing the time course of leaf area ratio (LAR) in corn at four planting densities.

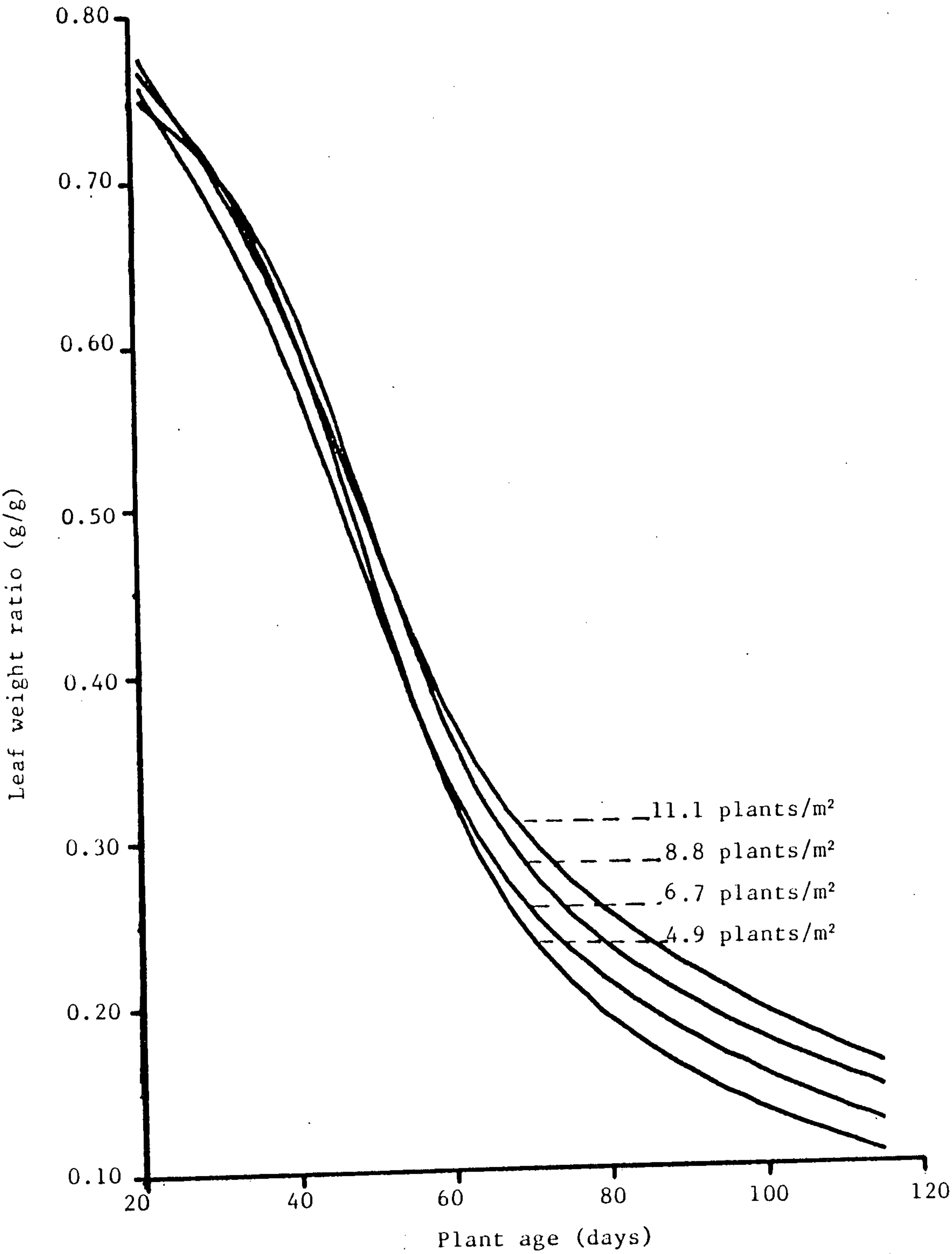

Figure 14 - Cubic spline regressions describing the time course of leaf weight ratio (LWR) in corn at four planting densities.

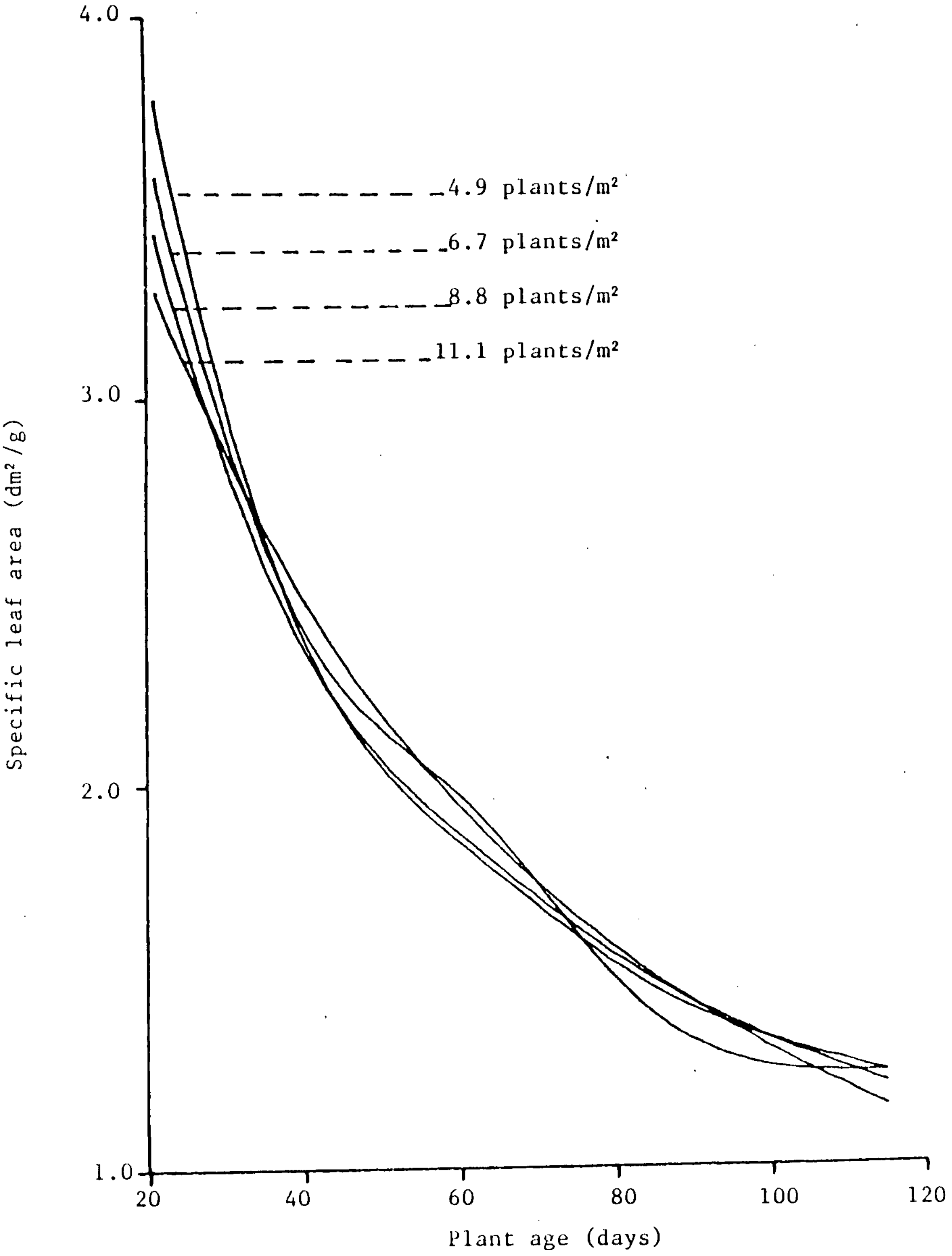

Figure 15 - Cubic spline regressions describing the time course of specific leaf area (SLA) in corn at four planting densities.

plant growth characteristics showed small responses to planting density (Figs. 16-18). The relative growth rates of leaf area (R_{LA}; Fig. 16), leaf dry weight (R_{WL}; Fig. 17) and stem dry weight (R_{WST}; Fig. 18) showed similar trends in time although they had different quantitative values. The relative growth rate curves generally lacked strong responses to density treatment. From these results, it is therefore evident that the variability which was visible among different primary growth characteristics as a result of planting density could not clearly be seen in the relative growth rates of those characteristics. The relative growth rates of individual primary characteristics therefore seem to be of little value in the interpretation of planting density responses. The time course of spline regression curves of ULR's responded more to plant aging effects than planting density.

However, some of the other plant growth indices, eg. CGR, LAI, ULR, LAR and LWR, do reveal the responses to planting density in considerable details (Figs. 9-11, 13 and 14).

4.3 Yield Component Analysis

Further analysis of the morphological basis of dry matter production in forage corn was based upon the yield component analysis equation described earlier (Chapter 3), which is repeated below. The morphological components were selected according to the chronological development of the plant. Thus, W was related to a set of morphological growth characteristics which included T, D, L_N, L_A and W_L (Table 5). As detailed in Chapter 3, these characteristics were converted into

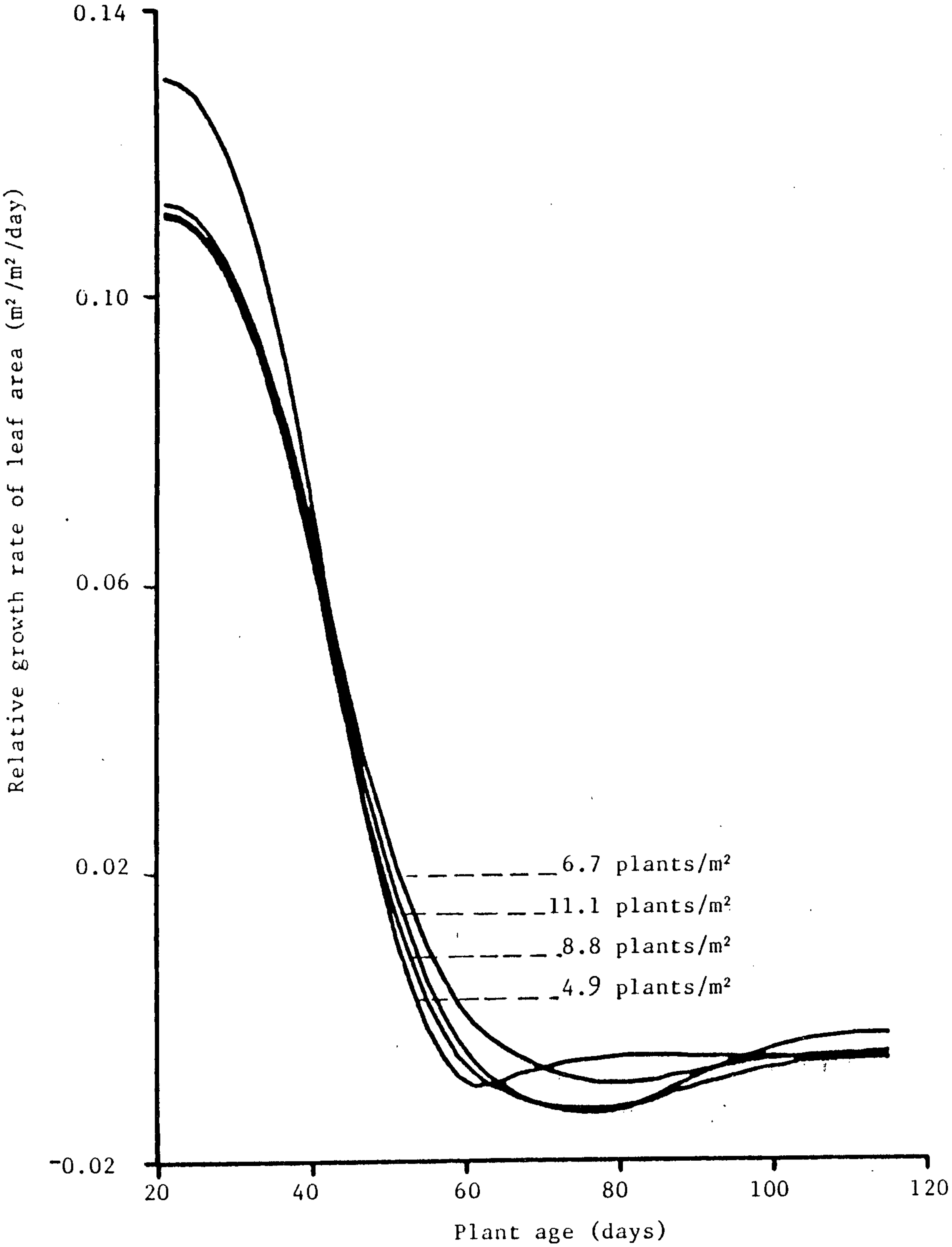

Figure 16 - Cubic spline regressions describing the time course of relative growth rate of leaf area per plant (R_{LA}) in corn at four planting densities.

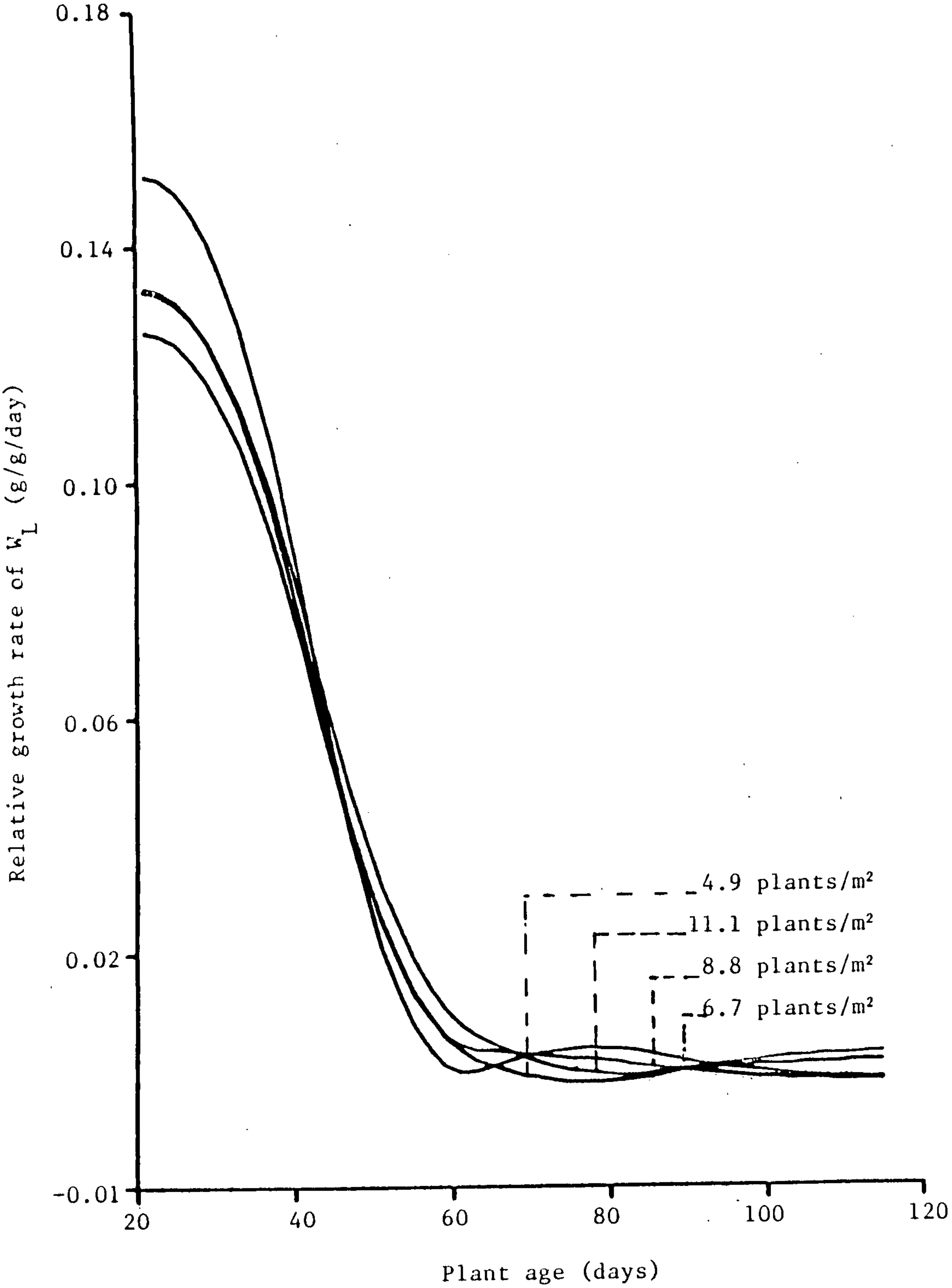

Figure 17 - Cubic spline regressions describing the time course of relative growth rate of leaf dry weight per plant (R_{WL}) in corn at four planting densities.

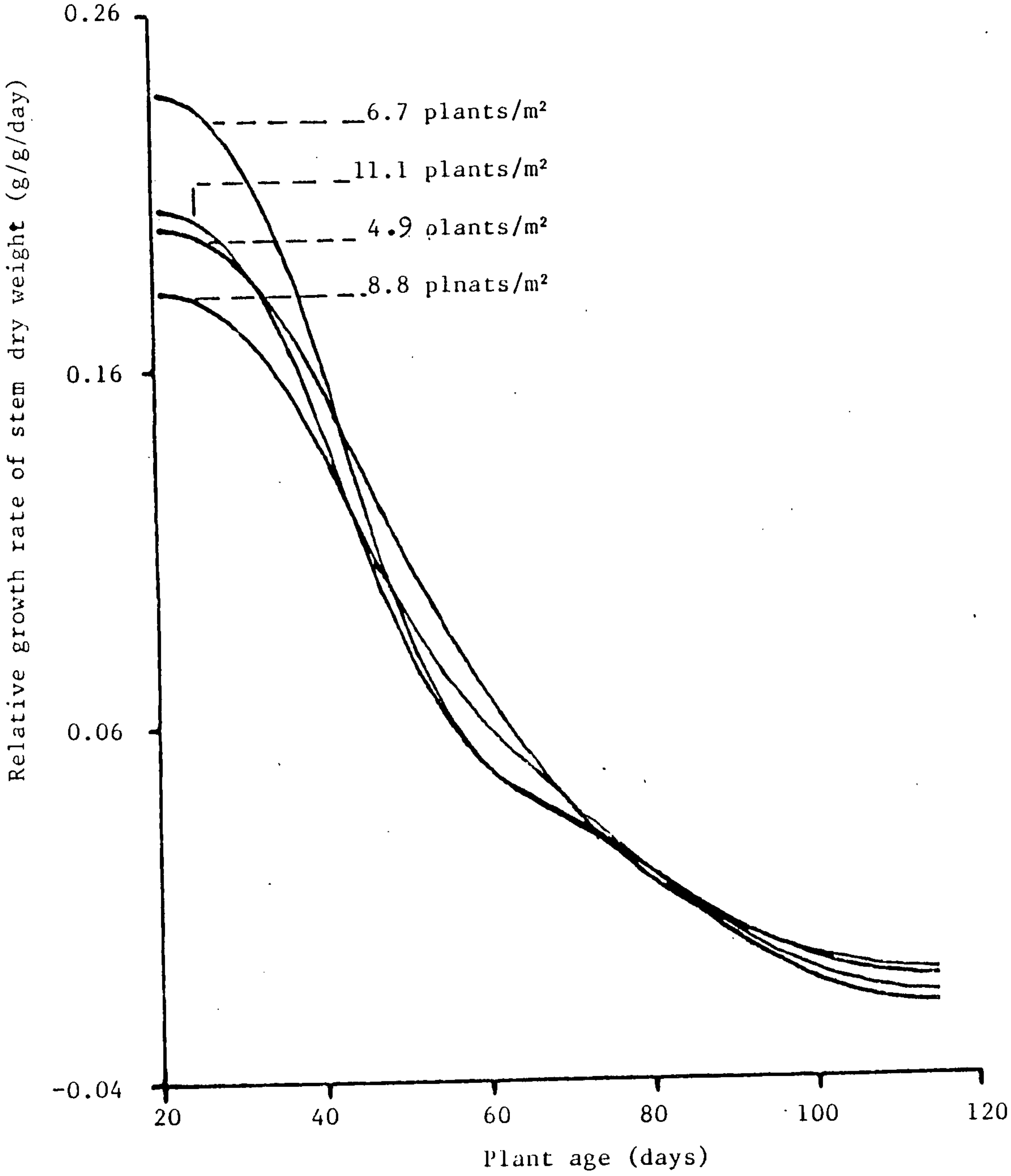

Figure 18 - Cubic spline regressions describing the time course of relative growth rate of stem dry weight/plant (R_{WST}) in corn at four planting densities.

a series of ratios (Table 6) which were then transformed into natural logarithms and analyzed by analysis of variance and two-dimensional forward and backward yield component analysis (TDP-YCA; Appendix II). Thus,

$$W = T \times D/T \times L_N/D \times L_A/L_N \times W_L/L_A \times W/W_L \qquad (8)$$

The forward and backward TDP-YCA may be used to identify the yield components responsible for yield variability. All of the variability in yield can be accounted for by this analysis. The overall forward TDP-YCA results showed that yield variability was largely due to the components T(95.32%), D/T (1.49%) and W/W_L (1.96%) (P<.001). In the other dimension, harvest time (95.65%), planting density (0.71%) and density x harvest (0.38%) were all significant (P<0.01; Table 7). The effects of planting density, harvest time, and density x harvest time on yield were consistent for both the forward and backward TDP-YCA. The effects of those treatments on individual yield components, however, varied (Tables 7 and 8).

While T, D/T and W/W_L were the significant yield components in the forward TDP-YCA, L_A/L_N (15.32%), W_L/L_A (6.26%) and W/W_L (77.35%) were the significant yield components in the backward TDP-YCA (Table 8; P<.001). All the significant yield components in both analyses were significantly affected by planting density, except for L_A/L_N which was not significantly affected by this treatment in the backward TDP-YCA (Tables 7 and 8). The non-significant components in the forward analysis (i.e., L_N/D, L_A/L_N and W_L/L_A) were

Table 5

Mean observations from individual morphological characteristics of each density and harvest of forage corn.

Planting Density (plants/m²)	Harvest[1]	Height (T)[1] cm	Diameter (D) cm	Leaves (L_N) #	Leaf area (L_A) dm²	Leaf weight (W_L) g	Yield (W) g
4.9	1	1.81	0.60	7.81	5.16	1.55	2.04
	2	25.40	2.11	11.44	36.04	16.38	28.39
	3	156.40	2.50	10.17	55.02	30.39	109.70
	4	194.70	2.64	7.86	46.48	31.56	189.70
	5	195.60	2.79	6.86	38.54	31.92	306.40
6.7	1	1.62	0.55	7.28	4.16	1.26	1.69
	2	33.00	2.16	11.11	38.87	17.56	32.15
	3	168.30	2.36	9.75	49.64	27.91	94.26
	4	201.80	2.50	7.69	42.94	29.56	157.20
	5	196.40	2.63	6.44	36.20	29.17	236.10
8.8	1	1.80	0.58	7.39	4.67	1.44	1.92
	2	27.69	2.03	10.97	33.81	14.89	25.33
	3	153.70	2.15	9.11	43.34	25.24	77.89
	4	194.90	2.32	6.89	36.30	26.32	126.50
	5	194.20	2.38	5.89	31.13	25.21	180.50
11.1	1	1.98	0.58	7.22	4.84	1.54	2.00
	2	30.00	1.90	11.19	33.50	14.15	24.68
	3	163.10	2.05	8.75	44.30	23.83	70.59
	4	200.20	2.15	7.03	34.05	23.14	100.30
	5	200.10	2.29	5.50	27.12	24.01	154.10
Grand Mean		117.13	1.96	8.32	32.50	19.88	64.75

1 - All variables expressed on a perplant basis.

Table 6

Mean Yield component values for forage corn at each density and harvest time.

Planting Density (plants/m^2)	Harvest	T cm/plant	D/T cm/cm	L_N/D #/cm	L_A/L_N dm/#	W_L/L_A g/dm^2	W/W_L g/g	Y g/plant
		cm/pl						g/pl
4.9	1	1.81	0.35	13.96	0.63	0.30	1.31	2.04
	2	25.40	0.09	5.51	3.15	0.45	1.73	28.93
	3	156.40	0.02	4.11	5.47	0.57	3.54	109.70
	4	194.70	0.01	2.99	5.94	0.68	5.99	189.70
	5	195.60	0.01	2.46	5.63	0.85	9.61	306.40
6.7	1	1.62	0.36	13.79	0.57	0.31	1.35	1.69
	2	33.00	0.07	5.18	3.54	0.45	1.82	32.15
	3	168.30	0.01	4.18	5.11	0.57	3.38	94.26
	4	210.80	0.01	3.12	5.64	0.70	5.29	157.20
	5	196.40	0.01	2.46	5.65	0.83	8.15	236.10
8.8	1	1.80	0.33	13.22	0.63	0.30	1.40	1.92
	2	27.69	0.08	5.47	3.09	0.44	1.68	25.33
	3	153.70	0.01	4.28	5.24	0.54	3.08	77.89
	4	194.90	0.01	2.98	5.26	0.75	4.78	126.50
	5	194.20	0.01	2.49	5.36	0.84	7.17	180.50
11.1	1	1.98	0.30	13.12	0.66	0.31	1.30	2.00
	2	30.00	0.07	6.04	3.21	0.42	1.72	24.68
	3	163.10	0.01	4.32	5.09	0.54	2.97	70.59
	4	200.20	0.01	3.33	4.88	0.69	4.34	100.30
	5	200.10	0.01	2.40	4.96	0.92	6.44	154.10
Grand mean		117.13	0.09	5.77	3.98	0.57	3.85	64.75

Table 7

Forward - YCA. Two-dimensional partitioning of the total sum of squares for yield expressed as percentages - data from all observations.

Yield Component or Product	Blocks %	Density %	Harvest %	Den. x Har. %	Error %	Total %
C_1C_1 (T)	0.44***	0.03**	93.67**	0.07***	1.11	95.32***
C_2C_2 (D/T)	0.06***	0.12***	0.89***	0.02***	0.41	1.49***
C_3C_3 (L_N/D)	0.01**	0.00	0.39***	0.01***	0.35	0.76
C_4C_4 (L_A/L_N)	0.00	0.00	0.00	0.00	0.01	0.01
C_5C_5 (W_L/L_A)	0.02**	0.00	0.00	0.00	0.44	0.46
C_6C_6 (W/W_L)	0.04***	0.36***	0.40***	0.19***	0.96	1.96***
C_1C_2	0.24	-0.07	-0.11	0.02	-0.08	0.00
C_1C_3	-0.00	-0.00	0.24	-0.01	-0.19	0.00
C_1C_4	0.01	-0.00	-0.03	-0.00	0.01	-0.00
C_1C_5	0.07	-0.01	0.01	0.00	-0.08	-0.00
C_1C_6	0.11	-0.12	0.17	0.05	-0.21	0.00
C_2C_3	-0.01	-0.01	-0.27	-0.00	0.29	0.00
C_2C_4	0.01	0.00	-0.01	0.00	-0.00	0.00
C_2C_5	0.04	0.01	0.01	0.00	-0.06	-0.00
C_2C_6	0.02	0.41	-0.60	0.08	0.09	-0.00
C_3C_4	-0.00	-0.00	0.03	0.01	-0.03	0.00
C_3C_5	-0.02	-0.00	0.05	-0.05	-0.04	0.00
C_3C_6	-0.04	-0.03	0.73	-0.00	-0.61	0.00
C_4C_5	0.00	-0.00	0.00	0.00	-0.01	0.00
C_4C_6	-0.00	0.01	0.03	-0.00	-0.03	0.00
C_5C_6	0.02	0.02	0.05	-0.02	-0.07	0.00
Ln Y	1.01***	0.71***	95.65***	0.38***	2.25	100.00***

TOTAL SS (100) = 2247.6

C_1 ---- C_6 and LnY are yield components 1 to 6 and yield (W).

*, **, *** - significant at P = 0.05, 0.01 and 0.001.

Table 8

Backward - YCA. Two-dimensional partitioning of the total sum of squares for yield expressed as percentages - data from all observations.

Yield Component or Product	Blocks %	Density %	Harvest %	Den. x Har. %	Error %	Total %
C_1C_1 (T)	0.03***	0.01**	0.07***	0.01*	0.43	0.55
C_2C_2 (D/T)	0.00	0.02***	0.03***	0.01***	0.04	0.10
C_3C_3 (L_N/D)	0.02***	0.01**	0.07***	0.01	0.33	0.43
C_4C_4 (L_A/L_N)	0.16***	0.00	11.14***	0.08	3.94	15.32***
C_5C_5 (W_L/L_A)	0.29***	0.15***	0.78***	0.26*	4.78	6.26***
C_6C_6 (W/W_L)	0.29***	0.85***	72.52***	0.64***	3.04	77.35***
C_1C_2	0.01	0.03	0.04	0.00	-0.09	0.00
C_1C_3	0.01	0.02	-0.05	0.01	0.01	0.00
C_1C_4	-0.06	-0.01	1.32	-0.04	-1.20	0.00
C_1C_5	0.15	-0.09	0.37	-0.03	-0.41	0.00
C_1C_6	0.07	0.21	-0.95	0.08	0.59	0.00
C_2C_3	0.01	0.02	-0.08	0.01	0.04	0.00
C_2C_4	-0.01	-0.01	-0.20	0.00	0.22	0.00
C_2C_5	0.04	-0.11	0.05	-0.05	0.07	0.00
C_2C_6	0.04	0.26	-0.53	0.11	0.12	0.00
C_3C_4	-0.01	-0.01	0.51	0.00	-0.50	0.00
C_3C_5	0.02	-0.06	-0.07	-0.09	0.20	0.00
C_3C_6	0.02	0.15	-0.12	0.13	-0.18	0.00
C_4C_5	-0.33	0.02	5.00	-0.06	-4.64	0.00
C_4C_6	0.09	-0.06	0.67	-0.03	-0.67	0.00
C_5C_6	0.16	-0.71	5.09	-0.67	-3.87	0.00
Ln Y	1.01***	0.71***	95.65***	0.38***	2.25	100.00***

TOTAL SS (100) = 2247.6

C_1 ---- C_6 and LnY are yield components 1 to 6 and yield (W).

*, **, *** - significant at P=0.05, 0.01 and 0.001

introduced into the multiple regression after most of the total variability in yield had already been accounted for by the earlier components, mainly by T (95.32%). Thus they had little opportunity to play a significant role as yield components in this analysis (Table 7). In the other direction, the non-significant components in the backward analysis (i.e., T, D/T and L_N/D) were introduced into the multiple regression after most of the total variability in yield had already been accounted for by the (biologically) later components, particularly W/W_L (77.35%). Thus they had little opportunity to play a significant role as yield components in this analysis (Table 8). W_L/L_A (6.26%) and L_A/L_N (15.32%) recovered their significance in the backward analysis. The W/W_L in the backward analysis was not as large as T (95.32%) in the forward analysis, thus permitting relatively higher contributions of the other yield components to the observed yield variability in the backward analysis. Comparing the results of the forward and backward analyses it can be concluded that T and D/T may have had their significant contributions to yield variability originating from chronologically subsequent components. Also, $_L/L_A$ and L_A/L_N may have had their significant contributions to yield variability originating from chronologically earlier components. The fact that L_N/D did not account for yield variability in either direction suggests that its contribution to yield variability was always assumed by the significant yield components, or it truly did not contribute to variation in yield. Similar methods of interpretation are applicable for all the TDP-YCA analyses that will be presented later in the text.

Tables (7) and (8) were obtained from the pooled data from all planting densities and harvests. Further steps were taken to analyse the effects of density on yield components. The further analyses were essential because of the overwhelmingly large effects of plant age on the variability of yield and its components (Tables 7 and 8).

One approach used for the further analysis was to describe the time course of yield components at different planting densities using fitted cubic spline regressions. Graphical presentation of the yield component regressions (Figs. 1 and 19-23) showed that, apart from W/W_L (Fig. 23), the other yield components had no obvious systematic responses to the planting density treatment (although an analysis of variance had earlier indicated significant effects of planting density on all the yield components ($P<.01$; ANOVA Table not presented)). The small though significant effects of density on D/T ($P<.01$) were evident in Figure (19) and the effects appear to be limited to the early stages of growth. The ranking of D/T among the different densities, however, varied during the stages of growth (Fig. 19). Conversely the effects of planting density on L_N/D were small during the early vegetative stage of growth and were more pronounced until the final harvest (Fig. 20). The ranking of L_N/D among the different planting densities, however, also varied during the course of growth. Planting density had larger effects on L_A/L_N especially in the later stages of plant growth (Fig. 21). Throughout that period, L_A/L_N generally tended to decrease with increasing planting density and this effect had not been previously identified by the TDP-YCA. Planting density had no well

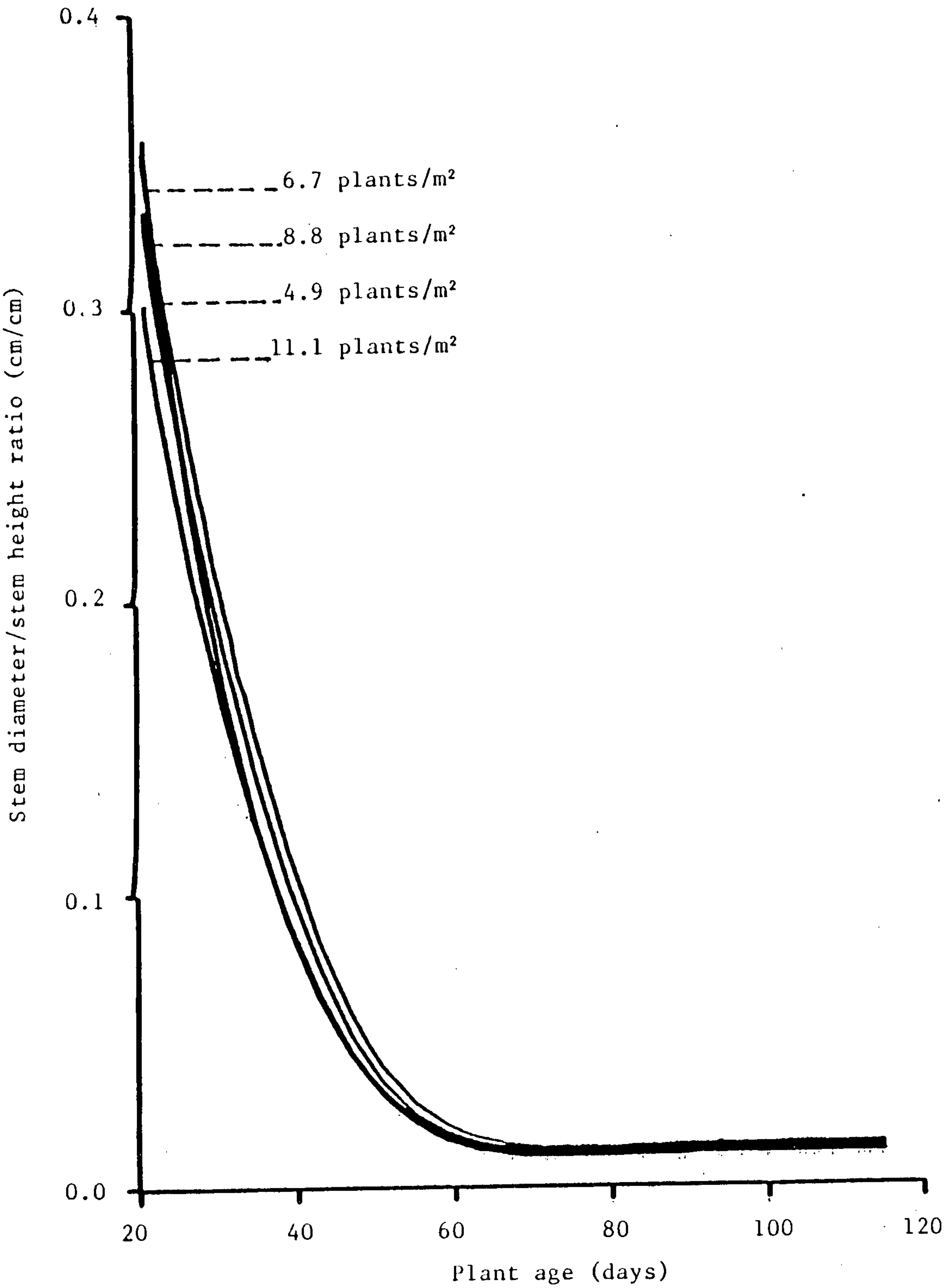

Figure 19 - Cubic spline regressions describing the time course of D/T-yield component of forage corn at four planting densities.

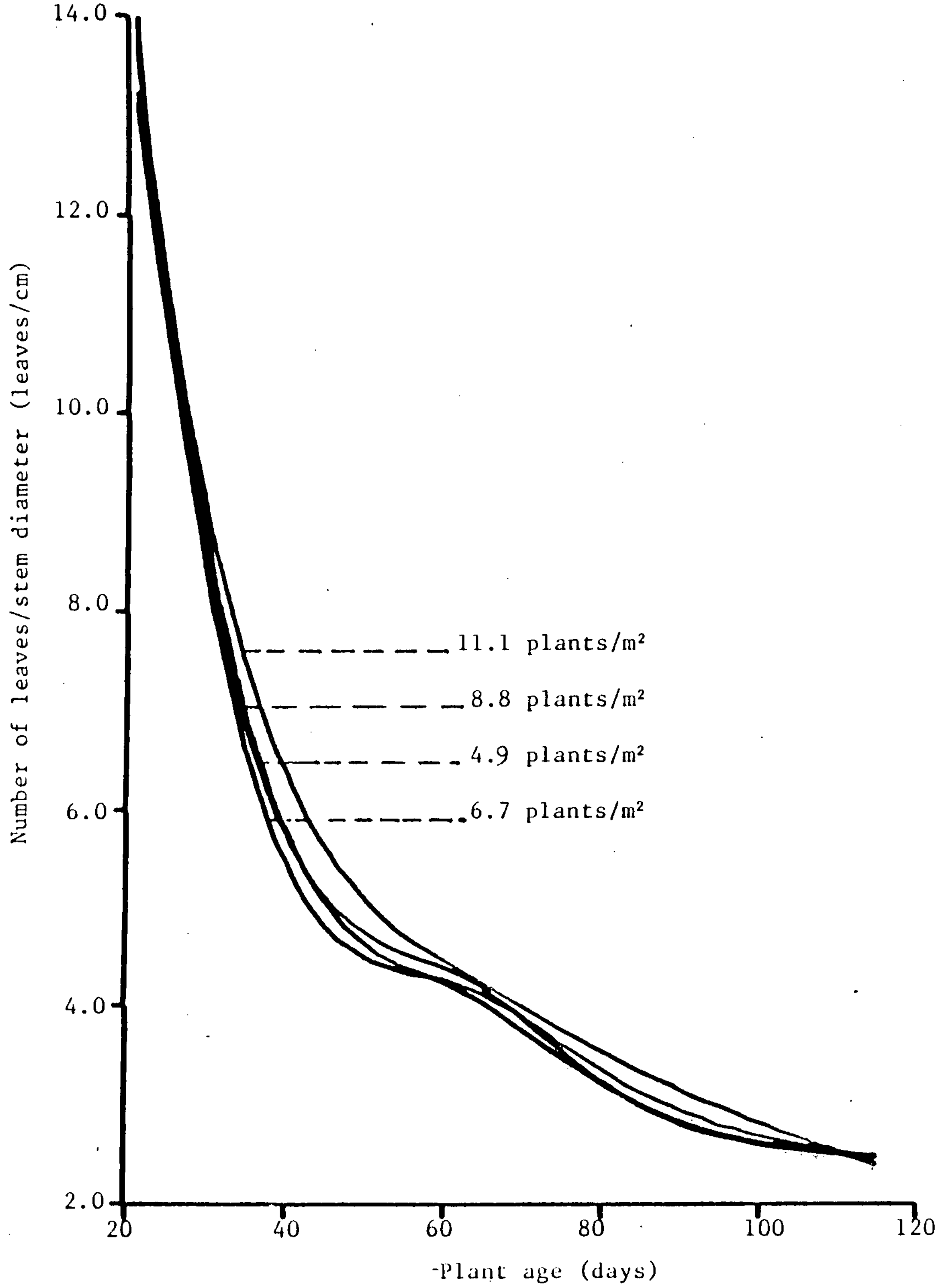

Figure 20 - Cubic spline regressions describing the time course of L_N/D-yield component of forage corn at four planting densities.

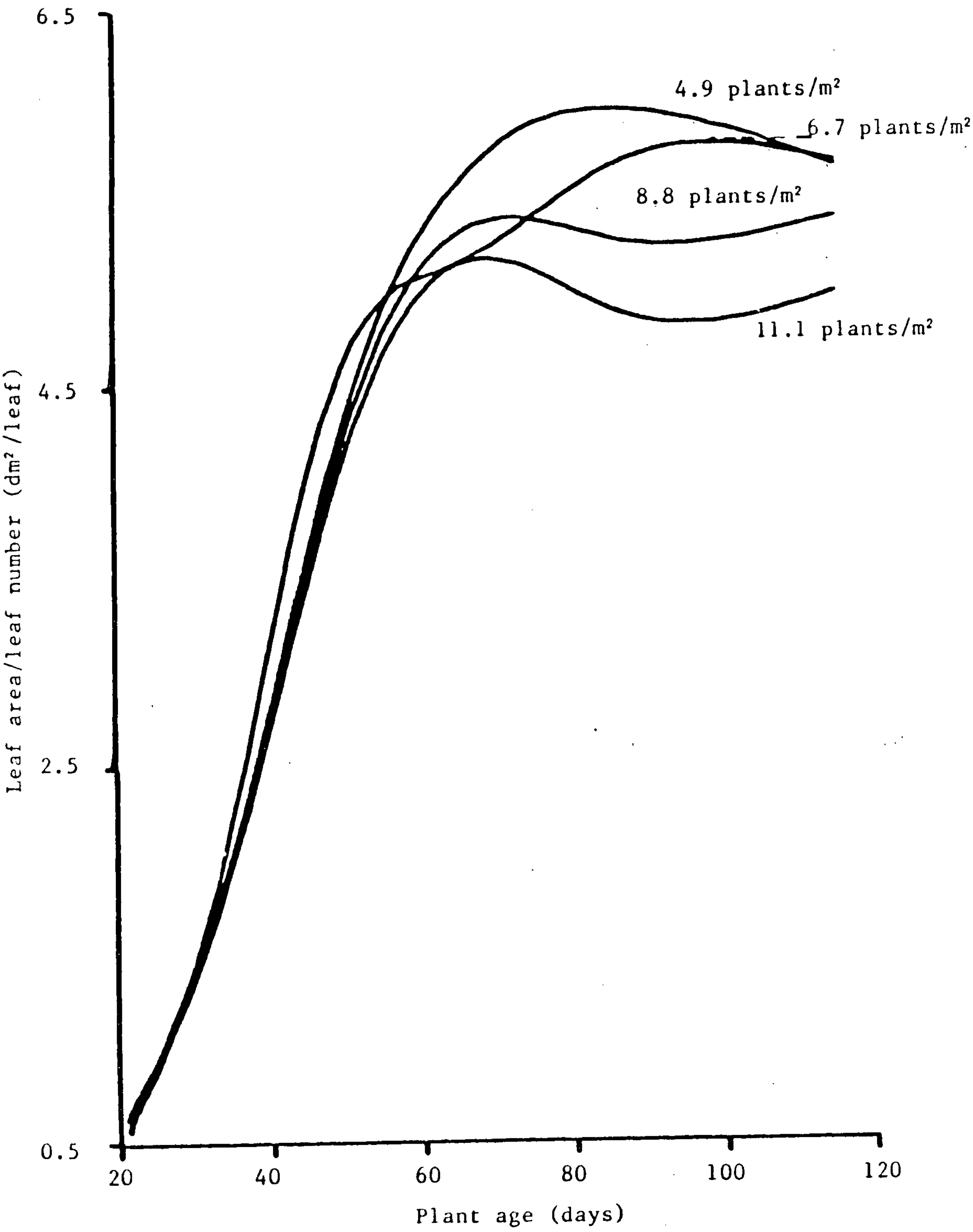

Figure 21 - Cubic spline regressions describing the time course of L_A/L_N-yield component of forage corn at four planting densities.

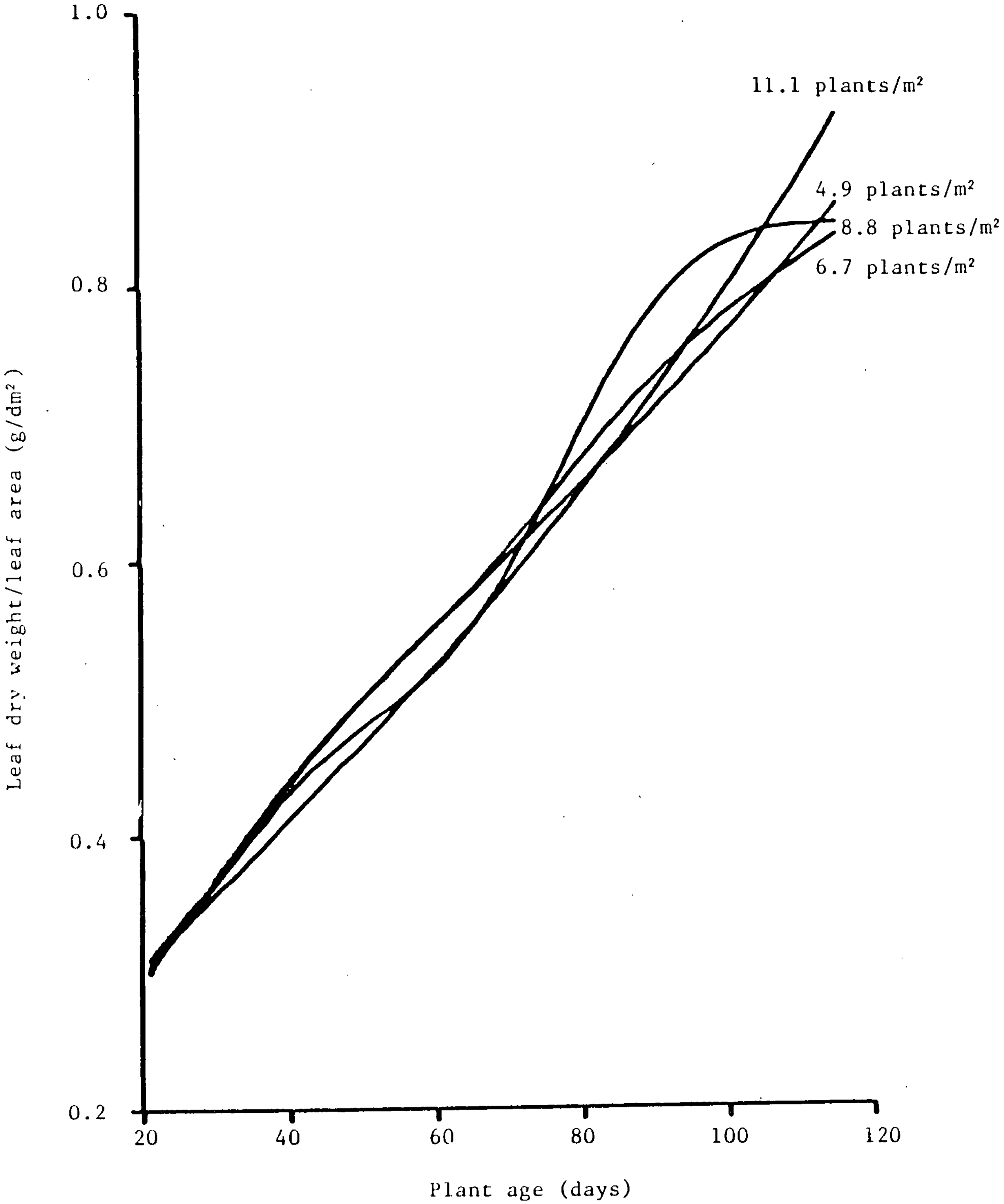

Figure 22 - Cubic spline regressions describing the time course of W_L/L_A-yield component of forage corn four planting densities.

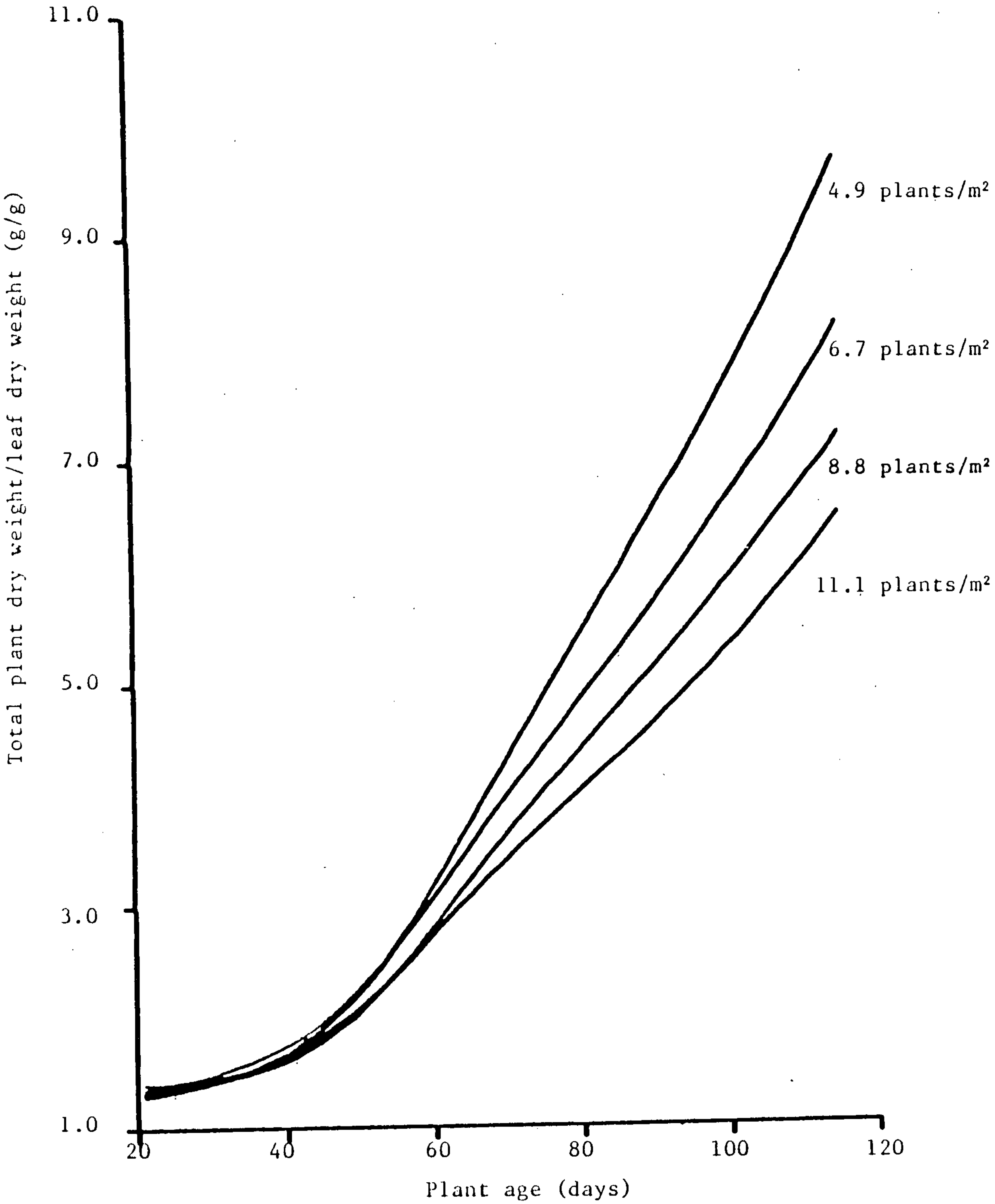

Figure 23 - Cubic spline regressions describing the time course of W/W_L-yield component of forage corn at four planting densities.

defined effects on the variability of W_L/L_A (Fig. 22). Figure (23) reveals the large and systematic effects of planting density on W/W_L, which was also evident in the TDP-YCA (Table 7). The time course of the fitted cubic spline regression curves were similar to those of W (Fig. 8), although they differed quantitatively. The resemblance of the W/W_L and W time course curves suggests the importance of this component in accounting for the observed yield variability among the planting densities.

Another approach used to define the effects of density on yield components of forage corn involved the application of TDP-YCA analysis at each harvest. The results of both the forward and backward analyses are summarized in Table (9).

The effects of planting density on yield (W) were not significant during early vegetative growth according to both forward and backward analyses (Table 9). Presumably this was because the plants were still small and had not started to interfere strongly with each other. However, after 21 DAE, the density effects on yield were highly significant (Table 9). The percentage variability among densities increased with harvest time and plant size (Appendices IV-XIII).

In the forward TDP-YCA, only L_N/D was not a significant yield component in the first two harvests. In the third harvest, L_N/D and L_A/L_N did not contribute significantly to the variability in yield. L_N/D, L_A/L_N and W_L/L_A were insignificant yield contributors in the fourth harvest. And, in the fifth harvest, only L_A/L_N and

Table 9

Yield components that were significant
at each harvest time, including density effects.

Plant Age (days)	Planting Density	Yield Component					
		T	D/T	L_N/D	L_A/L_N	W_L/L_A	W/W_L
		Forward TDP-YCA					
21	N.S	***+	***	N.S+	***	***	***
42	***	***+	***+	N.S	***+	***+	*+
63	***	***+	***+	N.S	N.S	***	***+
85	***	***	***+	N.S	N.S	N.S	***+
115	***	***	***+	***	N.S	N.S	***+
		Backward TDP-YCA					
21	N.S	N.S+	N.S+	N.S	***	***	N.S
42	***	***	N.S	N.S+	***+	***	***+
63	***	***+	***+	***+	***	***	***+
85	***	N.S	N.S+	***+	***+	N.S	***+
115	***	N.S	N.S+	***+	***	N.S	***+

*, *** - Significant at $P \leq .05$ and $P \leq .001$, respectively.

+ - including significant effects of planting density ($P \leq .05$).

N.S. - Not significant ($P \geq 0.05$).

W_L/L_A did not significantly contribute to the variability in yield. Thus, the general effects of planting density on yield components in the forward TDP-YCA were sporadic depending on age and type of yield component (Table 9).

In the backward TDP-YCA, all components contributed to yield variability in the third harvest. While L_A/L_N contributed to yield variability at all harvests in the backward analysis, all the other yield components were significant only sporadically among the harvests. Also, while W_L/L_A was not affected by the planting density at all harvests, the other yield components (significant or non-significant contributors to yield variability) were affected by planting density at certain times (Table 9).

It is evident from Table (9) that significant yield components in the forward analysis were not necessarily the significant yield components in the backward analysis. Also, the amount contributed by a yield component to variation in yield depended on its position in the YCA model for both the forward and backward analyses. Components included earlier in a model usually contributed relatively more to yield variability than later yield components (Appendices IV-XIII). Some yield components, however, appeared to be relatively stable in both the forward and backward TDP-YCA. For example, W/W_L, which was insignificant only at the 21 DAE harvest in the backward TDP-YCA analysis. W_L/L_A showed significant contributions to yield at same harvests in both the forward and backward TDP-YCA. Thus, it can be suggested that the significant yield components in forage corn depend not only on the age of the plant, but also on the direction of analysis of the YCA model. Also, the yield components that are significant at the same age in both forward and backward analyses are considered to be relatively stable contributors to yield variability than those components which had their significance showing up only in one direction of analysis. It is difficult in the present analysis of the yield components using TDP-YCA to attribute a relevant physiological role to the significant yield components which are affected by the planting density variation, because such attributes were not directly assessed by the analysis.

4.4 Relative Growth Rates of Yield Components

Relative growth rate has long been used in plant growth analysis as an index of the efficiency of plant growth. Ordinarily, relative growth rate has been applied to dry matter accumulation, but it has also been used as an index of performance of other plant characteristics (e.g. Hunt, 1982b). If V is a quantitative variate of a plant, then

$$R_V = \frac{1}{V}\left(\frac{dV}{dt}\right) = \frac{d(\mathrm{Log}_e\ V)}{dt} \tag{11}$$

The more generalized use of relative growth rate leads to its application in assessing the performance of yield components. As Jolliffe *et al*. (1983 (in preparation)) have shown, a yield component series may be transformed into an additive series of relative growth rates of yield components (e.g. see the previous Eqns. repeated below).

$$W = T \times D/T \times L_N/D \times L_A/L_N \times W_L/L_A \times W/W_L \tag{12}$$

$$\mathrm{Log}_e\ (W) = \mathrm{Log}_e(T) + \mathrm{Log}_e(D/T) + \mathrm{Log}_e(L_N/D) + \mathrm{Log}_e(L_A/L_N) + \mathrm{Log}_e(W_L/L_A) + \mathrm{Log}_e(W/W_L) \tag{13}$$

And

$$R_W = R_T + R_{D/T} + R_{LN/D} + R_{LA/LN} + R_{WL/LA} + R_{W/WL}\cdots\cdot \tag{14}$$

Equation (14) has been shortened as

$$R_Y = \sum_{i=1}^{n} R_{Ci} \tag{10}$$

The relationships among the relative growth rates of yield ($R_W = R_Y$) and yield components were analysed graphically (Figs. 24-27) and by multiple regressions.

At all densities there was a similar patern in the time course of the relative growth rates of yield and yield components (Figs. 24-27). The initially high values of R_W were supported by positive relative growth rates for T, L_A/L_N, W_L/L_A and W/W_L, while the rates for D/T and L_N/D were negative. The decline in R_W during the first 80 DAE was associated with large decreases in R_T and $R_{LA/LN}$ and a decrease in $R_{D/T}$ up to about 50 DAE. After about 80 DAE the relative growth rates of the yield components became relatively stable and small. Most of the components had positive relative growth rates during

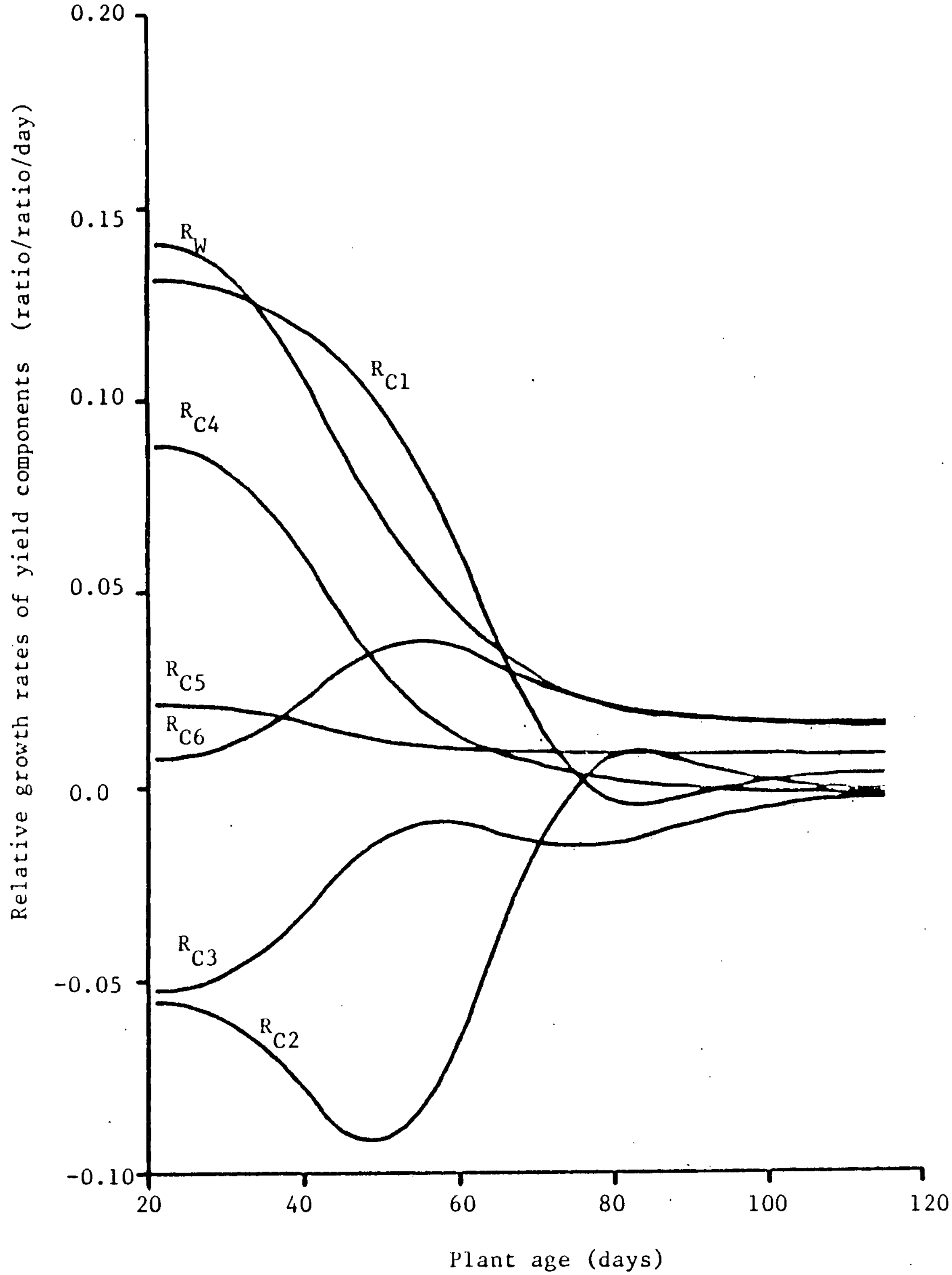

Figure 24 - Cubic spline regressions describing the time course of relative growth rate of yield (R_W) in density one (4.9 plants/m^2) and the relative growth rates of its yield components (R_{CD1}) in forage corn.

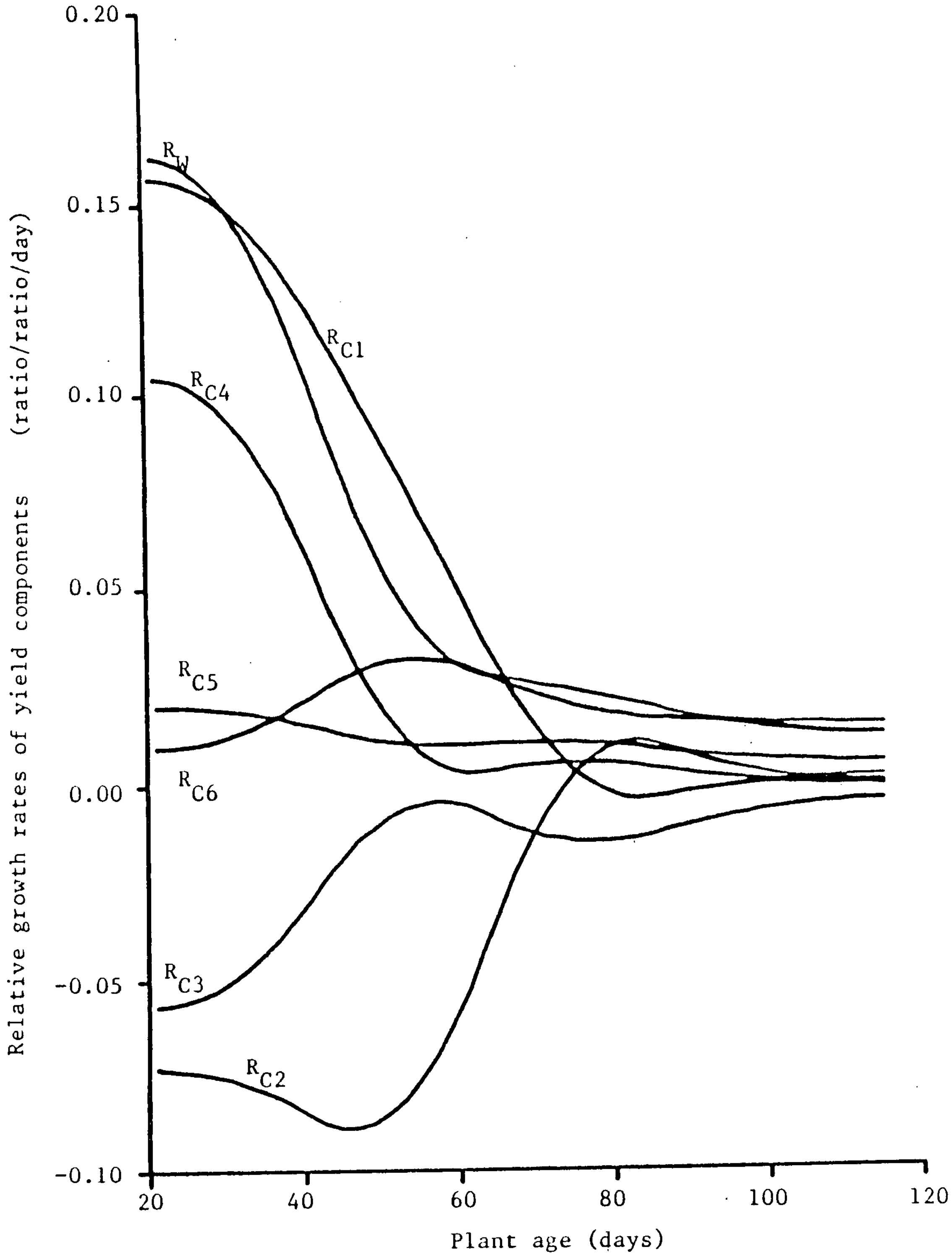

Figure 25 - Cubic spline regressions describing the time course of relative growth rate of yield (R_W) in density two (6.7 plants/m^2) and the relative growth rates of its yield components (R_{CD2}) in forage corn.

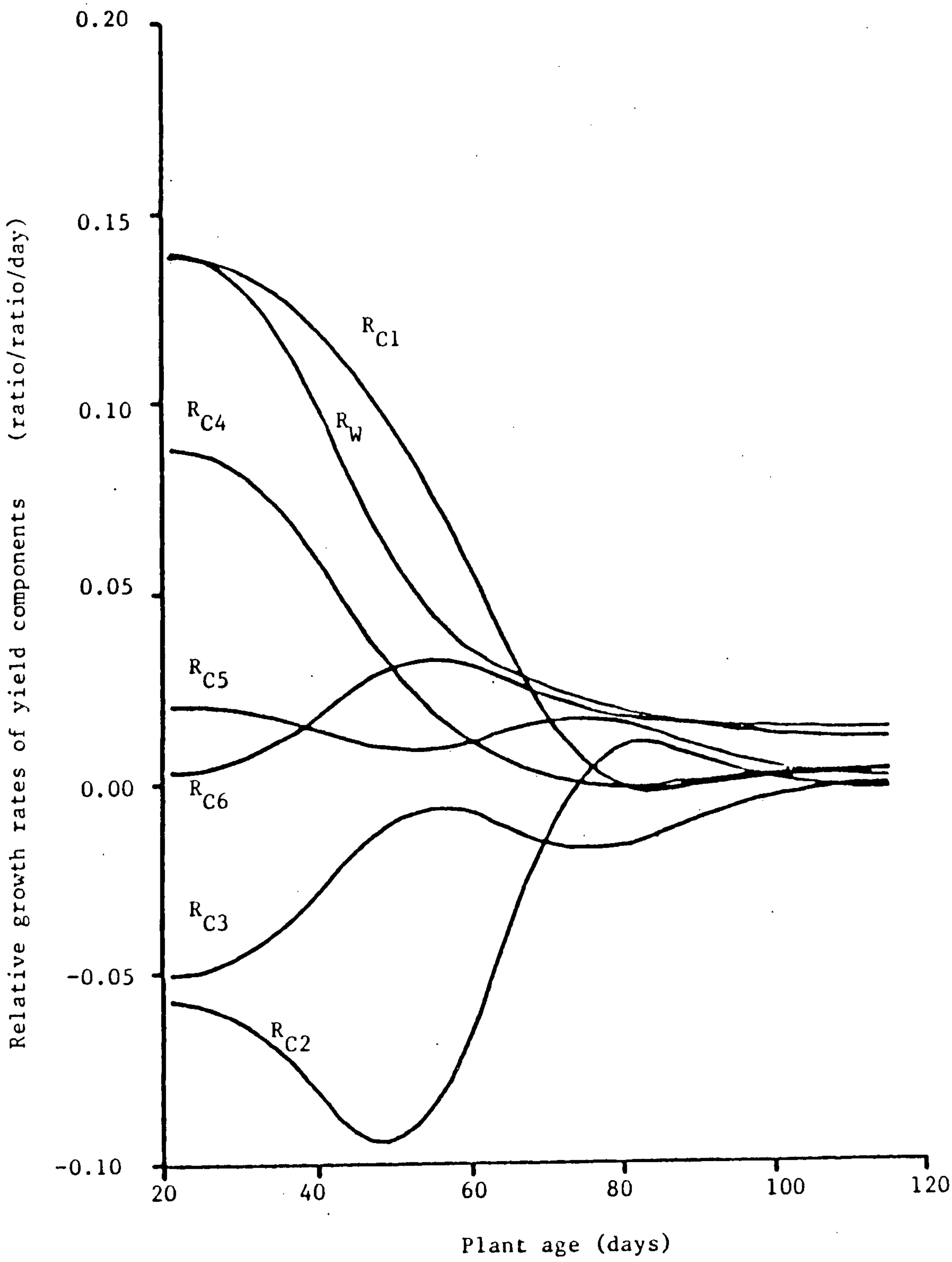

Figure 26 - Cubic spline regressions describing the time course of relative growth rate of yield (R_W) in density three (8.8 plants/m^2) and the relative growth rates of its yield components (R_{CD3}) in forage corn.

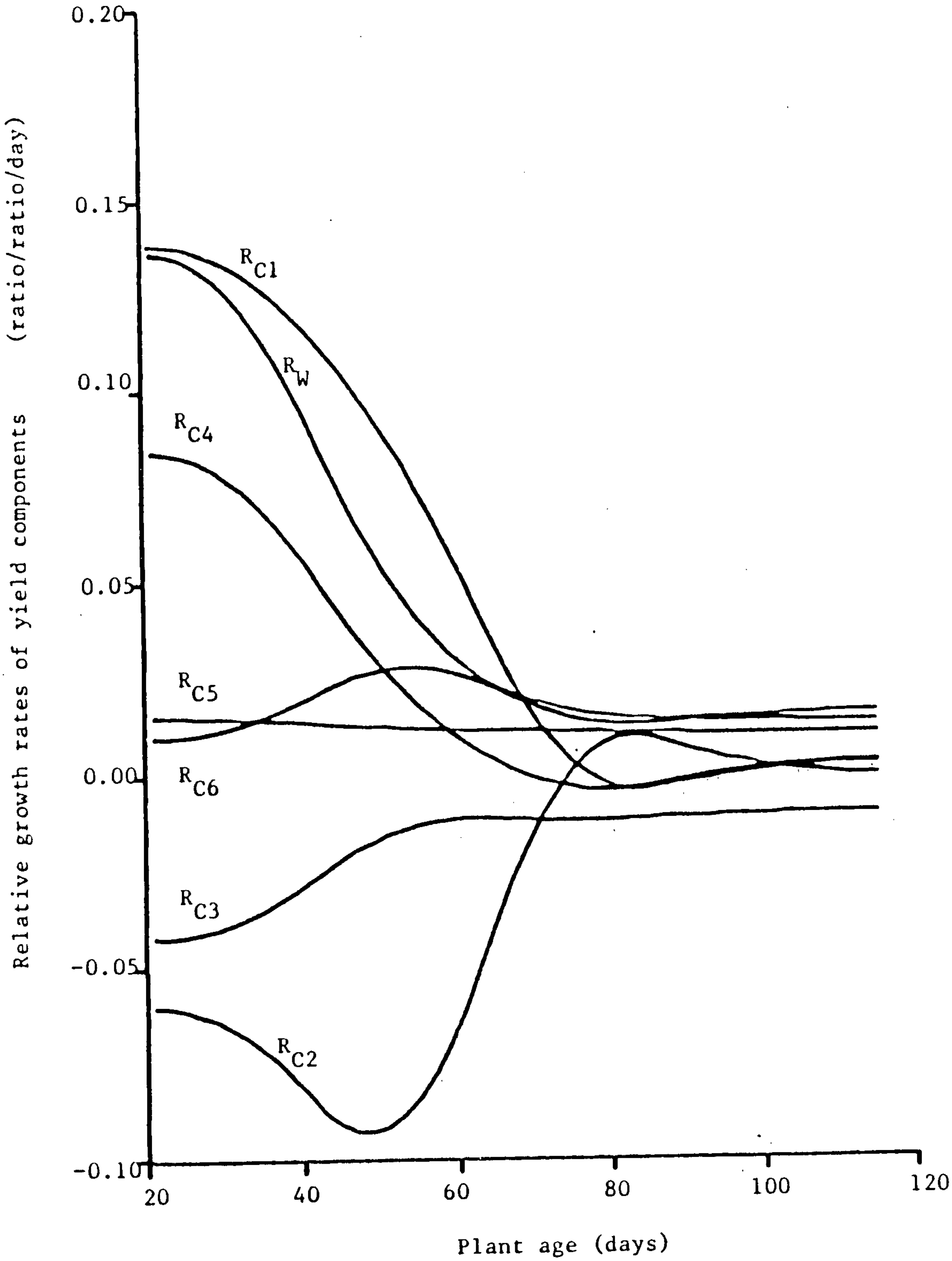

Figure 27 - Cubic spline regressions describing the time course of relative growth rate of yield (R_W) in density four (11.1 plants/m^2) and the relative growth rates of its yield components (R_{CD4}) in forage corn.

that period, and this sustained a positive relative growth rate of yield.

It is clear from Figs. (24) to (27) that the contributions of different yield components to R_W shift during growth. However, these graphs do not clearly reveal the manner in which planting density affects yield in forage corn.

A supplementary analysis involved the development of multiple regressions of R_W as a dependent variable on the combined relative growth rates of all the yield components (R_C's) throughout plant growth for each planting density. As suggested by Eqns. (8) and (13) the R_C's accounted for 100% of the coefficient of determination of R_W in every density (Table 10). These multiple regressions confirmed that R_W was the sum of the relative growth rates of the yield components. The variability of R_W among densities, therefore, depended on the variability of R_C's among densities. The regression coefficients alone, however, could not be used to explain differences of R_W and its components among the planting densities.

Table 10

Regression coefficients of the relative growth rates of yield (R_W) on the relative growth rates of yield components of forage corn observed in four planting densities.

Planting Denisty	Constant (a)	Regression Coefficient (b)) for Each Yield Component						Coefficient of Determination
		Rc_1	Rc_2	Rc_3	Rc_4	Rc_5	Rc_6	(R^2%)
4.9	0.0144***	0.478***	0.086	-0.506***	0.434**	0.217	-0.180	100***
6.7	0.0100***	0.194	-0.129	-0.599**	0.681**	0.459**	-0.223	100***
8.8	0.0123***	0.488**	0.119	-0.250	0.502*	0.506*	-0.313	100***
11.1	0.0112***	0.742***	0.401***	-0.286	0.412***	0.096	-0.155	100***

*, **, *** - Significant at P<0.05, 0.01 and 0.001, respectively.

5. DISCUSSION

The effects of planting density on the time course of growth and yield of corn were the main focus of this study. The planting densities used in this study ranged from 59% (49383 plants/ha) to 134% (111111 plants/ha) of the average planting density currently recommended for forage corn in the locality (83,000 plants/ha). The experiment has provided information on overall shoot dry matter yield and on many primary characteristics of growth. In addition,the primary results have been used to derive various indices of growth which help in the interpretation of the planting density effects as they arose during growth. A secondary aspect of the study is that it allows some assessment of the value of different methods for analyzing plant growth (i.e., plant growth analysis and yield component analysis).

Harvestable yield per hectare has always been the basis of agronomic planting density recommendations (Donald, 1963; Holliday, 1960; Iremiren and Milbourn, 1978; Remison and Lucas, 1982). Total yield per hectare increased with increased number of plants/m^2 overcoming the reduced yield per plant. Thus, the performance of individual plants, or the performance of individual plant parts, cannot solely be used to account for trends in yield per hectare with changing stand densities. It is well known that higher planting densities can have substantial yield advantages, but such yield advantages must be weighted against the initial costs of crop establishment and subsequent field management costs. It was visually evident, however, that weed problems were reduced in the highest planting density plots in my study, and the reduction in weed control requirements was one beneficial aspect of the high density.

At the forage corn maturity stage (30.8% crop dry matter content), the variability among the different planting densities in shoot dry matter yield per hectare were not extreme. The yields ranged from 15.1 to 17.1 MT/ha from the lowest to the highest planting densities. The intermediate densities both yielded 15.9 MT/ha. In comparison, the average yield of corn (cv. DK 24) grown in local growing areas was 14.9 MT/ha (mean based on observations from 6 trial locations; B.C. Ministry of Agriculture and Food, 1982). This average yield is based on recommended planting densities for the early maturity corn cultivars (e.g. DK 24) which range from 75000 to 90000 plants per hectare. The specific densities in the trial locations were not shown in the Field Corn Recommendations Summary (B.C. Ministry of Agriculture and Food, 1982). However, direct comparisons are limited by the planting configuration used in this study. Forage corn is generally grown closely spaced between plants within rows, but widely spaced (70-80 cm) between rows in order to achieve a desired planting density. The planting configuration used in my study was square (i.e., equidistant spacing in and between rows) for each planting density. This planting configuration was chosen to maintain a consistent geometry among the plants in treatments at different planting densities. Therefore, the difference between the square planting pattern and the pattern commonly used in forage corn production must be kept in mind in relating the results in this thesis to normal farming conditions. The increase in forage corn yield per hectare with increased planting densities suggests that it may be worthwhile for farmers to use greater than currently recommended seeding rates where conditions of growing corn are good. It should also be noted, however, that this suggestion is based on only one season's results from one growing site.

Crop growth rate is a widely used index of production efficiency in plant stands (Sestak *et al.*, 1971). The relatively stable shoot dry matter yields obtained at the lowest three planting densities can be attributed to the similar value of crop growth rates (CGR) observed at those densities during the course of plant growth (Fig. 9). Compared to the next two densities, the lowest planting density had initially lower values of CGR, up to about 55 DAE, and then relatively higher values toward crop maturity. The highest planting density on the other hand, maintained higher CGR both during vegetative growth (up to about 55 DAE) and at maturity, which could have accounted directly for the observed higher yields of shoot dry matter per hectare in this planting density (Fig. 9; Table 4). The CGR for the 2nd and 3rd planting densities were quantitatively similar at most times in the early vegetative growth (Fig. 9), a period during which vegetative dry weight is steadily generated by rapid crop growth rates.

Warren Wilson (1981) partitioned CGR according to the following sequence:

$$\begin{aligned} CGR &= LAI \times ULR \\ &= \frac{N}{A} \times W \times R_W \\ &= \frac{N}{A} \times W \times ULR \times LAR \\ &= \frac{N}{A} \times W \times ULR \times SLA \times LWR \qquad (14) \end{aligned}$$

It is clear that crop growth rate (CGR) may be dependent on a variety of indices, one of which is planting density (N/A). The contribution of the indices to the effects of planting density on CGR will be discussed in turn.

Leaf area index (LAI) is used to describe the extent of the assimilatory (i.e. photosynthetic) apparatus of a plant stand (Watson, 1952) and it serves as a key index for interpreting variations in yield of plants grown at different stand densities. Unit leaf rate (ULR) is an index of the efficiency of dry matter accumulation on a leaf area basis. ULR is strongly dependent on net photosynthesis rate, but is also dependent on the rates of respiration and inorganic accumulation. Both LAI and ULR were highly affected by the planting density but the effects varied during the growth of the crop (Figs. 10 and 11).

Leaf area index (LAI) increased strongly and systematically with increased number of plants per square metre (Fig. 10). This suggests that LAI made an important contribution to increased dry matter yield per hectare by increasing CGR values. Unit leaf rate (ULR) was always lowest in the highest planting density throughout most of the growing period of the crop (i.e., up to about 104 DAE), except the later values of ULR were higher at the lowest and highest planting densities than in the two intermediate planting densities toward crop maturity. Thus, although ULR tended to be reduced by increased planting density, this effect on CGR was overcome by increased assimilatory surface (LAI) of the crop stand. The relatively small differences in shoot yield and CGR observed at the lowest three densities seem to have been caused by responses in ULR and LAI which nearly cancelled each other.

Relative growth rate of shoot biomass (R_W) is an index of the efficiency of dry matter accumulation per unit dry matter. As Eqn. (14) indicates R_W contributes to CGR in conjunction with total biomass density (W x N/A), and R_W in turn depends on the interactive effects of ULR and leaf area ratio (LAR). R_W was a more important determinant of the time course of dry matter accumulation in shoots than it was at the response of shoot biomass productivity to planting densities (Fig. 12). It was observed that plants invested relatively more of their accumulated dry matter for self-generation during vegetative growth than during later on in development. Relative growth rate was low, but positive after 55 DAE (Fig. 12). CGR was maintained at high levels from 55 DAE onwards (Fig. 9), however, because of the high biomass densities maintained over the later stages of growth in all treatments.

Unit leaf rate (ULR) and leaf area ratio (LAR) are the components of R_W, and it is clear that the time course of R_W was dominated by the influence of LAR (Figs. 11 to 13). In contrast with ULR, LAR generally tended to increase with increasing planting densities, and the counteracting responses of ULR and LAR tended to dampen planting density response of R_W. While the effect of density on LAR was small throughout growth (Fig. 13), it appeared to arise at about the late vegetative growth (42 DAE) stage, making it an early reaction to the density treatment.

The large decrease in LAR during the course of crop growth was in turn due to joint contributions of declines in leaf weight ratio (LWR) and specific leaf area (SLA) (Figs. 14 and 15). The tendency of LAR to increase with increasing planting density, which is suggested in Figure (13), was entirely due to LWR since SLA exhibited an inconsistent response to planting density.

In summary, the effect of planting density on overall forage corn dry matter yield per hectare was significant and was the result of changes in many growth indices. Changes in CGR parallelled the changes in overall yield. The largest contributors to this density response, however, were made by alterations in LAI and biomass density (Eqn. 14).

Yield per plant decreased with increasing planting density (Fig. 8). Plant height (T; Fig. 1) was the only primary characteristic which increased with increasing planting density. All the other primary characteristics of individual plants decreased with increasing planting density (Figs. 2-7) and they combined to produce the decreasing yield per plant with increasing planting density. All the primary plant growth characteristics were significantly affected by planting density by the second harvest (42 DAE; Figs. 1-7). The differences among densities of yield per plant and the yields of individual plant parts widened with plant age.

The analysis of relative growth rates of shoot biomass (R_W) and the relative growth rates of individual morphological characteristics (R_{Gi}; Figs. 12, 16-18) did not reveal much about the effects of planting density. The major value of the relative growth rates of the primary growth characteristics is to express the dynamic partitioning of activities within the plant. Although the responses to planting density by the relative growth rates of primary growth characteristics (R_G) were not distinctive, the use of such indices should be continued in future work. Other factors besides planting density may cause characteristic changes in relative growth rates, and these indices are a meaningful expression of important biological characteristics.

Yield component analysis provided additional information on the growth and yield responses of forage corn to planting density. The two-dimensional partitioning of yield and yield components (TDP-YCA) analysis revealed that the variability in yield per plant not only depended on the stand density, but also depended on some morphological yield components (Tables 7-9).

It is clear that yield variability in the early harvest (21 DAE) was independent of the density treatment, but depended very strongly on the yield components T, D/T, L_A/L_N, W_L/L_A and W/W_L (Table 9; $P < .001$). By the use of yield component analysis, it was also possible to trace some of the early sources of density effects on plant growth. In the early vegetative growth (21 DAE), the density treatment had insignificant effects on the overall observed yield variability, but plant height (T), which was a significant yield component, was affected by the planting density treatment ($P < .001$). Thus, the early susceptibility of T to planting density reveals the possible importance of this component in determining subsequent effects of planting density on yield. This view is supported by the forward TDP-YCA results (Table 9) which shows that the variability in yield was highly correlated with variability in T. The importance of T as a yield component was observed by Buren *et al.* (1978) in forage corn; Douglas *et al.* (1958) in Crested wheat grass and Jolliffe *et al.* (1982) in field beans (*Phaseolus vulgaris* L.). D/T was a significant component throughout all the harvests, and was also highly susceptible to the effects of planting density after early vegetative growth (21 DAE). D/T is an indicator of the storage capacity of stems. Since a large proportion of W was obtained from the stems, the significant relationship between variabilities D/T and yield is perhaps not surprising. D/T decreased with increased number of plants/m^2 which showed that plant diameter (D) was more susceptible to planting density than plant height (T; Figs. 1, 2 and 19).

L_N/D was a significant yield component only at the final harvest in the forward TDP-YCA. This was due to the more rapid senescence of leaves in the older plants which was visible in the higher planting density especially during the reproductive growth of the plant. The backward TDP-YCA showed that L_N/D was a significant yield component from all harvests from 63-115 DAE. Thus, the variability of L_N/D before the final harvest was taken over by T and D/T in the forward analysis. The variabilities of W/W_L, W_L/L_A and L_A/L_N could not eliminate the contribution made by variability of L_N/D in the backward analysis (Table 9).

The significance of different yield components during growth was sporadic; individual components varied widely in their contributions at different plant ages and different directions of the TDP-YCA analysis. Yield components were both important contributors to yield variablity and sensitive detectors of planting density effects. More studies using similar components, however, are necessary to verify the yield component responses found in this study which involved data from a single cultivar, season and location.

The analysis of the relative growth rates of yield components (R_C) revealed large disparities among themselves during vegetative plant growth (Figs. 24-27). Toward crop maturity, however, the differences among them were relatively small. Also, it was noteworthy how the R_C's tended to concentrate toward R_W as crop maturity approached. The R_C's added up to the R_W, but there was very little effect of planting density on their trends. In view of some of the large changes in primary characteristics previously discussed, the stability in the contributions of R_C's to R_W is remarkable.

This is one of the first studies of the relative growth rates of yield and yield components. While the biological aspects of R_C's can be difficult to assess, the approach offers a direct and clear view of the contributions by yield components to the relative growth rate of yield.

Some of the advanced approaches to growth and yield analyses in forage corn were made possible by the refinement of procedures in traditional plant growth analysis (Hunt, 1977, 1982 a & b) and yield component analysis (Eaton et al. 1983; Jolliffe et al. 1983 (in preparation)). The analysis of variance (ANOVA) of all the primary growth characteristics studied including yield per hectare and yield per plant, gave the statistical significance of responses to age and density. However, given the large number of degrees of freedom for error, the significant differences of the means among treatments were very large, although the actual quantitative differences among means were not necessarily very large. The ANOVA results provided mean values and standard deviations for each of the four planting densities at all five harvests. Traditional methods of plant growth analysis, using trends and indices calculated from two consecutive harvest, would have provided a limited view of the time and density responses from this data.

Analysis of the data using the method of cubic spline regressions (Parsons and Hunt, 1981) provided closely spaced interpolated data points throughout the time course of crop growth. This technique not only gave smooth growth curves, but also described the growth rates of the individual plants, plant parts and yield components. Thus, the time course curves generated by these cubic spline regressions gave a clearer picture of the effects of density and age on plant growth characteristics and growth indices than was available from the primary data or ANOVA results.

Another technique used for analysing growth and yield was the two-dimensional partitioning technique (Eaton et al. 1983), and this proved to be highly valuable. The technique provided weighted variances among treatments and yield components, taking the total variability in yield to be 100%. The relative amount of variability contributed by a source in the analysis was influenced by the variability of other sources. Plant age dominated variability which caused relatively small variabilities to be contributed by the density treatment (Tables 7 and 8). This problem, however, was solved by two approaches. Firstly, all of the individual yield component means from the untransformed data were re-analysed using the cubic spline regression technique and plotted as described above. The variability in yield components among densities was then observed from the time course curves. A second approach was the use of TDP-YCA analyses involving data from each individual harvest in succession. The latter approach not only specified the yield components responsible for yield variability at each harvest, but also traced the early sources of the effects of planting density on the crop. Because the dominating effect of time was removed, the interpretation of the TDP-YCA analysis using data from individual age groups was clearer than when the analysis used pooled data among all densities and harvests.

A supplementary analysis of the whole data used the relative growth rates of the individual yield components, and this analysis was also facilitated by use of cubic spline regressions. This method clearly defined the contributions by yield components to the relative growth rate of yield throughout crop growth. The effects of planting density on the relative growth rates of the yield components, were not clearly defined from the time course curves.

In summary, the analysis of the present results on forage corn was facilitated by recent improvements in methods for the analysis of growth and productivity. It is clear that our ability to interpret the physiology of yield in crop plants relies heavily on the refinements of mathematical procedures available for plant growth analysis, and it is now possible to gain better insight into the management or improvement of crop growth. Growth analysis and yield component analysis are complementary approaches since they both aim to interpret productivity. Both approaches can be effectively used in the analysis of effects of treatments, such as planting density treatments, investigated in the present research.

6. CONCLUSIONS

1. The observation that yield per hectare of forage corn was significantly increased by increasing planting density suggests that planting densities higher than those currently recommended may be worthwhile. This is a tentative conclusion based on a limited study; it presumes that good circumstances will prevail for crop growth.

2. Yield per plant is reduced by increasing planting density because of decreases in most primary plant characteristics, and many of these effects originate within a few weeks of emergence. The relative growth rates of primary characteristics, however, did not reveal much about the effects of planting density on growth.

3. The effects of planting density on yield per hectare were correlated with changes in crop growth rate (CGR). The responses of crop growth rate in turn are dependent mainly on changes in leaf area index (LAI) or biomass density. Unit leaf rate (ULR) contributed to a lesser extent. Other components of CGR, including leaf area ratio (LAR) leaf weight ratio (LWR) and specific leaf area (SLA) did not strongly influence the yield: density relationship.

4. All the yield components studied contributed significantly to either the total variability in yield or the effects of planting density. The effects of yield components on yield, however, were sporadic depending on age and the direction of TDP-YCA analysis.

5. The relative growth rate of yield and the relative growth rates of the yield components did not reveal much about the effects of planting densities. However, they showed distinctive relationships

among the relative growth rate of yield and the relative growth rates of yield components throughout the course of yield formation.

6. Modern methods of growth and yield analysis used in the study give complementary information about the generation of yield and the responses to planting density.

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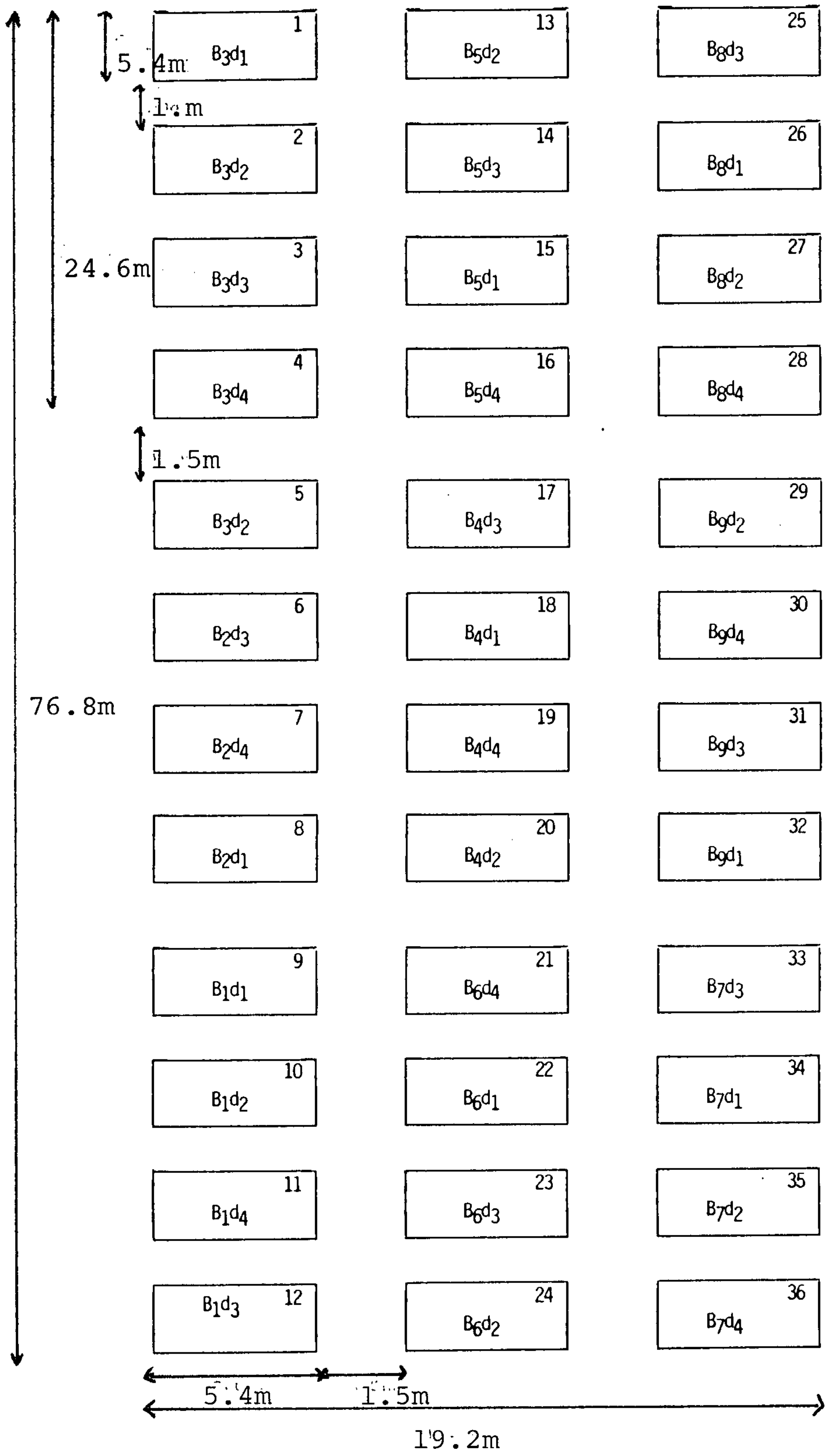
APPENDIX I

Experimental design Randomized complete block design (RCBD)



B = block d = density

Appendix II

Natural logarithms of yield component ratios - means for each density and harvest time.

Planting Density (Plant/m^2)	Harvest	Ln (T)	Ln(D/T)	$\ln(L_N/D)$	$\ln(L_A/L_N)$	$\ln(W_L/L_A)$	$\ln(W/L_L)$	Ln Y
4.9	1	0.54	-1.09	2.60	-0.52	-1.22	0.27	0.58
	2	3.17	-2.44	1.70	1.14	-0.81	0.54	3.31
	3	5.03	-4.12	1.40	1.69	-0.58	1.25	4.67
	4	5.27	-4.30	1.09	1.77	-0.39	1.78	5.21
	5	5.27	-4.25	0.89	1.72	-0.18	2.26	5.70
6.7	1	0.44	-1.07	2.60	-0.60	-1.23	0.29	0.44
	2	3.45	-2.69	1.64	1.25	-0.81	0.59	3.43
	3	5.12	-4.27	1.42	1.62	0.57	1.21	4.53
	4	5.30	-4.39	1.11	1.72	-0.37	1.65	5.03
	5	5.27	-4.31	0.86	1.72	-0.20	2.09	5.45
8.8	1	0.55	-1.13	2.57	-0.53	-1.23	0.31	0.55
	2	3.25	-2.55	1.69	1.12	-0.83	0.51	3.19
	3	5.03	-4.27	1.44	1.65	-0.63	1.12	4.34
	4	5.26	-4.43	1.08	1.65	-0.31	1.55	4.80
	5	5.27	-4.40	0.89	1.67	-0.20	1.95	5.17
11.1	1	0.64	-1.22	2.56	-0.50	-1.18	0.26	0.55
	2	3.33	-2.70	1.73	1.08	-0.87	0.54	3.16
	3	5.08	-4.37	1.45	1.62	-0.62	1.08	4.24
	4	5.29	-4.55	1.18	1.57	-0.39	1.46	4.58
	5	5.29	-4.46	0.86	1.59	-0.11	1.85	5.01
Grand Mean		3.89	-3.35	1.54	1.12	-0.64	1.13	3.70

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Appendix III

Mean orthogonal yield components at each density and harvest time.

Planting Density (Plants/m^2)	Harvest	C_1	C_2	C_3	C_4	C_5	C_6	Ln Y
1	1	0.54	-0.10	-0.02	-0.02	0.01	0.09	0.58
1	2	3.17	0.40	0.08	0.02	0.03	-0.08	3.31
1	3	5.03	0.03	0.22	0.03	0.00	0.04	4.67
1	4	5.27	0.02	-0.02	0.01	-0.01	0.22	5.21
1	5	5.27	0.07	-0.21	-0.10	0.02	0.48	5.70
2	1	0.44	-0.15	-0.06	-0.03	-0.01	0.07	0.44
2	2	3.45	0.35	0.08	0.05	-0.00	-0.13	3.43
2	3	5.12	-0.05	0.24	-0.00	-0.02	-0.08	4.53
2	4	5.30	-0.05	-0.01	-0.01	-0.00	0.06	5.03
2	5	5.27	0.01	-0.23	-0.05	0.01	0.28	5.45
3	1	0.55	-0.13	-0.06	0.02	-0.02	0.07	0.55
3	2	3.25	0.35	0.08	0.01	-0.01	-0.18	3.19
3	3	5.03	-0.12	0.21	0.12	-0.01	-0.13	4.34
3	4	5.26	-0.11	-0.08	-0.01	0.01	-0.13	4.80
3	5	5.27	-0.09	-0.26	-0.02	0.01	0.08	5.17
4	1	0.64	-0.17	-0.05	0.00	0.02	-0.00	0.55
4	2	3.33	0.25	0.15	0.01	-0.02	-0.13	3.16
4	3	5.08	-0.19	2.21	0.12	-0.01	-0.21	4.24
4	4	5.29	-0.20	0.01	-0.03	-0.03	-0.21	4.58
4	5	5.29	-0.13	-0.30	-0.08	0.04	-0.11	5.01
Grand Mean		3.89	-0.00	0.00	-0.00	0.00	0.00	3.70

C_1 - C_6 represents the orthogonal variables of components 1-6. Ln Y is the natural logarithm of total plant DM yield (W).

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Appendix IV

Forward - YCA. Two-dimensional Partitioning of the total sum of squares for yield expressed as percentages - in the early vegetative growth.

Yield Component or Product	Block	Density	Error	Total
C_1 (T)	11.27**	1.85*	22.14	35.25***
C_2 (D/T)	12.54*	0.75	20.76	39.47***
C_3 (L_N/D)	0.52***	0.18**	1.42	2.12
C_4 (L_A/L_N)	1.48**	0.01	6.50	8.00***
C_5 (W_L/L_A)	0.86	0.16	9.82	10.84***
C_6 (W/W_L)	0.24	0.07	4.02	4.33***
C_1C_2	11.03	-0.74	10.29	0.00
C_1C_3	0.25	0.16	0.08	0.00
C_1C_4	-1.57	0.13	1.44	0.00
C_1C_5	0.96	0.37	-1.33	0.00
C_1C_6	0.70	-0.12	-0.58	0.00
C_2C_3	0.20	-0.32	0.52	0.00
C_2C_4	-0.81	-0.05	0.86	0.00
C_2C_5	1.47	-0.34	-1.12	0.00
C_2C_6	0.48	0.03	-0.50	0.00
C_3C_4	0.30	0.02	-0.32	0.00
C_3C_5	-0.39	0.13	0.26	0.00
C_3C_6	-0.20	0.04	0.16	0.00
C_4C_5	-0.47	0.02	0.44	0.00
C_4C_6	-0.09	0.00	0.09	0.00
C_5C_6	0.11	-0.03	-0.09	0.00
Ln Y	70.40***	1.12	28.49	100.00

Total SS (100%) = 36.824

C_1 --- C_6 and Ln Y are Yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix V

Backward - YCA. Two-dimensional Partitioning of the total sum of squares for yield expressed as percentages in the early vegetative growth.

Yield Component or Product	Block	Denisity	Error	Total
C_1 (T)	0.45**	0.17*	2.23	2.86
C_2 (D/T)	0.03	0.03**	0.33	0.40
C_3 (L_N/D)	0.12***	0.00	0.28	0.40
C_4 (L_A/L_N)	30.26***	0.81	26.75	57.82***
C_5 (W_L/L_A)	8.16	0.13	29.11	37.41***
C_6 (W/W_L)	0.06	0.02	1.02	1.10
C_1C_2	0.04	0.04	-0.08	0.00
C_1C_3	0.01	0.03	-0.04	0.00
C_1C_4	1.46	0.11	-1.57	0.00
C_1C_5	1.43	-0.09	-1.34	0.00
C_1C_6	0.05	-0.01	-0.04	0.00
C_2C_3	0.01	0.01	-0.02	0.00
C_2C_4	0.23	-0.09	-0.14	0.00
C_2C_5	0.23	-0.05	-0.17	0.00
C_2C_6	-0.01	0.01	0.00	0.00
C_3C_4	-0.25	0.01	0.24	0.00
C_3C_5	0.02	0.02	-0.01	0.00
C_3C_6	0.02	-0.00	-0.02	0.00
C_4C_5	11.63	0.09	-11.72	0.00
C_4C_6	0.65	-0.08	-0.56	0.00
C_5C_6	0.18	0.01	-0.19	0.00
Ln Y	70.40***	1.12	28.49	100.00

Total SS (100%) = 36.824

C_1 --- C_6 and Ln Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix VI

Forward - YCA. Two-dimensional Partitioning of the total sum of squares for yield expressed as percentages in the late vegetative growth.

Yield Component or Product	Block	Density	Error	Total
C_1 (T)	41.84***	5.37**	28.05	75.26***
C_2 (D/T)	0.70*	1.56***	4.72	6.97***
C_3 (L_N D)	0.02***	0.00	0.09	1.18
C_4 (L_A/L_N)	1.01***	0.21*	2.71	3.92***
C_5 (W_L/L_A)	1.41*	1.22***	6.96	9.59***
C_6 (W/W_L)	0.41*	0.31**	3.31	4.04*
C_1C_2	0.89	-2.25	1.36	0.00
C_1C_3	0.06	0.22	-0.28	-0.00
C_1C_4	-2.93	0.69	2.24	-0.00
C_1C_5	7.58	-2.54	-5.05	0.00
C_1C_6	0.50	0.01	-0.50	-0.00
C_2C_3	-0.19	0.02	0.17	0.00
C_2C_4	-0.92	0.60	-0.32	-0.00
C_2C_5	0.53	2.68	-3.21	0.00
C_2C_6	-0.36	0.64	-0.27	-0.00
C_3C_4	0.26	0.01	-0.26	0.00
C_3C_5	-0.17	-0.19	0.19	0.00
C_3C_6	0.07	-0.03	-0.04	0.00
C_4C_5	-1.75	0.57	1.18	-0.00
C_4C_6	0.30	0.45	-0.75	0.00
C_5C_6	0.10	0.73	-0.83	-0.00
Ln Y	49.40***	10.48***	40.12	100.00

Total SS (100%) = 16.101

C_1 --- C_6 and Ln Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix VII

Backward - YCA. Two-dimensional partitioning of the total sum of squares for yield expressed as percentages in the late vegetative growth.

Yield Component or Product	Block	Density	Error	Total
C_1 (T)	1.08**	0.21	5.77	7.06***
C_2 (D/T)	0.00	0.00	0.00	0.00
C_3 (L_N/D)	0.04***	0.05**	0.83	0.92
C_4 (L_A/L_N)	2.79***	1.32***	12.06	16.17***
C_5 (W_L/L_A)	8.33***	0.41	7.72	16.46***
C_6 (W/W_L)	21.03***	4.99***	33.37	59.39***
C_1C_2	0.01	-0.04	0.04	0.00
C_1C_3	-0.30	-0.05	0.35	0.00
C_1C_4	-1.17	0.48	0.70	0.00
C_1C_5	3.48	0.39	-3.86	0.00
C_1C_6	-0.54	0.49	0.06	0.00
C_2C_3	0.00	0.01	-0.01	0.00
C_2C_4	0.06	-0.05	-0.00	0.00
C_2C_5	0.05	-0.04	-0.00	0.00
C_2C_6	0.15	-0.03	0.12	0.00
C_3C_4	0.37	-0.30	0.07	0.00
C_3C_5	-0.45	-0.24	0.69	0.00
C_3C_6	0.68	0.32	-1.00	0.00
C_4C_5	-3.24	0.74	2.50	0.00
C_4C_6	7.16	2.79	-9.95	0.00
C_5C_6	9.88	-0.94	-8.93	0.00
Ln Y	49.40***	10.48***	40.12	100.00

Total SS (100%) = 16.101

C_1 --- C_6 and In Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix VIII

Forward - YCA. Two-dimensional Partitioning of the total sum of squares for yield expressed as percentages in the early reproductive growth.

Yield Component or Product	Block	Density	Error	Total
C_1 (T)	9.41***	1.65**	18.38	29.44***
C_2 (D/T)	8.92***	21.81***	17.47	48.21***
C_3 (L_N/D)	0.04**	0.01	0.20	0.24
C_4 (L_A/L_N)	0.27*	0.05	1.50	1.82
C_5 (W_L/L_A)	0.15	0.05	5.99	6.20***
C_6 (W/W_L)	2.45**	2.56***	9.09	14.19***
C_1C_2	8.25	-1.99	-6.27	-0.00
C_1C_3	-0.37	0.11	0.26	0.00
C_1C_4	-0.86	-0.50	1.36	0.00
C_1C_5	-0.10	-0.33	0.43	-0.00
C_1C_6	-2.87	-1.70	4.57	-0.00
C_2C_3	-0.35	0.85	-0.50	0.00
C_2C_4	-1.79	1.08	0.71	-0.00
C_2C_5	-1.44	1.26	0.19	0.00
C_2C_6	-8.42	14.43	-6.02	0.00
C_3C_4	-0.01	-0.00	-0.00	0.00
C_3C_5	0.06	0.01	-0.07	-0.00
C_3C_6	0.20	0.23	-0.43	0.00
C_4C_5	0.10	0.09	-0.18	-0.00
C_4C_6	0.64	0.50	-0.50	-0.00
C_5C_6	0.83	0.51	-0.51	-0.00
Ln Y	15.11***	40.67***	44.22	100.00

Total SS (100%) = 9.8749

C_1 --- C_6 and In Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix IX

Backward - YCA. Two-dimensional partitioning of the total sum of squares for yield expressed as percentages in the early reproductive growth.

Yield Component or product	Block	Density	Error	Total
C_1 (T)	1.78***	0.40**	4.33	6.50***
C_2 (D/T)	0.69**	2.48***	3.07	6.24***
C_3 (L_N/D)	2.11***	0.82**	6.86	9.79***
C_4 (L_A/L_N)	1.24*	0.26	8.55	10.05***
C_5 (W_L/L_A)	1.26*	0.26	8.55	10.05***
C_6 (W/W_L)	8.76***	11.38***	37.34	57.47***
C_1C_2	0.20	0.30	-0.50	0.00
C_1C_3	-2.25	0.38	18.78	-0.00
C_1C_4	0.29	-0.35	0.05	0.00
C_1C_5	2.25	0.32	-2.57	0.00
C_1C_6	3.50	2.26	-5.76	-0.00
C_2C_3	-0.54	2.76	-2.24	0.00
C_2C_4	-0.59	1.10	-0.51	0.00
C_2C_5	-0.19	0.09	0.10	0.00
C_2C_6	-3.38	9.76	-6.37	-0.00
C_3C_4	-1.17	0.55	0.62	-0.00
C_3C_5	-2.10	0.15	1.95	-0.00
C_3C_6	-2.53	5.91	-3.38	0.00
C_4C_5	-0.14	0.12	0.26	0.00
C_4C_6	1.47	1.28	-2.76	-0.00
C_5C_6	4.46	0.85	-5.31	-0.00
Ln Y	15.11***	40.67***	44.22	100.00

Total SS (100%) = 9.8749

C_1 --- C_6 and In Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix X

Forward - YCA. Two-dimensional Partitioning of the total sum of squares for yield expressed as percentages in the late reproductive growth.

Yield component or product	Block	Density	Error	Total
C_1 (T)	4.07***	0.27	10.98	15.33***
C_2 (D/T)	1.31	25.71***	38.21	65.22***
C_3 (L_N/D)	0.35***	0.16**	1.50	2.01
C_4 (L_A/L_N)	0.02*	0.00	0.10	0.12
C_5 (W_L/L_A)	0.25**	0.04	1.42	1.71
C_6 (W/W_L)	0.85	2.21***	12.54	15.61***
C_1C_2	0.70	-2.19	1.49	-0.00
C_1C_3	0.27	0.02	-0.29	0.00
C_1C_4	-0.14	-0.00	0.14	-0.00
C_1C_5	-0.12	-0.07	0.20	0.00
C_1C_6	1.17	-0.79	-0.38	0.00
C_2C_3	-0.15	3.04	-2.89	-0.00
C_2C_4	-0.10	0.38	-0.28	0.00
C_2C_5	0.33	0.91	-1.24	0.00
C_2C_6	-0.03	14.76	-14.73	-0.00
C_3C_4	0.10	0.03	-0.13	-0.00
C_3C_5	-0.27	-0.03	0.30	-0.00
C_3C_6	-0.72	0.92	-0.20	0.00
C_4C_5	-0.05	0.00	0.05	0.00
C_4C_6	-0.06	0.11	-0.05	0.00
C_5C_6	-0.00	0.19	-0.19	-0.00
Ln Y	7.77**	45.68***	46.55	100.00

Total SS (100%) = 17.862

C_1 --- C_6 and In Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix XI

Backward - YCA. Two-dimensional partitioning of the total sum of squares for yield expressed as percentages in the late reproductive growth.

Yield component or product	Block	Density	Error	Total
C_1 (T)	0.41*	0.07	2.80	3.28
C_2 (D/T)	0.13***	0.10***	0.59	0.83
C_3 (L_N/D)	1.15*	0.53*	8.67	10.35***
C_4 (L_A/L_N)	1.01	1.35**	14.12	16.48***
C_5 (W_L/L_A)	5.28***	0.06	1.09	1.68
C_6 (W/W_L)	5.87*	23.67***	37.85	67.39***
C_1C_2	-0.20	-1.18	0.32	-0.00
C_1C_3	0.68	-0.09	-0.58	0.00
C_1C_4	-0.65	-0.37	1.02	-0.00
C_1C_5	-0.10	-0.04	0.15	0.00
C_1C_6	1.68	-1.51	-0.16	0.00
C_2C_3	-0.15	0.39	-0.25	0.00
C_2C_4	0.05	0.70	-0.76	-0.00
C_2C_5	-0.11	-0.01	0.12	0.00
C_2C_6	-1.42	3.10	-1.69	-0.00
C_3C_4	0.58	1.43	-2.01	0.00
C_3C_5	-0.40	-0.13	0.53	-0.00
C_3C_6	-0.14	6.44	-6.30	0.00
C_4C_5	-0.19	0.09	0.10	-0.00
C_4C_6	-0.74	10.49	-9.00	-0.00
C_5C_6	0.53	-0.48	-0.05	0.00
Ln Y	7.77***	45.68***	46.55	100.00

Total SS (100%) = 17.862

C_1 --- C_6 and Ln Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix XII

Forward - YCA. Two-dimensional Partitioning of the total sum of squares for yield expressed as percentages at forage maturity stage.

Yield Component or product	Block	Density	Error	Total
C_1 (T)	2.13***	0.04	3.62	5.79***
C_2 (D/T)	4.52**	40.14***	27.05	71.70***
C_3 (L_N/D)	0.76***	0.07	2.53	34.35***
C_4 (L_A/L_N)	0.04*	0.02	0.35	0.41
C_5 (W_L/L_A)	0.26	0.01	2.52	2.79
C_6 (W/W_L)	1.48	1.57**	12.89	15.95***
C_1C_2	4.77	-1.20	-3.57	0.00
C_1C_3	-0.23	-0.08	0.31	-0.00
C_1C_4	0.06	-0.05	-0.01	0.00
C_1C_5	-0.15	-0.00	0.15	0.00
C_1C_6	-0.09	-0.27	0.36	-0.00
C_2C_3	-1.28	3.08	-1.79	-0.00
C_2C_4	0.16	0.63	-0.79	0.00
C_2C_5	-0.37	1.21	-0.85	-0.00
C_2C_6	-1.02	13.55	12.52	0.00
C_3C_4	-0.10	0.05	0.06	-0.00
C_3C_5	0.47	0.04	-0.51	-0.00
C_3C_6	1.36	0.55	-1.91	0.00
C_4C_5	-0.19	-0.01	0.20	-0.00
C_4C_6	-0.02	0.07	-0.06	-0.00
C_5C_6	0.50	0.23	-0.73	-0.00
Ln Y	13.06***	59.65***	27.29	100.00

Total SS (100%) = 17.137

C_1 --- C_6 and Ln Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.

Appendix XIII

Backward - YCA. Two-dimensional Partitioning of the total sum of squares for yield expressed as percentages at forage maturity stage.

Yield component or product	Block	Density	Error	Total
C_1 (T)	0.68***	0.08	2.28	3.04
C_2 (D/T)	0.09***	0.05**	0.39	0.54
C_3 (L_N/D)	4.24***	1.42**	14.93	20.58***
C_4 (L_A/L_N)	0.60**	0.15	3.12	3.88***
C_5 (W_L/L_A)	0.17*	0.05	1.26	1.48
C_6 (W/W_L)	5.71**	33.58***	31.18	70.47***
C_1C_2	0.36	0.06	0.30	-0.00
C_1C_3	-0.26	0.30	-0.05	-0.00
C_1C_4	0.71	0.07	-0.79	-0.00
C_1C_5	0.04	0.06	-0.11	-0.00
C_1C_6	1.55	1.38	-2.93	0.00
C_2C_3	-0.37	0.51	-0.14	-0.00
C_2C_4	-0.16	0.16	-0.00	0.00
C_2C_5	0.04	0.02	-0.06	-0.00
C_2C_6	-1.12	2.40	-1.28	0.00
C_3C_4	-2.30	0.76	1.54	-0.00
C_3C_5	0.05	0.21	-0.26	-0.00
C_3C_6	3.30	13.76	-17.06	-0.00
C_4C_5	-0.14	-0.03	0.17	-0.00
C_4C_6	1.29	3.47	-4.76	0.00
C_5C_6	-0.73	1.17	-0.45	-0.00
Ln Y	13.06***	59.65***	27.29	100.00

Total SS (100%) = 17.137

C_1 --- C_6 and Ln Y are yield components 1 to 6 and natural logarithm of yield (W).

*, **, *** - Significant at P = 0.05, 0.01 and 0.001.