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Adaptability of Improved Rice Varieties in Senegal[†]

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ABSTRACT

Using yield gap and adaptability (modified stability) analyses, this study evaluated the potential relevance of improved rice varieties released by, or soon to be released by, the Senegalese Agricultural Research Institute (ISRA) in the Casamance Region of Senegal. Results from researcher-managed, on-farm trials indicated that level of fertiliser applied accounted for most of the difference in Yield Gap II (i.e. the difference between potential [experimental] and actual yields at the farm level), followed by variety. Also, the adaptability analysis results indicated that most of the improved varieties performed poorer than local varieties under poor production environments but better than local varieties under good production environments. We conclude that the rice breeding programme needs to pay greater attention to developing varieties better adapted to the varied production environments under which farmers operate. © 1998 Elsevier Science Ltd. All rights reserved

INTRODUCTION

The Casamance area is located in southern Senegal. The climate is classified as dry Guinean Savanna. Rice is an important source of nutrition in this traditional rain-fed rice growing region. The organization of rice production

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is tied closely to the social and religious stratifications of the community (Linares, 1981). A wide range of indigenous rice varieties traditionally have been grown in the area, although farmers recently have been very willing to experiment with new varieties. Considerable diversity exists in the area both in terms of farming/cropping systems and the conditions under which rice is grown. Three types of rice-based systems occur (i.e. aquatic, phreatic and rain-fed), with the variety grown being determined by the position of the plot on the toposequence. Superimposed on these differences is considerable variability in soil quality and management of the rice plots. Factors influencing management include differences in resources between farming households and differences in the managerial ability of farmers. Differences also result from stochastic events over which farmers have little control. For example, major trends or constraints that have emerged since 1973 include persistent patterns of drought and salt intrusion, which brings into question the continued suitability of many of the local varieties.

Because of farmers' risk aversion, the probability of widespread adoption of a new variety will be enhanced if that variety shows stable yield superiority over a range of production environments. The introduction of new rice cultivars with high yields and short duration has been viewed as a strategy to increase and secure rice production in the area. Accordingly, researah programmes and extension projects have focused on the development and diffusion of improved rice varieties through multilocational, on-farm, and adoption trials. The purposes of this study were to investigate the performance of new rice varieties across the different production environments faced by producers in the Casamance and to make recommendations for their improvement.

APPROACH

Three major techniques were used in this study: yield gap analysis, adaptability analysis and fertilizer response analysis.

Yield gap analysis

Yield gap analysis, developed by the International Rice Research Institute in the 1970s, has been used extensively to measure and analyse the determinants of yield gaps in farmers' fields in Southeast Asia where high yielding varieties have been adopted (De Datta et *al.*, 1978). Because the main focus is on Yield Gap II (i.e. the difference between potential [experimental] and actual yields at the farm level), it is essentially on-farm testing after the fact. This yield gap can be interpreted in either of two ways: first, as representing the potential production increment above farmers' yield levels or, second, as an indicator of more fundamental problems with the varieties themselves, particularly their poor adaptation to farmers' environmental or managerial constraints. If the principal factors causing the yield gap can be resolved practically at the farm level, greater weight should be given to the first interpretation, and steps to resolve these factors should be considered as necessary complements for the successful extension of the new varieties. However, if these factors cannot be resolved practically, then the second interpretation is relevant and the research objectives and methods that are producing such poorly adapted varieties must be reconsidered. The general objective was to identify the factors that explain the difference between actual and potential rice yields in selected environments. The contributions of test factors (variety, fertilizer, pest control) to Yield Gap II were determined by means of a factorial tria1 using a modified version of the design developed by De Datta *et al.* (1978). The experimental levels were the farmer's level (Level 1), consisting of local variety, no fertilizer and no pest control, and the recommended level (Level 2), consisting of improved variety, 150 kg/ha of fertilizer (urea) and pest control. Factor levels for each treatment are shown in Table 1, and the accompanying equations were used to calculate the contributions of the three factors to Yield Gap II.

TABLE 1
Treatments Included in the Yield Gap Tria1

Treatment	*Variety*	*Fertilizer*	*Prst control*	*All other factors*
1	1	1	1	1
2	2	1	1	1
3	1	2	1	1
4	1	1	2	1
5	2	2	1	1
6	2	1	2	1
7	1	2	2	1
8	2	2	2	1

Based on these treatment descriptions and using Y, to represent the yield of treatment *i*, the formula is:

$$\textit{Yield gap} = Y_8 - Y_1 \qquad \text{(T1)}$$

$$\textit{Contribution of variety} = \frac{Y_2 + Y_5 + Y_6 + Y_8}{4} - \frac{Y_1 + Y_3 + Y_4 + Y_7}{4} \qquad \text{(T2)}$$

$$\textit{Contribution of fertilizer} = \frac{Y_3 + Y_5 + Y_7 + Y_8}{4} - \frac{Y_1 + Y_2 + Y_4 + Y_6}{4} \qquad \text{(T3)}$$

$$\textit{Contribution of pest contrbl} = \frac{Y_4 + Y_6 + Y_7 + Y_8}{4} - \frac{Y_1 + Y_2 + Y_3 + Y_5}{4} \qquad \text{(T4)}$$

Adaptability analysis

Adaptability (formerly called modified stability) analysis techniques have been developed to compare the performances of cultivars across different environments. The technique involves regressing the yield of each variety at each site against the mean yield of all varieties at each site (Hildebrand, 1983; Hildebrand and Russell, 1996). The mean yield then represents a type of environmental index. A site where yields are low, due either to management or to physical site characteristics, is considered a poor environment, and a site with high yields is a good environment. With this definition, environment is measured as a continuous proxy variable across the range of average yields. In this study, we categorized and grouped the improved varieties according to four standard stability types: Type A occurs when the yield of an improved variety is superior to the local variety across all enviromnents; Type B is when the improved variety is superior to the local variety in poor environments but is inferior in good environments; Type C occurs when the yield of an improved variety is inferior to that of the local variety in poor environments but superior in good environments and Type D represents the case in which the improved variety is inferior over all environments. Because the level of fertilizer is likely to be one important factor determining the quality of the environment, two regression models were estimated at two levels of fertilizer use, namely one at 0 and one at 100 units of N. The regression estimated was as follows:

$$Y_{ikj} = a + b_1 Z_j + b_2 X_i + b_3 Z_j X_i + \epsilon \tag{1}$$

where

Y_{ikj} = yields for the improved variety i and the local variety k at location j,
Z_j = the average yield of all varieties at location j
X_i = a dummy variable that takes the value 1 for the improved variety and 0 otherwise
ϵ = a random variable with an assumed normal distribution

Fertilizer response analysis

Local varieties have evolved over generations and have become well adapted to environments that generally have received little in the way of soil amendments (i.e. inorganic fertilizer). In contrast, most improved varieties tend to be screened under more favourable environments in which application of inorganic fertilizer is the norm. Therefore, we estimated fertilizer response curves to answer two specific questions. The first is whether the improved varieties are more responsive to inorganic fertilizer when other inputs reflect farmers' management. That is, are their fertilizer response curves steeper than that of the local variety when facing on-farm stresses? Second, do the fertilizer response curves cross, such that the ordering of varieties with respect to yield changes significantly between low and high fertilizer levels (i.e. the so-called cross-over effect)? A J-test was performed to determine the correct specification of the response function. Two specifications were tried, the quadratic functional form and the three-halves functional form. The three-halves functional form, which also permitted the use of nested tests of hypotheses with respect to in-put use, was selected (Traxler and Byerlee, 1993). To address the two questions posed, we fitted the following regression model:

$$Y = b_0 + b_1X + b_2X^{1.5} + b_3D_1 + b_4D_1X + b_5D_1X^{1.5} + \epsilon \qquad (2)$$

where

Y- yield measured in kg/ha
X= fertilizer application measured in kg/ha
D_1 = 1 for improved variety and 0 for local variety
ϵ = a random variable with an assumed normal distribution

We tested two hypotheses. First, that nitrogen responses are the same for the improved varieties and the local varieties (b_4 = b_5 = 0) and, second, that outputs without nitrogen are the same for improved and local varieties ($b_3 = 0$).

DATA

Data used in the analysis were assembled during the 1982–87 period under the auspices of the Senegalese Institute for Agricultural Research (ISRA). Data on farmers' cultivation practices collected by the on-farm farming systems research (FSR) team indicated that the type of variety used, the level of fertilizer used and the degree of protection against pests used in the rice research programme differed significantly from those used by farmers. During 1986, the ISRA rice programme initiated a 2-year, researcher-managed and farmer-implemented on-farm tria1 to estimate the major determinants of Yield Gap II for rice. The tria1 was conducted on five farms in each of five villages in the study area. The three factors were tested at the station and farmers' levels in a factorial design with three interna1 replications. Different varieties (a total of 10) representing aquatic, phreatic and rain-fed rice and local varieties were evaluated. The fertilizer levels were zero nitrogen and 150 kg/ha of urea topdressed (the recommended dose). Protection against pests involved a single dose of the recommended fungicide (tricyclazole). During the same period and using the same research sites and the station for reference purposes, the rice programme also conducted another 2-year, researcher-managed and farmer-implemented trial to study the responses of different rice varieties to nitrogen. For this purpose, a split-plot design with four levels of urea topdressed (0, 50, 100 and 150 kg/ha) in three replications was used. Not all results from this comprehensive trial programme are reported in this paper, only those relating to varieties that either had already been recommended officially or were likely to be recommended in the near future. The rice varieties considered in different parts of the analysis were DJ684D (aquatic), DJ125 19, IKP and TOX728 (phreatic), and IRAT112 and IRAT 10 (rain-fed).

RESULTS AND DISCUSSIONS

Yield gap analysis

Data in Table 2 collected by the FSR team show that most of the varieties tested by ISRA since 1982 have experienced yield losses between 35% and 70% when transferred from research station trials (i.e. research-managed and research-implemented:) to farmers' management and implementation, when no inorganic fertilizer was used. Inorganic fertilizer is used rarely by farmers on the rice crop. The relative decline in yield generally appeared to be less for the twd local varieties (i.e. Ablaye Mano and Barafita).

In the yield gap trial, the three factors (i.e. fertilizer, variety and pest control; Table 3) explained most of the difference between the farm and

TABLE 2

Total Yield Gap (kg/ha) for Rice Varieties between Trials at Djibelor Station and Farmers' Tests in Casamance, 1982–86

Rice type	*Variety*	*Station*	*Farmer*	*Difference (%)*
Improved aquatic	DJ684D	2747	1551	43
Improved phreatic	DJ12519	4039	2564	36
	IKP	2454	1026	69
	TOX728	3208	1232	61
Local varieties	Ablayo Mano	1443	1433	7
	Barafita	2513	2036	19

Station yields were estimated under research-managed and research-implemented conditions, whereas farmers' yields were taken under farmer-managed and farmer-implemented conditions.

TABLE 3

Yield Gap II Trial and Contribution of Each Factor (kg/ha)

Rice type	*Variety*	*Yield Gap II*	*Variety*	*Fertilization*	*Pest Control*	*Residual*
Aquatic	DJ684D	3731	1064 (28.51)	2300 (61.64)	305 (8.17)	62 (1.68)
Phreatic	DJ12519	3905	1117 (28.60)	2700 (69.14)	71 (1.81)	17 (0.45)
	IKP	3683	483 (13.11)	2867 (77.84)	202 (5.48)	129 (3.57)
	TOX728	3550	833 (23.46)	1980 (55.77)	214 (6.03)	520 (14.74)

The numbers in parentheses are the contributions of each factor in percentage terms.

recommended levels, thus confirming the findings of the FSR team. The relative contributions of each factor were fairly constant across varieties. On average, fertilizer explained 61--78% of yield variation, variety explained 13–30% of yield variation and pest control explained only 2-8% of the yield variation. Implications arising out of these results are as follows:

- The results in Table 2 implied that with no fertilizer, the yield gap in actual and relative terms, was lower for local than for improved varieties. Because fertilizer was found to be the major determinant of the yield gap for improved varieties (Table 3), this implies that local varieties are relatively better adapted to zero fertilizer levels. There are a number of reasons why farmers are reluctant to use chemical fertilizer on their rice fields; for example, inadequacies in the credit programme, production risks from recurrent drought periods and major concerns about its toxic effect on fish. The obvious issue is the relevancy of a research programme that focuses excessively on improved varieties using only purchased inputs. Given the practical realities in the area, there would be merit in determining the potential substitutability of organic matter (i.e. manure, ashes, crop residues) for the expensive inorganic fertilizer. Another possible practical implication is to screen improved varieties under soil fertility conditions more typical of the farmers' level, a topic we will discuss further.
- The second most important determinant of the yield gap, in actual and relative terms, was the rice variety used. The results indicated that farmers theoretically could increase rice production by an average of 500-I 100 kg/ha through using an improved variety instead of their local variety. Whether or not the superiority of improved varieties over local varieties would be maintained under practical farming conditions is another question. Once again, we will discuss this issue further.
- Pest control appeared to contribute least to the yield gap both in actual and relative terms. In fact, the lack of major significance of this factor seems to be confirmed by recent studies (ISRA-DERBAC, 1993)

indicating that level of pest infestation only amounted to between 2% and 8% of all rice plants on farmers' fields.

Adaptability analysis

Turning to the adaptability analysis designed to assess the robustness of varieties across different environments, the results indicated that with no inorganic fertilizer, all the improved aquatic and phreatic rice varieties yielded more under better rather than poor production environments (i.e. Type C stability; Table 4). A similar relationship was found to exist for the phreatic varieties under the high fertility level (i.e. 100 units of nitrogen; Table 5), although of course the average yield was much higher than when no fertilizer was applied. Also, the statistical significance of the relevant variables when no inorganic fertilizer was applied and the lack of significance at the high fertilizer level implied that the improved varieties perform even less satisfactorily under very poor production environments. Although the improved varieties obviously are very responsive to inorganic fertilizer, other elements also influence the quality of the production environment. Unfortunately, data were not available to determine exactly what these were, but they could include not only physical factors (e.g. soil type and inherent soil quality including organic matter, weed problems), but also factors that are more socioeconomic in nature such as managerial ability and differences in accessibility to resources (e.g. labour available for farm operations, land/labour ratio, availability of cash). Given that the adaptability analysis trial was implemented under researcher-managed and farmer-implemented conditions, the production environment likely was influenced more by physical factors than by socioeconomic factors. However, under farmer-managed and farmer-implemented conditions, the relative influence of socioeconomic factors likely would be greater. Indirect evidence in support of this can be obtained from comparing the average yields of the varieties that appear in both Tables 2 and 4. The average incremental yield was 86% higher under

TABLE 4
Adaptability Analysis for Improved Rice Varieties at Zero Fertilizer

Rice type	*Variety*	*Intercept* (b_2)	*Slope* (b_3)	*Stability type*	*Yield (kg/ha)*	R^2
Aquatic	DJ684D	–	+	C	1800	68
Phreatic	DJ12519	–***	+ ***	C	3066	98
	IKP	–***	+ ***	C	2717	97
	TOX728	–***	+ ***	c	3016	04
Rain-fed	IRAT112	+	+	A	2280	75
	IRAT10	+ **	+	A	2428	75

** $p < 0.05$; *** $p < 0.01$.

TABLE 5
Adaptability Analysis for Improved Rice Varieties at 100 N Fertilizer

Rice type	*Variety*	*Intercept* (b_2)	*Slope* (b_3)	*Stability type*	*Yield (kg/ha)*	R^2
Aquatic	DJ684D		+	C	4265	77
Phreatic	DJ12519	–	+	C	4973	90
	IKP	–	+	C	4682	75
	TOX728	–	+	C	5014	55
Rain-fed	IRAT112	–	+	C	3331	55
	IRAT10	+	–	B	2423	56

the researcher-managed and farmer-implemented conditions (Table 4) than under the farmer-managed and farmer-implemented conditions (Table 2).

Turning to the improved rain-fed varieties, their performance was superior to that of the local variety with no fertilizer across all production environments (i.e. Type A stability; Table 4). These relationships were not maintained under the high level of inorganic fertilizer (Table 5). However, these results need to be interpreted with caution. Farmers traditionally have cultivated rice on newly cleared land. After 3 years or so, farmers usually had to begin contending with fertility and weed problems and, thus, tended to move to other plots. However, with increasing population densities, this is no longer feasible. Thus, the favourable situation depicted for improved rain-fed rice varieties under zero fertilizer levels likely will now be impossible to emulate in practice. Thus, if rain-fed rice varieties are to be grown, they are likely to experience conditions more analogous to those shown in Table 5. Those results are much less promising, and, in fact, the Type B stability shown by IRAT10 arises because, at high levels of nitrogen application, it becomes more sensitive to a particular type of rice blast (pyriculariose; Mbodj, 1991). In any case, the Senegalese government has been very reluctant to recommend widespread dissemination of rain-fed rice varieties in the Casamance. The reason for this is to encourage greater diversification of the farming systems away from rice, in order to reduce production risk. Rice is obviously the most desirable crop for the lowlands (i.e. aquatic and phreatic conditions), but the upland is suitable for other crops such as maize, sorghum, cowpeas and groundnuts.

Fertilizer response analysis

The results shown in Tables 6 and 7 indicate rejection of the hypothesis that improved and local varieties respond in an analogous manner to the application of nitrogen fertilizer; that is, the *F* value was 10.40 with (2, 354) degrees of freedom. Thus, improved varieties and local varieties under farmers' circumstances have different response curves. With respect to the

TABLE 6
Estimates of Response Functions for Rice Varieties[a]

Variable	*Aquatic*	*Phrentic*		*Rain-fed*	
	DJ684D	*IKP*	*DJ12519*	*IRAT112*	*IRAT10*
X	32.53	32.53	35.41	18·53	18·52
	(4.16)	(2.49)	(9.11)	(1.47)	(1.61)
$X^{1.5}$	−1·46	-1.47	-1.67	-0.96	−0·96
	(−2·34)	(-1.40)	(-5.39)	(-0.95)	(-1.04)
D_1	147·51	− 187.03	1092.00	−157·56	-121.41
	(0.69)	(-0.53)	(10.40)	(-0.46)	(-0.39)
D_1X	9.58	−14·28	2.66	25.18	23.92
	(0.86)	(-0.77)	(0.40)	(1.41)	(1·46)
$D_2X^{1.5}$	-0.70	1.16	-0.09	-1.51	-1.07
	(-0.79)	(0.78)	(-0.21)	(− 1.06)	(−0·82)
Intercept	2417.50	2417.00	2535.60	1397.00	1397.00
	(16.18)	(9.67)	(34.14)	(5.80)	(6·35)
R^2	92	84	92	30	46

[a]The t-statistics are in parentheses.

TABLE 7
Results of Hypothesis Testing for Fertilizer Response Curves

Null hypothesis	*Parumeter restriction*	*Test statistic*
Equal response to N	$b_4 = b_5 = 0$	$F = 10{\cdot}40$**
Equal response at N = 0		
Aquatic rice		
DJ684D	$b_3 = 0$	$t = 0{\cdot}69$
Phreatic rice		
DJ12519	$b_3 = 0$	$t = 10{\cdot}40$**
IKP	$b_3 = 0$	$t =$ -0.53
TOX728	$b_3 = 0$	$t = 7{\cdot}83$**
Rain-fed rice		
IRAT112	$b_3 = 0$	$t =$ -0.46
IRAT10	$b_3 = 0$	$t =$ -0.39

** Indicates rejection of hypothesis at $p < 0.05$.

hypothesis of equal responses of improved and local varieties at zero level of fertilizer, this was rejected in the case of two phreatic varieties, **DJ12.519** and TOX728, but not for the remainder. These results are somewhat ambiguous in indicating, contrary to what we showed earlier, that the yields of these two improved varieties are higher than those of the local varieties at zero fertilizer level. However, for the remaining improved varieties, a cross-over effect did occur, with the improved varieties performing better than local varieties as fertilizer level increased, thus confirming a Type C stability.

These results indicate that the ordering of a set of varieties according to yield is not necessarily identical at high and low levels of fertilizer application and may be affected by other physical and socioeconomic factors that determine the quality of the production environment. Certainly, under poorer production environments including a zero inorganic fertilizer level, the two local rice varieties, Ablaye Mano and Barafita, are competitive in terms of their yields and are especially vigorous at emergence (Posner *et al.*, 1991). The rice programme has used a high level of inorganic fertilizer application in its screening process. As a result, lodging problems have been minimized, although efforts to eliminate the problem of pyriculariose do not always appear to have been successful. Another very important implication borne out by the results of this study is that the variety screening process also appears to be inadequate in providing improved rice varieties well adapted to less favourable production environments, including the farmer's common strategy of not using any inorganic fertilizer. On balance, most of the existing improved rice varieties appear to be most appropriate for those farmers working in favourable production environments, including the extensive use of inorganic fertilizer. We conclude that, because less than 5% of the farmers applied inorganic fertilizer (ISRA-DERBAC, 1993), the production environments under which much of the rice is produced are less than ideal. Therefore, widespread adoption of improved rice varieties will require varieties well adapted to such suboptimal growing conditions. Thus, some adjustments are needed in the approach of the rice breeding programme, particularly with respect to the screening process and greater collaboration with agronomists, soil scientists and the FSR team in order to identify acceptable ways of improving the production environments of farmers.

CONCLUSION

In this paper, three different methods have been used to assess the potential suitability of rice varieties under varying production environments in the Casamance region of Senegal. All the approaches have their place. The yield gap approach, although intuitively appealing to station-based scientists in helping to highlight the major factors (especially physical/technical factors) contributing to the difference between experiment station and farm level yields, does not by itself indicate differences that arise as a result of variation in actual production environments. It in essence represents a single point on a production function. The production function (i.e. fertilizer response) approach can help assess the major determinants of yield (e.g. fertilizer and variety) but the values of the coefficients on the variables in the function will reflect the levels and qualities of the non-experimental variables. However, it is particularly sui ted to assessing the economic optima for different inputs for specific production environments. In terms of ability to assess robustness of the varieties across different practical production environments and, when necessary, develop multiple recommendations, adaptability analysis is the most suitable. However, to fully exploit the potential of adaptability, analysis, it would be desirable to go one step further than was possible in this paper, namely to identify more specifically the determinants of the different production environments as represented by different values of the environmental index.

The results of this study demonstrate the irrelevancy of a single approach to recommending the same rice varieties for all production environments found in the region. The analysis shows the need for multiple recommendations appropriate for farmers operating in different production environments. In the long run, major breakthroughs in rice production will be realized only through substantial improvements in the physical and socio-economic production environments of the majority of small farmers. However, this is likely to require a sustained incremental approach. Therefore, we believe the rice programme needs to focus its activities on two complementary strategies:

- The rice programme should produce varieties adapted to the varied production environments under which farmers operate. In FSR parlance, this requires the recognition of more than one research or recommendation domain for the improved rice varieties and a. scieening process that takes the different production environments into account. Because, for reasons discussed subsequently, breeders likely will have difficulty developing improved rice varieties with Type A stability across the range of production environments found in the region, a strategy of breeding some with a Type B stability and some with a Type C stability might be more appropriate.
- The rice programme should develop close collaborative relationships with agronomists, soils scientists and the FSR team to identify the determinants of the different production environments under practical farming conditions and, in cooperation with farmers, design and evaluate relevant strategies for their improvement. Also, improvement in organic matter and not relying too heavily on purchased inputs is likely to be more relevant for farmers operating in poor production environments. In developing high yielding varieties very responsive to inorganic fertilizer, breeders have tended to emphasize grain yield at the expense of stover (i.e. biomass). Varieties with Type A stability are likely to have such characteristics. Under poor production environments, rice varieties that have a higher stover/grain ratio are likely to be more effective in contributing organic matter to the soil. This is more likely to be the case with varieties of Type B stability. Also under poor production

environments, seeking practical ways of incorporating legumes into the cropping system would have merit.

In essence, what we are advocating is that ISRA should move away from a single blanket recommendation for rice varieties to one that emphasizes a smorgasbord of different rice varieties, accompanied by information as to when they work best (i.e. conditional and targeting information; Norman *et al.*, 1995), from which farmers can Select. Such an approach recognizes that limited-resource farmers live and work on farms characterized by a high degree of both biophysical and socioeconomic diversity. It also recognizes that farmers are rational and have the best knowledge about their own production environments. Consequently, we believe the close collaboration that we are advocating between station- and farm-based researchers (i.e. commodity-based programmes and FSR teams) and farmers is critically important, not only in developing relevant improved rice varieties but also in identifying practical strategies for improving the farmers' production environments. Also, such collaboration is needed because our research (Sall, 1997) has shown that farmers' decisions as to whether or not they will adopt improved varieties also involve criteria other than yield.

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