FERTILIZER RESPONSE FUNCTIONS OF RICE IN SRI LANKA:

ESTIMATION AND SOME APPLICATIONS

by

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SUMMARY

Rice fertilizer response functions, at the farm level as well as at the experiment station level, were estimated by type of variety and by type of irrigation condition, and applied to i) explain the long-term growth path of rice production in Sri Lanka after the independence; ii) identify the degree of contribution of the rice varietal improvements to the increase in rice production; iii) check the consistency of the past and current fertilizer recommendations for rice; and iv) examine the possible impacts of fertilizer subsidy withdrawal on rice production in the country.

The estimated response functions at the farm level reproduce well the macro growth path of rice production except for the 1970s when new improved varieties performed less satisfactory due to their susceptibility to insect, pest and drought. More than forty percent of the increase in rice production in the last four decades is attributable to the varietal improvements. The past and present fertilizer recommendations for rice are consistent with the response functions estimated. The long-run impacts of withdrawal of fertilizer subsidy in the rice sector would not be large as far as its yield impacts are concerned.

INTRODUCTION

Sri Lanka's records on rice production increase in the last four decades are impressive. Total rice production in the country increased at an annual compound growth rate as high as 5.1 percent from the time right after the independence to the late-1980s, the highest among 17 major Asian countries (Barker and Herdt 1985; 45), bringing the country from a state in which 60 percent of domestic rice consumption was met by rice import up to near self-sufficiency in rice. A critical factor that has brought about such a dramatic increase in rice production in Sri Lanka is, as in other Asian countries, the introduction and diffusion of new fertilizer-responsive rice varieties; the centerpiece of the trinity of "green revolution technology", i.e., modern variety, fertilizer, and irrigation (Barker and Herdt, 1985).

In the history of green revolution in Asia, Sri Lanka takes a unique position, in that, unlike in other countries in the Asian tropics where the revolution began with the modern varieties developed by the International Rice Research Institute in the late-1960s, the process commenced more than one decade earlier, based on the improved varieties developed by indigenous research efforts within the country. Traditional (local) varieties were first replaced by 'old improved varieties' which were in turn replaced by 'new improved varieties' (as to the history of rice varietal improvements in Sri Lanka, see, e.g., Senadhira et al. 1980).

Whenever one wants to analyze the process, impacts and consequences of developments in rice production technology, the most basic information needed is the functional relationship between rice yield and fertilizer under different types of irrigation conditions at the farm fields. In spite of the importance of having general knowledge on this, it seems that few systematic attempts have been made so far to consolidate scattered data, while keeping consistency with the unique nature of the technology developments specific to Sri Lanka, into a solid form that can be used as a basis for analyses in this field. An attempt to provide a set of rice fertilizer response functions in Sri Lanka was made by Herdt and Capule (1983). Unfortunately, however, since their study was intended to be a comprehensive overview of the issue in Asia covering 11 Asian countries, no detailed explanations of the estimation process were provided for Sri Lankan as well as for other country cases.

A major purpose of this paper is to fill this gap by estimating rice fertilizer response functions by type of variety and by type of irrigation condition. We first estimate the response functions using the data on variety-fertilizer trials carried out in various agricultural experiment stations in the country for a period from 1957 to date, and adjust them to the farmers' fields. Then, using the estimated fertilizer response functions, we simulate the long-term macro growth path of rice production after the independence; identify the contributions to the production growth of varietal improvements, increases in fertilizer use and development of irrigation infrastructure; check consistency of the past and current fertilizer recommendations for rice; and examine the possible production impacts of withdrawal of the fertilizer subsidies that is currently under way in the country.

ESTIMATION OF FERTILIZER RESPONSE FUNCTIONS

Among the three major nutrients of fertilizer, nitrogen has the most significant impact on rice yield. Although the application of phosphorus and potassium fertilizers is certainly essential to rice growth, their direct yield effects are generally far less appreciable than nitrogen (see, e.g., Constable 1966; Nagarajah 1980; and Shibata et al. 1990). It is a well established convention to represent the fertilizer-yield response relation by a quadratic equation of the following form:

$$Y = a + bN - cN^2 \qquad (1)$$

where Y denotes rice yield per hectare, N denotes nitrogen input per hectare, and a, b and c are parameters. Our aim in this section is to estimate farm-level response functions of this form, that can be considered as the average, or typical, functions for the country as a whole by type of variety and by type of irrigation condition.

There are two ways to attain this objective; first to estimate the farm-level functions directly using farm survey data, and second to estimate first the functions using the data generated in agricultural experiment stations and then adjust them down to the farm-level. Since there is no available farm survey data comprehensive enough to make the estimation of rice fertilizer response functions as required here possible, we adopt the latter method.

Response Functions at Experimental Fields

In order to estimate the response functions at the experimental field level, data on variety and fertilizer trials conducted in the agricultural experiment stations scattered around the country during the period from 1957 to date were gathered and sorted out into three variety groups; traditional, old improved, and new improved varieties.

The data used for the analysis are presented in Appendix by variety group. Although the best efforts were made to collected as much data as possible, we have to admit that the data set we collected is only a small part of the total variety and fertilizer trial experiments conducted in the country in the past. (A great difficulty encountered in this data collection process was that many records of past experiments have been scattered and lost because of non-existence of systematic data reporting system in the agricultural experiment stations. Many records of experiments conducted in these stations pertain to the researchers who conducted the experiments, and, therefore, difficult to get access after they left the stations. In order to make the maximum use of agricultural research, it is highly desirable to establish a well organized system for reporting and preserving the results of various experiments conducted in the stations.)

The response functions of the form Equation (1) were estimated using these experimental data by type of variety. Needless to say, fertilizer responsiveness differs from variety to variety even within a variety group. It is also well known that a variety shows different fertilizer responsiveness between the wet (maha) and dry (yala) seasons. There may exist differences among locations and years of experiments. In order to control these differences and arrive at the average function, intercept dummies were introduced in the estimation for season (maha-yala), growth duration (short-long), individual variety, location, and year. The results of estimation by using the ordinary least squares method are summarized in Table 1. Since the number of dummy variables included in each equation is large, their coefficients are not shown in the table except for the season and growth duration dummies.

The goodness of fit is satisfactory for all equations estimated. Even for the traditional varieties which reveal a wide variation in the yield level across individual varieties, 66 percent of the total variation is explained by the level of nitrogen and dummy variables. The estimated coefficients of nitrogen linear and nitrogen square are statistically different from zero, except for the coefficient of nitrogen square for old improved varieties, which is not significant at the conventional significance level but is different from zero at the **15** percent probability level. Such results support our model for fertilizer responsiveness of quadratic form.

It is clearly shown that the yield response to nitrogen becomes higher when one shifts from traditional varieties to old improved varieties, and further to new improved varieties. The average intercept, which is estimated by evaluating all dummy variables at their respective means, also increase from 2.7 (metric) tons for traditional varieties to 3.2 tons for old improved varieties, and to 4.0 tons for new improved varieties, suggesting that even with zero nitrogen newer varieties have higher yield potentials. As expected, the yield in the yala season is significantly higher than in the maha season except for traditional varieties. The growth duration dummy shows any significant impact on rice yield neither for old nor for new improved varieties.

Response Functions at Farm Level

The next step is to adjust the estimated response functions at the experimental field level down to the farm level. It is expected that the response functions at the farm level reveal less fertilizer responsiveness than at the experimental fields which have ideally controlled conditions in terms of soil, water, pest, disease and weed controls, and so on. Critical information needed for this adjustment is about a possible gap in the response functions between the experiment station and farm field levels, after controlling levels of fertilizer as well as other inputs. Only well designed experiments using both experimental and farmers' fields give appropriate information of this kind.

Jayawardena <u>et al</u>. **(1983; 89)** gives such an estimate. Their estimates of the yield gap between research stations and farmers fields center around 60%. Adopting this rate of gap, the response functions in Table 1 were adjusted vertically downward to arrive at the farm level functions under the irrigated condition. For old and new improved varieties, this adjustment was made including the (average) intercepts. For traditional varieties, the intercept of the farm level function was determined by referring to the national average rice yield for the period **1951-57**, while adjusting for the nitrogen input per hectare during the same period. The period **1951-57** was chosen because this was the period when **100%** of paddy fields were planted with traditional varieties: the first year when old improved varieties appeared in farmers' fields was **1958.**

The response functions at the farm level thus estimated were further adjusted downward to reach those under the rainfed condition. For doing this, it is necessary to find out an appropriate adjustment coefficient. Such a coefficient was obtained for new improved varieties from the production cost surveys conducted and compiled by the Department of Agriculture **(1985, 1987**, and 1988). This series, which gives the data on rice production including yield and nitrogen levels by district, includes some districts for which the costs are reported both for irrigated and for rainfed rice production. The number of districts for which such data are available is 15 for the maha 1984/85, 12 for the maha 1985/86, and 9 for the maha 1986/87. It should be noted that these seasons were selected for deriving the coefficient because the overwhelming majority of the sample farmers planted new improved varieties in these recent years. The adjustment coefficient was constructed by taking the average yield gap, over three seasons, between irrigated and rainfed fields for these districts, after accounting for the difference in nitrogen input levels. Based on this gap coefficient, 1:0.803, the response functions under the irrigated condition were reduced to 80% both vertically and horizontally.

The rice fertilizer response functions by variety group and by type of irrigation thus estimated are summarized as follows:

Traditional varieties;	irrigated	$Y = 1500 t 10N - 0.09N^2$
Traditional varieties;	rainfed	$Y = 1200 t 10N - 0.12N^2$
Old improved varieties;	irrigated	$Y = 1900 t 14N - 0.06N^2$
Old improved varieties;	rainfed	$Y = 1500 t 14N - 0.08N^2$
New improved varieties:	irrigated	$Y = 2400 t 21N - 0.08N^2$
New improved varieties;	rainfed	$Y = 1700 t 21N - 0.10N^2$

These functions are quite similar to those presented by Herdt and Capule (1983; 53), except that the intercepts of our functions are consistently lower than theirs. It is also noted that our estimates are comparable to those of the Philippines (David and Barker 1978; 183) and of other countries presented in Herdt and Capule (1983; 53).

APPLICATIONS

Long-Term Rice Production Growth Path in Sri Lanka

The rice fertilizer response functions estimated in the previous section are based on many heroic assumptions. How close these functions represent the national average response functions by type of variety and by type of irrigation? As a way to check it, we attempt to simulate the log-term growth path of rice production in the country based on the estimated response functions. The total rice production in the country can be estimated by, first, substituting actual levels of nitrogen input per hectare by type of variety and type of irrigation into respective response functions to obtain estimated yields per hectare; multiplying the estimated yields and actual harvested areas for respective categories; and then summing up over the six categories.

Actual levels of these variables are shown in Table 2 for selected years, together with the actual levels of total rice production. All data in the table are expressed in terms of five-year averages to deal with the long-term trend. Unfortunately, the data on actual nitrogen level per hectare of rice area harvested are available only for the overall average, not by type of variety and type of irrigation. Similarly, the data on percentage share of area planted to certain variety groups are available only for the country as a whole. To overcome these problems, the following assumptions were made: i) the differences in actual levels of nitrogen input per hectare by type of variety and type of irrigation are proportional to the differences in the optimum levels of nitrogen input per hectare by these types under the actual price ratio between nitrogen and rice; and ii) the varieties in a newer variety group, when they appeared, were first planted on the irrigated area. The data on nitrogen-rice price ratio are available only in and after 1958. For the prior years, the ratio is assumed to be 4:1. Since the nitrogen use for rice production during the 1950s was minimal as shown in Table 2, possible biases in this assumption would not bring in any substantial biases in our production estimates.

The series of estimated rice production is depicted in Figure 1, together with the actual series. The gaps between the actual and estimated levels for selected years are as follows:

	Actual	Estimated	Discrepancy
	(1000 mt)		(%)
1955	613	637	-4
1960	864	822	3
1965	990	1036	-5
1970	1409	1381	2
1975	1400	1725	-23
1980	2065	2305	-12
1985	2605	2663	-2

Except the 1970s during which our series overestimates the actual levels more than 20%, the response functions succeed to reproduce the actual levels of total rice production in the country within a range plus and minus 5%.

It should be noted that Sri Lanka experienced serious set-backs in the rice production during the 1970s; as shown in Figure 1, the total rice production decreased even in terms of five-year moving averages. These set-backs were the combined results of lower yields per hectare and lower rice harvested areas during the period, the former being much more serious than the latter. The national average rice yield that had once reached a level more than 2.5 mt/ha in 1969 started to decline towards the mid-1970s, and it declined to a level as low as 1.9 mt/ha in 1975. It was in 1980 that the 1969 yield level was recovered. As the trend of actual rice production returned to its long run trend line towards the early-1980s, the discrepancy between the actual and estimated rice production nearly disappeared.

Thus, the set-hacks in rice yields experienced in many countries in Asia in the mid-1970s due mainly to susceptibility of new rice varieties to such adverse growing conditions as insects, pests, and drought exerted pressure for the rice production in Sri Lanka to diverge from its long-term trend. The discrepancy between the actual and estimated rice production could be an indicator to measure the degree of damage that Sri Lanka suffered from the 'food crisis' in the 1970s.

Contributing Factors to Rice Production Growth

The fact that our rice fertilizer response functions, coupled with changing shares of variety groups and increasing levels of irrigated rice area and nitrogen input, simulate well the actual growth path of rice production implies that these factors have been major contributors to the production growth. An interesting question to be raised then is the relative contributions of these factors in the total rice production growth. It is difficult to give an exact answer to this question, partly because these factors are highly complimentary each other and partly because other factors that are not taken into account here, such as labor inputs, also affect the level of rice production. However, rough orders of contributions derived from these three factors could be worked out as follows:

First, estimate the rice production with the 1952 (1950-54 average) levels of variety ratio, nitrogen input per hectare, and irrigation ratio, and with the 1985 (1983-87 average) level of total rice harvested area, and subtract this from the estimated 1985 rice production. This difference represents the effects of all technological changes associated with varieties, fertilizer, and irrigation[13] between 1952 and 1985. Second, estimate the rice production with the 1985 level of total rice harvested area, but substituting separately one of the three factors at the 1952 level while keeping other two factors at the 1985 levels. Subtracting the resulting rice production estimates from the estimated 1985 rice production, the effect of technology change in a certain factor is singled out. However, because of complementarity among the three factors, the sum of individual effects over the three factors exceeds the total effect estimated in the first step. The contributions of each factors are adjusted proportionally so that the sum equals the total effect.

Third, subtract the estimated 1952 rice production from the production estimate obtained in the first step. This difference represents the contribution of harvested area increase to the increase in rice production. As made clear by Thorbecke and Svejnar (1987), the increase in rice harvested area in Sri Lanka during the post independence period has been due largely to the irrigation investments made in the dry zone. It may be, therefore, not a serious mistake to add up this contribution to the 'productivity' effect of irrigation obtained in the second step. Lastly, the total increase in rice production is obtained by subtracting the estimated 1985 production from the estimated 1952 production.

The total increase in rice production between 1952 and 1985, and contributions of variety, fertilizer, and irrigation are summarized as follows:

	(1000 mt)	(%)
Total increase	2087	(100)
Increase due to:		
Variety	861	(41)
Fertilizer	561	(27)
Irrigation	665	(32)

The impact of varietal improvements on the rice production increase was large. A hypothetical growth path of rice production in Sri Lanka, if there had been no varietal improvements (no old as well as new improved varieties), is depicted in Figure 2. This hypothetical growth path was estimated assuming that the rice varieties planted remain as in 1952 (traditional varieties 100%) and that other factors, nitrogen, irrigation ratio, and harvested area, increase as actually did.

Optimum Nitrogen Levels and Fertilizer Recommendations for Rice

There have been five fertilizer recommendations in Sri Lanka, including the current one, How are the recommended levels of nitrogen in these fertilizer recommendations for rice compared to the optimum levels of nitrogen derived from the response functions? The optimum nitrogen levels by type of variety and type of irrigation can be obtained by equating the first derivative of the response functions with the nitrogen-rice price ratio:

$$(P_f/P_r) = b - 2cN \qquad (2)$$

where P_f = price of nitrogen, P_r = price of rice, and the right hand side of the equation is the first derivative of Equation (1). Table 3 summarizes the optimum, actual, and recommended levels of nitrogen per hectare for selected years.

A distinct feature of Sri Lanka with respect to fertilizer use in the rice sector is that the price ratio between fertilizer and rice has been low because of heavy subsidies given to fertilizers. As shown in the table, the nitrogen-rice price ratio has been far below 2.0 except in 1960. As a result, the optimum levels of nitrogen have been quite high for all types of variety; throughout the period after 1960, it has been within a range from about 40 kg/ha for traditional varieties under the rainfed condition to 120 kg/ha for new improved varieties under the irrigated condition. These optimum levels are very close to the respective maximum nitrogen levels that correspond to the maximum attainable yields. The actual levels of nitrogen per hectare were lower than the optimum levels. The gaps between these two levels, however, had become narrower over time, and by 1985 the actual nitrogen use per hectare for each category reached a level that was 70% of the respective optimum level.

The recommended nitrogen levels have been revised upward from the first to the latest recommendations. The largest revision was made between the 1967 and 1971 recommendations, in which the highest nitrogen level was raised nearly twice as high as the previous level. The highest level given in the 1971 and 1980 recommendations is closer to, but yet within, the optimum level for new improved varieties under the irrigated condition. It is interesting to note that the lower bound recommended nitrogen level too was adjusted downward after the 1967 recommendations so that the optimum nitrogen level for traditional varieties under the rainfed condition fell within the recommended range. The fertilizer recommendations for rice in 1971 as well as in 1980 are thus consistent with the optimum levels of nitrogen derived from the fertilizer response functions.

Impact of Fertilizer Subsidy Withdrawal on Rice Production

As from January 1990, the government of Sri Lanka lifted up the heavy subsidies that had been put on fertilizers for a quite a long time. This withdrawal of subsidies would affect rice production negatively through raising fertilizer prices. A question is how serious the impact will be.

An answer could be given by applying the response functions as follows. First derive the demand function for fertilizer by rearranging Equation (2):

$$N = b(1/2c) - (1/2c)(P_f/P_r) \qquad (3)$$

Second, estimate new nitrogen levels for different variety groups under different irrigation conditions by substituting the new price ratio after subsidy withdrawal into Equation (3). Third, estimate new yield levels by substituting the new nitrogen levels into respective fertilizer response functions. Then, obtain the weighted average of yields for different variety groups under different irrigation regimes using percentage shares of each group as weights. The impact of subsidy withdrawal on rice yield is assessed by comparing the yields before and after the subsidy withdrawal.

An alternative way, which is more convenient for exposition, is to assume constant elasticity functions for fertilizer demand and rice yield, i.e.,

$$N = \alpha P^{-\sigma} \qquad (4)$$

$$Y = \beta N^{\delta} \qquad (5)$$

where N = nitrogen demand, P = price of nitrogen relative to rice price, σ = price elasticity, a = other demand shifters, Y = rice yield per hectare, 6 = production elasticity, and β = other yield shifters. By definition, $-\sigma = (dN/dP)/(P/N)$ and 6 = $(dY/dN)/(N/Y)$. Then, the following relations are derived:

$$(N'/N) = (P'/P)^{-\sigma} \qquad (6)$$

$$(Y'/Y) = (N'/N)^{\delta} \qquad (7)$$

where the variables with (') denote their respective level after subsidy withdrawal. By substituting Equation (6) into Equation (7), the impact of subsidy withdrawal on rice yield is expressed as:

$$(Y'/Y) = (P'/P)^{-\sigma\delta} \qquad (8)$$

Let us evaluate σ and 6 as the point estimates using the composite fertilizer response function at the 1985 (1983-87 average) variable levels. Given the percentage shares of areas planted to each variety group under each irrigation regime as in 1985, the response functions are aggregated into the following composite function:

$$Y = 2140 \text{ t } 20.4N - 0.086N^2 \qquad (9)$$

With this function and the nitrogen-rice price ratio of 1.75, the elasticities are estimated as a = 0.135 and 6 = 0.175.

The rate of subsidy given to nitrogen was, on the average for 1985-1987, Rs 3.4 per kg of nitrogen, while its retail price was Rs 6.7 per kg (NFS, 1988). It was Rs 5.7 per kg, with the retail price of Rs 8.5 per kg in 1989 (the information from NFS). These data indicate that the nitrogen price will be raised by 50 to 70% if the subsidy is totally withdrawn.

Let us assume here that the nitrogen price be increased by 100% because of subsidy withdrawal while the farm-gate price of rice is kept constant. Substituting 2.0 into Equation (8), we obtain $(Y'/Y) = 0.984$. That is, the percentage decline in rice yield due to the subsidy withdrawal for nitrogen would be 1.6%. Assuming no change in the rice area harvested, this implies a decrease in the total rice production of about 42,000 mt (in paddy term). This order of change could be said 'small'; any small changes in other factors related to rice production, particularly changes in rice price and weather, would cancel out, or obscure, the impact of fertilizer subsidy withdrawal. The first method to assess the impact of subsidy withdrawal gives essentially the same result.

It should be noted that such a small impact of subsidy withdrawal is projected primarily because of the low price elasticity of nitrogen demand, which is a result of the fact that the pre-withdrawal level of nitrogen intensity in rice farming in Sri Lanka was quite high. Should the intensity be lower and therefore the elasticity be higher the impact of withdrawal could be much larger. In other words, the 'matured' nature of rice farming in Sri Lanka in terms of seed-fertilizer technology absorbs the shock to be created by the fertilizer subsidy withdrawal.

Regarding this exercise, two qualifications should be in order. First, the impact assessed here is of long run nature; ceteris paribus, the level of impact projected here will be realized in the long run. In the short run, an actual impact could be larger than the long run impact, because of the adjustment process involved. Second, not only yield but also area planted to rice will be affected by a higher fertilizer price due to subsidy withdrawal. To the extent that shifts in area planted, either away from or to rice, are induced by changes in fertilizer-output relative prices for rice and non-rice crops, the impact on total rice production diverges from the impact on yield. In order to assess the total impact, it is necessary to have an area response function, in addition to the yield response function.

CONCLUSIONS

In this paper, we estimated rice fertilizer response functions at the farm level by type of variety and by type of irrigation condition through estimating first those at the experiment field level by using variety and fertilizer trial data and then adjusting them to the farm level. The estimated functions could reproduce well the long run macro growth path of rice production in Sri Lanka in the post independence period, except for the

1970s when the actual levels of total rice production diverged from its long term trend line because of less satisfactory performance of new improved varieties then due to their susceptibility to insect, pest and drought.

Among three critical factors, i.e., variety, fertilizer, and irrigation, that brought about the increase in rice production, varietal improvements contributed most, about 40% of the total increase, and other two factors contributed about 30% each. The recommended nitrogen levels in the fertilizer recommendations for rice are consistent with the optimum levels derived from the estimated response functions. The present recommended levels could be applicable even after the withdrawal of fertilizer subsidies. It was estimated that the yield impact of fertilizer subsidy withdrawal would be small in the long run, in the order of 1 to 2%. Such a small impact is due primarily to the fact that the price elasticity of nitrogen demand is quite low because of the high nitrogen intensity before the subsidy withdrawal.

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Table 1. Estimated fertilizer response functions at the experiment station field.[a)]

Variable	Traditional varieties	Old improved varieties	New improved varieties
Intercept[b)]	2515 (12.491)	4359 (22.298)	4834 (12.312)
N	16.4 (2.949)	24.2 (3.967)	34.3 (12.641)
N^2	-0.125 (-1.645)	-0.098 (-1.434)	-0.129 (-6.666)
Season[c)]	-354 (-1.443)	-678 (-5.271)	-627 (-4.864)
Growth duration[d)]		-40 (-0.205)	-318 (-1.069)
Intercept(average)[e)]	2750	3253	4015
R^2	0.660	0.841	0.805
Degree of freedom	39	170	253
Number of dummy variables included[f)]	14	23[g)]	33

Note: a) The fertilizer response function is of the following quadratic equation: $Y=a+bN-cN^2$, where Y=rice yield (kg/ha) and N=nitrogen input (kg/ha). Figures inside parenthesis are t-ratio. In the estimation, intercept dummy to represent variety and location and time of experiments were included in addition to those listed in this table. For the data used in the estimation, see Appendix.

b) The intercepts represents the yala season; the long-duration varieties: Bathalagoda Experiment Station: 1957 for traditional and old improved varieties and 1966 for new improved varieties: and Pachcha Perumal traditional varieties, H-4 for old improved varieties, and BG 11-11 for new improved varieties.

c) Season dummy: aaha = 1, yala = 0.

d) Growth duration dummy: short-duration (3-3.5 months) = 1, long-duration (4 months or longer) = 0.

e) The average intercept when all intercept dummy variables are evaluated at their mean.

f) The number of dummy variables included in the regression analysis except for the two dummy variables listed in the table.

g) For old improved varieties, two slope dummies are included in the analysis, but, since the regression coefficients of these dummies are not statistically different from zero at the conventional confidence level, they are not shown in the table.

Table 2. Total rice production, rice harvested area, nitrogen inputs used for rice production per hectare, irrigation ratio, and rice variety composition in the post independence period in Sri Lanka.[a]

	Total rice production (1000 mt) (1)	Harvested area (1000 ha) (2)	Nitrogen per hectare (kg/ha) (3)	Irrigation ratio[b] (%) (4)	Variety ratio[c] (----- % ----) (5)		
					TV	OIV	NIV
1952	494	423	1.7	48	100	-	-
1960	864	545	8.3	57	87	13	-
1970	1409	667	32.9	60	32	59	9
1980	2065	802	57.2	62	13	15	72
1985	2605	842	75.5	66	2	6	92

Note: a) Five-year averages centering the years shown.
b) Irrigated rice planted area/total rice planted area.
c) Percentage share of rice varieties planted: TV=traditional varieties; OIV=old improved varieties; NIV=new improved varieties.

Source: **(1):** Department of Census and Statistics **(1988).** **(2)** and **(4):** Department of Census and Statistics (various issues). **(3):** for **1950-60**, estimated from **IRRI (1988);** for **1961-86**, Department of Census and Statistics (various issues). **(5):** Rice Breeding Center of the Department of Agriculture.

Table 3. Fertilizer-rice price ratios, and optimum, actual and recommended levels of nitrogen after 1960.

	Fertilizer-rice price ratio	Optimum nitrogen level[a]						Recommended nitrogen level[b]
		TV		OIV		NIV		
		Irri-gated	Rain-fed	Irri-gated	Rain-fed	Irri-gated	Rain-fed	
	(Rs/Rs)	kg/ha						
1960	2.16	49 (8)	37 (6)	99 (17)	74 (13)	-	-	12-51 (1959)
1965	1.49	53 (13)	40 (10)	104 (26)	78 (20)	-	-	21-57 (1964)
1970	1.26	54 (22)	41 (16)	106 (42)	80 (32)	123 (50)	99 (40)	43-57 (1967)
1975	1.82	51 (22)	38 (16)	102 (42)	80 (32)	120 (50)	96 (40)	35-108 (1971)
1980	1.53	53 (30)	39 (22)	104 (58)	78 (44)	121 (69)	97 (55)	30-108 (1980)
1985	1.75	51 (36)	38 (27)	102 (70)	77 (53)	120 (83)	96 (66)	30-108 (1980)

Note: a) Derived by equating the fertilizer-rice price ratio with the first derivative of the response functions. Figures inside parenthesis are the actual nitrogen input per hectare at the farmers' fields.

b) The years in parenthesis are those when the fertilizer recommendations were made.

Source: Rice prices from Department of Census and Statistics (various issues), nitrogen prices from IRRI (1988) and National Fertilizer Secretariat (1987), recommended nitrogen levels from Nagarajah (1985-86; 12).

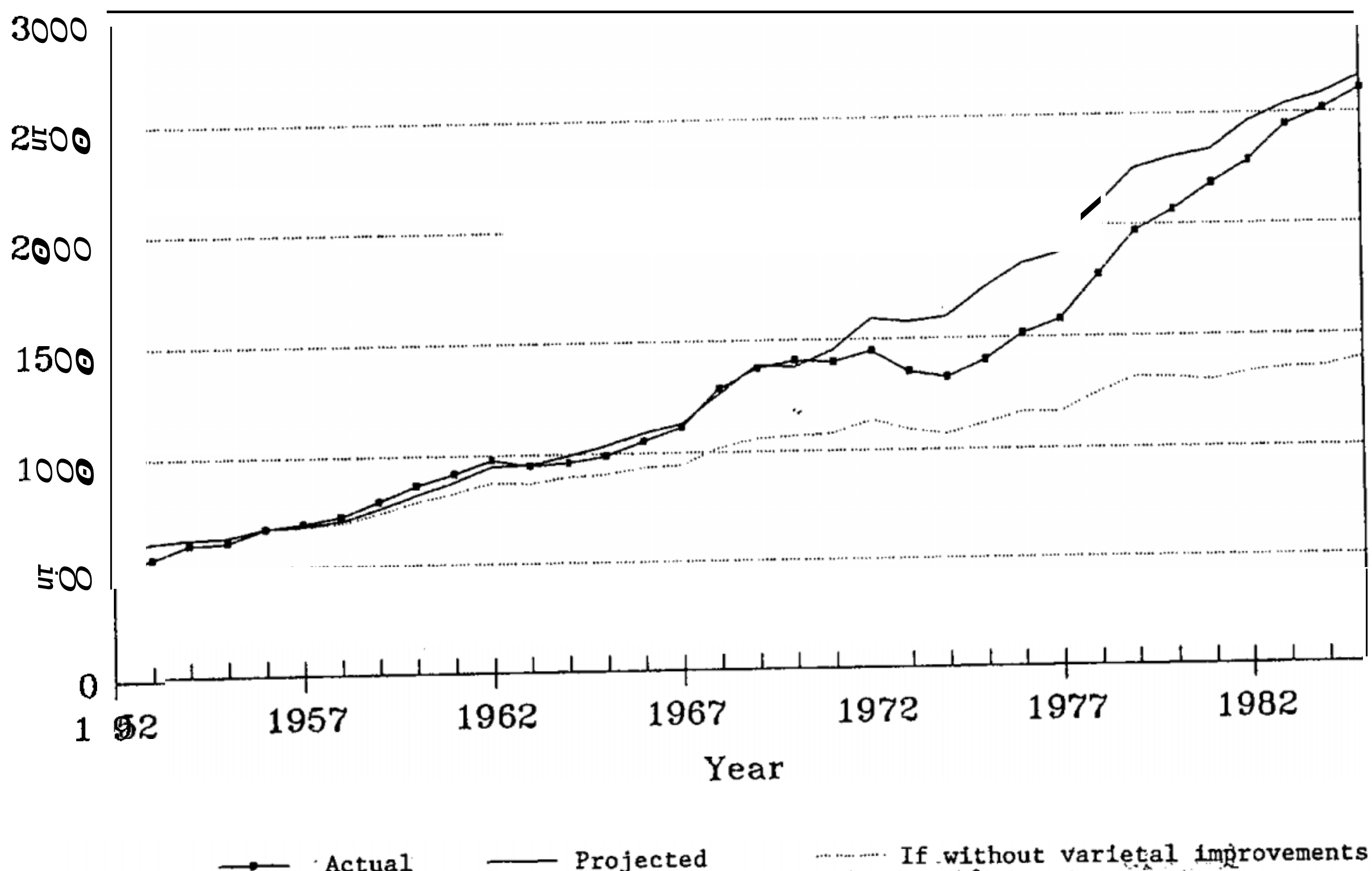

Figure 1. Actual and projected rice production in Sri Lanka, five-year moveing averages.

Appendix Variety and fertilizer trial experiment data

Experiment station	Year	Season	Variety	Duration	Nitrogen & yield levels (Kg/Ha-Kg paddy/Ha)					Source
I. Traditional varieties										
Oathalagoda	1957	maha	POOIYEE	long	0-2075	33.7-2334	61.4-2691			1
Oathalagoda	1951	maha	KOHUMAWEE	long	0-2749	33.7-3060	67.4-3579			1
Bathalagoda	1951	maha	KURULUTHUD	long	0-2594	33.7-2957	67.4-2957			1
Bathalagoda	1951	yala	1302	long	0-2801	22.5-3008	44.9-3008	67.4-3216		1
Bathalagoda	1958	iaha	1302	long	0-2230	33.7-3268	67.4-3838			1
Bathalagoda	1958	yala	n-302	long	0-3423	33.7-3683	67.4-3838			1
Bathalagoda	1958	yala	DAHANALA	long	0-3008	33.7-3475	67.4-3268			1
Bathalagoda	1958	yala	M-307	long	0-3112	33.7-3787	67.4-3527			1
Oathalagoda	1958	yala	PP2462/11	long	0-2594	33.7-2801	67.4-2490			1
Bathalagoda	1959	naha	V128061	long	0-2023	33.7-2542	67.4-2697			1
Bathalagoda	1959	maha	113	long	0-2075	33.7-2438	67.4-2853			1
Oathalagoda	1959	yala	M307	long	0-2905	33.1-3060	61.4-3060			1
Bathalagoda	1959	yala	PP2462/11	long	0-2905	33.1-3312	67.4-3320			1
Oathalagoda	1959	yala	SUOUYEE	long	0-2957	33.7-3423	67.4-3320			1
Bathalagoda	1959	yala	1302	long	0-3320	33.7-3735	67.4-3683			1
Bathalagoda	1964	yala	PP2462/11	long	0-2121	33.1-3112	67.4-3060			1
Oathalagoda	1964	yala	PP2462/11	long	0-2645	33.7-2853	67.4-3268			1
Bathalagoda	1965	yala	PP2462/11	long	0-3527	33.7-4098	67.4-4098			1
Oathalagoda	1361	naha	POOIYEE A8	long	0-2490	44.9-3060	89.8-3112			1
II. Old improved varieties										
Bathalagoda	1951	iaha	H4	long	0-3735	22.5-4305	44.9-4357	67.4-4409	89.8-4357	1
Bathalagoda	1951	maha	H5	short	0-3683	22.5-4150	44.9-4253	67.4-4357	89.8-4305	1
Bathalagoda	1957	iaha	H6	long	0-3008	22.5-3268	44.9-3527	67.4-3579	78.6-3631	1
Bathalagoda	1058	iaha	H5	short	0-2954	33.7-3631	67.4-4409			1
Bathalagoda	1958	maha	H4	long	0-2334	33.7-3579	67.4-4668			1
Bathalgoda	1958	iaha	H5	short	0-2691	22.5-3423	44.9-3994	67.4-4668	89.8-5187	1
Bathalagoda	1958	maha	H4	long	0-2853	22.5-3423	44.9-4305	67.4-4513	89.8-5291	1
Bathalagoda	1958	yala	H5	short	0-3890	33.7-4201	67.4-4253			1
Bathalagoda	1958	yala	H4	long	0-3475	33.7-3890	67.4-4253			1
Bathalgoda	1959	maha	H4	long	0-2334	33.7-2853	67.4-3372			1
Bathalagoda	1959	yala	H4	long	0-2853	33.7-3423	67.4-3683			1
Bathalagoda	1960	maha	H105	long	0-2127	33.7-3008	67.4-3423			1
Bathalgoda	1960	maha	H501	long	0-2075	33.7-2438	67.4-2957			1
Bathalgoda	1960	maha	H104	long	0-2075	33.7-2386	61.4-3112			1
Bathalagoda	1960	yala	H105	long	0-2015	33.1-3060	67.4-3683			1
Bathalgoda	1960	yala	H501	long	0-2542	33.1-3164	61.4-4098			1
Bathalgoda	1961	maha	H-6	long	0-1816	33.7-2179	61.4-2282			1
Bathalgoda	1961	maha	60-1136	long	0-1764	33.7-2438	61.4-3008			1
Tissamaharama	1961	maha	H105	long	0-3141	44.9-3828	89.8-4831			1
Tissamaharama	1961	maha	H101	long	0-2954	44.9-3851	89.8-4782			1
Tissamaharama	1961	maha	H501	long	0-3210	44.9-4107	89.8-4328			1
Tissamaharama	1961	maha	H4	long	0-2987	44.9-4828	89.8-5990			1
Ambalantota	1961	maha	H101	long	0-3994	44.9-5071	89.8-5436			1
Ambalantota	1961	maha	H501	long	0-3911	44.9-4378	89.8-4655			1

Continued (P.2)

Ambalantota	1961	maha	H4	long	0-4085	44.9-5502	89.8-5911		1
Ambalantota	1961	maha	H105	long	0-3522	44.9-4644	89.8-5324		1
Bathalagoda	1961	yala	H-6	long	0-2334	33.7-3008	67.4-2282		I
Bathalagoda	1962	yala	61-531	short	0-2691	33.7-3320	67.4-3838		1
Bathalagoda	1962	yala	61-555	short	0-2951	33.7-3216	67.4-3838		1
Bathalagoda	1962	yala	61-595	short	0-2957	33.7-3423	67.4-4098		1
Tissamaharama	1962	yala	H-105	long	0-3843	44.9-4408	89.8-4906		1
Tissamaharama	1962	yala	n-4	long	0-4095	44.9-5263	89.8-5487		1
Tissamaharama	1962	yala	H-501	long	0-3885	44.9-4313	89.8-4616		1
Tissamaharama	1962	yala	H-101	long	0-3695	44.9-5154	89.8-4625		1
Ambalantota	1962	yala	H-101	long	0-3794	44.9-5116	89.8-5225		1
Ambalantota	1962	yala	H-105	long	0-3876	44.9-4587	89.8-5210		1
Ambalantota	1962	yala	H-4	long	0-4211	44.9-5785	89.8-5989		1
Ambalantota	1962	yala	H-501	long	0-3879	44.9-4338	89.8-5049		1
Bathalagoda	1963	maha	61-555	short	0-2697	33.1-3415	67.4-3683		I
Bathalagoda	1963	iaha	61-531	short	0-2490	33.1-3415	67.4-3994		1
Bathalagoda	1963	maha	61595	short	0-2438	33.7-3527	67.4-3890		1
Bathalgoda	1964	iaha	H-1	short	0-2282	33.7-3423	67.4-4046		1
Bathalagoda	1964	maha	61-595	short	0-2386	33.7-3164	67.4-3579		I
Bathalagoda	1964	yala	62-9	short	0-2749	33.7-3372	67.4-3683		1
Bathalagoda	1964	yala	62-305	short	0-2853	33.7-3527	61.4-3181		1
Bathalagoda	1965	maha	H-4	long	0-2334	33.1-3112	67.4-3579		1
Bathalagoda	1965	yala	63-53	short	0-3623	33.7-4357	67.4-4720		1
Bathalagoda	1965	yala	H-4	long	0-3423	33.7-3942	67.4-4201		1
Bathalagoda	1965	yala	63-610	short	0-3631	33.1-4201	67.4-4565		1
Bathalagoda	1965	yala	64-415	long	0-3268	33.7-3994	61.4-4150		1
Bathalagoda	1966	maha	H-4	long	0-3060	44.9-3787	101.0-4253		1
Bathalagoda	1966	iaha	H-8	long	0-3216	44.9-3890	101.0-4565		1
Bathalagoda	1966	yala	H-4	long	0-3787	33.7-4253	67.4-4616		1
Bathalagoda	1966	yala	64-415	long	0-2594	33.7-3060	67.4-3268		1
Bathalagoda	1961	maha	65-100	long	0-3942	44.9-4876	89.8-5446		I
Bathalagoda	1969	yala	62-355	short	0-3890	67.4-5550	101.1-5706	33.1-4828	1
Bathalagoda	1970	rahc	H-7	short	0-2542	44.9-3735	89.8-4616	134.7-4824	1
Ambalantota	1914	maha	H4	long	0-3745	22.5-4033	44.9-4441		1
Bathalagoda	1974	yala	H-4	long	0-5239	44.9-6224	89.8-6121	134.8-6550	1
MahailluppaIlama	1975	maha	H4	long	0-4969	67.4-5931	33.7-5742		2
Bathalagoda	1915	yala	H-4	long	0-4816	44.9-5913	89.8-6743	134.8-6691	1
Bathalagoda	1916	yala	n-4	long	0-4876	44.9-6017	89.8-6951	134.8-6951	1

III. New improved varieties

Sathalagoda	1969	maha	BG34-1	short	0-2075	44.9-2905	89.8-2594	101.1-1556	1
Bathalagoda	1969	maha	BG34-8	short	0-2438	44.9-3683	89.8-4409	101.1-4513	1
Sathalagoda	1969	maha	BG34-12	short	0-2490	44.9-3787	89.8-3683	101.1-3423	1
Bathalagoda	1969	yala	BG19-3	short	0-3112	33.7-4668	67.4-5343	101.1-5758	1
Bathalagoda	1969	yala	BG19-2	short	0-3423	33.7-4461	67.4-5394	101.1-5809	1
Bathalagoda	1910	maha	BG50-4	short	0-2957	44.9-3112	89.8-4305	134.8-4772	1
Bathalagoda	1970	maha	BG73-2	short	0-2386	44.9-4046	89.8-5291	134.8-5498	1
Sathalagoda	1970	iaha	BG48-1	short	0-2438	44.9-3683	89.8-4668	134.8-5550	1
Paranthan	1970	maha	BG11-11	long	0-2749	44.9-4409	89.8-4772	134.8-5031	3
Ambalatota	1910	iaha	BG11-11	long	0-5013	44.9-5654	89.8-7366	134.8-7039	3

Continued (P.3)

Polonnaruwa	1910	raha	BG11-11	long	0-3521	89.8-5498	44.9-5083	134.8-5654		3
Bathalagoda	1970	yala	BG34-8	short	0-3164	44.9-5083	89.8-6328	134.8-6639		1
Bathalagoda	1910	yala	BG34-12	short	0-3519	44.9-5135	89.8-5706	134.8-6484		1
Bathalagoda	1970	yala	8634-11	short	0-2853	44.9-4357	89.8-5187	134.8-6011		1
Paranthan	1971	maha	BG11-11	long	0-3060	44.9-5602	89.8-5861	134.8-6432		3
Paranthan	1971	maha	MI273	long	0-3683	44.9-5758	89.8-6743	134.8-1106		3
Ambalatota	1971	iaha	MI273	long	0-2951	44.9-5291	89.8-6276	134.8-6380		3
Ambalatota	1911	maha	BG11-11	long	0-3994	44.9-4980	89.8-6276	134.8-6536		3
Polonnaruva	1911	maha	BG11-11	long	0-4668	44.9-6173	89.8-6899	134.8-7054		3
Ambalatota	1971	yala	BG34-11	short	0-2542	44.9-2853	89.8-3372	134.8-3735		3
Polonnaruva	1971	yala	BG34-11	short	0-3112	44.9-4253	89.8-4980	134.8-5550		3
Polonnaruva	1971	yala	BG34-8	short	0-4150	44.9-5135	89.8-5758	134.8-6691		3
Bathalagoda	1912	maha	66-1	long	0-4980	44.9-5913	89.8-6899	134.8-7521		1
Bathalagoda	1912	yala	BG69-4	long	0-4824	44.9-6173	89.8-7366	134.8-8092		1
Karandiyanaru	1972	yala	BG34-8	short	0-3631	39.3-3181	78.6-4409	95.4-4409	157.2-4876	3
Paranthan	1972	yala	BG34-8	short	0-3366	39.3-4928	78.6-5809	111.9-6068	151.2-6121	3
Paranthan	1912	yala	BG34-2	short	0-3164	39.3-4772	78.6-5343	117.9-6100	151.2-6328	3
Ambalantota	1972	yala	BG34-8	short	0-3366	39.3-4513	78.6-3859	117.9-3890	151.2-3268	3
Polonnaruva	1912	yala	BG34-8	short	0-4969	39.3-5291	78.6-5965	111.9-6536	157.2-7002	3
Polonnaruva	1912	yala	BG34-2	short	0-4513	39.3-6121	78.6-6743	117.9-6743	157.2-7469	3
Bathalagoda	1913	maha	8690-2	long	0-5758	44.9-6847	89.8-8092	134.8-8351		1
Bathalagoda	1913	iaha	8690-2	long	0-3890	44.9-6276	89.8-6951	134.8-7832		1
Bathalagoda	1913	iaha	8666-1	long	0-3415	44.9-6011	89.8-6639	134.8-7002		1
Ambalantota	1914	iaha	8611-11	long	0-4419	22.5-5959	44.9-6145	89.9-1054		4
Bathalagoda	1914	yala	8611-1	long	0-4150	44.9-5706	89.8-7054	134.8-7158		1
Bathalagoda	1914	yala	8694-2	short	0-2853	44.9-3631	89.8-4720	134.8-5291		1
Bathalagoda	1974	yala	BG94-1	short	0-2905	44.9-3838	89.8-4565	134.8-5291		1
Ambalatota	1915	maha	8690-2	long	0-6314	31.4-6823	62.9-6799	89.8-7839		4
Mahailluppallama	1975	maha	BG11-11	long	0-4809	33.1-5814	61.4-6601			5
Kahailluppallama	1915	raha	BG34-8	short	0-5677	33.7-5690	67.4-5890			5
Bathalagoda	1915	yala	BG11-11	long	0-2119	44.9-3787	89.8-5135	134.8-5343		1
Bathalagoda	1915	yala	8611-I1	long	0-4150	44.9-5187	89.8-5809	134.8-6639		1
Bathalagoda	1915	yala	BG90-2	long	0-3060	44.9-4253	89.8-5706	134.8-5861		1
Ambalantota	1976	iaha	BG90-2	long	0-6700	31.4-7200	62.9-8000	89.8-8700		3
Bathalagoda	1976	maha	BG96-3	long	0-4357	44.9-5706	89.8-6536	134.8-6847		1
Bathalagoda	1916	maha	BG90-2	long	0-4305	44.9-5498	89.8-6743	134.8-6795		1
Bathalagoda	1976	yala	BG90-2	long	0-4876	44.9-6536	89.8-7832	134.8-8092		1
Bathalagoda	1977	maha	BG12-1	long	0-3112	44.9-4409	89.8-4720	134.8-4824		1
Bathalagoda	1977	maha	BG11-11	long	0-2801	44.9-4046	89.8-5446	134.8-5602		1
lathalagoda	1977	maha	BG402-1	long	0-3320	33.1-4305	67.4-4616	101.1-5135		1
Bathalagoda	1911	maha	BG402-2	long	0-3112	33.7-3890	67.4-4876	101.1-5239		1
lathalagoda	1911	raha	BG94-1	short	0-2853	33.7-3838	67.4-4098	101.1-4720		1
Puttalama	1911	maha	BG34-8	short	0-3612	44.9-5317	22.5-4492	89.8-7054		3
Bathalagoda	1911	yala	BG74-1	long	0-4357	44.9-5446	89.8-6380	134.8-6276		1
Bathalagoda	1911	yala	BG90-2	long	0-4616	44.9-5965	89.8-6432	134.8-6380		1
Bathalagoda	1918	maha	BG34-8	short	0-2853	44.9-4357	89.8-5031	134.8-5135		1
Bathalagoda	1918	iaha	BG726-5	short	0-3164	44.9-4616	89.8-5446	134.8-5706		1
Bathalagoda	1978	maha	BG380-2	long	0-4928	44.9-6121	89.8-7262	134.8-7366		1
Bathalagoda	1978	maha	BG90-2	long	0-4201	44.9-5758	89.8-6328	134.8-6380		1
Bathalagoda	1918	iaha	280-1	short	0-3060	44.9-4257	89.8-5031	134.8-5187		1
Bathalagoda	1918	yala	BG401-1	long	0-5602	44.9-6173	89.8-6795	134.8-7314		1

Continued (P.4)

Bathalgoda	1978	yala	BG304-2	short	0-5158	44.9-6639	89.8-7158	134.8-7314		1
Bathalagoda	1978	yala	BG400-1	long	0-5343	44.9-6691	89.8-7366	134.8-7158		1
Bathalagoda	1978	yala	BG90-2	long	0-5343	44.9-7054	89.8-7731	134.8-7729		1
Bathalagoda	1918	yala	BG94-1	short	0-5654	44.9-6278	89.8-6380	134.8-6484		1
Bathalagoda	1919	maha	BG94-1	short	0-3258	33.7-3836	67.4-4451	112.3-4633		1
Mahailluppallama	1979	maha	BG94-1	long	0-3258	30-3836	60 -4341	100 -4633		2
Bathalagoda	1979	yala	BG379-3	long	0-5498	44.9-6432	89.8-7106	134.8-6951		1
Bathalagoda	1919	yala	BG90-2	long	0-5708	44.9-6691	89.8-6899	134.8-1002		1
Bathalagoda	1980	yala	86319-2	long	0-5708	44.9-6951	89.8-7677	134.8-1832		1
Bathalagoda	1980	yala	8690-2	long	0-5809	44.9-7366	89.8-7781	134.8-7884		1
Mahaillppallama	1980	yala	BG94-1	short	0-4603	33.7-4981	67.4-5525	112.3-5570		2
Gall	1980	yala	BW272-6	short	0-2750	15 -3080	45 -3140	65 -3200	85-3050	6
Gall	1980	yala	BW272-6	short	0-3910	25 -4150	45 -4560	65 -4270	85-4230	6
Gall	1980	yala	BW272-6	short	0-2480	25 -3500	45 -3150	65 -3860	85-3370	6
Kalutara	1980	yala	BW267-3	long	0-4110	25 -4950	45 -5910	65 -5480	85-5330	6
Kalutara	1980	yala	BW267-3	long	0-4150	25 -4210	45 -4570	65 -1320	85-4260	6
Kalutara	1980	yala	11261-3	long	0-3520	25 -4210	45 -4780	65 -4510	85-4030	6
Girandurukotte	1986	maha	86915	short	0-3965	40 -4591	80 -5550	120 -5549		7
Girandurukotte	1986	yala	BG43-8	short	0-3733	40 -4560	KO -5229	120 -5514		1
Girandurukotte	1987	yala	BG915	short	0-4500	40 -4700	80 -5200	120 -5110		1
Girtndurukotte	1988	maha	BG1165-3	short	0-4090	40 -4420	80 -5380	120 -5250		7
Girandurukotte	1988	yala	BG1165-3	short	0-4980	40 -5580	80 -6850	120 -6820		7
Girandurukotte	1989	yala	BG1165-3	short	60-4270	80 -5090	100 -5490	120 -5120		7

Note: 1. Bathalagoda rice breeding center, the Department of Agriculture.

2. Agricultural research station, Mahailluppallama, of the Department of Agriculture.

3. Office of the Deputy Oirector Research, the Department of Agriculture.

4. Agricultural research station Ambalantota, the Department of Agriculture.

5. Quarterly reports of the agricultural research station, Mahailluppallama.

6. Jayawardena, S.D.G., et al, JARQ 17 (2), 1983.

I, Shibata et al. (1990).