STRIGA IN INDIA - THE PROBLEM AND OPTIONS FOR ITS CONTROL - AN ANALYSIS

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1. Introduction

Striga, an old world root parasite of cereals and legumes, has attracted much attention of late, as a causative agent for serious losses in crop production in the semi-arid tropics. *Striga* is reported to occur in almost all sorghum growing semi-arid parts of Asia, including India, Pakistan, China, Japan, Indonesia, Thailand and Burma. *Striga* is a serious problem in India and certain parts of Pakistan on sorghum and pearl millet. In other countries, *Striga* is a recognized yield reducer on crops such as maize (Thailand), sugarcane (Australia), and rice (Burma, Indonesia, Thailand). In addition to being a major problem on sorghum and pearl millet, in restricted areas in India, *Striga* is also a problem on sugarcane, maize, rice and minor millets. There are two morphotypes of *S. asiatica* occurring in Asia. White flowered *S. asiatica* is reported from India, Pakistan and Burma and the yellow flowered form is reported from Thailand and Indonesia. There are also reports of yellow flowered types of *S. asiatica* in the Malnad tract of Karnataka (Hosmani 1978). There could be some implications of this with reference to host reactions and consequently on breeding of resistance lines.

2. *Striga* Problem in India and the Nature of Crop Loss

In India, which has the largest area under sorghum in Asia, *Striga* was a problem with marginal economic implications in traditional farming using local cultivars. The problem has, however, grown in magnitude since the introduction of hybrids, as all the released hybrids are highly susceptible. Under traditional farming systems using local varieties, some *Striga* seed is always present in the soil because most local varieties are tolerant and yield well in spite of *Striga* infestations. Some local cultivars have evolved resistance because of their cohabitation with *Striga* over centuries, but they are not immune. Consequently, when susceptible hybrids are introduced, the level of *Striga* infestation in the soil which hitherto remained low increases considerably. However, a few years were required to build up economically damaging *Striga* levels on hybrids. The problem assumed economic proportions only after a few years of continuous hybrid cultivation in the same field.

In addition to *S. asiatica*, *S. densiflora* and *S. euphrasioides* occur in India. *S. densiflora* is a recognized problem on the postrainy season sorghums in parts of Karnataka, and Maharashtra. It is interesting that though this species occurs very frequently on grasses in other parts of India in kharif, it is not seen in cultivated fields in the same season.

Striga is also a serious problem on pearl millet in Nagour, Sikar, Junjhunun, and Alwar districts of Rajasthan. In Andhra Pradesh, it is reported on pearl millet from Anantapur. In the pearl millet growing regions of India, *Striga* is more serious on the relatively lighter types of soils.

S. asiatica and *S. euphrasioides* are also reported to cause damage to upland rice in Nellore district, Andhra Pradesh, on the Malabar Coast, Tamil Nadu and in Quillon district, Kerala. Losses of 80-90% are reported.

Of late, *Striga* has also been reported to cause damage to sunflower in Tamil Nadu and Karnataka states. The species involved is presumed to be *S. asiatica*, but detailed studies are required to verify this.

3. Working Group Meeting on *Striga* Control

Realizing the importance of the crop loss due to *Striga*, the 1982 All India Coordinated Sorghum Improvement Project (AICSIP) Workshop held at Pune recommended that a working group meeting should be held to review the current knowledge on this problem and organize the research to control *Striga*. This meeting was jointly sponsored by AICSIP and ICRISAT and was held at the ICRISAT Center on 30 Sep - 1 Oct 1982. The meeting brought together for the first time *Striga* scientists working in different organizatrions and institutes without formal or informal contacts between them. The working group has made very useful recommendations to organize *Striga* research in India in future. The proceedings of this meeting, available as a departmental report from the Sorghum Improvement Program of ICRISAT, is an excellent upto date review of *Striga* research in India and also contains the recommendations of the meeting.

4. Options for Control

Several strategies have been adopted in the past and many control measures with different degrees of success have been recommended. These control measures can broadly be grouped into three categories.

4.1. Genetic control. This is through deploying the resistance genes in the resistant lines to control *Striga*. Genetic control option appears most plausible because a resistant variety is a noncost input once it is produced and it can effectively avert the subterranean damage compared to other options.

4.2. Agronomic Control Agronomic control finds a significant place in the integrated *Striga* control package. At present, though, very high levels of resistance is available, absolute resistance is not available (may not be desirable also). Therefore, whatever *Striga* emerge in resistant varieties, will have to be weeded out using some agronomic measure, especially in the first year of its cultivation. Agronomic control is also desirable, and at a much intense level, in susceptible hybrids which are under large scale cultivation at présent.

4.3. Bio-control. *Striga* control using pests and pathogens of *Striga*, though, an interesting option, is not possible at present because the biocontrol feasibility scores of the pests and pathogens is less than the required standards (Thobbi and Singh, 1982; Greathead 1983).

5. Past Efforts in Asia

India is the only country in the world other than South Africa, where work on breeding for *Striga* resistane in sorghum was initiated as early as the 1930's. Vasudeva Rao (1983) reviewed the past Indian work on resistance breeding activities in sorghum. Several varieties were reported resistant to *S. asiatica* by different workers (Table 1). Most *Striga* research efforts in the past had short term objectives and were not adequately sustained. The progress in breeding for *Striga* resistance in the past was slow. Possible reasons are: the absence of long term support, both fiscal and physical, to sustain the continuity of research efforts, the absence of immunity to *Striga* in sorghum coupled with the lack of valid field screening techniques which resulted in the terms 'resistant' and 'tolerant' being used indiscriminately.

6. Screening for Resistance Mechanisms

Two approaches were adopted by past researchers: screening for the individual mechanism which confers resistance to the host, or screening for field resistance. Three resistance mechanisms have been identified in sorghum, low stimulant production, mechanical barriers (anti-haustorial factors), and antibiosis factors. At ICRISAT Center, nearly 15,000 germplasm lines have been screened for their capacity to stimulate the germination of *S. asiatica* from the Patancheru site, and 640 low stimulant lines have been identified. Only N 13, a high stimulant and a highly stable field resistant line has been identified as having mechanical barriers. Little work has been carried out on the third mechanism although it is indicated to exist (Saunders 1933).

The usefulness of low stimulant production as a predictor of the field resistance of sorghum lines has often been questioned. Initial efforts to correlate *Striga* numbers in the field and stimulant production indicated a low, but positive correlation. Further studies have lead to the following conclusions (Vasudeva Rao et al. 1982a).

(i) The proportion of field resistant lines among low stimulant lines is higher than that among the high stimulant lines.

(ii) Simple correlation coefficients between *Striga* numbers and stimulant production obtained from different trials were positive and at some locations and trials, significant indicating that stimulant production could be a useful indicator of field reaction (Table 2).

7. Genetics of *Striga* Resistance

7.1. *Inheritance of low stimulant production*. The first report on inheritance of low stimualnt production was from ICRISAT Center (ICRISAT 1978), it indicated that a single recessive gene, 'sal', controlled stimulant production. Further analysis indicated that the character was also preponderance of additive genetic variance (Vasudeva Rao et al. 1983a). Shinde and Kulkarni (1982), in a seven-parent complete diallel, while confirming the higher additive gene action for this character, also reported reciprocal differences indicating maternal effects. IS 2221, S 1841 and SPV 86 were reported to be good combiners for low-stimulant production.

7.2. *Inheritance of field resistance*. Studies on the inheritance of field resistance are plagued by two main difficulties, the absence of a field technique that assures a uniformly high level of *Striga* challenge for each host plant, and the interpretation of data based on a single external manifestation (emerged *Striga* counts) of reaction which is the result of actions and interactions of one or more resistance mechanisms, each of which are likely to be controlled by different genes. Chandrasekharan and Parthasarathy (1953) reported that *Striga* resistance was dominant while Narasimhamurthy and Sivaramakrishnaiah (1963) reported that the nature of inheritance varied with the parents involved in a cross. 23-4, N 13 and NJ 1515 in their crosses showed dominant susceptibility, IS 5603 in its crosses showed dominant resistance, and in crosses with IS 6942 there was partial dominance. A preliminary study at ICRISAT using line x tester analysis has indicated that susceptibility is dominant over resistance (Vasudeva Rao et al. 1983b). Shinde and Kulkarni (1982) using a seven-parent diallel reported that field resistance was controlled by both additive and nonadditive gene actions with a preponderance of additive gene action, and suggested that pedigree selection was effective for field resistance.

There is no work on the inheritance of other mechanisms other than low stimulant production.

8. Transfer of Resistance

Concerted efforts have been made since work began at ICRISAT to identify stable resistant lines by multilocation testing.

Though there is no absolute resistance or immunity to *S. asiatica* there are stable low susceptible lines such as N 13, 555, IS 2203, IS 4202, IS 7471 and IS 9985 (Vasudeva Rao et al. 1983a). Crosses are made every year among resistant lines and between resistant lines and high yielding susceptible lines. The absence of reliable single plant screening technique to differentiate resistant and suceptible plants in the segregating generation is a major drawback. However, the segregating generations are grown and advanced in *Striga*-sick fields. The best looking plants are selected and once they attain some uniformity, they are processed through a three-stage screening (see Section 10). The best advance generation progenies are being identified as SAR (*Striga asiatica* Resistant) lines. SAR 1 to SAR 34 are lines with good levels of *striga* resistance that have moderate yield levels even under severe *striga* infestations. SAR 1 and 2 are currently undergoing farmers' field testing in Maharashtra state.

Apart from the work of ICRISAT in India, Akola is another Center, where some notable progress has been made in identifying resistant source lines and transfer of resistance to improved backgrounds.

9. Breeding for Stable Resistance

Striga is a versatile parasite capable of parasitizing different hosts and in different environments. There are different levels of organization within the genus *Striga*, i.e., with reference to differences between species, morphotypes within a species, and host-specific races within a morphotype. Taxonomically distinct species like *S. asiatica*, *S. densiflora* and *S. euphrasioides* coexist in India. Variations in morphological characters among plants of *S. asiatica* existing in the same field have been noticed (Vasudeva Rao et al. 1983a). Recent observations near Anantapur, Andhra Pradesh, indicated that in a restricted area *Striga* attacks pearl millet. From cross inoculation tests, using *Striga* from sorghum and pearl millet collected in the same area, it has been found that pearl millet-*Striga* parasitized both sorghum and pearl millet, while the sorghum-*Striga* could only parasitize sorghum. Therefore, the resistance which is bred into variety should be 'stable' resistance, i.e., resistance of the host across different levels of organization within the genus *Striga*.

The stability of resistance with reference to *Striga* pressures, as expressed in the number of emerged *Striga* plants per unit area has also been studied. Data from advanced *Striga* resistance trial conducted at five locations in India using a checkerboard layout was utilized to plot the number of emerged *Striga* plants in test entries against the positional check average (average of the four check plots surrounding each test entry plot). Three representative varieties were studied (Fig. 2). N 13, a very stable variety, held its resistance even at the highest pressure recorded, while SRN 4841, a moderately resistant variety held its resistance under low *Striga* pressure, but became susceptible at higher pressures. T 233B, a susceptible variety, showed high *Striga* counts even at low pressures. It was found that a graphical approach using the multilocation checkerboard layout data is a very useful way to identify varieties with stable resistance (Gilliver et al. 1983).

In addition to breeding stable resistant varieties, it is important to protect the products of breeding, i.e., the *Striga* resistant varieties, from loosing their resistance. In the past, excellent resistant varieties such as 'Radar' failed to maintain resistance apparently due to outcrossing (Grobbelaar 1952). At present, there are no specific procedures for monitoring the seed production of varieties bred for specific resistances. Stringent seed production procedures may have to be developed to avoid the breakdown of resistance due to mutation, outcrossing or other reasons. This procedure will become even more crucial when *Striga* resistant sorghum hybrids are developed.

10. Screening Methodology

Lack of proper screening methodology has hindered significant progress in *Striga* resistance breeding activities in the past. The main problems to be countered are variability in infestations as measured by the emerged *Striga* counts from year to year and variability from spot to spot in the field in any one year. The emerged *Striga* count is an unknown percentage of the subterranean *Striga* numbers. Major efforts at ICRISAT Center have been directed to solve the later problem. A 'three-stage' screening methodology specifically suited to *Striga* resistance breeding activities (Fig. I) has been developed (Vasudeva Rao et al. 1982b). The three stages are;

Stage I - Observation Nursery - This consists of a single replication of a large number of breeding lines with a frequently-repeated (one in five plots) susceptible check. A minimum of two rows of each entry are grown and susceptible lines are rejected based on *Striga* counts relative to the closest check.

Stage II - Preliminary Screening - The entries, advanced from stage I, are tested at more than one location in three row plots and replicated atleast thrice with checks arranged in such a way that every test entry plot will have one check plot adjacent to it (Fig. 1). *Striga* counts are determined on the central row of each plot. Trials are classified as all-zero, some-zero or no-zero based on *Striga* emergence in the susceptible check plots. In an all-zero trial, where *Striga* has not appeared in the susceptible check, trial data may be used for yield evaluations. In the some-zero trials, where *Striga* has appeared in some parts of the trial and not in other parts, data may be analysed using a 'single-unit comparison' system (Vasudeva Rao et al. 1983a), wherein comparison between test entries are limited to a unit of eight plots with the susceptible check being in the center. In the no-zero trials, where *Striga* appears in all check plots, the reactions of test entries are computed as *Striga* counts percent of the susceptible check, in the same unit. Data is then analysed as per the experimental design.

Stage III (Advanced Screening). Resistant entries from Stage II are tested in five row plots arranged in such a way that every test entry plot is surrounded by susceptible check plots on four sides, giving the field a checkerboard appearance (hence the name checkerboard layout). This layout provides a useful opportunity to estimate grain yields from replicated test entry plots in *Striga*-sick fields, and at the same time, to monitor, estimate and utilize the information on *Striga* infestations in the suceptible check plots which are regularly interspersed in the experimental area for assessing the variability of *Striga* infestation. Statistical procedures involve either lot assessment, covariance analysis, or a graphical approach (Gilliver et al. 1983).

The three-stage screening methodology is fully operational at the ICRISAT Center and has been found quite useful in identifying resistant lines. The checkerboard layout has been adopted by AICSIP in their multilocation coordinated *Striga* trial in 1982 and has since then generated useful data with good confidence levels associated with it.

11. Farmers' Field Testing

A procedure which involves sowing of resistant and susceptible lines in alternate strips (Fig. 3) has been developed to test resistant lines in farmers' fields. The length and width of each strip is variable. The alternate strips are very convenient for use in farmers' fields and very convincing when *Striga* is seen on either side of resistant strips. Data on *Striga* counts and yields may be collected from two to five samples from each strip taking into consideration the variation in *Striga* population and effects in the susceptible strips.

12. Future Strategies to Control *Striga* in India

In India, *Striga* is a problem associated with varietal transformation. Therefore, the key for its control is a retransformation of the current susceptible varieties and hybrids with *Striga* resistant varieties and hybrids. However, the final answer to *Striga* in India is a *Striga* resistant hybrid. The development of a *Striga* resi hybrid may take atleast five to ten years if determined efforts are made. It will be another five years till it is tested and sufficient quantities of seeds built up. This period till a resistant hybrid is made availabel to the farmers, will have to be filled up by a two pronged approach to control Striga.

(a) In heavily infested fields where cultivation of hybrids has become almost uneconomical due to Striga, resistant varieties will have to be recommended. The best available resistant varieties with acceptable grain quality have moderately high yield levels in Striga-free situations, but have consistently proved their yield superiority over the hybrids, to the tune of 200 to 300%, both in the All India Striga trials as well as in the ICRISAT multilocation trials. It will be essential to make sure that in the first year of cultivation of these resistant varieties, the few Striga plants that emerge are not allowed to flower and produce seed. This is a precautionary step to avoid the selective progression of newer types of Striga adapted to the resistant lines.

(b) In moderate and less infested fields, if tolerant hybrids are identified in the immediate future, they may be grown with adequate agronomic protective measures. Use of nitrogen, use of preemergence (of Striga) application of 2,4-D may be the useful agronomic practices. It is also essential that if these hybrids are grown for the first time in a new field, any *Striga* plant that is seen in the first year of its cultivation, is destroyed before flowering.

13. Future *Striga* Research Proiorities

(A) The current research input on *Striga* is grossly inadequate, and is not commensurate with the magnitude of the problem. A strong coordination between the various organizations involved in *Striga* research is required.

(B) Efforts to breed *Striga* resistant sorghums need to be intensified urgently. Following are the important areas in breeding that need attention.

a) Efforts at ICRISAT Center as well as sporadic efforts by others in India have resulted in the identificatioin of several locally adapted resistant source lines. These lines could be utilized in breeding programs as resistance gene donors.

b) Among source lines for each mechanism, at ICRISAT Center, we have identified 640 germplasm low stimulant lines. However, only N 13 has been identified as a source line for mechanical barriers. It is coincidental that N 13 is also the most stable resistant line available at present. Therefore, it may pay off to identify some more mechanically resistant lines.

c) Considerable systematic efforts have already gone into the transfer of resistance to elite background at ICRISAT resulting in the identification of SAR 1 and SAR 34. These could be used in other breeding projects to increase the gene freqency for *Striga* resistance in their material. SAR 1 and SAR 2 have performed well in the AICSIP and ICRISAT trials in *Striga* sick plots and have proved their superiority over the hybrids. Minikit results from Maharashta of these lines in *Striga* endemic areas in India is encouraging. Therefore these lines could be considered for farmers' use in *Striga* endemic areas.

d) Susceptibility to *Striga* has been found to be dominant in resistant (no *Striga*, no yield loss) x susceptible (high *Striga*, severe yield losses) crosses. However, it is not known whether such crosses result in tolerant (high *Striga*, no yield loss) hybrids. In this respect, SAR lines are valuable because of their potential use as resistant R-lines to be used with susceptible A-lines. However, identification of tolerant lines is a completely new area which needs development of valid criterion for their evaluation.

e) To find a real answer to the *Striga* problem, *Striga* resistant hybrids will have to be produced. Both the parents of the hybrid will have to be resistant since susceptibility is dominant in the hybrids. Though *Striga* resistant R-lines are available at present, *Striga* resistant A-lines are not available. Special efforts will have to be made to develop A-lines resistant to *Striga*. To add *Striga* resistance to good A-line like 296A, F2's between the B-lines and SAR lines may be testcrossed to A-plants in *Striga*-sick fields and selective backcrossing could be done with best looking plants. Superimposing selection for low stimulant production and selecting for agronomic expression every alternate generation (in the off-season) assures a certain levels of agronomic eliteness in the final product.

f) Seed certification procedures will have to developed to specifically monitor the seed production of *Striga* resistant lines. This becomes all the more essential when *Striga* resistant hybrids are produced.

(C) Future agronomic research to control *Striga*.

a) Based on the available research results, the working group meeting recommended that 2,4-D as preemergence (of *Striga*) treatment 30 days after planting @ 2 kg a.i./ha can kill all the germinated *Striga* plants. This recommendation needs to be tested in large scale in farmers' fields in the country.

b) More efforts are required in the identification of *Striga*-specific herbicides, which could be applied to the young host plant, which would then get translocated to the *Striga*-host interface and dislodge the contact. The biochemical clue has to be found in the differences between *Striga* and host at the point of contact which could then be destroyed or modified using

Striga-specific herbicides.

c) Quantified information on the influence of various environmental factors like moisture, N, organic matter, cultural operations etc. on *Striga* is pathetically insufficient. Such information would be useful for (i) increasing the *Striga* infestation by simulating these factors in *Striga*-sick fields for research purposes, (ii) avoiding these factors while formulating cultural practices to reduce *Striga* attack.

(D) Intensified efforts are required to develop more efficient methods for screening single plants for host resistance. This will help speed up progress in breeding. Field screening methodology needs to be improved to obtain reliable *Striga* infestations year after year. Involvement of agronomists to do this is essential. Studies are required on the management of *Striga*-sick fields.

(E) Systematic surveys are required in the country to locate *Striga* 'hot-spots', to identify the species occurring and to understand the host range and magnitude of the problem.

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Table 1. Varieties reported to be resistant to *Striga asiatica* from India

Variety	Place	Reference	Remarks
Bilichigan	Temburni Maharashtra	Gadgil (1933)	Selection from Maldandi
Mudinandyal Burma K.K. Burma Y.K. Agikodal Malleswar	Poona Maharashtra	Jenkins (1944)	Resistant in pot tests
S. versicolor *S. purpureosericeum* *S. nitidum*	Poona Maharashtra	Deodikar (1951)	--
AS 4003 (Boganhilo) AS 4693 (Bilichigan) CO-7 CO-11 CO-20 (AS 9028)	Coimbatore Tamil Nadu	Sivaraman (1952)	--
N-13 (Culture 109)	Nandyal Andhra Pradesh	Nagur et al. (1962)	Selection from local 'Patchajonna'
BH 4-1-4	Bailhongal Karnataka	Kajjari et al. (1967)	Also resistant to SDM
BO-1	Akola Maharashtra	Anonymous (1979)	Selection from Local NJ-156
PJ-13 PJ-16K Khedi 2-2-10	Parbhani Maharashtra	Chopde et al. (1973)	

Table 2. Simple correlation coefficients between low stimulant production and field reaction to *Striga asiatica*

Season	Trial No.	No. of entries	Location	'r' value	Remarks
Rainy '81	53	13	Akola	0.91**	Checkerboard layout
			Bhavanisagar	0.65*	"
			Bijapur	0.34	"
Rainy '82	71	15	Akola	0.85**	"
			Bijapur	0.70**	"
			Indore	0.86**	"
			Parbhani	0.47	"
			Patancheru	0.85**	"
Rainy '82	72	78	Akola	0.51**	Preliminary stage Screening
			Bijapur	0.36**	"
			Parbhani	0.58**	"
			Patancheru	0.47**	"
Rainy '82	73	54	Akola	-0.32*	"
			Bijapur	0.28*	"
			Patancheru	0.023	"
Rainy '82	74	20	Akola	0.27	"
			Bijapur	0.39	"
			Patancheru	0.56**	

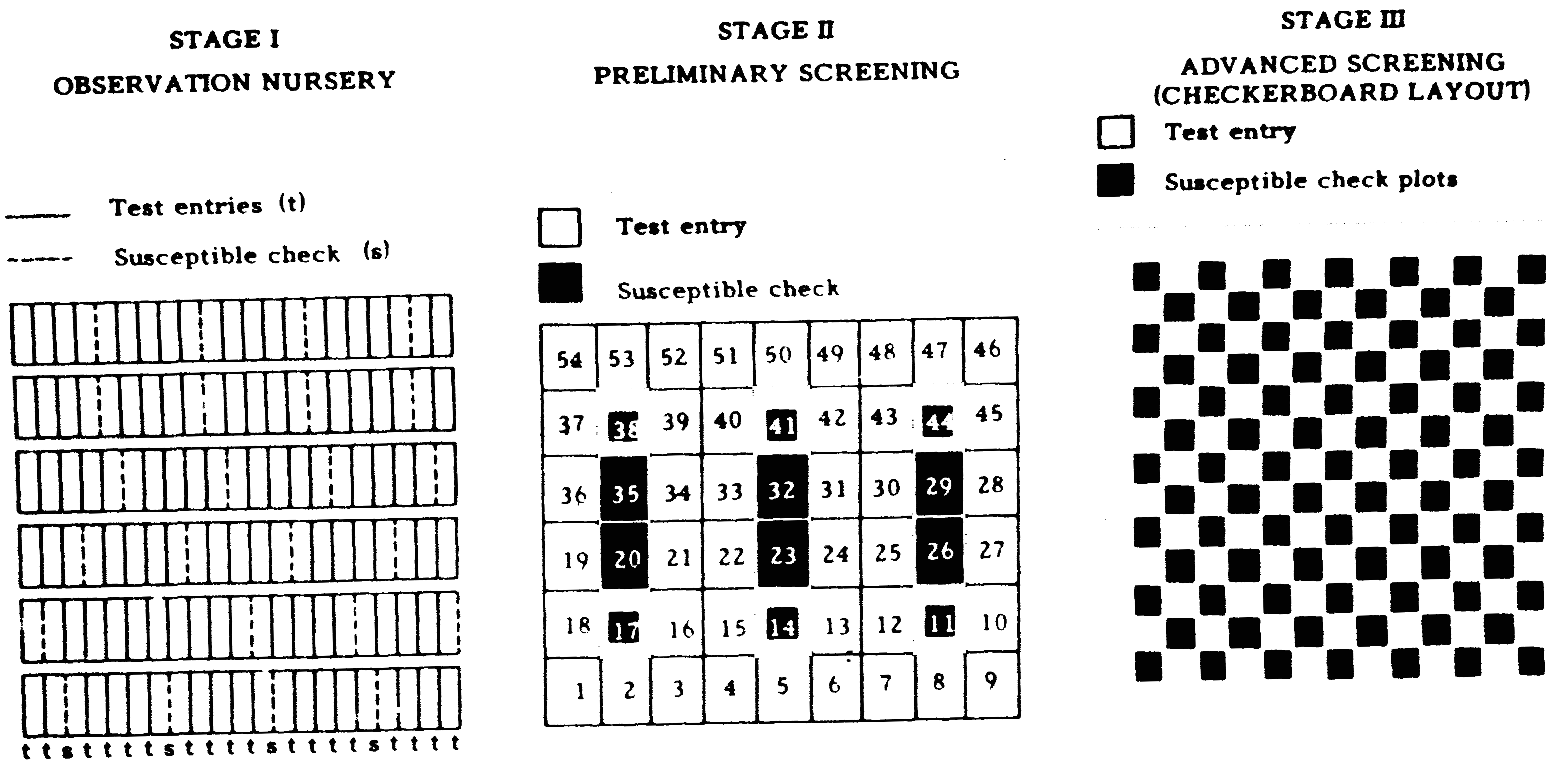


Fig. 1. A three-stage Screening Methodology for Striga Resistance Breeding in Sorghum (Vasudeva Rao et al., 1983c).

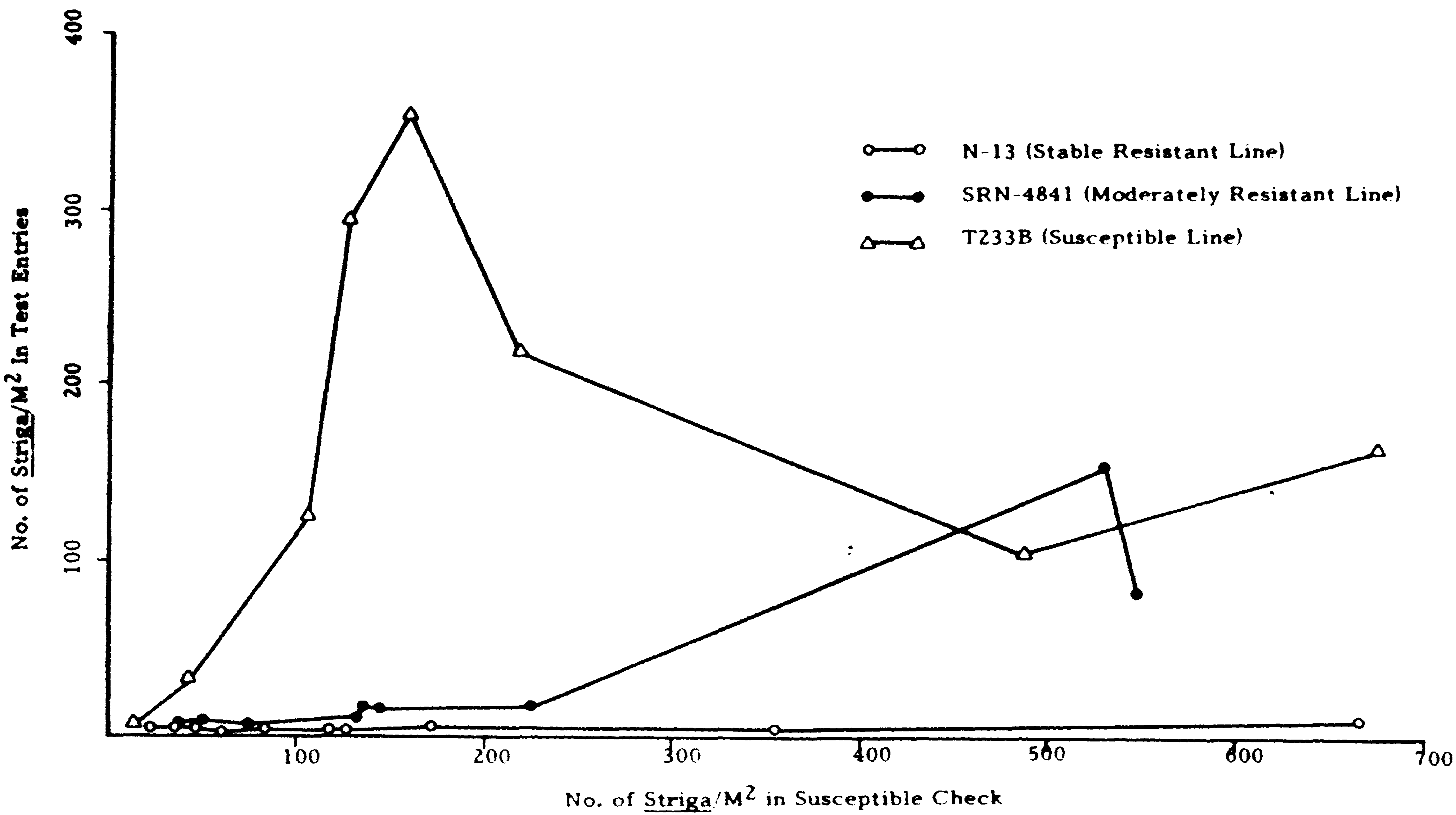
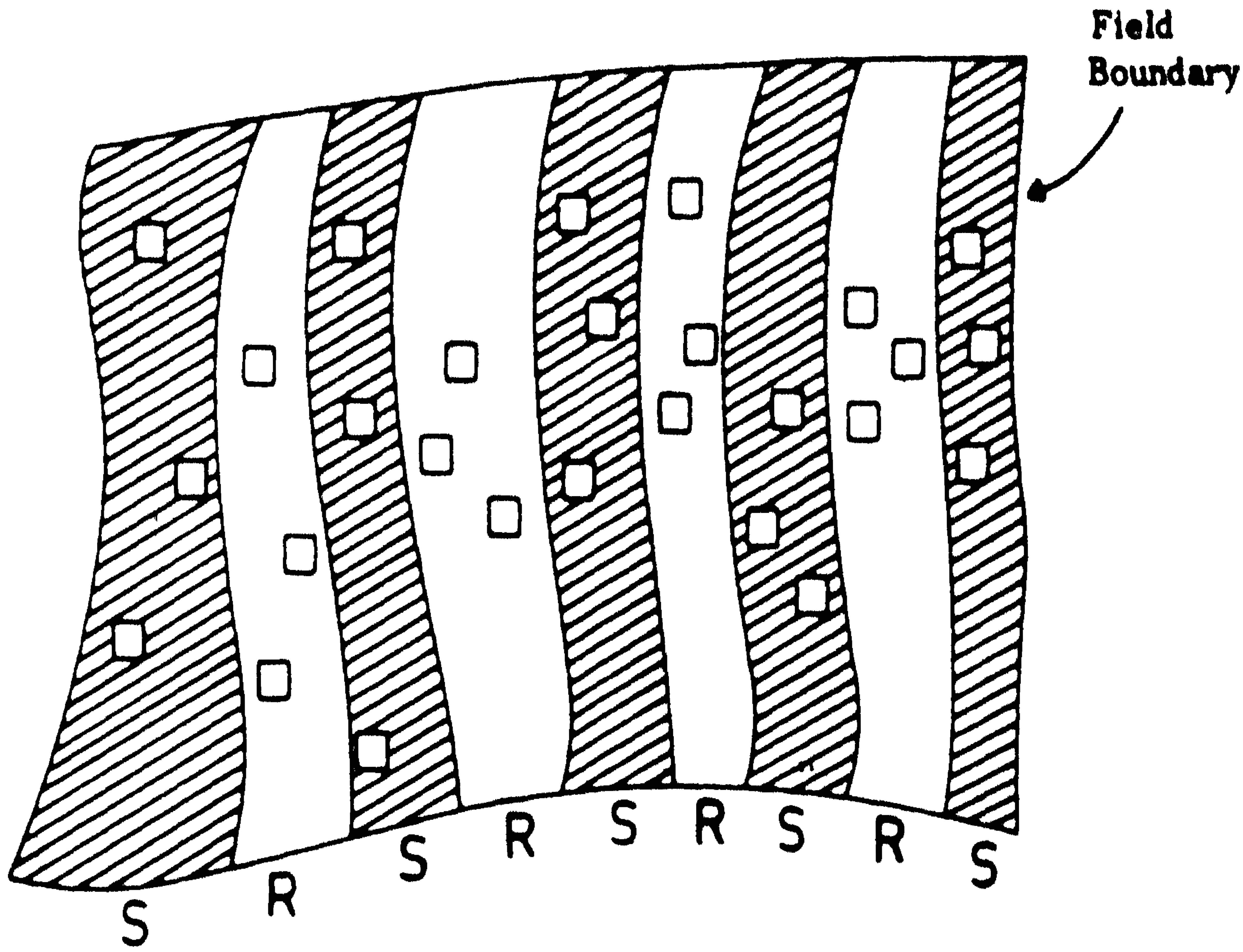


Fig. 2. Association between Striga numbers in test entries and the Striga intensity in the soil measured by the number of Striga with a susceptible check (Gulliver et al., 1983).



S = Susceptible check

R = Resistant varieties

□ = Sample area for Striga counts and yield estimation

Fig. 3. Farmer's Field Testing of Striga resistant Varieties in Alternate Strips