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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

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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

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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 checker-board 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 m² 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, statewide 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 statewide area and production of sorghum and the statewide 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	<i>Striga</i> 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	<i>r</i> between <i>Striga</i> (M^{-2}) and grain yield (ha^{-1})	μ , \pm SE	β , \pm SE	Significance of β	Per cent yield loss at the load of <i>Striga</i>		
						Minimum	Maximum	Mean
Rainy season								
Akola	1981	-0.26	970.4 \pm 210	- 0.46 \pm 0.44	NS	4.12	40.18	17.10
Akola	1982	-0.49**	1545.6 \pm 158	- 5.35 \pm 1.85	**	1.52	87.57	15.44
Akola	1983	-0.20*	1699.1 \pm 159	- 1.98 \pm 0.74	**	1.94	38.92	16.71
B Sagar	1981	-0.06	552.9 \pm 167	- 1.29 \pm 2.45	NS	0.00	27.95	9.24
ICRISAT Centre	1982	-0.43**	4685.5 \pm 274	- 4.21 \pm 1.56	**	4.89	22.98	13.77
Parbhani	1982	-0.39*	2648.5 \pm 207	- 18.95 \pm 5.75	**	6.80	54.16	19.53
Indore	1982	-0.55**	2080.1 \pm 172	- 2.29 \pm 0.42	**	0.62	71.64	27.62
			Weighted mean over all trials			3.66	46.26	17.46
Post-rainy season								
Bijapur	1981	-0.56**	1141.0 \pm 202	- 13.67 \pm 4.53	**	5.15	98.60	39.66
Bijapur	1982	-0.32**	3012.6 \pm 320	- 1.21 \pm 0.58	**	7.60	32.80	20.09
Bijapur	1983	-0.28	285.6 \pm 107	- 0.88 \pm 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

¹At the all-India productivity level (783.3 kg ha^{-1}) for rainy season, though hybrids are known to have higher productivity levels.

²Calculated at an approximate price of Rs 1250 t^{-1} of sorghum grain. For source of statistical data, refer to Materials and methods.

³Not 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

availability of nutrients to the roots. In the trial at ICRISAT Centre in 1982, the minimum, maximum and mean *Striga* numbers in the trial were high, but the potential loss estimate was only 23%, the lowest among all trials. It is possible that, in this trial, the high soil fertility did not reduce *Striga* numbers, but reduced the *Striga* effects by providing higher soil nutrient levels, for which *Striga* depends on its host. Therefore, under higher fertility status of the soil, though the *Striga* numbers are not reduced, its deleterious effects are less visible.

Estimates of crop loss due to Striga

Most of the reported crop loss estimates relate to *S. hermonthica* and almost none to *S. asiatica*. With *S. hermonthica*, the crop loss estimates reported are: 50% yield loss (Last, 1960); 63.8% loss of sorghum dry matter (Younis and Agabawi, 1965); 2-3 kg yield loss ha⁻¹ 1000⁻¹ *Striga* plants (Doggett, 1965); 65% yield loss (Bebawi and Farah, 1981); 30% yield loss in resistant and 80% yield loss in susceptible lines (Obilana, 1983); 10-35% yield loss (Ramaiah, 1984). In contrast, there are no quantified loss estimates from *S. asiatica*, though Parker (1983) quotes Sawyer (1925) that 4-46% sorghum yield loss occurred in Burma as the result of *Striga*. Hosmani (1978) quoted losses of 15-100% in India with no data to substantiate the figures. However, the literature contains many statement indicating total loss from *Striga* in Indian farmers' and experimental fields in some years.

In the present study, the mean yield loss estimates ranged from 9.24 to 27.62% of the potential yield of the hybrid in the rainy season and 21.94 to 39.66% in the post-rainy season. In the post-rainy season in India, sorghums are grown on stored soil moisture that constantly diminishes as the season progresses. The chances of late-season rains are also small. Hence the *Striga* effects become cumulative in the post-rainy season and recovery because of late-season rains is low. In the rainy season, the late-season rains could allow for some recovery from *Striga* effects. Both at Akola and Bijapur, where trials were conducted for 3 successive years, yield loss estimates were different in each of the years indicating that seasonal effects significantly influenced crop loss estimates. The potential loss estimates indicated that a near total loss (more than 85% of the potential yield) of the sorghum crop was possible from *Striga* at some locations in some years. The average of the trials showed that *S. asiatica* was causing a mean loss of 17.5% to sorghum in India in the rainy season and about 25.2% mean loss in the post-rainy season, when it occurred in the intensities that were recorded in these trials. These results indicate that, if left unchecked, *Striga* has the potential to cause extensive loss to hybrid sorghum in India.

Grain and monetary loss from Striga

There are no known estimates of national sorghum grain loss and consequent monetary loss from *Striga* in India. The present study has obtained re-

liable damage functions (percent grain loss estimates from *Striga*) at specific locations and years. To predict national grain yield losses, information on the extent and level of incidence of *Striga* in farmers' field is essential. Unfortunately, because no systematic surveys have been carried out documented evidence is not available on this aspect. However, it is generally known that *Striga* occurs in the entire sorghum-growing areas in India (ICRISAT, 1982; Vasudeva Rao et al., 1983; Vasudeva Rao, 1984) where the *Striga* effects are more serious on hybrids than on local varieties (ICRISAT, 1982; Vasudeva Rao, 1984). All the sorghum hybrids currently grown in India are equally (and highly) susceptible to *Striga* (ICRISAT, 1982). Hence in the present study loss estimates are restricted to sorghum grain produced by the hybrid cultivars in the sorghum-growing areas in India. National grain and consequent monetary loss estimates have been derived on the assumption that 10% of the hybrid sorghum area has *Striga* occurring at the damage levels recorded in these trials. Even at this level of occurrence, the data suggest a national annual loss of about 53 000 t of sorghum grain worth about 67 million Indian rupees (equivalent to U.S. \$4.9 million). This estimate does not include the loss occurring in Karnataka state, because in this state the damage estimates were obtained in the post-rainy season and the hybrid coverage is almost entirely in the rainy season. *Striga* also causes severe reduction in shoot growth, which leads to reduction in fodder yield. Fodder yield loss has not been calculated in the present study. Hence the real monetary loss is probably more than estimated. This significant loss figure suggests the need for intensified research efforts to reduce the *Striga* menace on hybrid sorghums in India. It is possible that in other countries where *Striga* is present similar losses in yields of sorghum and other hosts occur.

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REFERENCES

- Andrews, F.W., 1946. Parasitism of *Striga* sp. on *Dolichos lablab* L. Nature (London), 157: 515.
Andrews, F.W., 1947. Parasitism of *Striga hermonthica* on leguminous plants. Ann. Appl. Biol. 34: 267-275.

- Bebawi, F.F. and Farah, A.F., 1981. Effects of parasitic and non-parasitic weeds on *Sorghum bicolor*. *Exp. Agric.* 17: 415-418.
- Digby, P.G.N., 1979. Modified joint regression analysis for incomplete variety \times environment data. *J. Agric. Sci. (Cambridge)*, 93: 81-86.
- Doggett, H., 1965. *Striga hermonthica* on sorghum in East Africa. *J. Agric. Sci.*, 65: 183-194.
- Government of India, 1984. Ministry of Agriculture, Department of Agriculture and Cooperation. Jowar. In: Area and Production of Principal Crops in India 1981-84. New Delhi, India, Controller of Publications, pp. 80-89.
- Hosmani, M.M., 1978. *Striga*—a noxious root parasite. University of Agricultural Sciences, Bangalore, India, pp. 165.
- ICRISAT, 1982. Proceedings of ICRISAT-AICSIP(ICAR) Working Group Meeting on *Striga* Control, ICRISAT Centre, 30 September-1 October 1982, Departmental Report (SB-4) Sorghum Breeding, ICRISAT, Patancheru, A.P., India.
- Last, F.T., 1960. Effect of cultural treatments on incidence of *Striga hermonthica* (Del.) Benth. and yields of sorghum in the Sudan: field experiments 1957/58. *Ann. Appl. Biol.*, 40: 207-229.
- Obilana, A.T., 1983. *Striga* studies and control in Nigeria. In: Proceedings of the Second International Workshop on *Striga*, 5-8 October 1981, Ougadougou, Upper Volta. ICRISAT, Patancheru, A.P., India, pp. 87-98.
- Parker, C., 1983. *Striga*—analysis of past research and summary of the problem. In: Proceedings of the Second International Workshop on *Striga*, 5-8 October 1981, Ougadougou, Upper Volta. ICRISAT, Patancheru, A.P., India, pp. 9-16.
- Pesch, C., Pieterse, A.H. and Stoop, W.A., 1983. Inhibition of germination in *Striga* by means of urea. In: Proceedings of the Second International Workshop on *Striga*, 5-8 October 1981, Ougadougou, Upper Volta. ICRISAT, Patancheru, A.P., India, pp. 37-38.
- Ramaiah, K.V., 1984. Patterns of *Striga* resistance in sorghum and millets with special emphasis on Africa. In: Proceedings of Workshop on the Biology and Control of *Striga*, 14-17 November 1983, Dakar, Senegal. ICSU Press, Paris and IDRC, Ottawa, pp. 71-92.
- Ramaiah, K.V., Parker, C., Vasudeva Rao, M.J. and Musselman, L.J., 1983. *Striga* Identification and Control Handbook. ICRISAT, Patancheru, A.P., India, 52 pp.
- Stynes, B.A. and Veith, L.G., 1983. Determining crop losses—a complex regression problem. In: Proceedings of the Fourth International Congress of Plant Pathology, 17-24 August 1983, Melbourne, Australia, p. 4.
- Teng, P.S., 1985. Construction of predictive models: II. Forecasting crop losses. *Adv. Plant Pathol.*, 3: 179-206.
- Vasudeva Rao, M.J., 1984. Patterns of resistance to *Striga asiatica* in sorghum and millets, with special reference to Asia. In: *Striga: Biology and Control*. Paper presented at a Workshop on the Biology and Control of *Striga*, 14-17 November 1983, Dakar, Senegal. ICSU Press, Paris, France and IDRC, Ottawa, Canada.
- Vasudeva Rao, M.J., 1987. Techniques for screening sorghums for resistance to *Striga*. In: L.J. Musselman (Editor), *Parasitic Weeds in Agriculture I. Striga*. CRC Press, Boca Raton, Florida, pp. 281-304.
- Vasudeva Rao, M.J., Chidley, V.L., Ramaiah, K.V. and House, L.R., 1983. Breeding sorghum with resistance to *Striga asiatica* at ICRISAT Centre. In: Proceedings of the Second International Workshop on *Striga*, 5-8 October 1981. ICRISAT, Patancheru, A.P., India, pp. 61-76.
- Yates, F. and Cochran, W.G., 1938. The analysis of groups of experiments. *J. Agric. Sci. (Cambridge)*, 28: 556-580.
- Younis, A.E. and Agabawi, K.A., 1965. Effect of *Striga hermonthica* Benth. and nitrogen application on the growth and nitrogen content of *Sorghum vulgare* L. *Acta Biol. (Hungary)*, 15: 361-369.