Plant growth analysis of maize (*Zea mays* L.) inter-cropped with cassava (*Manihot esculentus* Cranz)

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ABSTRACT

Growth analysis was used in an investigation as an aid in the quantitative interpretation of plant growth of different stands of two maize (*Zea mays* L.) varieties ('Dorke' and 'Dobidi') and two cassava varieties ('Bosome Nsia' and 'Ankra') established as intercrops in experiments at Fumesua (1986) and Kwadaso (1987) in Kumasi (6° 43' N, 1° 36' W). The trials were conducted in a randomized complete block design with a 2^4 factorial arrangement of four main factors. There were four blocks per trial. In Trial 1 (Fumesua 1986 first (major) rainy season), the treatments in the intercrop were maize variety ('Dorke' and 'Dobidi'), maize density (20 000 and 40 000 plants/ha), cassava variety ('Bosome Nsia' and 'Ankra'), and maize fertilization (45 and 180 kg/ha N). In Trial 2 (Kwadaso 1987 second (minor) rainy season), the treatments in the intercrops were similar to those of 1986 at Fumesua, except that the maize fertilization treatment was replaced by a cassava density treatment at 10 000 and 20 000 plants/ha. The use of this analysis to detect differences in growth between years for one variety and between varieties in one year was essential in this analytical approach to crop studies. The investigations pointed out the genotypic and phenotypic differences in growth between varieties and their relationship to economic yield. Leaf area development (LAD) was important in the accumulation of dry matter and led to higher grain yield in maize. As expected, the early-maturing variety ('Dorke') showed a pronounced decline in leaf area towards the end of the growth cycle, while in the full-season variety ('Dobidi') this decline was less pronounced, resulting in the production of more dry matter late in the growth cycle. A higher peak of leaf area could not alone account for the estimated 20 per cent higher grain yield of 'Dobidi' over 'Dorke'. Leaf longevity estimated by the values of LAD calculated seemed to have an important influence on yield. The comparisons made indicated that for intercropped maize, the magnitude of the shoot dry weight differences between varieties did not relate to grain yield differences. Growth rates did not relate directly to yield either. Important factors that were not estimated but

RÉSUMÉ

ASAFO-AGYEI, J. N., OHEMENG-DAPAAH, S. & OSAFO, D. M.: *Analyse de la croissance de plante du maïs* (Zea mays *L.*) *semé en lignes alternantes avec le manioc* (Manihot esculentus *Cranz).* Analyse de croissance était utilisée dans une enquête en tant qu'une aide à l'interprétation quantitative de la croissance de plante des différentes récoltes sur pieds des deux variétés ('Dorke' et 'Dobidi') de maïs (*Zea mays* L.) et deux variétés ('Bosome Nsia' et 'Ankra') de manioc (*Manihot esculentus* Cranz) enraciné comme deux cultures semées en lignes alternantes dans les expériences à Fumesua (1986) et Kwadaso (1987) à Kumasi (6° 43° N, 1° 36° W). Les essais se sont déroulés dans un dessin de bloc complet choisi au hasard avec 2^4 arrangement factoriel de 4 facteurs principaux. Il y avait 4 blocs par essai. En Essai 1 (Fumesua 1986 première saison des pluies (majeure), les traitements dans les deux cultures semées en lignes alternantes étaient: variété de maïs ('Dorke' et 'Dobidi'), densité de maïs (20,000 et 40,000 plantes/ha); variété de manioc ('Bosome Nsia' et 'Ankra') et fertilisation de maïs (45 et 180 kg/ha N). En Essai 2 (Kwadaso 1987 seconde saison des pluies (mineur), les traitements dans les deux cultures semées en lignes alternantes étaient semblables à ceux de 1986 à Fumesua, sauf que le traitement de fertilisation de maïs était remplacé par un traitement de densité de manioc à 10,000 et 20,000 plantes/ha. Son usage de cette analyse à détecter des différences en croissance entre les années d'une variété et entre les variétés en une année était essentiel dans cette façon analytique d'aborder les études de culture. Les enquêtes signalaient les différences génotypiques et phénotypiques en croissance entre les variétés et leur rapport avec le rendement économique. Le développement de la surface foliaire (DSF) était découvert d'être important à l'accumulation de matière sèche et menait au rendement plus élevé de grain de maïs. Comme espéré la variété ('Dorke') de maturation tôt montrait une diminution marguée dans la surface foliaire vers la fin du cycle de croissance, alors que dans la variété ('Dobidi') de pleine saison cette diminution était moins marguée, aboutissant à la production de plus de matière sèche tard dans le cycle might have had contributory effects appeared to be the duration of the grain-filling period and photosynthetic rates which prevailed during the period. All the growth functions declined significantly and rapidly as the plant matured, suggesting a progressively declining rate of dry matter increase.

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de croissance. Un maximum élevé de la surface foliaire seul ne pourrait pas justifier le 20 pour cent d'estimation de rendement de grain plus élevé de 'Dobidi' au-dessus de 'Dorke'. La longévité de feuille estimée par les valeurs de DSF calculé semblait d'avoir une influence importante sur le rendement. Les comparaisons faites indiquaient que pour le maïs semé en lignes alternantes l'ampleur des différences entre le poids de la pousse sèche des variétés n'ont pas de rapport avec les différences de rendement de grain. Les proportions de croissance n'ont pas de rapport direct avec le rendement non plus. Les facteurs importantes qui n'étaient pas estimées maïs auraient pu avoir des effets contribuants semblaient être la durée du stade de remplissage des grains et les proportions photosynthétiques, qui régnaient pendant le stade. Toutes les fonctions de croissance diminuaient considérablement et rapidement comme la plante mûrissait, suggérant une proportion de diminution progressive de l'augmentation de la matière.

Introduction

The simplest approach to a quantitative description of growth, as has been suggested by France & Thornley (1984), is to fit suitable mathematical functions, represented by smooth curves, to the recorded values of the primary data (dry weights and leaf areas) to obtain a relationship between the primary data and time to approximate the real growth curve. The growth functions could then be constructed, based on their general definitions, from values given by the fitted curves of the relationships. France & Thornley (1984) further observed that such mathematical models provided the following, among others:

1. a quantitative description and understanding of biological problems,
2. a conceptual framework which may help pinpoint areas where knowledge was lacking and might stimulate new ideas and experimental approaches,
3. a recipe by which research knowledge could be made available in an easy-to-use form, and
4. a means of not only summarizing data, but also a method of making more complete use of data for interpolation and extrapolation.

In their investigations, Vernon & Allison (1963) used parabolic functions. Hughes & Freeman (1967), however, preferred exponential functions. Although these polynomials are simple to use, observations by Hurd (1977) has drawn attention to the dangers of over-fitting and spurious responses in the cubic and higher order expressions. He has, therefore, suggested that expressions beyond the quadratic should be avoided especially, since they most often do not contribute significantly to the accuracy of fit.

In growth analysis, dry weight values of whole plants and/or their parts and the dimensions of the assimilatory apparatus are, therefore, measured in growing plant material, at specified time intervals (Kvet *et al.,* 1971) and used to estimate various indices and characteristics that describe the growth of the plants and their parts. The relationship between the assimilatory apparatus and dry matter production is also described.

Though growth analysis principles have been used extensively in crops grown as sole, the procedure is rare in mixed intercrops. The objective of this study, therefore, was to quantify plant growth in maize intercropped with cassava by using growth analysis principles. This was to generate information to serve as a basis for the design of adaptive research in mixed-cropping experiments for potential yield improvement either through crop breeding or crop production agronomy.

Materials and methods

The experiment involved maize intercropped with cassava as intercrops at Fumesua and Kwadaso, two similar locations in Kumasi (6°43' N, 1°36' W) in the central forest belt of Ghana, in 1986 and 1987. There are two rainy seasons, major and minor, in these locations. The major season rains normally begin in March and end in July. There is a short, dry spell in August and then the minor season rains begin and end in October or November. The following varieties were used:

1. *Dorke*, a 90-day early white dent maize variety. It is open-pollinated and was developed in 1984 by the Crops Research Institute, Kumasi, Ghana.
2. *Dobidi*, a 120-day full season white dent variety. It is also an open-pollinated variety developed at the Crops Research Institute, Kumasi, Ghana, in 1984.
3. *Bosome Nsia,* an early (8-9 months maturity) but late-branching local cassava cultivar grown mainly in the coastal savanna areas of Ghana. It grows to a height of about 180 cm in 9 months. It probably originated from a local collection from Kpeve in the Volta Region of Ghana which was called *Asram Asia*, meaning a 6-month variety.
4. *Ankra*, a long season (12-18 months maturity) late-branching local cassava cultivar widely grown in the forest and transitional areas of Ghana. It was selected in 1933, according to Doku (1965), from an introduction from Mauritius. It grows to a height of about 280 cm in 12 months, and it is very susceptible to African cassava mosaic virus (ACMV).

The soils at the experimental sites used generally support a wide variety of cereal crops, root and tuber crops, and grain legumes. Continuous cultivation, with fertilizer application and exposure of soil to the tropical weather, are known to have affected the properties of these soils. The continuous N fertilizer application on these soils has contributed to reducing the soil *p*H to below 6, and soil organic matter contents are very low. With the intensive cropping practised on these soils for over 10 years, N, P and some micronutrients can become limiting.

At Fumesua, the common slope gradients ranged from 2 to 6 per cent. The topsoil has usually 2-3 layers. The top layer, about 5 cm thick, is dark-grey, gritty loam to gritty clay loam. The subsoil contains mainly quartz gravel in a clay matrix. Mixed ironstone concretions and quartz gravel are contained in the clay matrix in some profiles. The soils are deep, porous, well-drained, and well-aerated with good tilth. Moisture retention is fairly good in the sub-soil, but the upper horizons tend to dry out rapidly during prolonged dry spells. The plots used for the trials at this location had a previous history of continuous cultivation with maize and cassava, and had fallowed for about 3 years.

The soil at the Kwadaso location occurs on gentle to moderately steep upper slopes. The soil of the series generally has good physical conditions for plant growth. It is deep, porous, freely drained, well-aerated, and has good tilth. Moisture retention is fairly good in the sub-soil, but the upper horizons tend to dry out rapidly during prolonged dry spells. The top soil has at least two or more layers with a total thickness of about 16-21 cm. The sub-soil consists of a red to yellowish red clay loam or clay containing quartz gravel and ironstone concretions. Plots cropped had a previous history of cultivation especially with maize for over 10 years.

Cultural practices

At the two locations where the trials were conducted, the land was prepared by disc ploughing and harrowing to obtain a smooth seed bed. Unbranched hardwood middle stems of cassava were obtained from a uniform bulking plot planted 1 year earlier. The cassava stem cuttings were 20 cm long, and were planted on the flat in rows spaced 1 m apart. Maize seed was protected from predators by Furadan 350 ST (carbofuran) at a rate of 30 ml commercial product in 15 ml water per kilogram of seed.

Row length was 8 m and plots measured 8 m ×

8 m. In all the trials, cassava was interplanted with maize on alternate rows. Row width was 1 m such that two rows of cassava were spaced 1 m while two rows of maize were also spaced 1 m. Cassava row was 50 cm from a maize row and *vice versa.* For the intercrops, the interplanting of cassava into the maize and maize planting were simultaneous,except in situations where time did not permit this. In such cases, the cassava planting was completed within 8 days of planting of the maize. For the monocrops, planting of maize or cassava was at the same time as the intercropped maize and cassava, respectively, were planted. Fertilizer applied to maize, unless otherwise stated, was equivalent to 90:38:38 (comprising 38:38:38 kg/ha N:P_2O_5:K_2O of compound fertilizer at planting, and 52 kg/ha N of sulphate of ammonia side-dressed at 5-6 WAP maize). All fertilizer applications were by banding in furrows, 5 cm from the maize plants.

Plant density, fertilizer rates, and other husbandry practices for monocropped maize and cassava were those recommended for their varieties when sole-cropped. In all the trials, the within row spacings for maize and cassava were adjusted for the desired plant population densities. Weeds were controlled in each trial by a pre-emergent application of Primagram 500, a herbicide comprising a combination of 250 g/l metolachlor (CIBA-GEIGY) and 250 g/l atrazine (DU-PONT) at a rate of 2.0 kg a.i./ha. Supplementary handweeding was done in all the trials where necessary to control weed regrowth after the herbicide application. Maize harvesting period was between 90 and 105 DAP for 'Dorke', and between 120 and 130 DAP for 'Dobidi'.

Tables 1 and 2 present meteorological data on rainfall and radiation for this period, respectively.

TABLE 1

Monthly Total Rainfall (mm) for Fumesua and Kwadaso, 1987 and 1988

Month	Fumesua 1986	Fumesua 1987	Kwadaso 1987	Kwadaso 1988
Jan	22	2	12	0
Feb	42	40	74	0
Mar	94	126	114	32
Apr	112	119	230	119
May	156	46	66	128
Jun	214	156	238	357
Jul	139	136	178	98
Aug	14	156	144	13
Sep	62	210	352	145
Oct	133	88	120	162
Nov	0	8	0	8
Dec	0	4	0	0

Metolachlor = 2-chloro-N-(2-ethyl-6-methyl-phynyl)-N-(2-methoxy-1-methylethyl) acetamide.
Atrazine=2-chloro-4-(ethylamino)-6-(isopropyl-amino)-s-triazine.

TABLE 2

Mean Monthly Solar Radiation Income (watts m^{-2}) for Kumasi Area

Month	1964-1988	1986	1987	1988
Jan	172.1	184.8	156.2	158.9
Feb	195.1	208.9	186.7	187.6
Mar	207.4	195.0	195.5	196.8
Apr	211.8	211.6	204.3	202.4
May	206.6	208.9	199.6	207.9
Jun	181.8	190.4	179.3	177.5
Jul	154.0	135.9	155.3	162.7
Aug	140.4	135.9	147.0	125.7
Sep	159.0	155.3	171.0	150.6
Oct	186.1	171.9	188.6	189.5
Nov	194.8	183.9	187.6	183.0
Dec	162.1	160.8	151.6	160.8

Experiment

The design was a 2^4 factorial combination of four factors arranged in a randomized complete block. There were four blocks per trial. Each of the four factors was evaluated at two levels. In 1986 at Fumesua, the four factors were maize variety ('Dorke' and 'Dobidi'), maize density (20 000 and 40 000 plants/ha), cassava variety ('Bosome Nsia' and 'Ankra'), and maize fertilization (45 and 180 kg/ha N). The maize was planted at 100 cm × 50 cm spacing, one plant/hill for the lower density and two plants/hill for the higher density. The fertilizer was applied as 45:19:19 (comprising 19:19:19 kg/ha N:P_2O_5:K_2O of compound fertilizer at planting, and 26 kg/ha N of sulphate of ammonia side-dressed at 5-6 WAP of the maize) at the lower fertilizer level. At the higher level, four times this rate of N was applied. Planting dates were as follows: 1) intercropped maize, 26 March 1986; and 2) intercropped cassava, 3 April 1986.

In 1987 at Kwadaso, the four factors were similar to those of 1986 at Fumesua, except that the maize-fertilization treatment was replaced by a cassava-density treatment at 10 000 and 20 000 plants/ha. The cassava was planted at 100 cm × 100 cm spacing for the lower density, and at 100 cm × 50 cm spacing for the higher density. Planting dates for Trial 2 were as follows: 1) intercropped maize, 8 July 87; and 2) intercropped cassava, 9 July 1987.

Data collection

Growth characteristics of maize were determined from dry weight and leaf area data of samples measured at the various stages of growth at Fumesua in 1986 during the major rainy season, and at Kwadaso in the minor rainy season of 1987.

Growth in maize was measured at plant height, leaf area, and shoot dry weights at specified times (Table 3). These periods of measurement were chosen as much as possible to reflect the following: active vegetative phase of maize growth, flowering stage, blister stage of the kernel, milk stage of the kernel, dough stage of the kernel, and dent stage of the kernel. Leaf area per plant in maize was determined as the sum of the surface area per leaf which was given by the 'length × the width × 0.75' (Montgomery, 1911) for all leaves. The percentage of the area that was green was then estimated as the true assimilating surface area of the leaf. Measured variables at each sampling were determined from five plants of maize and were taken from rows bordered on each side. Final harvest was made in two rows from an area of 14 m^2. Yield data on maize grain yield were also collected in 1986 and 1987.

Statistical analysis

The main analyses were confined to total dry weight per plant and total leaf area per plant yielding, respectively the growth functions, relative growth rate (RGR), leaf area ratio (LAR), and unit leaf rate (ULR). RGR was the main index used. The computer programme, *Hpcurves* (Hunt & Parsons, 1974, 1994), was used. This is an *IBM*-compatible *PC* edition of a stepwise polynomial regression programme for plant growth analysis (and related applications). When presented with replicated measurements of two plant variables *Y* and *Z* (most commonly *Y* is whole-plant dry weight and *Z* is total leaf area) at four or more harvests in time t, *Hpcurves* fits first, second or third-order polynomial exponential curves to the trends in *lnY* versus *t* and *lnZ* versus *t*. The choice of order of polynomial exponential can either be determined automatically by the programme (at $P<0.05$) or set by the user.

TABLE 3

Sampling Periods for Maize

	'Dorke'		'Dobidi'	
	1986	*1987*	*1986*	*1987*
	DAP		*DAP*	
1	30	33	30	33
2	46	48	46	48
3	61	63	61	63
4	75	70	75	77
5	99	77	99	84
6		84		91
7				98

Thus, the computer programme reads and transforms the raw data, carries out an analysis of variance (ANOVA), and prints out the ANOVA table. This is followed by a print of the polynomials used for calculating fitted values. The programme then calculates and prints for each value of *t*, the observed and fitted values for the logarithms of the variates *Y* and *Z*, *lnY* and *lnZ*, respectively, and the values of *dY/dt* and *dZ/dt*. The fitted values have standard errors and 95 per cent confidence limits. The derived functions, *(1/Y)(dY/dt)* and *(1/Z)(dZ/dt)*, are calculated next and printed together with standard errors and 95 per cent confidence limits, followed by observed and fitted values for function *Z/Y* also with standard errors and limits attached to the fitted values. Finally, the programme calculates and prints values for the function $(1/Z)(dY/dt)$, again with standard errors and 95 per cent limits.

RGR is the increase in plant weight per unit of plant weight per unit of time. If by definition, RGR=$1/w \times dw/dt$ (Hunt, 1982; Evans, 1972), where w = dry weight of shoot in g/plant and dw is the dry matter production during a period of dt, then R in polynomial notation = $(b+2ct)/(a+bt+ct^2)$, where a, b, and c are equation parameters, and $w=(a+bt+ct^2)$ according to the method outlined by Radford (1967) and Kvet *et al.* (1971). Units of measurement with dry weight were in gg^{-1} day^{-1}. ULR is the net gain in weight/leaf area, or the photosynthetic efficiency measure. If ULR = $1/LA \times dw/dt$ (Hunt, 1982), where LA is the leaf area per plant in dm^{-2}, then ULR=$(b+2ct)/(a'+b't+c't^2)$, where LA= $a'+b't+c't^2$ and a', b', and c' are equation parameters, according to the method outlined by Radford (1967) and Kvet *et al.* (1971). Units of measurement were in gdm^{-2} leaf area day^{-1}. LAR is the ratio of assimilatory tissue area to total phytomass dry weight. Thus, LAR expresses the ratio between the area of leaf lamina or photosynthesizing tissue and the total respiring plant tissue or total biomass. LAR reflects the leafiness of a plant. If LAR=LA/w (Hunt, 1982), then LAR=$(a'+b't+c't^2)/(a+bt+ct^2)$, according to the method outlined by Radford (1967) and Kvet *et al.* (1971). Units of measurement were in $dm^2 g^{-1}$.

Relevant graphs showing these relationships were then drawn (SASI, 1987). The predicted values were maintained in the transformed scale because applying the inverse transformation directly to the predicted values gives estimates of the median of the distribution of the response instead of the mean as suggested by Montgomery & Peck (1982). Procedures for producing unbiased predictions in the original units were beyond the scope of this work. In all the equations, the quadratic terms were all significant (confidence limits calculated at $P<0.05$). Significant terms of higher order were not pursued because they had very small effect, and interpretations may be very complex and beyond the scope of this work. Differences between any two points on the same graph or on different graphs were compared for significance based on methods outlined by Hughes & Freeman (1967).

Essentially, it stated that a straightforward comparison could be made between the fitted values at any given time by using their corresponding SEs to test for significance. For example, if the mean value of RGR at 61 DAP for 'Dorke' and 'Dobidi' in 1986 are 0.0422 and 0.0504 gg^{-1} day^{-1}, respectively, and the corresponding SEs are 0.0052 and 0.0062 gg^{-1} day^{-1}, then twice the value of the square root of the sum of the squares of the two appropriate SEs is $2 \times 0.008092=0.016184$ which is higher than the difference between the two RGR values which is 0.0082 gg^{-1} day^{-1}. The difference between the two maize varieties at 61 DAP in 1986 is, therefore, not significant.

Other parameters calculated were leaf area index (LAI) and leaf area duration (LAD). LAI is the total leaf area $plant^{-1}$/ground area $plant^{-1}$, which is an estimate of the surface area available for photosynthesis and LAD, in quantitative terms, is the length of time a plant or stand maintains its active assimilatory surface and was derived by integration of the regression equation between LAI and time (Ondok & Kvet, 1971).

Results and discussion

Leaf area per plant in 'Dorke' increased significantly from an initial low value at 30 DAP to a peak at 55 DAP, and then declined sharply as a result of leaf senescence and leaf fall (Fig. 1). A similar trend in leaf area development was recorded for 'Dobidi', although the 'Dobidi' values were significantly higher than those of 'Dorke', and reached a peak at 63 DAP. 'Dobidi' had 13 per cent more leaf area than 'Dorke' when the peaks were reached.

The peak dry weight production of fitted values was at 83 DAP in 'Dorke' and only 4 days later in 'Dobidi' (Fig. 2). The differences between the fitted values for the two varieties were such that at the final sampling date, 'Dobidi' had produced 12 per cent more dry matter, although the pattern of dry

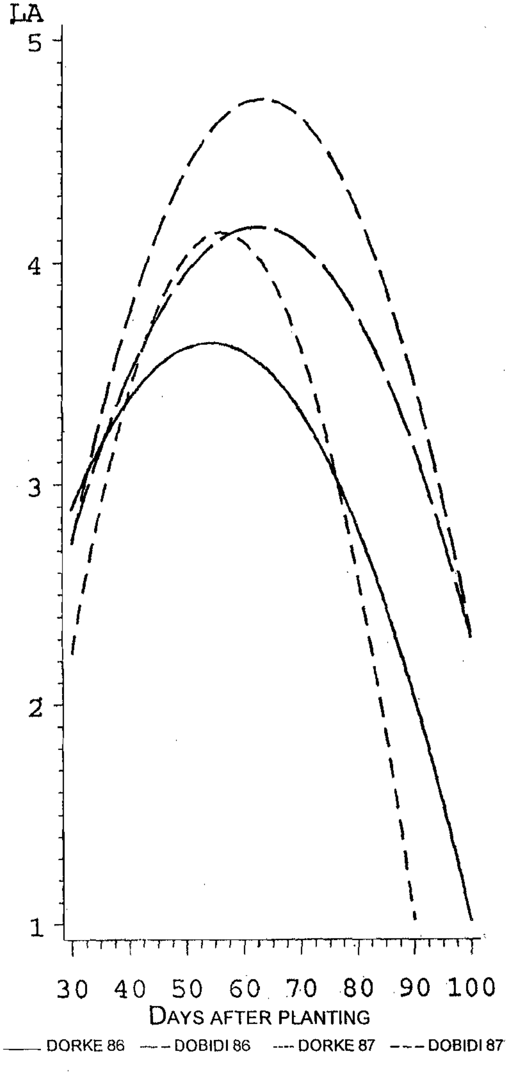

Fig. 1. Fitted curves for leaf area per plant during intercropped maize growth. Fitted quadratic polynomials (t in days) were:

'Dorke', 1986
$Log_e A$ (dm^2 $plant^{-1}$) = $-0.09524 + 0.13726t - 0.001261t^2$
'Dobidi', 1986
$Log_e A$ (dm^2 $plant^{-1}$) = $-1.05619 + 0.16665t - 0.001330t^2$
'Dorke', 1987
$Log_e A$ (dm^2 $plant^{-1}$) = $-4.58198 + 0.30965t - 0.002749t^2$
'Dobidi', 1987
$Log_e A$ (dm^2 $plant^{-1}$) = $-2.49168 + 0.22794t - 0.001797t^2$

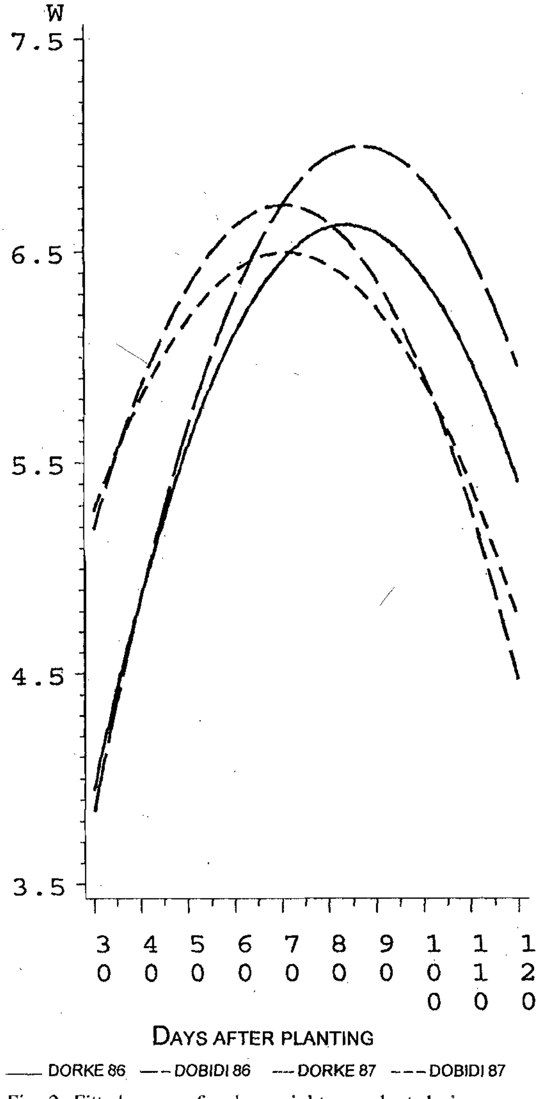

Fig. 2. Fitted curves for dry weight per plant during intercropped maize growth. Fitted quadratic polynomials (t in days) were:

'Dorke', 1986
$Log_e W$ (g $plant^{-1}$) = $-0.13058 + 0.15515t - 0.000926t^2$
'Dobidi', 1986
$Log_e W$ (g $plant^{-1}$) = $-0.31900 + 0.16777t - 0.000962t^2$
'Dorke', 1987
$Log_e W$ (g $plant^{-1}$) = $-2.83459 + 0.10309t - 0.000725t^2$
'Dobidi', 1987
$Log_e W$ (g $plant^{-1}$) = $-2.10906 + 0.13047t - 0.000923t^2$

weight increase was similar for the two maize varieties. For both varieties, there was not much decline in dry weight after the peaks were reached. In this study, the 13 per cent higher peak leaf area in 'Dobidi' led to an overall increase of about 15 per cent in its dry weight compared to 'Dorke'. Work reported by GGDP (1986) records a 20 per cent higher grain yield for 'Dobidi' over 'Dorke'.

It would appear, therefore, that the extent of development of leaf area alone cannot explain the 20 per cent higher grain yield of 'Dobidi' over 'Dorke'. Other factors like leaf longevity and mutual shading could also be important. The leaf area duration (LAD) estimated by using the first and the last sampling dates at Fumesua, was 66 days (9.5 weeks) for 'Dorke' and 109 days (15.6 weeks) for 'Dobidi'. This represents the duration and also the extent of the photosynthetic tissue developed in the two varieties. The values indicated that while the leaf photosynthetic surface senesced 39 days before maturity in 'Dorke', it was just 11 days in 'Dobidi'. This suggests that the efficiency of the leaf, as an assimilatory organ, was over a period more than three times as long in the field for 'Dobidi' as for 'Dorke'.

Gardner, Pearce & Mitchell (1985) have stated that large differences in total biomass production are often more the result of the duration than perhaps the rate of net photosynthesis. Thus, the longer time for which 'Dobidi' sustained its leaf area may have contributed significantly to its superior yielding ability. LAD is closely correlated with total yield because interception of solar radiation over longer periods of time generally leads to greater total dry matter production (Gardner *et al.*, 1985). Comparison of dry weight values (untransformed) for intercropped and monocropped maize (Fig. 3) showed that the monocrops performed better than their corresponding intercrops.

The results for maize at Kwadaso in 1987 were somewhat similar to those at Fumesua in 1986. Leaf area reached a peak at 56 DAP in 'Dorke' and 64 DAP in 'Dobidi' and then declined sharply (Fig. 1). The data were quite variable and this was

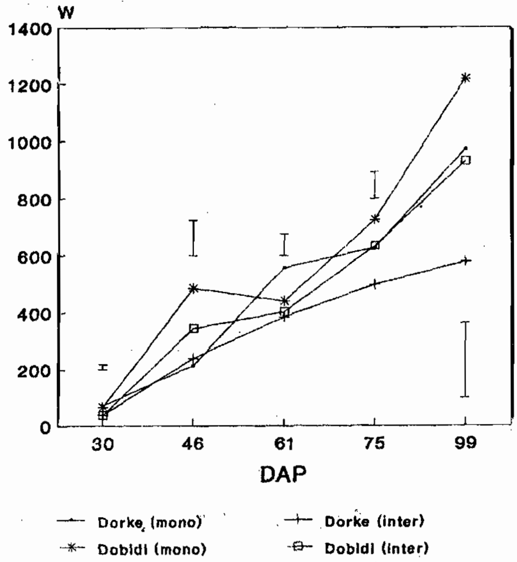

Fig. 3. Dry weight, W, (gm^{-2}) of maize, monocropped (mono) and intercropped (inter), Fumesua, 1986. I = twice the SE for each dry weight harvest date.

attributed mainly to inherent soil variation at this location. The variability could also have been due to the large plot sizes mandatory in trials involving a semi perennial shrub like cassava. The results, therefore, could not show the expected dry weight increases, especially after the peak leaf areas were attained. Total dry weight reached a peak at 71 DAP in 'Dorke' and 80 DAP in 'Dobidi' (Fig. 2), and there was no much decline afterwards.

Differences between the varieties were observed in 1987. For example, a 10 per cent difference in dry weight at 84 DAP between the varieties in 1986 was maintained in 1987, while the 13 per cent leaf area difference at the peak was also maintained in 1987. In both years, the decline in leaf area after the peak was sharper in 'Dorke' because of its earlier maturity than in 'Dobidi'. In 1987 at Kwadaso, the intercrops surprisingly performed better compared to their monocrops (Fig. 4). The irregular rainfall pattern often shown in the minor season in Ghana could have exposed the monocropped plots to harsher conditions of water loss which will probably be minimized on the intercropped plots due to the more vegetative

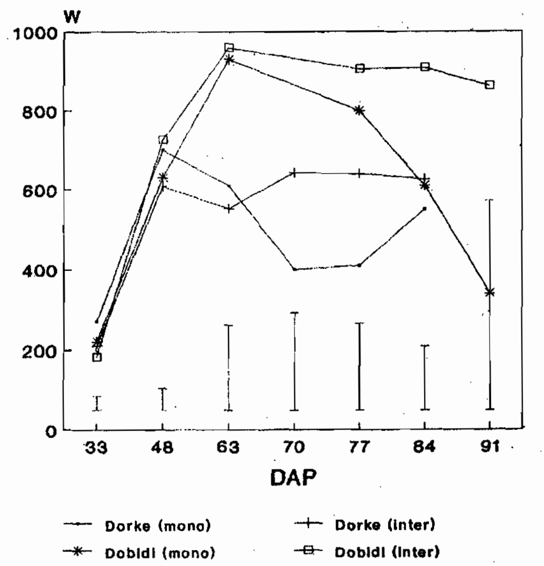

Fig. 4. Dry weight, W, (gm^{-2}) of maize, monocropped (mono) and intercropped (inter), Kwadaso, 1987. I = twice the SE for each dry weight harvest date.

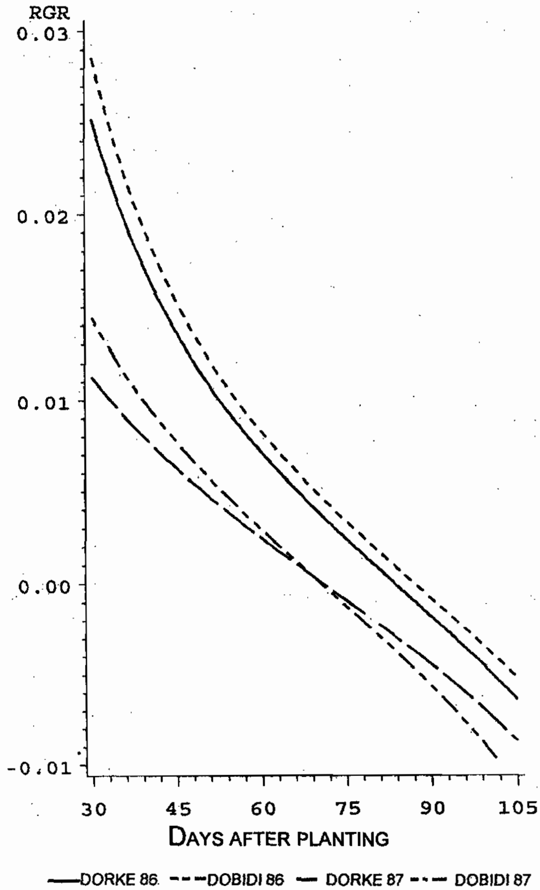

Fig. 5. Progress curves of RGR ($gg^{-1}day^{-1}$) for intercropped maize derived from Fig.1 by differentiation.

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The most important feature of the curves of estimated RGR values (Fig. 5) showed that as the plant matured, growth rates in both maize varieties declined significantly and rapidly to a relatively constant rate from 61 DAP onwards. Work reported by Jollife, Tarimo & Eaton (1990) in Canada has also shown RGR to decrease rapidly between the first and the second harvest and more gradually thereafter. Comparisons indicated that at 46, 61, and 75 DAP, there were no significant differences between growth of the two varieties as estimated by their RGR values in 1986. Similarly, no significant differences were established between the varieties in 1987. However, significant differences were found between 'Dorke' 1986 and 1987, and also between 'Dobidi' 1986 and 1987. Differences were up to 70 per cent by 61 DAP.

Growth analysis as a tool becomes meaningful if growth differences or similarities detected related to economic yield. Results for this work indicated that this situation might not always hold. Grain yields for the two maize varieties (Dorke 1986=2.7 t ha^{-1}; Dorke 1987= 2.1 t/ha^{-1}; Dobidi 1986=3.4 t/ha^{-1}; Dobidi 1987=3.5 t/ha^{-1}) indicated that while growth in Dorke, as estimated by its RGR, closely corresponded with its yield, growth in Dobidi was otherwise. The RGR curves (Fig. 5), however, definitely related to the progress curves of dry weight (Fig. 2) as far as variety or year was concerned. This is to be expected, since RGR is a derivative of dry weight. But the progress curves of RGR did not relate to that of leaf area shown in Fig. 1. Leaf area values were significantly higher in 1987 for the two maize varieties between 40 and 80 DAP.

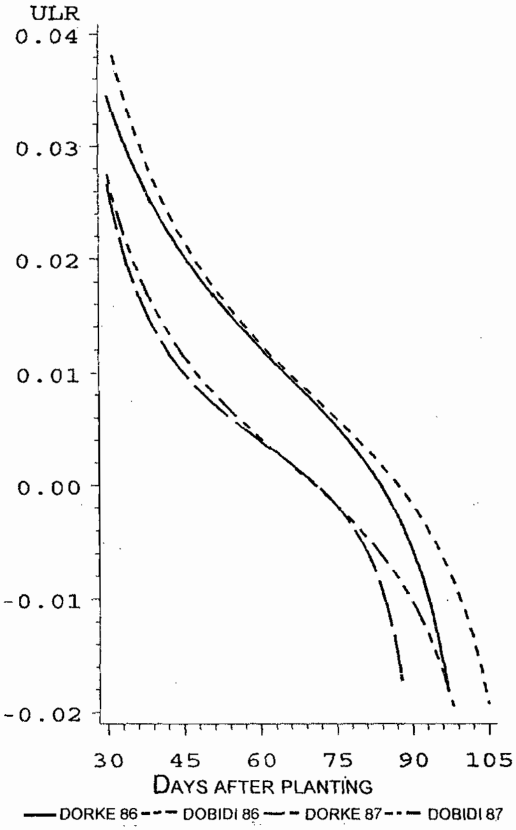

Fig. 6. Progress curves of ULR (gdm^{-2} day^{-1}) for intercropped maize derived from fitted quadratics of Log_eA from Fig. 1 and Log_eW from Fig. 2 by differentiation and division.

Like RGR, ULR also declined with time, but did not show the relatively constant rate shown by the RGR values after 61 days (Fig. 6), but differences between varieties and years were similar to what was derived for RGR. Photosynthetic efficiency of the leaf measures the rate of photosynthesis over the rate of dry matter loss through respiration, and therefore a possible increase in respiratory activity of growing grains could have led to a decrease in net photosynthetic rates. It is also probable that the steep decline was a result of shading, the accelerated leaf abscission, and declining photosynthetic efficiency of the leaves as the plant matured, especially after the peak leaf areas were reached.

The 1986 values for the growth functions RGR and ULR were higher than the 1987 values (Fig. 5 and 6), suggesting an environmental influence on growth rate. In both years, growth rates were negative after the peak dry weights were reached. For example, negative RGR values estimated were at 84 and 88 DAP in 'Dorke' and 'Dobidi', respectively, in 1986. In 1987, they were at 72 and 81 DAP, respectively. Negative values imply the loss of dry matter through leaf abscission instead of accumulation through photosynthesis. The decline in dry weights definitely accounted, at least partially, for the negative rates calculated.

From an initial high at 30 DAP, LAR declined sharply in 'Dorke' and more steadily in 'Dobidi' (Fig. 7) in 1986. Since LAR is the ratio of assimilatory tissue area to total biomass, the

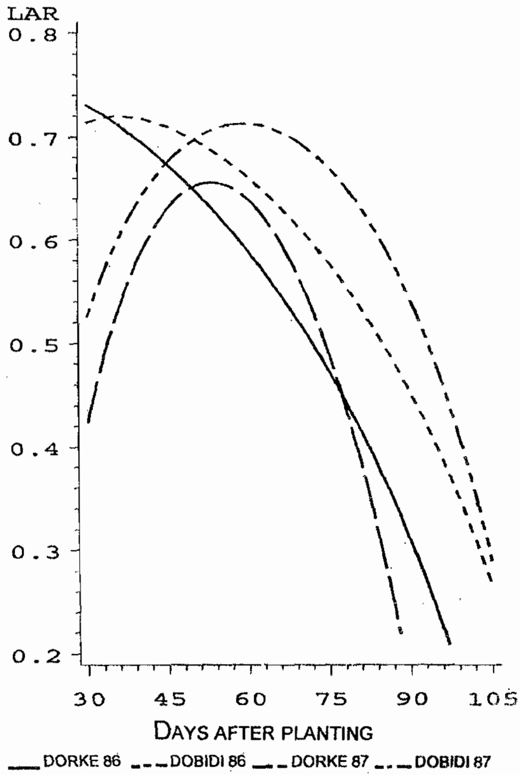

Fig. 7. Progress curves of LAR (dm^{-2} g^{-1}) for intercropped maize derived from fitted quadratics of Log_eA from Fig. 1 and Log_eW from Fig. 2 by division.

decline in LAR indicated that as the season progressed, proportionately less dry matter supported leaf growth or expansion, the rest being used for the growth of other plant parts. With the increasing leaf senescence, therefore, less leaf area was available for photosynthesis as the season progressed (Fig. 1). There were differences also in the LAR values as found in 1986 (Fig. 7), but unlike in 1986, a steady rise in LAR was observed, until 52 and 55 DAP in 'Dorke' and 'Dobidi', respectively, and then there was a decline in the values with time. There was a close similarity in the curves of ULR and LAR in 1986 which was not evident in 1987. If the growth characteristics are mutually dependent, and RGR = ULR × LAR, then both the net photosynthetic efficiency and size of the assimilatory organs had similar influence on RGR in 1986. The equation also suggests that RGR comprised a 'physiological component', ULR, and a 'morphological component', LAR (Friend, 1966). The curves for 1987 suggested a greater influence on RGR by the physiological component.

The comparisons made in this study indicated that for intercropped maize, the magnitude of the shoot dry weight differences between varieties did not relate to grain yield differences. Growth rates did not relate directly to yield either. Important factors that were not estimated but might have had contributory factors appeared to be the duration of the grain-filling period and photosynthetic rates which prevailed during the period. All the growth functions declined significantly and rapidly as the plant matured, suggesting a progressively declining rate of dry matter increase.

It must be emphasized that the use of RGR as a growth measure can be limited because of the following: dry weight determination is based on top growth only, and not on whole plant weight of top and roots; and photosynthesis was estimated to be limited to the green leaf lamina, but it actually extends to the unsheathing green leaf bases. It must also be emphasized that the foregoing analysis glossed over the values if any of the influence of the intercropped cassava on the determinants of growth as estimated. This was purposely done to limit the discussion to the objective of the study.

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