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Radiation-Use Efficiency and Grain Yield of Maize Competing with Johnsongrass

James R. Kiniry*

ABSTRACT

Accurate simulation of the impact of weeds on crops requires adequate quantification of weed effects on crop biomass and on the partitioning of crop biomass into grain. The first objective of this study was to determine whether radiation-use efficiency (RUE) values of maize (*Zea mays* L.) and johnsongrass [*Sorghum halepense* (L.) Pers.] grown in monoculture could be applied to these species grown in mixed plantings. The second objective was to investigate how maize yield and harvest index (HI) respond to johnsongrass competition. Monoculture plots of maize and johnsongrass and plots with the two species competing were established on Houston black clay (fine, montmorillonitic, thermic Udic Pellustert) in the field at Temple, TX, in 1991 and 1992. Sequential measurements of light interception (IPAR) and of biomass were used to calculate values for RUE prior to anthesis. Yield and HI of maize were measured after physiological maturity. Johnsongrass reduced grain yield of maize by 5% in 1991 and by 33 to 49% in 1992. The greater competition in the second year also reduced maize HI from 0.55 in the first year to 0.43 in the second. Values of RUE of maize and johnsongrass growing together were similar to weighted means of monoculture RUE values. The weights were the relative fraction of each species in the mixture. The measured values of maize–johnsongrass mixtures differed from weighted means by 3 to 11% in both years.

COMPETITION between two plant species has application in modeling the impact of weeds on crops, interpreting intercropping response, and assessing the impact of a woody species on a competing grass. Given the within-field variability in plant spacings and in leaf orientations, models can easily become so complex that they outpace available input data. An approach recently implemented in the ALMANAC model (Kiniry et al., 1992b) is to simulate light interception by each species and simulate biomass increase based on the amount of plant dry mass produced per unit intercepted solar radiation or *radiation-use efficiency* (RUE) of each. This model partitions light interception according to plant height, light extinction coefficient, and leaf area index of each species using the system of Spitters and Aerts (1983).

Radiation-use efficiency is easily measured in field experiments and easily applied in plant growth models. Possible problems with RUE determination were recently discussed by Demetriades-Shah et al. (1992). The stability of RUE across environments has been of interest since its application in CORNF (Stapper and Arkin, 1980), CERES-Maize (Jones and Kiniry, 1986), SORKAM (Rosenthal et al., 1989), and EPIC (Williams et al., 1989). Recent studies have shown RUE is negatively correlated with vapor pressure deficit (VPD) for some species (Stockle and Kiniry, 1990; Manrique et al., 1991; and Kiniry et al., 1992a). Such a response, once quantified for a species, can be simulated by estimating the VPD from daily maximum and minimum temperatures (Stockle and Kiniry, 1990).

The ALMANAC model simulates total biomass assuming there is no allelopathy. Thus, in the absence of nutrient or drought stress, the reduction in growth of maize infested with johnsongrass is assumed to be proportional to the reduction in intercepted solar radiation per maize plant. It follows that RUE values of the two species growing together should equal the weighted mean of RUE values of the two species. Weights for this mean are based on the relative biomass production by each species. The assumption of no allelopathy has yet to be tested with field data for maize and johnsongrass.

Once the biomass of each of the two species is accurately simulated, competition models need to predict grain yield. Again, ALMANAC provides a readily implemented system, using the modified harvest index (HI) approach of the EPIC model (Williams et al., 1989). Deficiency of a required resource such as N, P, or water can limit crop dry matter increase and thus reduce grain yield based on HI. However, the effect of johnsongrass on maize HI has not been quantified in field experiments.

My objectives in the present study were twofold. First, I investigated how closely the RUE of maize and johnsongrass growing together corresponded to the weighted mean of RUE values for these species in monoculture. This was designed to evaluate how closely the combined biomass of the two species could be simulated with RUE values from monoculture data. Second, I measured the response of maize grain yield and maize HI to severe johnsongrass infestations. With these data, I could examine how maize HI responded when yield was reduced by johnsongrass.

MATERIALS AND METHODS

Maize hybrid Deltapine G4673B was planted at 48 000 plants ha^{-1} in 0.69-m rows on 19 Mar. 1991 on Houston Black clay (fine, montmorillonitic, thermic Udic Pellustert) at the Grassland, Soil and Water Research Laboratory near Temple, TX. The field was severely infested with johnsongrass. After seedling emergence, plots were selected to be either maize alone, johnsongrass alone, or maize competing with johnsongrass. Plants were removed by hoeing accordingly. There were three replications of a randomized complete block design, with each plot being 10 m long and 8.3 m wide (12 maize rows). In both years, prior to planting, plots were fertilized with 30 kg N ha^{-1} and 77 kg P ha^{-1} as 18-46-0 N-P-K and with 112 kg N ha^{-1} as urea.

On 20 Mar. 1992, maize hybrid B73 × Mo17 was planted in the same field at 50 000 plants ha^{-1} in 0.69-m rows. Again, there were three replications of a randomized complete block design. Plots were established as before, with each plot being 13.4 m long and 4.14 m wide (six maize rows). While johnsongrass was removed from maize monoculture plots at the initiation of measurements, wet weather prevented adequate hoeing of these plots during the season so that by anthesis some johnsongrass infested these plots. Such plots were treated as a maize treatment with a lower infestation of johnsongrass than the other maize–johnsongrass plots. Thus, in 1992 there were no plots of maize without johnsongrass in the experiment; however, con-

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Abbreviations: HI, harvest index; IPAR, intercepted photosynthetically active radiation; PAR, photosynthetically active radiation; RUE, radiation-use efficiency; VPD, vapor pressure deficit.

Table 1. Monthly meteorological values during two growing seasons at Temple, TX.

Month	Rainfall		Solar radiation		Temperature			
					1991		1992	
	1991	1992	1991	1992	min	max	min	max
	mm		MJ m^{-2} d^{-1}		°C			
March	34	105	15.6	16.1	10	23	10	22
April	65	52	16.8	19.2	16	27	14	25
May	193	202	18.9	17.6	19	29	17	28
June	116	119	22.9	24.2	21	32	21	33
July	49	46	24.7	25.1	22	35	21	35
Totals	457	524	–	–	–	–	–	–
Means	–	–	19.8	20.4	18	29	17	29

Table 2. Maize grain yield (155 g kg^{-1} moisture) and harvest index, with and without competing johnsongrass (JG).

Year	Yield		Harvest index	
	Without JG	With JG	Without JG	With JG
	kg ha^{-1}			
1991	9181 ± 1927†	8716 ± 1794‡ (0.95)§	0.50 ± 0.08	0.54 ± 0.01
1992	6657 ± 3517	4459 ± 1821¶ (0.67)	0.55 ± 0.04	0.44 ± 0.05
1992	–	3391 ± 879# (0.51)	0.55 ± 0.04	0.43 ± 0.06

† Mean ± SD.
‡ 42% of final biomass at anthesis was johnsongrass.
§ Fraction of control yield in parentheses.
¶ Low population of johnsongrass, 43% of final biomass at anthesis was johnsongrass.
# High population of johnsongrass, 53% of final biomass at anthesis was johnsongrass.

trol values for RUE were obtained from a nearby field of B73 × Mo17 with the same population density, fertilized the same, and on the same type soil as the experimental planting. Likewise, control grain yield in 1992 was measured in plots adjacent to the main experiment on an area with total weed suppression by an application of Beacon[1] (3-[4,6-bis(difluoromethoxy)-pyrimidin-2-yl]-1(2-methoxycarbonyl phenylsulfonyl)urea) at 0.040 kg a.i. ha^{-1}.

On each date of destructive sampling, three random samples per plot were collected in 1991 and one random sample per plot in 1992. Each sample consisted of the aboveground biomass from an area 0.5 m down a row and 0.69 m wide, centered on a maize row if maize was in the plot. Samples were dried for at least 3 d at 65°C in a forced-air drier and weighed. Destructive sampling dates in 1991 were 30 April, 16 May, and 3 June. Destructive sampling dates in 1992 were 21 April, 4 May, 27 May, and 3 June. All these dates preceded anthesis of the two species.

To estimate photosynthetically active radiation (PAR) intercepted by plant canopies, fraction of PAR intercepted was periodically measured and daily estimates for the fractions were determined by interpolation. Fraction of PAR intercepted was measured by rapidly taking 10 measurements above the canopy, 10 below the canopy, and 10 more above the canopy with a 0.80-m-long Decagon Ceptometer (Decagon Devices, Pullman, WA) between 1030 h and 1430 h. The mean of each set of 10 readings was recorded and there were three such sets of measurements taken in each plot in rapid succession each date. The Ceptometer was moved diagonally across the rows as the below-canopy measurements were taken and PAR readings were taken in areas not previously harvested for biomass. Intercepted PAR was measured on 1 May, 9 May, 13 May, and 20 June, 1991, and 21 Apr., 27 Apr., 28 Apr., 21 May, and 3 June 1992. Daily values for incoming PAR were calculated from values of total solar radiation measured near the site, assuming that 45% of the total solar radiation was PAR (Monteith, 1965; Meek et al., 1984).

Radiation-use efficiency was calculated from the slope of the regression line for dry matter as a function of intercepted PAR. This RUE for the two-species mixture was compared with the weighted mean of the two individual species' values for RUE, the weights based on the relative biomass contributions to the total in the final biomass harvest (just prior to anthesis). By so weighting RUE values, measured total biomass growth of the two species was partitioned between maize and johnsongrass. Such a comparison was a test of the effectiveness of the RUE approach in simulating biomass of two competing species.

Maize grain yield in 1991 was based on three samples of 0.5 m of row per plot. Total aboveground dry matter and dry grain mass were measured for each sample after drying for at least 3 d at 65°C in a forced-air oven. In 1992, there were five samples of 1.0 m of row per plot, each treated as in 1991. Value of HI was calculated as the dry grain mass divided by the total aboveground plant dry mass. Mean grain yields and mean values for HI were compared with a *t*-test at the 95% confidence level.

RESULTS AND DISCUSSION

The early spring in 1992 was wetter than in 1991 (Table 1). Rainfall in the fallow period from August 1990 through February 1991 was 579 mm, whereas for the same period ending in 1992 it was 953 mm. Excessive moisture during March in 1992 may have caused increased denitrification or leaching of N.

Mean control (weed-free) maize yield in 1992 was 73% of the mean control yield in 1991 (Table 2). This difference was not specific to this field, as a nearby experiment with B73 × Mo17 at 48 000 plants ha^{-1} yielded 81% as much in 1992 as in 1991.

Johnsongrass decreased maize yield more in 1992 than in 1991. In 1991, johnsongrass comprised 42% of the combined biomass for the harvest near anthesis. Mean maize yield was reduced 5% relative to the control. In 1992, johnsongrass comprised 43% of the biomass for the harvest

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[1] Mention of a proprietary name is for readers' information only, and is not an endorsement by the USDA, nor does it imply its approval to the exclusion of other products that may also be suitable.

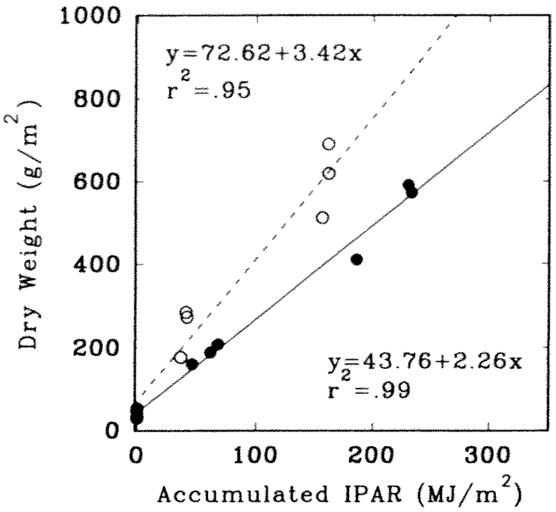

Fig. 1. In 1991, dry biomass of maize alone (open symbols and dotted line) and johnsongrass alone (closed symbols and solid line) as a function of accumulated intercepted photosynthetically active radiation (IPAR). Both biomass and IPAR are on a unit ground-area basis.

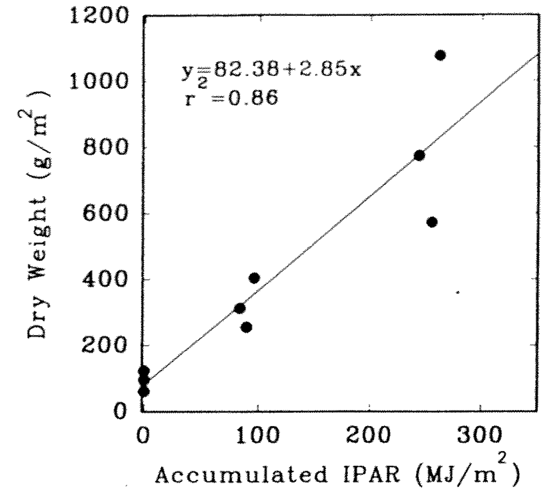

Fig. 2. In 1991, combined dry biomass of maize and johnsongrass growing together, as a function of accumulated IPAR. Both biomass and IPAR are on a unit ground-area basis.

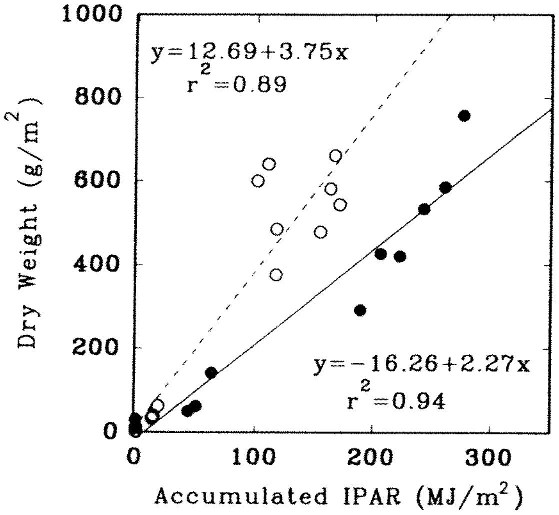

Fig. 3. In 1992, dry biomass of maize alone (open symbols and dotted line) and johnsongrass alone (closed symbols and solid line) as a function of accumulated IPAR. Both biomass and IPAR are on a unit ground-area basis.

near anthesis, but maize grain yield was reduced 33%. When johnsongrass comprised 53% of the biomass, the maize yield was reduced 49%. Thus, it appeared that in the year with lower control yields, there was competition for a limited resource such as N.

Harvest index of maize responded differently to competition each year. In 1991, mean HI was 0.04 greater when johnsongrass was present. These means were not significantly different when tested with a *t*-test (95% confidence level). In 1992, mean maize HI with johnsongrass present was 0.12 less than for maize alone. These means were significantly different when tested with a *t*-test at the 95% confidence level. Thus, competition with johnsongrass in the lower-yielding year, when a resource was limited, caused maize to be less effective in partitioning biomass to grain.

In 1991, RUE of maize was 51% greater than that of johnsongrass when the species were in monoculture (Fig. 1). When grown as a mixture, combined RUE (Fig. 2) was intermediate to the RUE values for the two species in monoculture. Using relative fractions of biomass of each species in the final harvest of competition plots (near anthesis) and the RUE of each species in monoculture, the weighted mean RUE was 2.93 g MJ^{-1}. This value was 3% greater than the measured value of 2.85 for competition plots.

The 1992 data were similar to 1991 data, with maize in monoculture having greater RUE than johnsongrass and with RUE of the mixture being intermediate to monoculture values. Maize RUE was 65% greater than that of johnsongrass, with each in monoculture (Fig. 3). The weighted mean RUE for 43% johnsongrass and 57% maize was 3.11 g MJ^{-1}. This was 11% greater than the measured RUE of 2.81 for low population density of johnsongrass growing with maize (Fig. 4). For 53% johnsongrass and 47% maize, the weighted mean RUE was 2.97. This was 2% less than the measured RUE of 3.04 for high population density johnsongrass with maize.

The two equations, for 43 and for 53% johnsongrass, were not significantly different at the 95% confidence level. This was determined by using an *F*-test to compare the error sum of squares (SSE) of a full model (with two separate regression lines) with the SSE of a reduced model (with only one regression line) (Neter and Wasserman, 1974).

After pooling the two data sets of johnsongrass with maize in 1992, the equation was similar to the expected value based on the weighted mean of RUE values for each species in monoculture. Slope of the fitted regression was 2.95 and the r^2 was 0.95. Using the mean weight value for johnsongrass of 0.48, the expected RUE of the mixture was 3.04. Thus, the expected RUE of the two species together was 3% greater than the measured, just as in 1991.

In conclusion, the RUE of maize and johnsongrass growing together was adequately described with individual species' RUE values, weighted by relative fraction of each

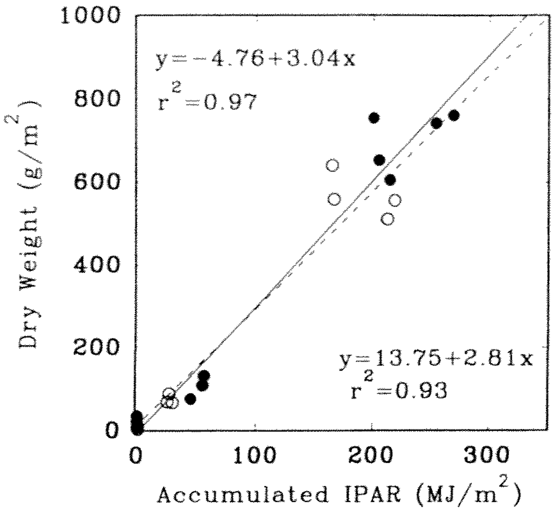

Fig. 4. In 1992, combined dry biomass of maize and a high population density of johnsongrass growing together (open symbols and dotted line) and of maize and a low population density of johnsongrass growing together (closed symbols and solid line), as a function of accumulated IPAR. Both biomass and IPAR are on a unit ground-area basis.

species in the mixture. Measured values of such mixtures differed from such weighted means by 3 to 11% in both years. There apparently was no allelopathy affecting biomass production in this experiment.

The weighting, based on measured final biomass of each species, quantified how much of total biomass growth of the mixture was maize growth and how much was johnsongrass growth. Accurate measurement of light intercepted by each species in the mixture was impossible, due to the intermingling of leaves of both species in the canopy.

While these results are not a test of the light partitioning in the ALMANAC model, these results do provide support for the use of RUE values from monoculture experiments in describing johnsongrass-maize competition. Similar research with other weed-crop combinations is needed to test the generality of these findings.

The HI responses raise questions needing additional research. Johnsongrass caused greater decreases in maize yield and in HI in the second, lower-yielding year. Maize HI was not significantly changed by johnsongrass competition the first year. Thus, modeling impacts of johnsongrass infestation on maize yield probably requires dynamic simulation of nutrient and water use by the crop and the weed, as in ALMANAC. Field experiments with maize and johnsongrass competing, in variable soil moisture treatments and with variable soil fertility levels, would be valuable to further define interactions between these species.

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