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GROWTH ANALYSIS OF IRRIGATED SORGHUM × SUDANGRASS*

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BULLOCK D. G., DUGARTE-FERNADEZ M., FOWLER J. L. and MOORE K. J. *Growth analysis of irrigated sorghum × sudangrass.* BIOTRONICS **20**, 9–17, 1991. Sorghum × sudangrass hybrids increase forage yield in response to irrigation, but the effect of irrigation on the various crop growth analysis variates, such as crop growth rate (*CGR*), leaf area index (*LAI*), net assimilation rate (*NAR*), and specific leaf area (*SLA*), are unknown. The objective of this New Mexico field study was to determine the effect of irrigation amount on the growth and development of a sorghum × sudangrass hybrid crop. Treatments consisted of amount of water recieved by the crop. We labeled treatments as: wet (69.41 cm total water), normal (58.85 cm total water) and dry (45.60 cm total water). There was a total of ten irrigations and each irrigation was applied when soil moisture tension in the normal plots reached 30 kPa. The wet, normal, and dry levels resulted in maximum plant dry weight (*PDW*) of 1800, 1400 and 1,000 g m^{-2}; maximum leaf dry weight (*LDW*) of 480, 440 and 410 g m^{-2}; and maximum *LAI* of 11.4, 10.2 and 9.5 respectively. Thus, *LAI* and *LDW* did increase with increasing irrigation, but less than *PDW*. The increase in *PDW* with increasing irrigation was preferentially partitioned into grain and stalk portions rather than leaves. Leaf morphology also changed in response to irrigation. With the exception of the last part of the season, there was a general increase in the specific leaf area (*SLA*) with increasing irrigation. Thus, with ample moisture the canopy not only increased slightly in size (*LAI*) and weight (*LDW*), but the leaves were thicker (*SLA*). Changes in the *LAI*, *LDW* and *SLA* were small in comparison to the change in *PDW*. The wet, normal, and dry irrigation levels allowed maximum *CGR* of 324, 271 and 204 g $week^{-1}$ and maximum *NAR* of 49.5, 46.9 and 45.8 g m^{-2} $week^{-1}$. The large increases in *CGR* with increasing moisture were due to increases in both the *LAI* and *NAR*, but the *NAR* was the much larger.

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Key words: *Sorghum bicolor* L.; crop growth rate; net assimilation rate; moisture stress; drought tolerance.

INTRODUCTION

Watson (*8*) described crop growth rate (*CGR*) for a group of plants per unit area land by introducting and relating the concept of *LAI* to *NAR* (*3, 9*) as shown in equations (1) and (2). *LAI* can be expressed as a product of *LDW* and *SLA* (*2,5*), as shown in equations (3) and (4). An additional variate which is often of use is leaf weight ratio (*LWR*) (*5*) equation (5).

$$CGR = LAI \times NAR \qquad (1)$$
$$1/L \times dw/dt = A/L \times (1/A \times dw/dt) \qquad (2)$$
$$LAI = LDW \times SLA \qquad (3)$$
$$SLA = LDW/L \times A/LDW \qquad (4)$$
$$LWR = LDW/PDW \qquad (5)$$

Where *W* is the total plant dry weight, *A* is the total leaf area, *L* is the arbitrary land area, *LDW* is the leaf lamina dry weight, and *PDW* is toral plant dry weight.

The *CGR* is the rate of growth in terms of weight per unit land area time (g m^{-2} t^{-1}). *LAI* is a unitless measure of leaf area per land area (m^2 m^{-2}). *NAR* is the rate of increase in whole-plant dry weight per unit leaf area time (g m^{-2} t^{-1}). *SLA* is a measure of leaf thickness (m^2 g^{-1}). And *LWR*, another unitless measure (g g^{-1}). quantifies the partitioning of dry weight between the leaf and non-leaf components of the crop.

The use of *CGR, LAI, NAR* and related variates to quantify and describe crop growth is commonly referred to as plant growth analysis (*4*). Plant growth analysis is an excellent tool if one is interested in changes in leaf morphology and the net partitioning of photosynthates between leaf and non-leaf sections of the plant as well as the relative contributions of photosynthetic area (*LAI*) and net photosynthetic rate (*NAR*) to changes in biomass production and crop growth.

Forage sorghum (*Sorghum bicolor* [L.] Moench) × sudangrass (*Sorghum bicolor* [L.] Moench) hybrids are grown widely for summer forage production. Sorghum species are relatively drought and heat tolerant; especially compared to maize (*Zea mays* L.) (*1*). However, severe water stress during critical reproductive growth stage will decrease yield of sorghum species (*7*). Therefore, in hot arid regions of the Southwestern U. S. forage sorghum × sudangrass hybrids are irrigated. In arid regions, irrigation increases forage sorghum × sudangrass hybrid forage yield, but the simultaneous relative effect of irrigation on *LAI* and *NAR* under hot arid conditions has not been reported.

The objective of this field study was to determine the effect of soil moisture level on the growth and development of a sorghum × sudangrass hybrid crop.

MATERIALS AND METHODS

This field experiment was conducted at the New Mexico State University, Leyendecker Plant Science Research Center near Las Cruces, New Mexico during the 1989 growing season. The soil type is a Gelendale (mixed calcareous, thermic family of Typic Torrifluvent) clay loam. The forage sorghum × sudangrass hydrid 'Sordan' was planted into dry soil on 10 May 1989 at approximately 150000 seeds ha^{-1}. New Mexico is in a desert region and sorghum × sudangrass production is dependent upon irrigation. The contribution by natural rainfall is minimal and thus the environmental effect on soil moisture level is very small. In desert regions soil moisture level is determined mainly by irrigation management rather than the environment. A sprinkler irrigation system was used to apply 7.62 cm of warter for stand establishment. We labeled treatments as : wet (69.41 cm total water), normal (58.85 cm total water) and dry (45.60 cm total water). In each treatment total water consisted of irrigation water and 7.95 cm of natural rainfall. A tensiometer measured soil moisture tension of 30 kPa at 30 cm is the normal recommended point for sorghum × sudangrass irrigation in New Mexico. There was a total of ten irrigations and each irrigation was applied when soil moisture tension in the normal plots reached 30 kPa as measured by tensiometers at a depth of 30 cm. The amount of water applied by treatment by date (*DAP*) plus the precipitation during the growing season are given in Table 1. Row width was 30.5 cm. Each plot was 183 cm (6 rows) wide and 27.4 m long. Irrigation treatments were applied via a drip irrigation system. Drip lines with emitters spaced at 20 cm were laid on the soil surface between two rows on in alternate row pattern at 61 cm intervals, so that three drop lines irrigated each six-row plot. The three trickle lines in each plot were connected to a common header line through a solenoid valve, flow control valve, and water meter to an irrigation well adjacent to the plot area.

Table 1. Irrigation dates and amounts, rainfall, and total water applied per treatment.

Water Source	Date (*DAP*)	Treatments Dry	Normal (cm)	Wet
Establishment irrigation	0–10	7.62	7.62	7.62
Seasonal irrigation	28	3.99	4.80	5.89
	40	2.16	2.41	3.00
	47	3.28	5.59	8.05
	54	5.51	9.32	12.90
	61	3.61	5.61	6.99
	69	2.08	2.67	3.40
	76	3.05	5.11	5.18
	81	3.00	2.79	2.41
	89	3.35	4.98	6.12
Total irrigation		37.65	50.90	61.46
Natural rainfall		7.95	7.95	7.95
Total water		45.60	58.85	69.41

The amount of water was controlled and measured for each plot.

The experimental design was a randomized complete block with nine replications. Ten harvest plots of one row by 1 m in length were split over each plot in one of the four central rows and randomly designated as harvest weeks 1 through 10. Each subplot was bordered on each side by at least 1 m of plants in adjacent rows and on each end. Weekly harvests were begun on 12 June 33 *DAP*. All plants within the 1-m subplots were harvested at ground level and separated into leaves, sheath, stem and panicle (when present). Leaf area was measured with a LICOR model LI-3000 leaf area meter and a model LI-3050A conveyor belt accessary (LICOR, Inc., Lincoln, Nebraska). Following fractionation, the verious plant parts were dried in a forced draft oven at 65℃ to a constant weight.

All data were transformed to the natural log form prior to curve fitting to overcome heterogeneity of error (*4*). As described by Hunt (*4*), a quadratic function was fit to *LAI* and *LDW* data of each plot and the logistic function was fitted to the *PDW* of each plot. The *LAI, LDW,* and *PDW* functions from each plot were used to calculate the functions describing *CGR, LAI, NAR, SLA* and *LWR* for each plot as described by Hunt (*4*). Statistical analysis was conducted with the PROC NLIN and GLM procedures of SAS (*6*).

RESULTS AND DISCUSSION

Analysis of variance for *PDW, LAI,* and *LDW* indicated that irrigation and harvest time had large significant affects on the measured parameters. The asymptotic nonlinear logistic function for *PDW* and the quadratic function for *LDW* and *LAI* were well suited to this data in both an empirical and mechanistic sense. In an empirical sense the functions describe the data well (Figs. 1, 2 and 3). The lowest R^2 value was 0.95 (Fig. 2). From a mechanistic sense the functions were also reasonable. It is accepted that the *PDW* of sorghum species reaches a plateau while the *LAI* and *LDW* reach relative maximum then decline due to lower leaf senescene.

Increasing irrigation resulted in an increase in *PDW* (Fig. 1). Note that the curves in Fig. 1 are fitted to transformed data in order to overcome heterogeneity of error. When transformed back into original units (g m^{-2}) the maximum values of *PDW* for the wet, normal and dry irrigation treatments were approximately 1800, 1400 and 1000 g m^{-2} respectively. Thus relieving moisture stress increased *PDW* by approximately 80%.

The *LDW* also increased with irrigation, but the magnitude of the increase was much smaller. When transformed back the wet, normal and dry irrigation treatments produced *LDW* of approximately 480, 440 and 410 g m^{-2} respectively (Fig. 2). Thus, relieving moisture stress increased *LDW* by 17% which was far smaller than the increase noted for *PDW*.

With the exception of slight dip in the normal irrigation treatment between harvests 9 and 10, the *LAI* curves (Fig. 3) were similar to the *LDW* curves. When transformed back the *LAI* for the wet, normal and dry irrigation levels

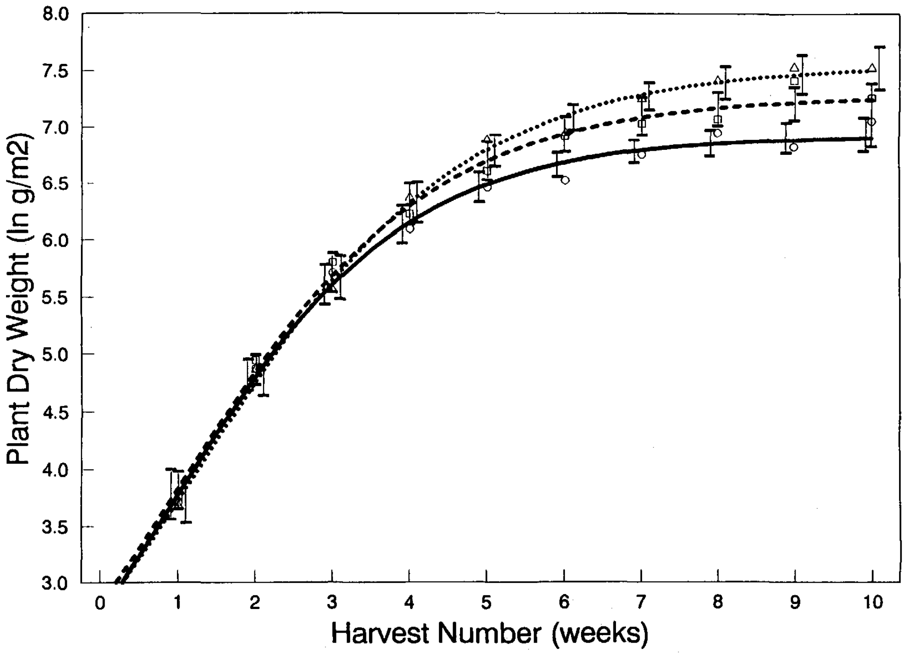

Fig. 1. Plant dry weight *(PDW)* curves depicting primary data and fitted curves with 95 per cent confidence limits for the sorghum × sudangrass hybrid 'Sudan' grown with three soil moisture levels: wet (△ ······), normal (□ ----), dry (○ ——).

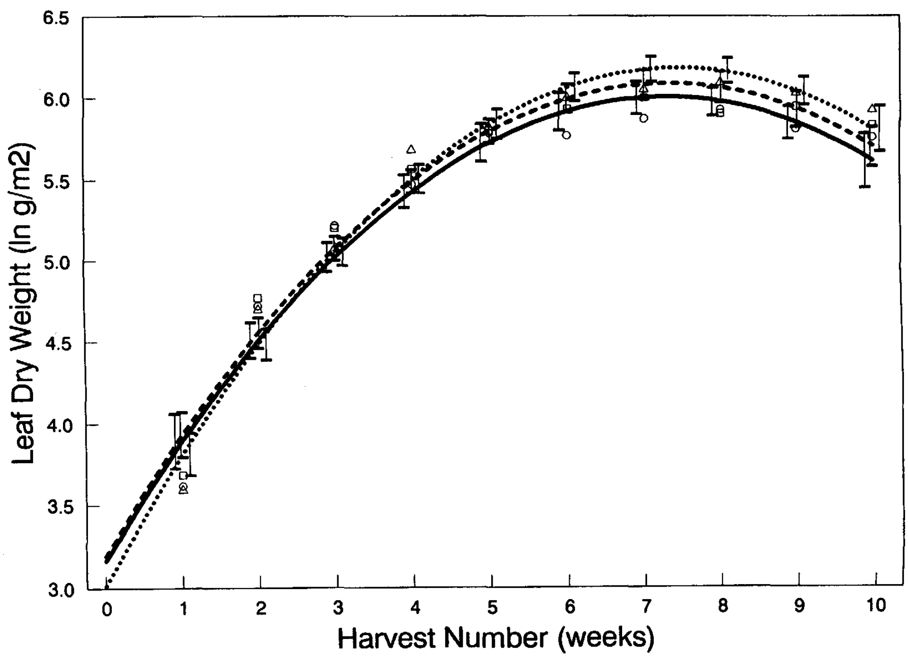

Fig. 2. Leaf dry weight *(LDW)* curves depicting primary data and fitted curves with 95 per cent confidence limits for the sorghum × sudangrass hybrid 'Sudan' grown with three soil moisture levels: wet (△ ······), normal (□ ----), dry (○ ——).

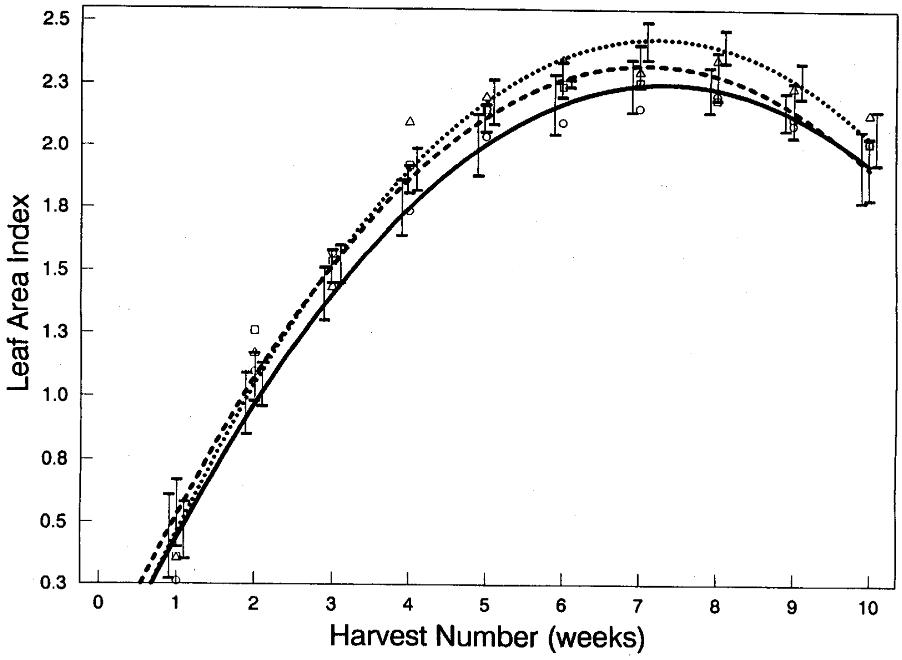

Fig. 3. Leaf area index (*LAI*) curves depicting primary data and fitted curves with 95 per cent confidence limits for the sorghum × sudangrass hybrid 'Sudan' grown with three soil moisture levels: wet (△ ······), normal (□ ----), dry (○ ——).

showed a maximum *LAI* of about 11.4, 10.2 and 9.5 respectively. This was a 20% increase in *LAI* with the relief of moisture stress.

Figures 1, 2 and 3 indicate that both the *LAI* and *LDW* did increase with increasing irrigation, but not nearly to the extent that *PDW* did. This relationship is clear in the *LWR* curves (Fig. 4). The *LWR* curves are similar until the period of weeks three to four after which increasing irrigation results in a decrease in the *LWR*. Thus, the increase in dry weight with increasing irrigation was preferentially partitioned into grain and stalk portions of the plant rather than the leaves.

Leaf morphology also changed in response to irrigation. In this experiment, with the exception of the last part of the season, there was a general increase in the *SLA* with increasing irrigation (Fig. 5). Thus, with ample moisture the canopy not increased slightly in size (*LAI*) and weight (*LDW*), but the leaves themselves were thicker (*SLA*). However, note that the changes in the canopy and leaves are small in comparison to the change in *PDW*.

The substantial increase in *PDW* with increasing irrigation was reflected in a large increase in the *CGR* as well as a delay in the time of the maximum *CGR* (Fig. 6). The wet, normal and dry irrigation levels produced maximum *CGR*'s of approximately 325, 270 and 205 g m^{-2} $week^{-1}$ at the 4.7, 4.2 and 3.8 weeks respectively. Thus, by relieving moisture stress *CGR* was increased approximately 37%.

CGR is the product of *NAR* and *LAI* (Eq. 1). For these data the *NAR* curves

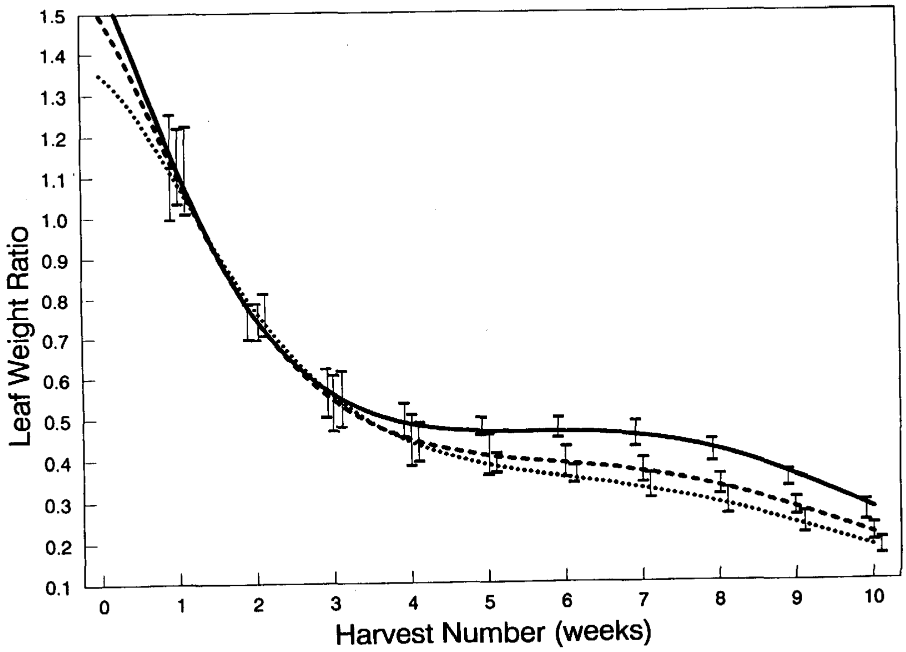

Fig. 4. Leaf weight ratio *(LWR)* curves with 95 per cent confidence limits for the sorghum × sudangrass hybrid 'Sudan' grown with three soil moisture levels: wet (······), normal (----), dry (——).

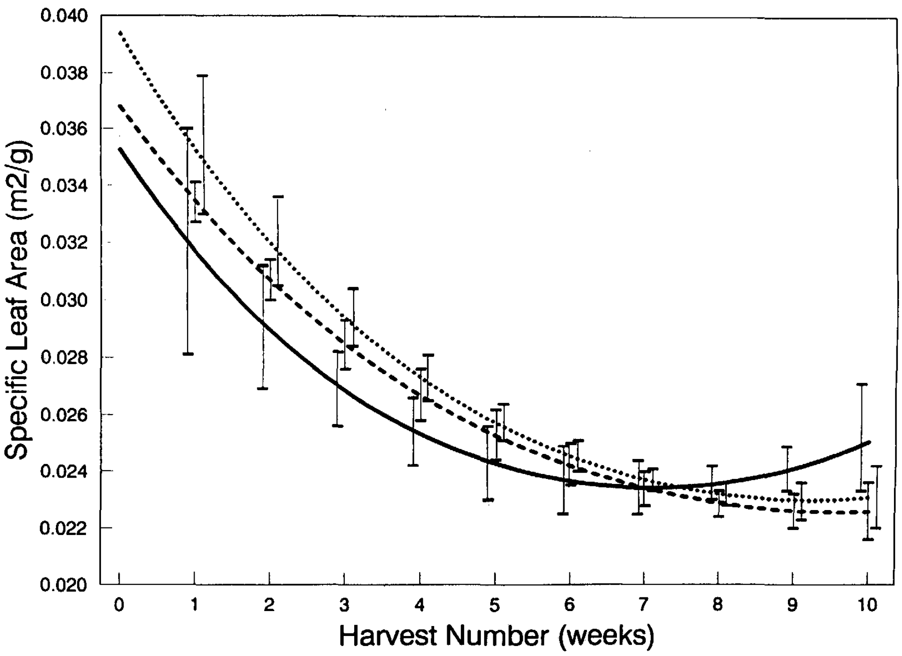

Fig. 5. Specific leaf area *(SLA)* curves with 95 per cent confidence limits for the sorghum × sudangrass hybrid 'Sudan' grown with three soil moisture levels: wet (······), normal (----), dry (——).

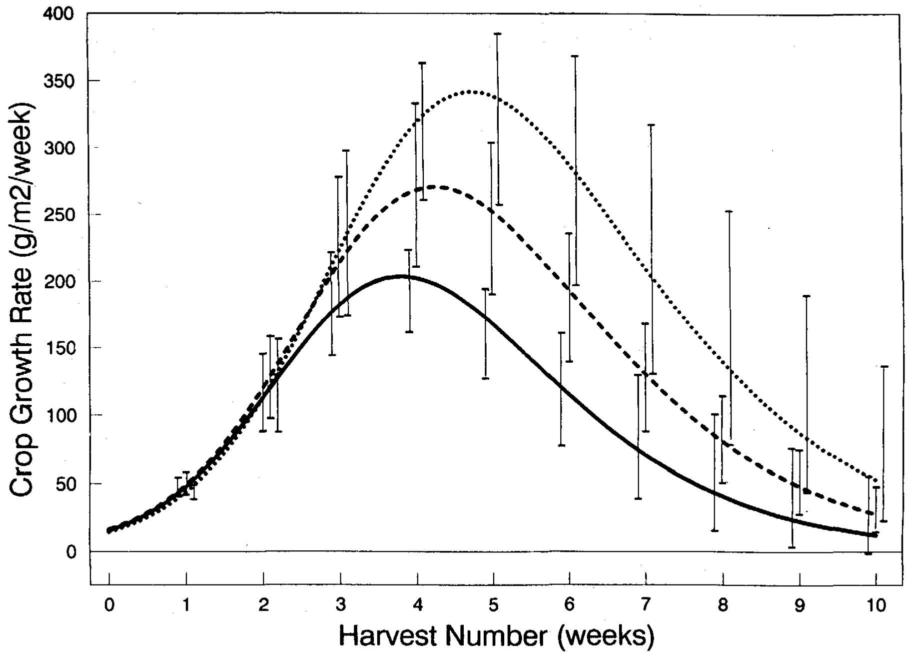

Fig. 6. Crop growth rate (*CGR*) curves with 95 per cent confidence limits for the sorghum × sudangrass hybrid 'Sudan' grown with three soil moisture levels: wet (······), normal (----) , dry (——).

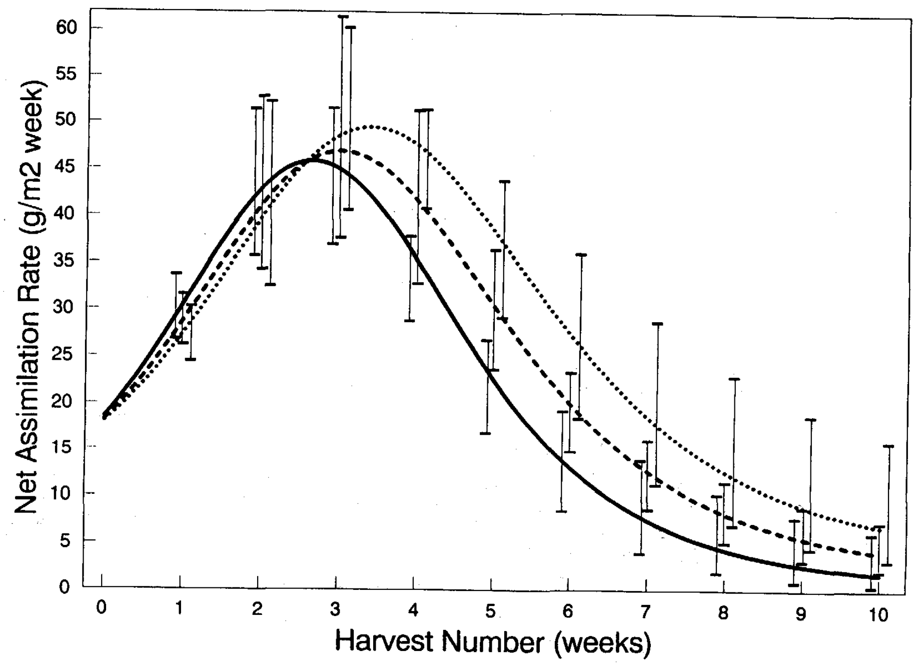

Fig. 7. Net assimilation rate (*NAR*) curves with 95 per cent confidence limits for the sorghum × sudangrass hybrid 'Sudan' grown with three soil moisture levels: wet (······), normal (----), dry (——).

(Fig. 7) are very similar to the *CGR* curves (Fig. 6). The *NAR* also showed an increase in magnitude and time of occurrence of its maximum value. The wet, normal and dry irrigation levels produced maximum *NAR* values of approximately 50, 47 and 46 g m^{-2} $week^{-1}$ at 3.4, 3.1 and 2.6 weeks respectively. By harvest week 6 the wet, normal, and dry irrigation levels produced *NAR* values of approximately 18.5, 11.3 and 10.0 respectively. This indicated that for this hybrid the large increases in *CGR* with increasing moisture were due to increases in both the *LAI* and *NAR*, but the *NAR* was the largest contributor.

This hybrid demonstrates why sorghum species are so widely grown in the arid regions of the world. The crop developed a relatively large *LAI* even under the dry moisture conditions. That is an essential characteristic if a crop is to take advantage of improved moisture conditions later in the season. For example, maize, a species which is less tolerant of drought, shows as much as a 50% reduction in *LAI* if exposed to severe early season drought. Thus, even if conditions improve and moisture is increased maize *CGR* and yield can not respond and take advantage of the improved conditions because of reduced photosynthetic area.

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