BENEFITS OF CROP ROTATION WITH SOYBEAN AND COWPEA IN SAVANNA CEREAL BASED SYSTEMS

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ABSTRACT

In this paper we review results of research from the West African savannas which has been conducted to quantify benefits of rotation of soybean and cowpea, to cereal-based systems. Results of research show that soybean and cowpea do not always contribute N to a subsequent cereal crop, but give indications of when to expect and how to favor, through management, a substantial benefit.

Field tests with cultivars of cowpea and soybean selected for efficacy in germinating *Striga hermonthica* seeds have shown tremendous benefit in reducing levels of *S. hermonthica* infection on both sorghum and maize. But, not all cultivars of these legumes have the same effect and *S. hermonthica* has site specific strains and races. Furthermore, field screening for efficacious cultivars is too inefficient to bring good materials to the farm level in a short period of time. Rather, national research programs should be encouraged to begin laboratory selection of cultivars for effective *S. hermonthica* seed germination. A simple inexpensive and proven laboratory technique for screening efficacious legume cultivars for *S. hermonthica* control has been developed by IITA for easy integration into national research programs.

INTRODUCTION

Improved grain legume rotation systems should be based on contributions of the grain legume to the subsequent cereal. Two major constraints to cereal production in the savannas of West Africa are N availability and *Striga hermonthica* parasitism. Soybean and cowpea varieties should be chosen for rotation with cereals based on N benefit and reduction of *S. hermonthica* seedbank. Review of past work is presented below as well as future adaptive research strategy.

NITROGEN BENEFIT TO SUBSEQUENT CEREALS

Nitrogen contribution by legumes to another crop occurs as a result of fixation of atmospheric N by *Rhizobium* spp in symbiosis with the legume, followed by decomposition of the legume plant organs (roots, nodules, leaves, stems). It is often assumed that grain legumes contribute N to the soil and therefore to a subsequent crop, but the contribution is highly variable. In some cases it is substantial while in others it is less than the limit of detection in field trials or even negative. The contribution depends on species, variety, soil, climate and management factors.

The potential N contribution to a subsequent crop depends on the N in the legume residues after grain removal which was derived from legume-*Rhizobium* symbiosis. It can be estimated from 1) the total N content of the legume, 2) the percent of total N which is derived from atmospheric N_2 fixation (Ndfa), and 3) the N removed in the grain (N harvest index or NHI). Generally speaking, if the NHI $<$ Ndfa, an N contribution can be expected. NHI $>$ Ndfa indicates soil N depletion by the legume crop.

Past work done on soybean and cowpea will be reviewed to help guide development of grain legume - cereal rotation systems. In West Africa, much more work has been done with cowpea than with soybean since the former is an indigenous crop.

Soybean Estimates of N fixation have ranged from 26 to 188 kg ha^{-1} in a review of work done in the tropics (Giller and Wilson, 1991). These quantities represent 70 to 90 % of the N in the above ground soybean dry matter. Many factors are responsible for this tremendous variability. Major plant characteristics which determine the amount of N_2 fixation are plant duration, vigour, nodulation, physiology of N_2 fixation and soil or fertilizer N use (Giller and Wilson, 1991).

Even high N fixation may not guarantee N accrual to soil and subsequent cereal. Soybean is a plant which is very efficient at translocating photosynthate and N to the grain. Eaglesham *et al.* (1982) found more N in harvested grain than the estimated amount fixed (Table 1). So we would not expect a high N contribution to subsequent maize in these studies. Indeed, Eaglesham *et al.* (1982) calculated very low contributions of 10 to 25 kg N ha^{-1} when fertilizer N addition was low and definite depletion of soil N when 100 kg N ha^{-1} was applied as fertilizer.

Table 1. Components of N balance (kg ha^{-1}) for two soybean cultivars estimated by Eaglesham *et al.* (1982).

Cultivar	Mineral N uptake	Calculated N fixed	Total N aboveground	Grain N removal	N in residues
N59-5253	28	188	216	204	12
Williams	23	120	143	141	2

The N harvest index (N in harvested portion/total N) is an indicator of the potential N supply to a subsequent crop. A smaller harvest index indicates a larger proportion of N left in the soil after grain harvest. Some workers measure the aboveground harvest index (N in harvested grain/total aboveground N). It is much easier to measure than the total NHI but it is an underestimate of the amount of N left to a subsequent crop, since root N is not included. Aboveground N harvest index values for soybean are generally in the range of 75 to 90 % (Eaglesham *et al.*, 1982).

Soybean is a relatively new crop to Africa which holds much promise. As soybean varieties are being developed for sustainable cropping systems, they need to be systematically screened for N fixation using an appropriate reference crop (non-fixing with similar duration and rooting depth). Ideally, total N harvest index should also be measured to give a real indication of potential N contribution to a subsequent crop. The difficulty of sampling roots and nodules may prevent this being done. Alternatively, the contribution to a succeeding crop should be measured directly. The N contribution to subsequent cereals should be compared to the amount of applied N as fertilizer which results in a cereal grain or total dry matter yield equivalent to that produced by the cereal test crop when grown after the legume without added N. An example of this information is given in Table 2 for several grain legume crops. This kind of screening should be done using elite soybean cultivars. Care must be exercized in the choice of preceeding crop. As can be seen in the example, maize as a preceeding crop would have overestimated the effect of the previous legumes. The choice of preceeding crop should be governed by the options available to farmers. An uncropped control should be considered if fallow is an option available to farmers. In some cases, two setsof controls might be used.

Table 2. Contribution of grain legumes to a subsequent maize crop in northern Ghana compared to N fertilizer (in kg ha^{-1}) (From Kaleem, 1993).

Previous crop	N applied to subsequent maize	subsequent maize yield (kg ha^{-1})
Maize	0	850
Bambara groundnut	0	2900
Groundnut	0	3750
Cowpea	0	3100
Soybean	0	3350
Yam	0	1800
Yam	20	2550
Yam	40	3200
Yam	80	4100

Note: All crop residues were incorporated into the soil before maize planting.

Soybean plants are often hand harvested and taken to an area where threshing is done. Residues are rarely returned to the soil. Thus the major plant organs contributing N to the soil and subsequent crop are the roots, nodules, and leaf litter which fell before harvest. Results from a study of the contribution of soybean in several sites in the guinea savanna of Nigeria show that even when soybean residues are removed from the field, the effect on a subsequent maize crop is measurable (Table 3).

The N contribution under alternative residue management should be studied such as return of aboveground residue after threshing or harvest of pods (by machine) so that aboveground residue stays on field. This should be compared to entire aboveground residue removal.

Table 3. Effect of 1993 soybean and 1994 fertilizer (in kg ha^{-1}) on 1994 maize grain yield in 10 sites in the guinea savanna of Nigeria.

Previous crop	N applied to subsequent maize	Subsequent maize yield (t ha^{-1})
Maize	20	2.35
Maize	60	3.50
TGx1456-2E	20	2.89
TGx1660-19F	20	3.56

Cowpea Worldwide tropical estimates of N fixation by cowpea are even more variable than those of soybean, from 9 to 201 kg N ha^{-1} (Giller and Wilson, 1991). Estimates from West Africa were 47 to 201 kg ha^{-1}, representing 54 to 76 % of total aboveground N. An important indicator of potential N fixation appears to be growth duration. Eaglesham *et al.* (1982) found N fixation by cowpea to increase in the order determinate < semi-determinate < indeterminate.

The N harvest index of cowpea is generally lower than that of soybean. In a trial where the aboveground N harvest index of two soybean varieties was greater than 95 %, comparable values for cowpea ranged from 37 to 60 % (Eaglesham *et al.*, 1982).

Thus cowpea is more likely than soybean to leave N in the soil for a subsequent crop. Within cowpea variability is substantial, however. Eaglesham *et al.* (1982) reported aboveground harvest indices of 37 % for an indeterminate variety, 54 % for semi-determinate, and 59 to 60 % for two determinate varieties. Aboveground N harvest index of short duration cowpea (two crops per year) at Nyankpala, northern Ghana, was 40 % in one year and 49 % in the next (Horst and Hardter, 1994). Total N harvest index of IT82-18 at Nyankpala was 34 % (Dakora *et al.* 1987).

A summary of results available from West Africa suggests substantial N benefit of cowpea to a subsequent maize crop. Horst and Hardter (1994) left residues from two short duration cowpea crops on the surface of plots where maize was then grown in the following year. The yield of maize following cowpea was higher than maize fertilized with 80 kg N ha^{-1} which was preceded by maize (Table 4). This is the only result from the West African which comes from two cycles of experimentation. Dakora *et al.* (1987) rototilled cowpea residues into the soil and found subsequent unfertilized maize yield to be equivalent to maize which was fertilized with approximately 60 kg N ha^{-1} as ammonium sulfate following a previous crop of maize (Table 5). Likewise, the results of Kaleem (1993) allow estimation of the fertilizer N value of a previous cowpea crop equivalent to 40 kg ha^{-1} to maize following yam (Table 2).

Table 4. Effect of previous cowpea crop and subsequent year fertilizer N (kg ha^{-1}) on subsequent year maize grain yield (t ha^{-1}) (From Horst and Hardter, 1994).

Previous crop	1985		1986	
	N applied	Maize yield	N applied	Maize yield
Cowpea	0	2.7	0	2.7
Maize	0	1.8	0	2.2
Maize	80	2.4	80	2.6

The difference in N fertilizer equivalents between the studies appears to be understandable. The highest value, roughly 80 kg N ha^{-1}, from Horst and Hardter (1994) came from two crops of cowpea grown in the first and second growing seasons of the first year followed by maize in the second. The second highest estimate, approximately 60 kg N ha^{-1}, from Dakora *et al.* (1987) came from first season cowpea followed by second season maize. The lowest estimate of 40 kg N ha^{-1} from Kaleem (1993) came from first year cowpea followed by second year maize.

Table 5. Effect of previous legume crop and subsequent year fertilizer N (kg ha^{-1}) on subsequent year maize grain yield (From Dakora *et al.*, 1987).

Previous crop	N applied to subsequent maize	Subsequent maize yield (t ha^{-1})
Cowpea	0	1.80
Groundnut	0	1.85
Maize	0	0.95
Maize	30	1.39
Maize	60	1.87
Maize	90	1.31
Maize	120	1.47

In the trials summarized above, residues were left on the soil surface of the plots where the cowpea was grown and even incorporated into the soil. However, cowpea vines are often collected for dry season fodder in the guinea savanna. In this case the contribution of the roots, nodules and leaf litter before harvest must be known. In some trials to evaluate rotation effects of cowpea, aboveground cowpea residues have been removed to simulate taking of fodder.

Nnadi *et al.* (1981), working at Samaru in northern Nigeria, grew three varieties of cowpea and removed the residue from the field after grain harvest.

They recorded higher yields of maize following cowpea cultivars 'Ife Brown' (2.6 t ha^{-1}) and 'NEP 593' (3.1 t ha^{-1}) than following a previous crop of sorghum (1.9 t ha^{-1}). NEP 593 was shown in another study (Nnadi and Balasubramanian, 1978) to have a much higher root N concentration (2.5 %) than 'Ife Brown' (1.5 %). In laboratory incubation, NEP 593 released inorganic N from the beginning and 'Ife Brown' roots immobilized soil inorganic N. Results like these may explain why the effect of a preceding cowpea crop on a subsequent cereal has been nearly undetectable in some cases as experienced by Jones (1974) working with one variety at Samaru.

Synthesis Generally more N contribution to subsequent cereals might be expected from cowpea than from soybean because of the lower N harvest index of the former. Just as the potential contribution from cowpea increases with growth duration, a similar effect can be anticipated from soybean. More study is needed to quantify the N content of unharvest plant organs of cowpea and soybean. Special attention should be paid to belowground organs since aboveground residues are often taken as fodder (cowpea) or in the grain harvesting process (soybean). This requires measurement of belowground dry matter and N concentration. An alternative method which does not require measurement of root biomass and N concentration is to compare the yield of a test crop following the legume to the yield of the test crop with various levels of N fertilizer. The major disadvantage of this method is the period of time required to measure the effect on a subsequent crop.

At IITA, N fixation potential is now a selection criterion for soybean. Soybean varieties are being screened for their N fixing ability using the ureide technique (Herridge and Peoples, 1990). In the national programs, elite varieties of cowpea and soybean should be screened for their effect on a subsequent cereal crop before release.

STRIGA HERMONTHICA SEEDBANK REDUCTION

Elimination of soil reserves of *Striga hermonthica* seeds is the cornerstone of any effective *S. hermonthica* control strategy. *S. hermonthica* seeds germinate only after the seeds have been exposed to the proper temperature and moisture conditions and subsequently to a germination stimulant. If there is no host present and no suitable parasitic link is established, *S. hermonthica* seedlings die several days after germination. A promising approach to reducing soil levels of *S. hermonthica* seeds, in Africa, is the use of non-host rotational crops (Doggett, 1984; Parkinson *et al.*, 1987). Some commonly grown crops, like cotton and cowpea, are not hosts for *S. hermonthica*, but the root exudates of these crops can stimulate parasite seed germination. After stimulation, *S. hermonthica* seeds germinate and subsequently die in the absence of an attachment site. However, very little research has been done on identifying the more potent *S. hermonthica* germination inducers among crops or among cultivars of crops.

Screening and identification of effective rotation crops has been tried under field conditions (Parkinson *et al.*, 1987) but the process generally requires two or more seasons to establish uniform *S. hermonthica* infestation, grow the trap crop and evaluate with a susceptible host the following season. When combined with the problem of tremendous field variability in *S. hermonthica* seed densities, field screening shows little promise in developing *S. hermonthica*-suppressive cropping systems.

Recently IITA has developed a laboratory procedure using cut roots of non-hosts to test for plant efficacy in stimulating *S. hermonthica* seed germination (Dejongh *et al.*, 1993; Berner *et al.*, 1993). The technique requires only a minimum of laboratory equipment (basic microscopes with 30X capability, autoclave or steam sterilizer, petri dishes, hand-held counters, forceps, filter paper, small pots), and eliminates the long time periods necessary for evaluation in the field and the associated field variability. To do this, surface disinfested *S. hermonthica* seeds are placed on 8-mm glass-fiber filter paper discs (25-30 seeds/disc) placed on moistened filter paper in petri dishes. Seeds are conditioned by incubating at 30°C in darkness for 10 days. Roots of 7-day-old seedlings of the test plant are cut into 1-cm pieces, weighed and placed into a 2-cm-diam. aluminum ring centered on moistened filter papers in a petri dish. Glass-fiber disks with the conditioned *S. hermonthica* seeds are placed around the central ring in 4 radii of 3 concentric rings with the first one touching the stimulant source. After incubating for 48 hours at 30°C, percent *S. hermonthica* seed germination is determined. Distances from the germination source and root weight are used as covariates in analyses of cultivar differences (Berner *et al.*, 1993).

Soybean. Using this technique IITA has been able to quantitatively distinguish between crops and cultivars high in stimulant activity. Tests with 55 soybean cultivars (Alabi *et al.*, 1994) showed significant differences in cultivar efficacy in stimulating *S. hermonthica* seed germination (Table 6).

Table 6. Summary of variability in germination of *S. hermonthica* seeds induced by cut roots[a] of soybean cultivars (Alabi *et al.*, 1994).

Cultivar	Relative germination (%)[b]	Standard error
TGx1649-11F	63.4	2.75
TGx1707-4E	53.6	2.43
TGx1660-15F	52.4	2.58
. . .	. . .	. . .
TGx1485-1D	20.9	4.21
TGx1648-3F	20.0	3.65
TGx1660-18F	17.5	2.76
Deionized water	17.2	4.21

[a] One gram of cut roots of each cultivar was used in analysis.
[b] Germination relative to 10 ppm of a synthetic germination stimulant

The distribution of the 55 cultivars with respect to efficacy in stimulating *S. hermonthica* germination is shown in Figure 1. The cultivars are distributed apparently normally, indicating the potential for selection of highly efficacious cultivars. However, because most cultivars are in the lower (< 50% germination) class, recommendations on the use of soybean as a rotation crop to control

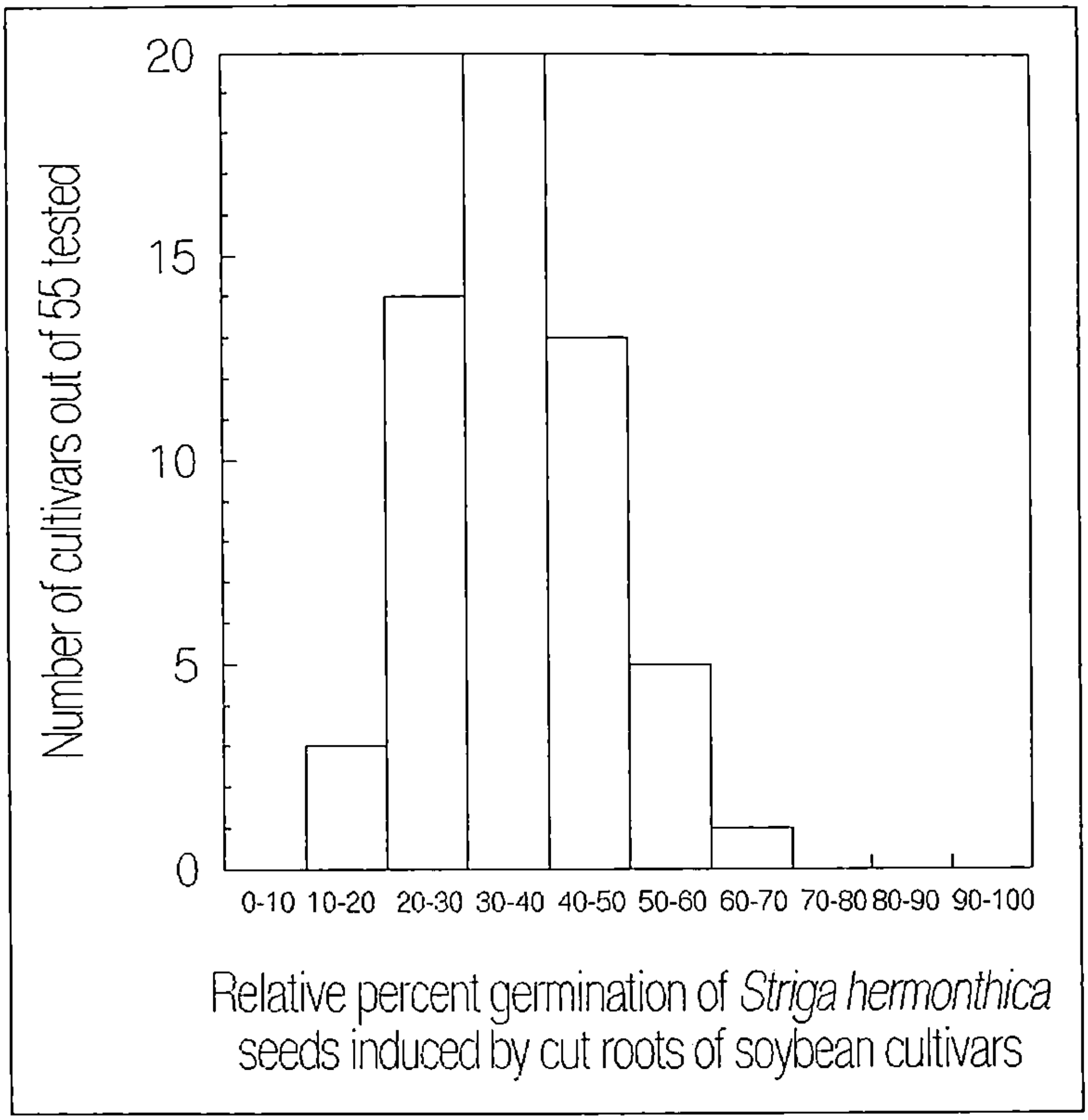

Figure 1. Induction of *S. hermonthica* seed germination by soybean cultivars (Alabi *et al.*, 1994).

S. hermonthica should be made with caution. Given the great variability among just a few cultivars in ability to stimulate *S. hermonthica* seed germination, it would certainly be a mistake to recommend planting soybean to control *S. hermonthica* if the cultivar being planted had no greater efficacy than distilled water. Thus cultivars, as well as crops, need to be screened for efficacy in germinating *S. hermonthica* seeds.

To validate results of the laboratory screening, a three year field trial was established with a selected subset of the soybean cultivars tested in the laboratory.

In this trial, local sorghum was planted in a *S. hermonthica* infested field following either sorghum cultivation or cultivation of one of the selected soybean cultivars the previous season. Preliminary results indicate that germination induced by cut roots of the cultivars in the laboratory correlated with *S. hermonthica* emergence ($r = -0.96^{*}$) and straw yield ($r = 0.96^{*}$), attributable to the respective cultivars, in the field (Alabi *et al.*, 1994). Grain yield results are yet to be collated and analyzed. Based on the correlations already obtained between laboratory and field results, the laboratory screening technique appears to be an excellent tool for selecting efficacious germplasm. Using this technique, IITA has initiated a soybean breeding program to produce high yielding cultivars which are effective N fixers and are also efficacious in stimulating *S. hermonthica* germination.

Because soybean leaves senesce, drop, and contribute to under-canopy litter during the growing season, the contribution of leaves to *S. hermonthica* seed germination may be an important adjunct to germination stimulation by soybean roots. Using the described technique, leaves and stems of soybean cultivars were tested for efficacy in stimulating *S. hermonthica* seed germination (Ariga *et al.*, 1994). There was again considerable variability among cultivars in efficacy in stimulating *S. hermonthica* seed germination (Figure 2). This variability was constant for the three isolates of *S. hermonthica* seeds used, indicating stability of efficacy across locations. The range of germination extended from greater than that induced by the synthetic stimulant, GR24, to the same as distilled water. Thus, selection of cultivars must be carried out before recommendations can be made. If the stimulant ability of the leaves of the highly effective cultivars remains constant over the life of the soybean plant, then their contribution to *S. hermonthica* seed germination and reduction of parasite seed densities in the soil may be substantial and an important additional selection criterion for crop rotation.

Cowpea. Using the laboratory technique, a cowpea cultivar, TVx3236, highly effective in stimulating *S. hermonthica* seed germination was selected for screenhouse and field tests (Ariga *et al.*, 1994). In the screenhouse, TVx3236 was compared with a cultivar of cotton, Abuja local, known to be effective in stimulating *S. hermonthica* seed germination. Results are shown in Figures 3 and

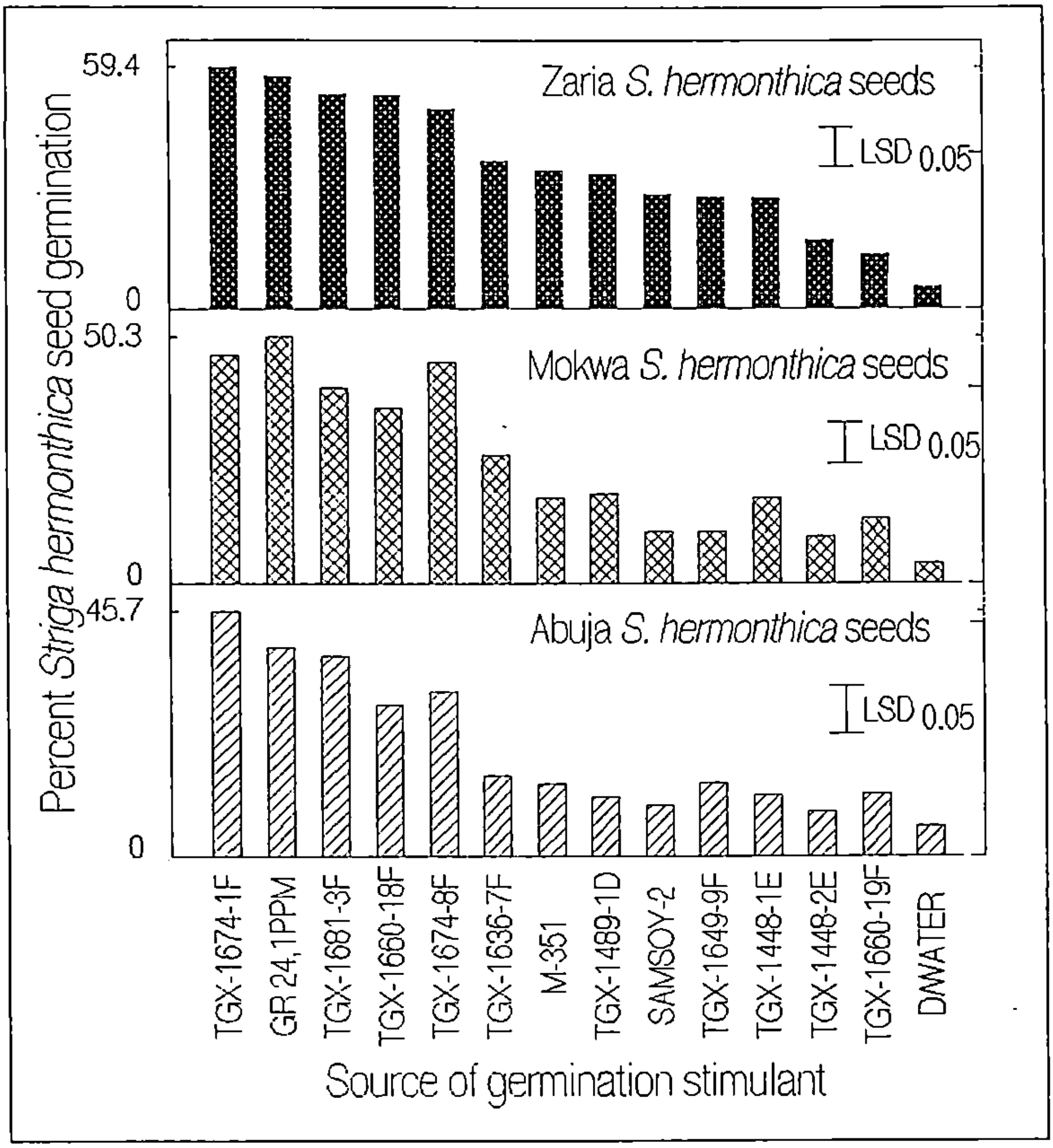

Figure 2. Germination of *Striga hermonthica* seeds by leaves and stems of 10-day-old soybean cultivars (Ariga *et al.*, 1994)

4. A significant reduction in attached *S. hermonthica* and a significant yield increase was found on the maize crop following only ten days growth of the cotton cultivar. After 40 days growth both cowpea and cotton cultivars significantly reduced *S. hermonthica* attachments and increased yield on the subsequent maize crop. After 40 days there were no significant differences between the cotton and cowpea cultivar in either *S. hermonthica* attachments or yield on the subsequent maize crop. In field tests, the effectiveness of TVx3236 in rotation was compared with three soybean cultivars, a cotton cultivar, and a maize cultivar. Residues of

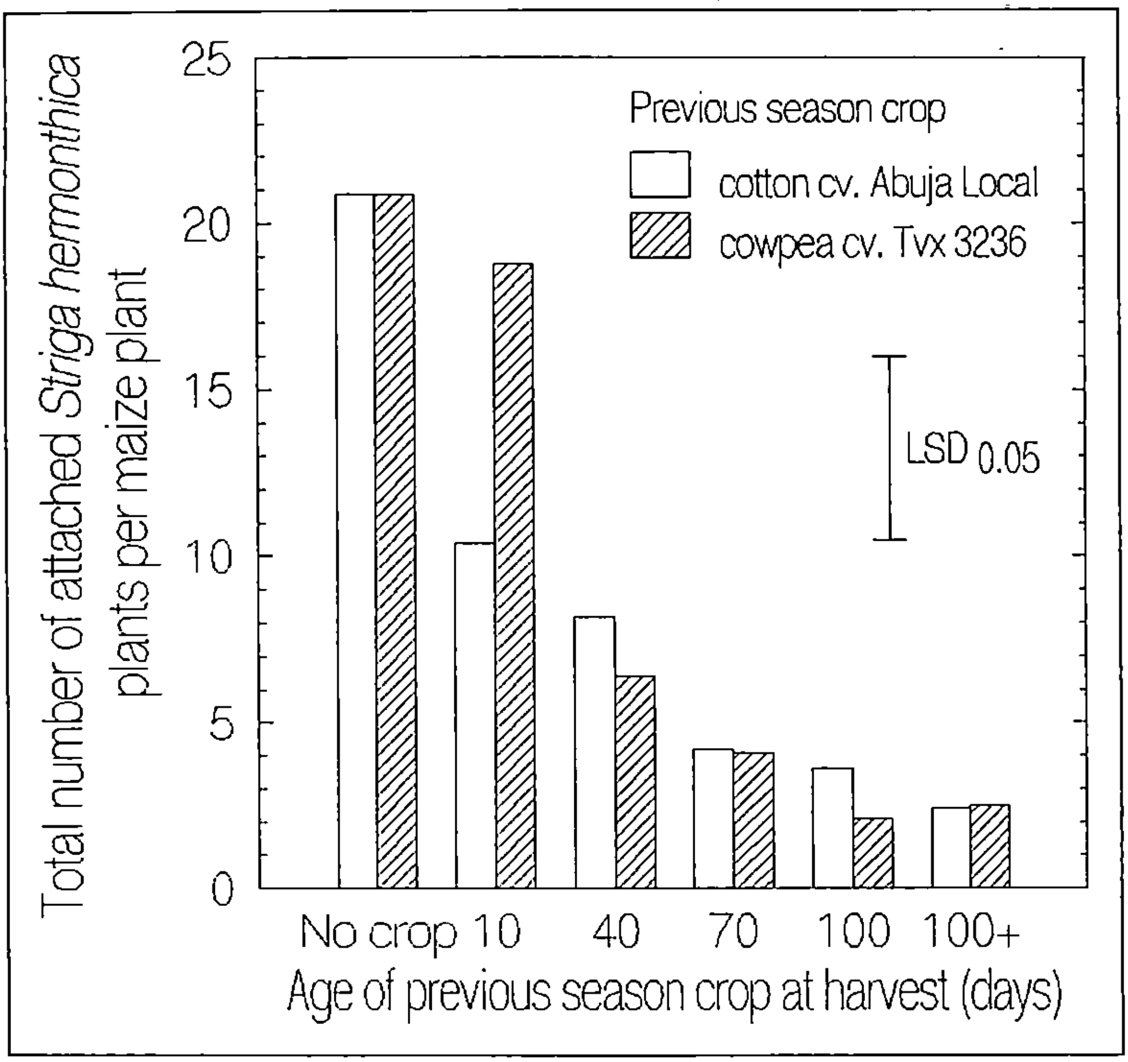

Figure 3. Effect of previous crop on *S. hermonthica* on maize in the screenhouse (Ariga *et al.*, 1994).

these cultivars were also placed in plots for comparison. Results of these field tests are shown in Figures 5 and 6. Significant reduction in emerged *S. hermonthica* was observed for cotton and two soybean cultivars, compared with continuous maize cultivation. When residue was added, the cowpea cultivar also significantly reduced *S. hermonthica* emergence. Without the addition of residue, only one

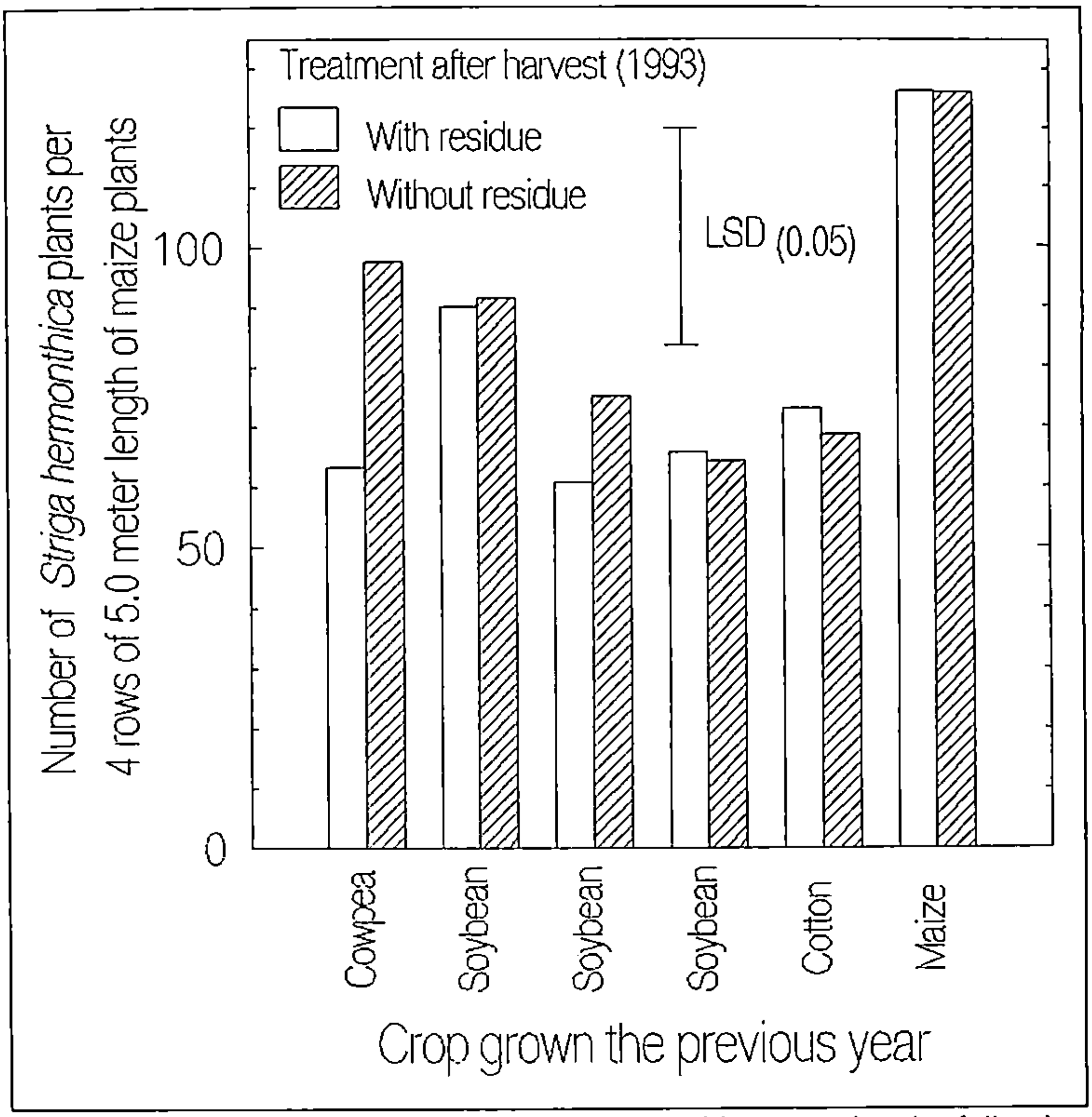

Figure 4. Effect of previous crop on *S. hermonthica* on maize the following season in field

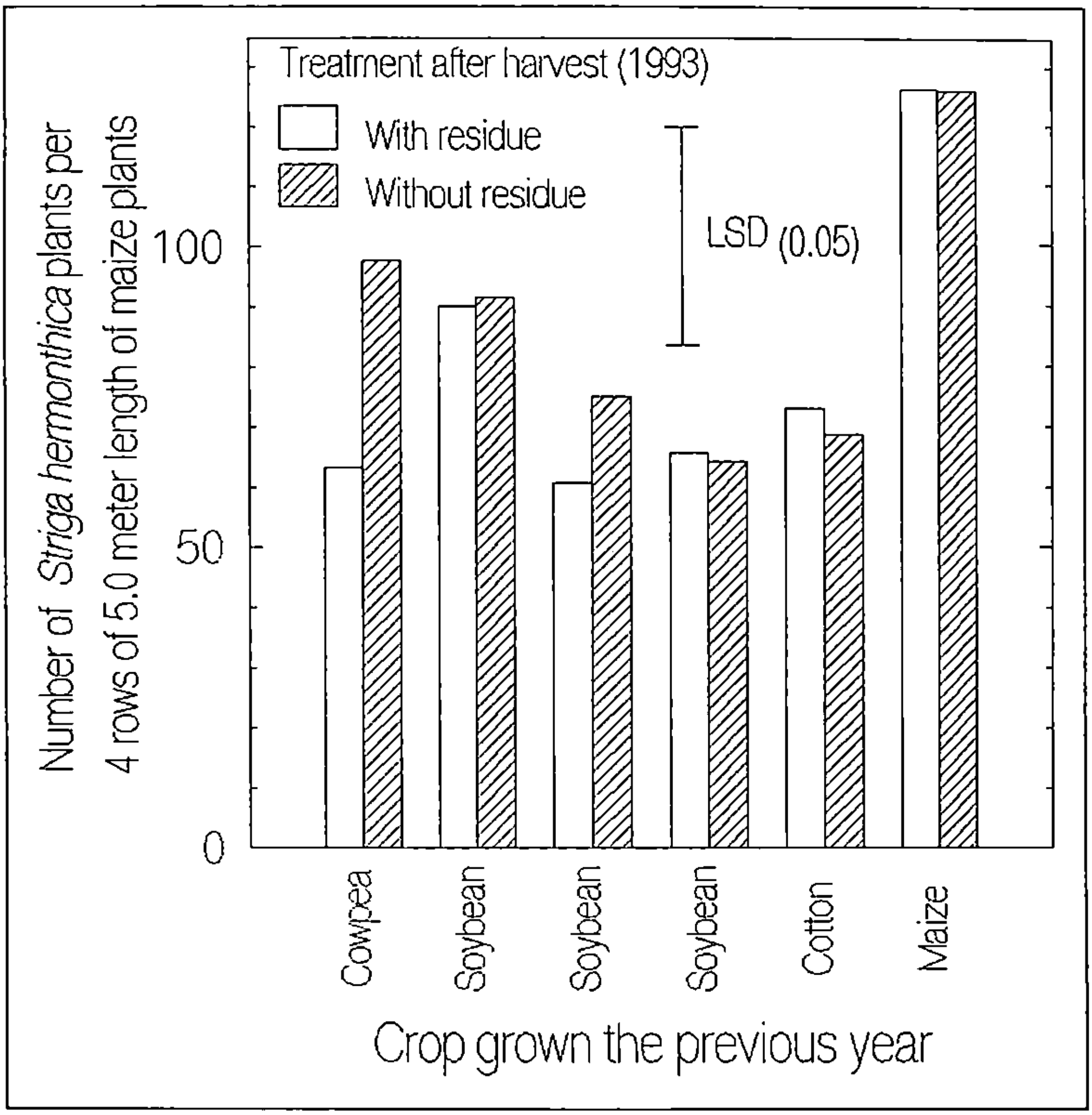

Figure 5. Effect of previous crop on *S. hermonthica* on maize the following season in field

soybean cultivar produced a significant yield increase on maize in the subsequent season. With the addition of residue, cowpea produced the greatest yield increase on maize. Cotton failed to produce a maize yield increase either with or without added residue. Since cotton was as effective as cowpea in reducing *S. hermonthica* parasitism and maize yield loss in the screenhouse, the difference in the field results are likely due to N fertility benefit of cowpea. However, the results of the screenhouse and field trials indicate that effective cowpea cultivars can be selected in the laboratory to provide control of *S. hermonthica* through rotations as effective as cotton—a standard rotation for *S. hermonthica* control.

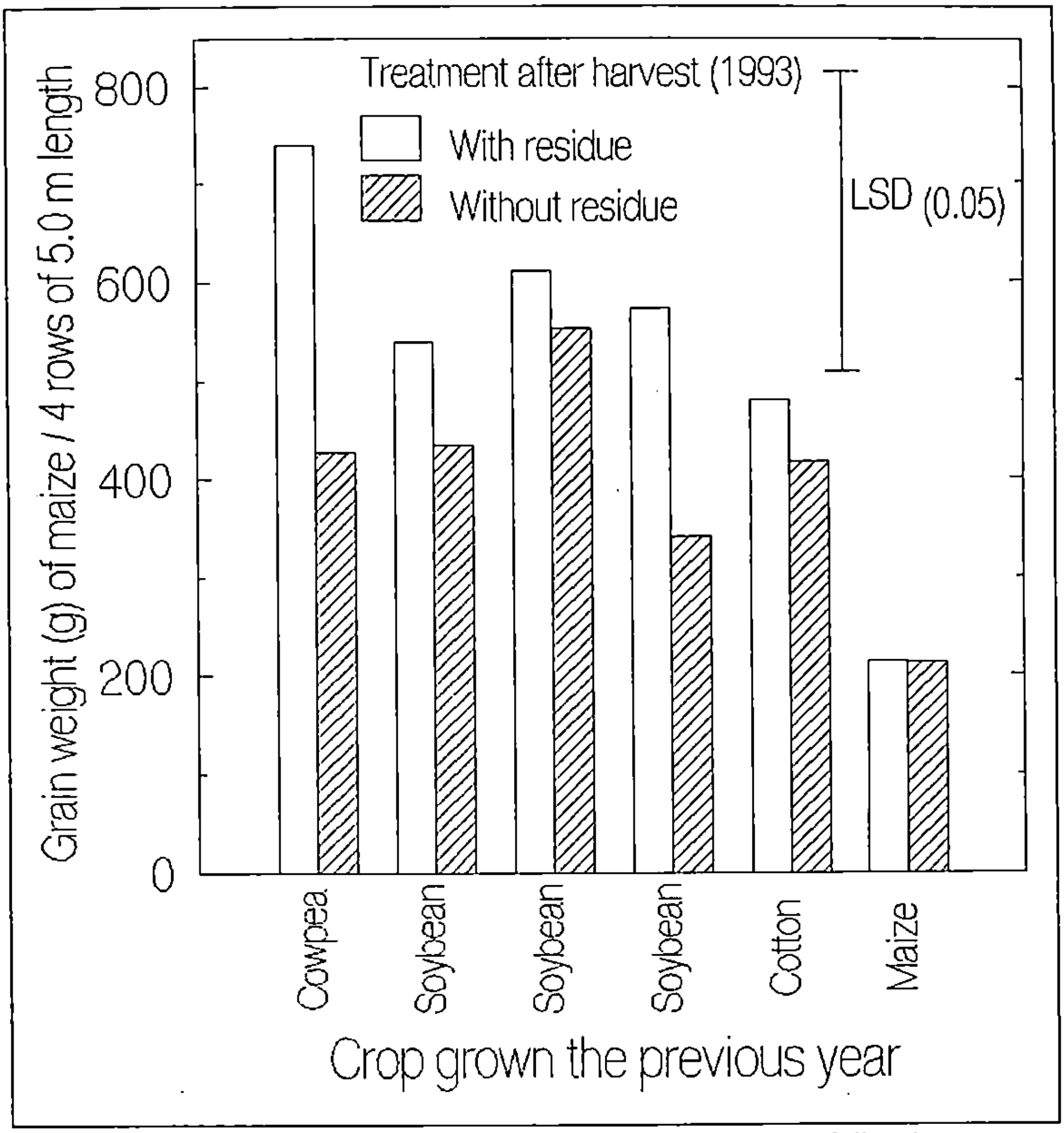

Figure 6. Effect of previous crop on maize grain yield the following season in field

Because the laboratory technique requires only elementary equipment and some training of personnel, national research programs can routinely conduct rotation-crop screening in the laboratory. Field trials can then be efficiently conducted with a reduced amount of selected materials and can be focussed on locally predominant crops and cropping systems. This provides programs with a quick assay for screening crops, cultivars, and breeding lines and facilitates development of highly effective trap crops and cropping recommendations.

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