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IMPROVING LOCAL CULTIVATION OF SOYBEAN IN INDONESIA THROUGH FARMERS' EXPERIMENTS

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SUMMARY

The results of 86 replicated experiments on soybean (*Glycine max*) cultivation practices in eight provinces – planned, conducted and analysed by farmers – were examined to identify local differences in the effects of cultural practices on yield, and to explore the potential for farmers to improve their practices. Plant spacing consistently improved yield relative to broadcast seeding. The comparison between a moderate and a high dose of N, and between local spraying practices and integrated pest management, also had a relatively consistent effect on yield. Conversely, the effects of straw mulch, of moderate doses of N compared to zero N, and of weeding, were highly location-specific. A change in cultural practices influenced yield and economic benefits more strongly in low- than in high-yield situations. Modifications of current cultivation practices often resulted in a significant yield increase. This suggests that farmers need training in how to improve their cultural practices and that it should utilize locally conducted field experiments. Training in experimental skills made farmers less dependent on external measures and advisers, and enabled them to become 'experts' who utilize science.

INTRODUCTION

Soybean (*Glycine max*) is a major food crop in Indonesia with 1.5×10^6 ha planted each year – roughly half of which is grown in rotation with wetland rice – but the national average yield is only 1200 kg ha^{-1} (Anonymous, 1996). To meet its demand for human consumption and animal feed, Indonesia has imported soybean annually for the past decade. Major problems in soybean cultivation are poor growing conditions in paddy fields, low seed quality and misuse of insecticides.

In 1986, Indonesia adopted a policy of implementing integrated pest management (IPM) in rice-based cropping systems, including soybean. Under the technical guidance of FAO, a National Programme was initiated to train farmers in season-long 'field schools' to make independent decisions on crop health management through their own observations of the crop ecosystem (Kenmore, 1991; Dilts and Hate, 1996). Soybean field schools, conducted as follow-up training for rice field-school graduates, dealt with i.a. pest- and pesticide-related issues and seed quality. However, the influence of poor growing conditions on crop health demanded further attention.

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A survey of 100 soybean farmers in East Java showed that farmers' cultivation practices varied considerably at district and village level (H. van den Berg, unpublished data, 1996). Initial experimental trials suggested that their practices often were not optimally adapted to account for local conditions. Consequently, farmer training in field experimentation – covering topic selection, conceptual frameworks, plot design, seasonal observations, yield analysis, interpretation of results, and economic analysis – was added to the curriculum of a number of soybean field schools in 1996–97. In this paper, the yield data of these experiments are analysed, with the objective of determining to what extent modifications in farmers' practices affect soybean production, how this varies between sites, and whether there is a potential for farmers to improve their practices.

MATERIALS AND METHODS

Project staff selected sites for soybean field schools in areas in eight provinces where soybean was grown in rotation with rice; only sites with actively collaborating farmers who had previously graduated from rice field schools were selected. At each site, the participating farmers decided on a factor and three treatment levels of soybean cultivation to be studied locally; the training curriculum aimed at developing the skills of farmers to conduct all stages of the study independently (van den Berg, 2000). Consequently, the factor and treatment levels varied between sites, unlike in centrally planned studies.

A completely randomised design with three treatments and three replications was used at each site, with 21 × 21 m to 30 × 30 m field sizes (individual plot size 7 × 7 m to 10 × 10 m). Trials in 1995 had indicated that a three-by-three design was a good compromise with regard to limited field sizes, high within-field variability, and ease of observation and analysis by farmers. At harvest, farmers cut an area 2.5 × 2.5 m from the centre of each plot, and dried and weighed the seeds. In addition, farmers observed various aspects of the crop ecosystem during the season; however, these data were not collected for this study.

Soybean yields were analysed in treatments at the individual sites and across sites. The term 'treatment pair' is used to indicate a comparison of two treatments at an individual site, whereas the term 'treatment combination' is applied to a comparison of two treatments across sites. Only treatment combinations recurring at five or more sites (i.e. treatment pairs) were considered for the analysis. Less common combinations were omitted. The eleven treatment combinations thus selected, each with 5–22 treatment pairs, represented 86 sites. At 38 sites a second treatment pair was selected and hence the total was 124 treatment pairs. The sites roughly represented the soybean-growing areas in eight provinces of Indonesia (Fig. 1), although the soybean areas in eastern Java and southern Sumatra were under-represented while those in Lombok and Sumbawa were over-represented.

In experiments on planting method, three treatments were considered: broadcast seeding, close spacing and wide spacing (Table 1). Analysis across sites was conducted for broadcast seeding versus plant spacing (with close and wide spacing

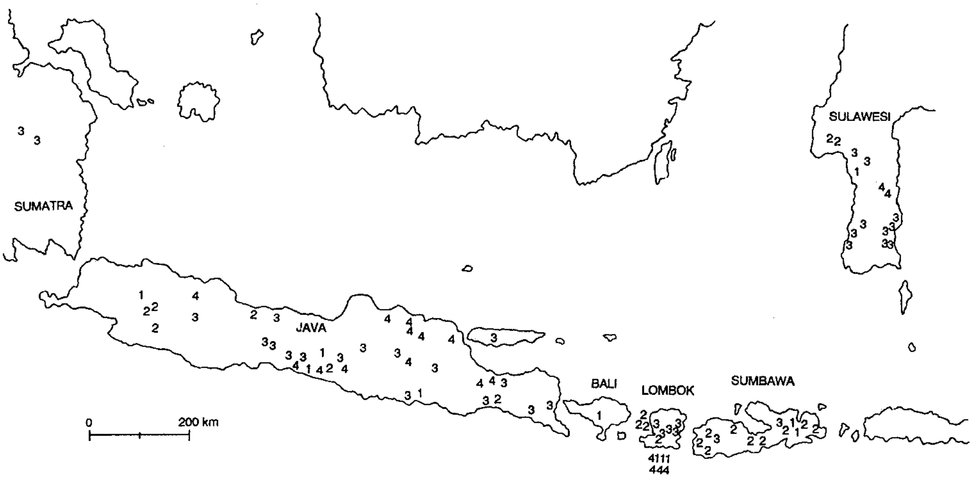

Fig. 1. Map of part of Indonesia, showing 86 sites for farmers' experiments. 1, planting method (11 sites); 2, use of rice straw (20 sites); 3, fertilizers (37 sites); and, 4, crop management (18 sites).

Table 1. Description of the experiment types and treatments in the selected farmers' experiments. Methods of soybean cultivation other than the treatments were constant within sites but variable between sites in accordance with local practices. Indonesia, 1996–97.

Experiment type	Treatments	Description
1 Planting method	a. Broadcast seeding	Unknown seed quantity broadcast by hand
	b. Close spacing	3–5 seeds hill^{-1} planted at fixed spacing of 25 hills m^{-2}
	c. Wide spacing	3–5 seeds hill^{-1} planted at fixed spacing of 12.5 hills m^{-2}
2 Use of rice straw	a. Straw mulch	4–10 cm layer of rice straw distributed evenly over the plots
	b. Straw ash	Ashes of burned rice straw distributed evenly over the plots
	c. Without straw	All rice straw removed from the field
3 Fertilizers		
Nitrogen	a. Low N	22–27 kg N ha^{-1}, applied as urea (45% N) at, or shortly after, planting
	b. High N	45 kg N ha^{-1}, applied as urea (45% N) at, or shortly after, planting
	c. Without N	Zero added N
Phosphorus	a. With P	22–45 kg P ha^{-1}, applied as TSP (45% P) at planting
	b. Without P	Zero added P
Potassium	a. With K	25–50 kg K ha^{-1}, applied as KCl (50% K) at planting
	b. Without K	Zero added K
4 Crop management		
Pests	a. Local practice	5–10 (mean 8.2) pesticide applications season^{-1}; no herbicides
	b. IPM	0–4 (mean 1.7) pesticide applications season^{-1}; no herbicides
	c. Unsprayed	Zero pesticide applied
Weeds	a. 2 × weeding	Hand weeding twice in vegetative crop stage; no herbicides
	b. Without weeding	No weed control measures

combined), and for close spacing versus wide spacing. With respect to mulch application, the treatments straw mulch, straw ash and no straw were considered (Table 1).

In experiments on fertilizers, nitrogen, phosphorus and potassium fertilizers were treated separately. Three treatment categories were considered for nitrogen: low N, high N, and zero N (Table 1). For phosphorus and potassium, only two treatment categories were considered: with and without, but the application levels in the former treatment category varied from 22–45 kg P ha^{-1} and 25–50 kg K ha^{-1}.

In experiments on crop management the effects of pests and weeds were considered separately. Three pest management treatments were applied: the local practice (prior to adoption of IPM), IPM, and the unsprayed treatment. In the IPM treatment, pest management decisions were based on farmers' weekly observations of the crop ecosystem, as learnt during the farmer field school, which resulted in a reduced number of applications, as indicated in Table 1. Two weed management treatments were applied: 2 × weeding and zero weeding (Table 1).

Soybean varieties were identified by farmers as 'Wilis' (65 sites) or under 9 other names (21 sites); however, farmers commonly bought unlabelled seed for planting.

Environmental variables, including local practices of soybean cultivation other than the experimental treatment, remained unknown. Hence, their influence on the observed treatment effects could not be explored. The main purpose of this large-scale study, however, was to evaluate the general trend in yield advantages associated with each modified cultural practice across all sites, and to provide an insight into the prospects for farmers to improve their soybean yields. Moreover, the degree of variation in yield increments between sites was evaluated to suggest the need for either, a generalized training curriculum (if a cultural practice caused consistent yield advantages), or for on-site empirical experiments (if yield advantages were variable between sites).

Analysis was conducted at two levels: at the individual sites and across sites. At the individual sites, yield data in treatment pairs were analysed using the *t* test (n = 3, $p < 0.05$). Yield increments across sites were studied by examining mean yield in treatments *a* and *b* ($Y(a)$ and $Y(b)$) of each treatment pair, and calculating the mean yield increment Y_i of treatment *b* relative to treatment *a* for *n* sites as:

$$Y_i = \left\{ \sum_n (Y(b)_n - Y(a)_n)/Y(a)_n \right\} \Big/ n$$

The advantage of this method compared with regression analysis is that it gives a single measure of yield increment. Data were not weighted and, hence, a 20% increase at 500 kg ha^{-1} was valued as much as a 20% increase at 2000 kg ha^{-1}. This was consistent with the project's focus on smallholder farmers, not on general production. The yield increments were separately examined in relation to yield level.

The degree of variation in relative yield increments between treatment pairs was determined by the standard deviation of the mean. The t test was used for each treatment combination to determine whether the yield increment across sites was significantly different from zero ($p < 0.05$). For graphical presentation, yield of treatment a was plotted against yield of treatment b for a number of sites.

Thus far the analysis of yield data has been described irrespective of which treatment was the current practice and which was a modified practice. What was current practice at one site would be considered a modified practice at another site. To explore the prospects for farmers to increase their soybean yield through modification of their practices, the treatment which represented the current practice at each site was identified. Information on current practices was absent from 15 sites; these sites were omitted. Whether yield in the modified practice treatment was significantly higher than that in the current practice treatment (t test, $n = 3$, $p < 0.05$) was determined for the remaining 71 sites.

In the preliminary trials farmers calculated the average yield per treatment without considering the variation between replications, often resulting in premature or erroneous conclusions. To help farmers improve their analyses, a simple statistical test was developed. It established, through graphical presentation, that two treatments differed if their ranges from minimum to maximum value of three replications did not overlap. The validity of this method was tested: the data of each of the 124 treatment pairs were analysed with both the 'Statistical Test for Farmers' and the t test ($p < 0.05$); the decisions of the two tests were compared.

After harvest, the farmers determined the cost of inputs, labour and land rental, yield weight and the local price of their produce in order to calculate the economic benefit per unit area. Economic data was obtained from 14 sites; benefits at the other sites remained unknown.

RESULTS

This study indicated that farmer groups are able to plan, conduct and evaluate their own field experiments. The 86 studies produced a wide range of yields varying from 360–3300 kg ha^{-1} (mean 1400 kg ha^{-1}).

In experiments on planting method, fixed plant spacing gave, on average, 42% higher yield across sites than did broadcast seeding (Table 2), and variation between sites was small, indicating a consistent effect. At four individual sites, the effect was significant (Fig. 2a). The comparison between close and wide spacing showed no effect across sites. At two individual sites, however, wide spacing gave significantly higher yields whereas, at another site, close spacing was significantly superior.

The use of rice straw for mulching increased yield across sites by 41%, but variation between sites was large, suggesting that the effect of mulching was highly location-specific. Fig. 2a shows that mulching doubled yield at some sites whereas no effect was observed at several other sites. Application of straw ash gave a more modest yield increase of 15% (Table 2).

Table 2. Relative yield increments of soybean (mean and SD across sites) associated with modified cultural practices. Eleven treatment combinations are presented each of which recurred at a number of farmers' experimental sites. The yield increment is the yield advantage of the second treatment relative to the first treatment in each treatment combination.

Experiment type	Treatment combination		Sites (*n*)	Relative yield increment (%)			
				Mean	SD	*t*-value	*p*
1 Planting method	Broadcast	*vs* Plant spacing	8	41.6	4.5	5.95	0.001
	Close spacing	*vs* Wide spacing	7	12.3	7.5	2.09	0.08
2 Use of rice straw	Without straw	*vs* Straw mulch	20	40.9	30.9	3.80	0.001
	Without straw	*vs* Straw ash	13	14.5	16.3	2.21	0.05
3 Fertilizers	Without N	*vs* Low N	22	18.1	16.6	3.53	0.002
	Low N	*vs* High N	5	−2.8	4.6	0.53	0.6
	Without P	*vs* With P	14	20.3	8.8	4.48	0.001
	Without K	*vs* With K	6	8.8	9.6	1.56	0.2
4 Crop management	Local practice	*vs* IPM	11	−2.3	3.4	1.44	0.2
	Unsprayed	*vs* IPM	12	15.9	10.0	3.01	0.01
	Without weeding	*vs* 2 × weeding	6	33.2	14.7	3.09	0.03

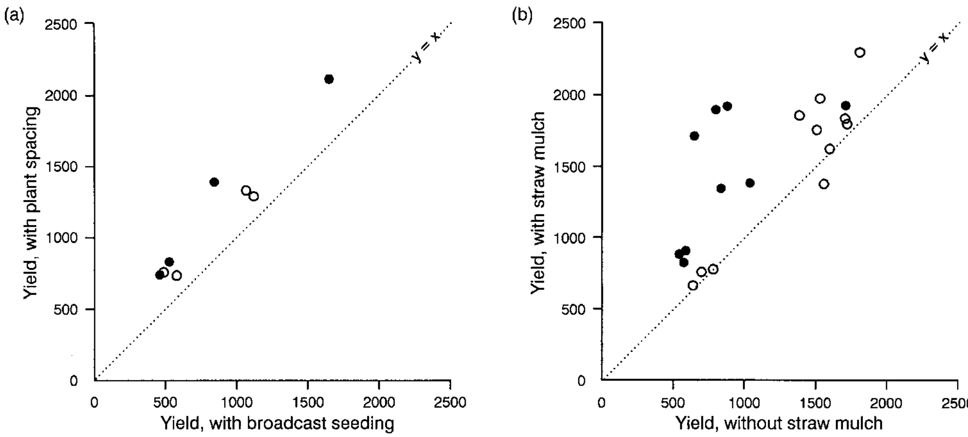

Fig. 2. Comparison of soybean yield (kg ha^{-1}) in treatments pairs at farmers' field sites; circles indicate individual sites; solid circles indicate sites with a significant effect (t test, n = 3, $p < 0.05$). (a) Broadcast seeding *versus* fixed plant spacing; (b) rice straw removed *versus* rice straw used as mulch.

Low doses of N fertilizer generally increased yield by 18%, but variation in the effect of N was large. The increase was significant at seven sites, but at others no effect of N was found (Fig. 3a). A higher dose of N did not increase yield in comparison with a low dose (Table 2). In fact, one site showed a significant yield decrease at a higher dose, and additional farmers' observations indicated an increased vegetative growth but a decreased number of fruiting bodies at the higher dose. Application of P fertilizer generally increased yield by 20%, with substantial variation between sites. Added K did not increase yield significantly, but the number of experiments on its use was small (Table 2).

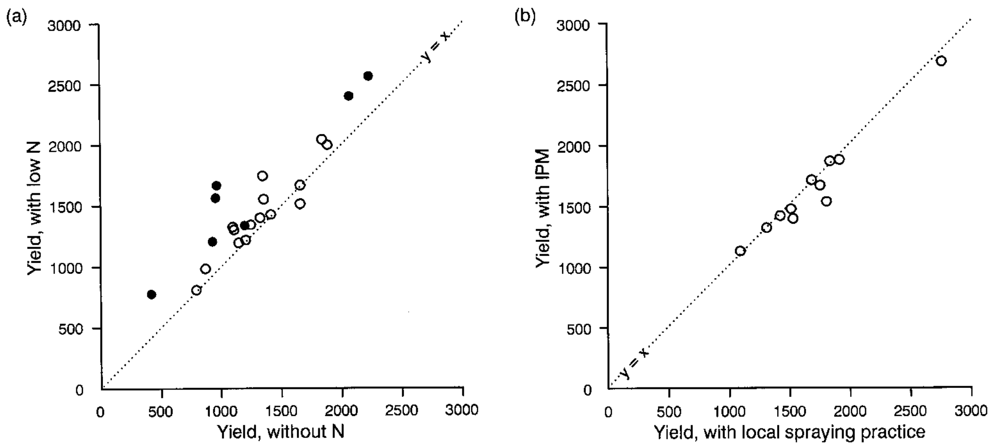

Fig. 3. Comparison of soybean yield (kg ha^{-1}) in treatment pairs at farmers' field sites; circles indicate individual sites; solid circles indicate sites with a significant effect (*t* test, n = 3, $p < 0.05$). (a) Without N *versus* low dose of N (22–27 kg ha^{-1}); (b) local spraying practices *versus* IPM (see text).

In experiments on crop management, the IPM treatment gave similar yields to those of the local practice treatment, with little variation across sites (Fig. 3b). The average pesticide input was substantially reduced in the IPM treatment (from 8.2 to 1.7 applications per season). Yields were lower in the unsprayed treatment than in the IPM treatment, but the effect varied across sites. In the local practice, insecticides were generally applied before pod-set of soybean, i.e. when the adverse effect on natural enemies is most severe (van den Berg *et al.*, 1998), even though soybean is generally least vulnerable to insect feeding during vegetative growth (Shepard and Shepard, 1997). Twice-weeding increased yield by 33% across sites (Table 2); again, variation in the effect was large, owing to local differences in competition with weeds.

The average yield difference between the two treatments in a treatment pair was independent of the yield level (of the treatment with the lowest yield): in low yield situations the absolute difference was similar to that in high yield situations (Table 3). The proportional difference, however, was substantially larger at low

Table 3. Average yield difference between two treatments in each treatment pair, classified according to the yield level of the treatment with the lowest yield (irrespective of which was the current treatment); *n* indicates the number of treatment pairs.

Yield level (kg ha^{-1})	Average yield difference		*n*
	kg ha^{-1}	%	
<1000	297	41.5	38
1000–1500	202	16.8	38
1000–2000	211	12.5	42
>2000	352	13.5	6

Table 4. Number and percentage of sites, arranged by experiment type, where the experiment indicated a potential to improve soybean production locally, which was determined by yield in the modified practice treatment being significantly higher than that in the current practice treatment (t test, $n = 3$, $p < 0.05$).

	Sites showing potential for improvement		
Experiment type	Number	%	Total sites
1 Planting method	5	50	10
2 Use of rice straw	9	50	18
3 Fertilizers	7	26	27
4 Crop management	2	13	16
Total	23	32	71

yields, indicating that soybean in low yield situations is more strongly influenced by a change in cultural practices.

At many sites, the modified practice treatment gave a significantly better yield than did the current practice treatment, suggesting a large potential for farmers to improve soybean production (Table 4). In experiments on planting method and use of rice straw, the alternative treatment was superior in half of the treatment pairs. With respect to experiments on fertilizers, the alternative treatment was superior in roughly one quarter of the sites. In experiments on crop management – predominantly pest management – the potential to increase yield was lower but the cost of pesticides could be substantially reduced.

The Statistical Test for Farmers was compared with the t test, using the data of all treatment pairs; in only 7 out of 124 treatment pairs (5.6%) did the two tests differ, the latter being more conservative (Table 5). Therefore, the Statistical Test for Farmers is roughly comparable to the t test for experiments with three replications. On various field visits, it was observed that the test was suitable for use by small groups of farmers. It helped farmers to avoid drawing erroneous or premature conclusions from field data.

Table 5. Comparison of decisions of two statistical methods, the Statistical Test for Farmers and the t test ($p < 0.05$), based on the yield data of individual treatment pairs, each treatment having 3 replications. The number of treatment pairs in each category are presented.

	Statistical test for farmers†	
t test	Effect	No effect
Effect	51	0
No effect	7	66

† This test establishes that two treatments are different if their ranges from minimum to maximum value of three replications do not overlap.

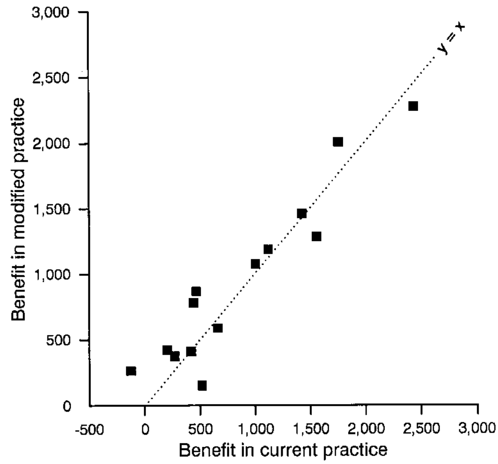

Fig. 4. Comparison of economic benefits of soybean production in current practices versus modified practices at 14 farmers' field sites (in '000 Indonesian Rp.); squares indicate individual sites.

Economic analysis conducted by farmers suggested that there is potential for farmers to increase their benefits by modifying their cultivation practices, particularly in low yield situations (Fig. 4).

DISCUSSION

The wide range of soybean yields reflected the diverse field conditions for soybean grown in rotation with rice. A change in soybean cultivation practices often increased yield to an extent that was measurable by farmers in simple, small-scale field experiments. The potential to improve production and to increase economic benefits was particularly large in low-yield situations.

Certain practices had a consistent effect on yield; others showed an inconsistent or location-specific effect. Plant spacing consistently improved yield relative to broadcast seeding. Also, comparisons between a moderate and a high dose of N, and between local spraying practices and IPM, displayed a relatively consistent effect on yield. Hence, this information might be suitable for a general training curriculum or list of recommendations. Conversely, the effects of straw mulch, moderate doses of N compared to zero N, and of weeding were highly location-specific. Clearly, these practices demand an on-site empirical approach.

The beneficial effect of straw mulch – through reducing soil temperature and, hence, crusting of soil and evaporation of soil moisture (Verma and Kohnke, 1951) – depends on the degree of moisture stress and the physical properties of the soil. The plant's response to N fertilizer may be related to soil acidity or to the presence of compatible strains of rhizobium bacteria (*Bradyrhizobium japonicum*) (Brotonegoro *et al.*, 1991). N fixation may also be adversely influenced by moisture stress and high soil temperatures (Dawson *et al.*, 1976), conditions that prevail for soybean grown during the dry season in paddy fields.

Despite the importance of location-specific variables, many farmers had not adjusted their practices to account for field conditions and, thus, the potential to increase yield (or, to reduce inputs) was high. This suggests, first, that farmers need training on how to improve their cultural practices and, second, that training should utilize locally conducted field experiments. Top-down demonstration plots or extension messages would not be able to deal effectively with the heterogeneous and dynamic field conditions for soybean in Indonesia. More importantly, training in experimentation skills gave farmers the confidence and competence to be less dependent on external measures and advisors, to become 'experts' who utilize science.

If farmers are involved in all stages of a field study, from planning through evaluation of results, the adoption level of experimental results and the impetus for follow-up activities will be high (Ooi *et al.*, 1999). Farmer training in field experimentation has now been added to the training curriculum for all soybean field schools. Traditionally, farmers in different parts of the world have been experimenting in their own fields (Harwood, 1979), often with replications taken over time (Bentley, 1994). Clearly, part of this expertise was lost during the Green Revolution when farmers became more dependent on external technologies. Our results indicate that farmers can both reverse this trend and improve their traditional methods of experimentation.

Farmers' experimentation skills are crucial in the current phase (1999) of the IPM programme in Indonesia. In rice-growing regions, 30–60% of farmer groups have graduated from farmer field schools, mainly on rice. In addition, the role of Field Trainers at the sub-district level is gradually being taken over by farmer trainers; farmer trainers (currently 26 000 in number) are farmers who were trained to be farmer field school leaders. Furthermore, follow-up training is strengthening farmer group activities and networking at the village and sub-district level (FAO, 1997). Hence, a transition is taking place from extension via training in IPM towards community-based IPM, where farmers are no longer recipients of technology but active players in the development of local programmes. In a heterogeneous and dynamic agricultural environment, soybean farmers will continually face local or new problems that require empirical field experiments.

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