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Estimates of Grain Yield Losses Caused in Sorghum (*Sorghum bicolor* L. Moench) by *Striga asiatica* (L.) Kuntze Obtained Using the Regression Approach

M.J. VASUDEVA RAO, V.L. CHIDLEY* and L.R. HOUSE**

International Crops Research Institute for the Semi-Arid Tropics, Patancheru, 502 324, A.P. (India)

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ABSTRACT

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Regression approach was used to predict sorghum grain yield losses from *Striga asiatica* (L.) Kuntze in the susceptible sorghum hybrid cultivar, CSH 1, in India. Four hundred and eighty eight pairs of grain yield and *Striga* counts data obtained from 10 checkerboard trials were used in the regression analysis. Experiments were conducted at 6 locations in India and in some locations over 3 years. The R^2 value of the best-fitted joint regression equation was 0.787. Mean grain yield loss estimates ranged from 9.2 to 27.6% of the potential yield between locations with an average loss of 17.5% in the rainy season. In the post-rainy season the average loss was 25.2% with a range of 20.1-39.6% across years. Potential loss estimates indicated the possibility of up to 98.6% crop loss at some locations in some years. Assuming only 10% of the hybrid sorghum crop area to be affected by the *Striga* infestation levels realized in these trials, it was predicted that, in India, about 53 000 t of sorghum grain worth about U.S. $4.9 million (approximately 67 million Indian rupees) is being lost every year.

INTRODUCTION

Striga asiatica (L.) Kuntze, a phanerogamic root parasite of several cereals, is a significant yield reducer of its host crops. Crop loss estimates obtained using appropriate statistical methodology are very few and inadequate in accurately predicting the produce lost because of this parasite. Loss estimates of

*Present address: Department of Agricultural Botany, University of Reading, Reading, Gt. Britain.
**Present address: SADCC/ICRISAT Regional Sorghum and Millet Improvement Program, P.B. 776, Bulawayo, Zimbabwe.

sorghum yields from *Striga* face 3 major difficulties: (i) it is difficult to create control (uninfested) vs. infested contrasts; (ii) the number of *Striga* plants that emerge above ground represent an unknown and often variable percentage of the total number of *Striga* plants that actually parasitize the host's roots; (iii) the crop loss estimates are influenced by the intervening soil factors, the major ones being soil fertility and moisture. This study is the first report on the use of regression approach to obtain sorghum yield loss estimates from *Striga asiatica* utilizing the data on naturally-occurring variability in *Striga* infestation in a single sorghum cultivar.

MATERIALS AND METHODS

Emerged *Striga* counts and grain yields from 488 plots of CSH 1 (Coordinated Sorghum Hybrid 1), were collected in the advanced *Striga* resistance trials conducted in "*Striga*-sick" fields which had a good history of *Striga* occurrence every year. Trials were conducted at 6 locations in India. At Akola and Bijapur the trials were carried out over 3 years. In these trials a checkerboard layout (Vasudeva Rao, 1987) was used. In this layout, test entry plots (of different resistant test entries) are interspersed uniformly among check entry plots (of the same susceptible check entry) in such a way that each test entry plot is surrounded on all its 4 sides by check entry plots. This layout enables measurement of the intensity of *Striga* infestation to be made at regular points in the experimental area, thus generating information on variability of *Striga* intensities. Each plot had 5 rows of which the central 3 rows were used as the net plot to record observations on *Striga* counts and grain yield. Net plot sizes varied from 3 to 9 m^2 between locations. Emerged *Striga* were counted 3 times in the season between flowering of sorghum and its harvest in order to include the *Striga* plants that emerged later in the season. The maximum of the 3 counts was used as the final count. Grain yield was measured as the weight of the sun-dried threshed grain from the net plot.

To obtain crop loss estimates at the national level, statewise figures for area and production of sorghum were used. However, as *Striga* is more serious on hybrid sorghums, the loss estimates were restricted only to that part of the sorghum production contributed by the hybrids. Statistics on statewise area and production of sorghum and the statewise coverage by hybrids were obtained from the publications of Ministry of Agriculture and Rural Reconstruction, Government of India, through the kind courtesy of the Project Coordinator (Sorghum), All India Sorghum Improvement Project, Hyderabad (Tables 1 and 4). Statistical data for the 3 years, viz. 1980/81, 1981/82, 1982/83, were used to coincide with the experimental data.

TABLE 1

Area, production and productivity of sorghum in rainy and post-rainy seasons in important sorghum-growing states in India (average of 1980/81, 1981/82 and 1982/83 statistics)

State	Rainy season			Post-rainy season			Total		
	Area ($\times 10^3$ ha)	Production ($\times 10^3$ t)	Productivity (kg ha^{-1})	Area ($\times 10^3$ ha)	Production ($\times 10^3$ t)	Productivity (kg ha^{-1})	Area ($\times 10^3$ ha)	Production ($\times 10^3$ t)	Productivity (kg ha^{-1})
Maharashtra	2972.4	3121.2	1050.0	3581.8	1535.8	428.7	6554.2	4657.0	710.5
Andhra Pradesh	1064.9	603.1	566.3	1004.4	628.6	625.8	2069.3	1231.7	595.2
Karnataka	828.9	917.0	1106.3	1116.3	632.3	566.4	1945.2	1549.3	796.4
Madhya Pradesh	2232.0	1707.2	764.8	28.4	21.5	757.0	2260.4	1728.7	764.7
Tamilnadu	488.0	363.2	744.2	108.1	103.4	956.5	596.1	466.6	782.7
Other states	2580.8	1252.3	485.2	166.8	170.5	1022.1	2747.6	1422.8	517.8
All India	10167.0	7964.0	783.3	6005.8	3092.1	514.8	16172.8	11056.1	683.6

Source: Government of India, 1984.

Statistical analysis

Grain yield values were regressed over *Striga* counts. Square root and log transformations of *Striga* counts, log transformation of yield and untransformed data values of both the variables were used in different combinations to fit several regression equations. The regression equations fitted were of the linear and quadratic types, with and without trial effects, for individual trial data sets, on data combined across trials (assuming variable trial effects and constant rates of loss across trials, and assuming variable trial effects and variable rates of loss across trials). The equation with the best fit was

$$y_{ij} = \mu_i + \beta_i (x_{ij} - \bar{x}_i)$$

where:

y_{ij} = yield of *j*th plot in *i*th trial; μ_i = effect of the *i*th trial = potential yield of the trial site if *Striga* was absent; x_{ij} = *Striga* counts m^{-2} in *j*th plot in *i*th trial; $\bar{x}_i$ = mean *Striga* counts of the *i*th trial; β_i = rate of loss in yield with increasing *Striga* numbers in the *i*th trial; *i* = number of trials = 1....10; *j* = number of plots in a trial.

This joint regression equation, based on the procedure described by Yates and Cochran (1938) and Digby (1979), gave an R^2 value of 0.787 and in the analysis of variance the regression source of variation was significant. Hence this equation was used in crop loss prediction in the different trials.

The minimum, maximum (potential) and the mean percent yield loss estimates were calculated at the observed minimum, maximum and mean *Striga* levels, respectively, for individual trials using the potential yield estimates (μ_i) as the base. The β_i values were tested for statistical significance using their respective standard errors. All the crop loss estimates were restricted to the observed levels of *Striga* loads. Potential yield estimates (μ_i) were used as weights to obtain mean yield loss estimates across trials.

Based on the area covered by hybrid sorghum and percentage crop loss estimates, the estimates of loss of grain and the consequent monetary loss in rupees were calculated for individual states. The grain and monetary loss estimates were restricted to: (1) that part of the sorghum production that is contributed by the hybrids; (2) the rainy season when the hybrids are extensively cultivated; (3) the actual season and year when the loss percentages were estimated in individual states.

RESULTS

Significant variation was observed in *Striga* counts both between and within the trials (Table 2). At Akola and Bijapur, where trials were conducted for 3 successive years, variation was observed in *Striga* counts both between and

TABLE 2

Variability for *Striga asiatica* infestations and grain yield in CSH 1 in 10 checkerboard trials

Location	Year	No. of plots	*Striga* counts (m^{-2})			Grain yield (kg ha^{-1})		
			Minimum	Maximum	Mean	Minimum	Maximum	Mean
Rainy season								
Akola	1981	40	87	851	362	231	1449	805
Akola	1982	40	4	253	45	444	2519	1307
Akola	1983	110	17	333	143	444	3611	1415
B Sagar	1981	39	0	120	40	0	1975	502
ICRISAT Centre	1982	40	54	256	153	3022	5267	4041
Parbhani	1982	40	10	76	27	667	3833	2131
Indore	1982	39	6	651	251	62	3164	1506
Over all trials		348	0	851	145	0	5267	1624
Post-rainy season								
Bijapur	1981	40	4	82	33	17	1975	689
Bijapur	1982	40	189	817	501	37	2407	805
Bijapur	1983	60	1	210	71	0	833	223
Over all trials		140	1	817	183	0	2407	522

within years. An examination of *Striga* counts across the plots within the trials failed to show any trend in *Striga* distributions. The highest mean and highest maximum *Striga* infestation levels were noticed at Bijapur in 1982 and at Akola in 1981, respectively. The *Striga* numbers recorded ha^{-1}, in general, were very high, the highest maximum being equal to 8.5 million emerged *Striga* plants ha^{-1} recorded at Akola in 1981. The highest mean *Striga* level, recorded at Bijapur in 1982, was about 5 million *Striga* plants ha^{-1}.

Significant variations were also noticed in grain yield between plots both across and within trials. ICRISAT Centre in 1982 registered the highest mean grain yield of 4041 kg ha^{-1}. However, all the other trials recorded medium to low grain yield levels.

The correlation coefficients between *Striga* counts and grain yield were negative in all 10 trials and significant in 7 of them (Table 3). All ten regression coefficients, β_i, were negative and 7 of them were statistically significant. High values of β_i were recorded at Parbhani in 1982 and at Bijapur in 1981. The trial at ICRISAT Centre in 1982 with the highest potential yield estimate also recorded a significant negative regression coefficient, indicating that even in high-yielding environments, *Striga* could significantly reduce yields. However, there was little consistency between potential yield estimates and regression coefficients, and between potential yield estimates and percentage crop loss esti-

TABLE 3

Regression parameters and estimates of crop loss in CSH 1 caused by Striga asiatica

Location	Year	r between *Striga* (M^{-2}) and grain yield (ha^{-1})	$\mu_i \pm SE$	$\beta_i \pm SE$	Significance of β_i	Per cent yield loss at the load of *Striga*		
						Minimum	Maximum	Mean
Rainy season								
Akola	1981	−0.26	970.4 ± 210	− 0.46 ± 0.44	NS	4.12	40.18	17.10
Akola	1982	−0.49**	1545.6 ± 158	− 5.35 ± 1.85	**	1.52	87.57	15.44
Akola	1983	−0.20*	1699.1 ± 159	− 1.98 ± 0.74	**	1.94	38.92	16.71
B Sagar	1981	−0.08	552.9 ± 167	− 1.29 ± 2.45	NS	0.00	27.95	9.24
ICRISAT Centre	1982	−0.43**	4685.5 ± 274	− 4.21 ± 1.56	**	4.89	22.98	13.77
Parbhani	1982	−0.39*	2648.5 ± 207	−18.95 ± 5.75	**	6.80	54.16	19.53
Indore	1982	−0.55**	2080.1 ± 172	− 2.29 ± 0.42	**	0.62	71.64	27.62
			Weighted mean over all trials			3.66	46.26	17.46
Post-rainy season								
Bijapur	1981	−0.58**	1141.0 ± 202	−13.67 ± 4.53	**	5.15	98.60	39.66
Bijapur	1982	−0.32**	3012.6 ± 320	− 1.21 ± 0.58	**	7.60	32.80	20.09
Bijapur	1983	−0.28	285.6 ± 107	− 0.88 ± 1.18	NS	0.22	64.72	21.94
			Weighted mean over all trials			6.50	51.77	25.24

*Significant at $P = 0.05$; **Significant at $P = 0.1$; NS = not significant.

mates which indicated that yield loss from *Striga* could occur at all fertility levels.

The regression equation which included the trial effect and the rate of loss effect varying with the trial had a large R^2 value of 0.787, indicating a high level of confidence associated with the crop loss estimates obtained using this regression equation.

In the post-rainy season, the mean loss was 25.2% with 17.5% in the rainy season (Table 3). Mean crop loss estimates ranged from 9.2% at Bhavanisagar in 1981 to 39.7% at Bijapur in 1981. The crop loss estimates at the maximum observed *Striga* infestation indicated that at Akola in 1982 and Bijapur in 1981 the maximum loss possible was more than 85% of the potential yield.

Estimates of loss of sorghum grain and the consequent loss in monetary terms were obtained assuming that only 10% of the hybrid sorghum growing area was affected to the levels observed in these trials (Table 4). At all-India level, the data indicated that about 53 000 t of sorghum grain worth about 67 million Indian rupees was lost every year from *Striga*. Among the states, Maharashtra recorded losses of about 27 000 t of sorghum grain worth about 34 million Indian rupees. The monetary loss estimates were not calculated for Karnataka state because the crop loss estimates were from the post-rainy season, and the hybrid coverage is almost entirely in the rainy season.

TABLE 4

Statewise coverage of hybrids in India and estimates of yield loss in hybrids due to *Striga asiatica* (average of 1980/81, 1981/82 and 1982/83 statistics)

State	Hybrid coverage (% of total area)	Area covered by hybrids ($\times 10^3$ ha)	Grain production by hybrids[1] ($\times 10^3$ t)	Estimated mean grain yield loss (%)	Crop loss estimates assuming only 10% of hybrid area is affected	
					Loss of grains ($\times 10^3$ t)	Monetary loss[2] ($\times 10^3$ Rs)
Maharashtra	31.2	2044.9	1601.8	17.19	27.535	34418.75
Andhra Pradesh	20.6	426.3	333.8	13.77	4.596	5745.00
Karnataka	26.1	507.7	397.5	-[3]	-	-
Madhya Pradesh	27.3	617.1	483.2	27.62	13.346	16682.50
Tamilnadu	30.9	184.2	144.2	9.24	1.332	1665.00
Other states	4.9	134.6	105.4	-	-	-
All-India total	24.1	3913.8	3065.7	17.46	53.527	66908.75

[1]At the all-India productivity level (783.3 kg ha^{-1}) for rainy season, though hybrids are known to have higher productivity levels.
[2]Calculated at an approximate price of Rs 1250 t^{-1} of sorghum grain. For source of statistical data, refer to Materials and methods.
[3]Not available for rainy season hybrid crop.

DISCUSSION

Methodologies of Striga *crop loss estimations*

In the past, the following 3 approaches have been used to obtain crop loss estimates from *Striga*.

(i) By comparing the plant/crop yield in pots/field conditions, with or without adding *Striga* seeds (Andrews, 1946, 1947; Younis and Agabawi, 1965). The main limitation of this approach is that the loss estimate is at that particular level of *Striga* which was realized during experimentation.

(ii) By creating control vs. infested treatments in the field, where *Striga* plants that emerge above the ground in the control plots are removed by hand weeding (Doggett, 1965; Bebawi and Farah, 1981) or by application of 2,4-D (Last, 1960). In this procedure, *Striga* plants are removed or killed after emergence from the soil. As *Striga* does most of its damage before it emerges above the ground (Ramaiah et al., 1983), this procedure allows part of the damage effect of *Striga* to be included in the "no-*Striga*" plots leading to incorrect comparisons.

(iii) By surveys of infested fields and making visual estimate of the loss based on *Striga* infestation levels, soil fertility levels, moisture and degree of damage to the host crop. These types of estimates, which are often seen in the literature, are subjective and of limited use in crop loss predictions.

In the present study the regression approach has been used to arrive at crop loss estimates. This approach is being increasingly recognized as an important means for obtaining statistically-valid and reliable estimates of crop loss (Stynes and Veitch, 1983; Teng, 1985). A limitation is the validity of the prediction equation, which is determined by the R^2 value. However, in the present study a high R^2 value of 0.787 was obtained. It may be possible to further increase this value in future studies by monitoring soil factors like fertility, particularly nitrogen, and moisture in each plot, which could then be included as additional independent variables in the multiple regression equation.

Striga *emergence and yield loss estimates*

Last (1960) and Doggett (1965), in Sudan and Tanzania, respectively, found that in *Striga hermonthica* 1.73–4.44 million *Striga* plants occur ha^{-1} and that only 10–30% of them emerge above the ground. The present study has used emerged *Striga* counts to estimate the *Striga* infestation. Hence there is an underlying assumption in the present study that the unknown ratio of emerged *Striga* plants to the total number that parasitize the host roots was the same across all the plots.

Three trials had much higher yield loss rates compared to the other 7 trials. These 3 trials were also the ones with lower *Striga* levels. It appeared that in these 3 trials the emergence of *Striga* was impeded, though the deleterious effects of the subterranean *Striga* plants were registered. It has generally been observed that a drought during *Striga* emergence reduces the number that finally emerge. It has been noticed in such instances that the delicate subterranean *Striga* plants dry up in the top 2–5 cm dry layer of the soil without emerging. It is possible, that, in these 3 trials, the deleterious effects of *Striga* were registered on the plot yields, but the *Striga* counts were small because of incomplete emergence of the *Striga* populations.

Striga *effects in relation to soil fertility status*

It is generally believed that *Striga* does not cause serious damage in highly-fertilized soil (Last, 1960; Younis and Agabawi, 1965; Pesch et al., 1983). It was clear in the present study that in the trial at ICRISAT Centre in 1982, which recorded the highest potential yield among the trials, there was significant loss from *Striga*. Two different aspects of fertility effects on *Striga* could be visualized–one on the numbers of *Striga* plants and another on the effects of *Striga*. It is known that *Striga* depends on its host for the nutrients taken up by the host roots (Pesch et al., 1983). Under higher fertility conditions the host could, perhaps, cope with such nutrient loss to parasite because of higher