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ESTABLISHING PRIORITIES FOR ALLOCATING FUNDS TO RICE RESEARCH

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There has been an increasing interest in recent years in the problems and procedures related to establishing priorities in agricultural research programs. In developed countries this is a reflection of tighter budgets for research. In the developing countries, the interest arises out of a growing recognition of the critical role played by research in the development process, and the severe limitations imposed by the lack of trained manpower as well as funds for research.

Agricultural research, particularly in the biological sciences, has many of the general characteristics of a public good. The use of the product by one farmer or group of farmers does not exclude its use by others. Furthermore, it normally is not possible to exclude from utilization those who have not paid for it. This does not imply that information from research is equally available to all in the society. Certainly this has not been the case with the new rice technology. But it does indicate that private individuals cannot readily internalize the benefits from the research even through such procedures as patents. Therefore, investment in agricultural research in the biological sciences is undertaken largely by the government rather than by the private sector.

A number of recent studies have shown clear evidence of an underinvestment of public funds in research in the developing countries. This explains in part the rapid development of the network of international agricultural research centers. The creation of these centers has brought to the fore a number of important issues with respect to the allocation of research funds for agriculture. How much in total could or should the developed country donor agencies contribute to agricultural research? What types of research centers and activities should be supported? What should be the balance of support between national and international programs; between focus on basic science and development of technology; between focus on current re-

search problems and development of research capacity? How can national governments be encouraged to provide more support for research activities and for training research workers? The above questions are of concern to the international centers themselves who obtain their financial support from the Consultative Group on International Agricultural Research (CGIAR) and who have the dual role of engaging in research and facilitating the development of indigenous research capacity. Furthermore, the CGIAR, which is composed of representatives from the donor agencies, is warning of the possibility of a sharp slowdown in the growth of its own contribution (which now exceeds $100 million annually). Pressure is being brought on the individual research centers to improve their procedures for establishing priorities in the allocation of funds. In achieving this objective, an understanding of the interrelationship between the research in the international centers and in national programs is of paramount importance.

In this paper we report the results of an exercise undertaken by one of the international centers, the International Rice Research Institute (IRRI), in an effort to clarify its own research priorities. Both the procedures followed and the results obtained should be of general interest to professional economists, research administrators, and others concerned with agricultural policy.

The paper is divided into five parts. The first section sketches the historical development of rice breeding research in Asia. The second reviews the productivity of research investment and the structure of the research system. Methodologies for establishing priorities among rice research programs is discussed in the third section. The fourth section presents the results of the analysis, and the fifth discusses the implication of these results for rice research in Asia.

Historical Perspective on Rice Breeding Research

New arable land, in particular; land that could be brought into paddy production,

became increasingly scarce in East Asia (Japan, Korea, and Taiwan) around the turn of the century. Organized research in rice breeding in Asia dates from the establishment of the National Agricultural Experiment Station in Japan in 1893. The rediscovery of the Mendell papers in 1900 paved the way for scientific rice breeding. Advances in agricultural chemistry and soil science in the German tradition, and the introduction of chemical fertilizers first in Japan and later in the colonies of Korea and Taiwan encouraged the development of fertilizer-responsive rice varieties. As a result, production gains in East Asia came to be based on modern technology - new seeds, fertilizer, and water control - leading to increases in yield and cropping intensity.

By contrast, in tropical Asia neither the pressures of population nor the priorities of the colonial administrations dictated the need for a major research effort to increase rice yields. Rice yields remained static. By mid-century an emerging food problem was becoming evident, but the belief was widespread that the indica varieties would not respond, like the japonicas, to conditions of intensive cultivation and heavy fertilization.[1/] The potential for altering the indica plant type through breeding was yet to be recognized.

The virtual disappearance of the arable land frontier in South and Southeast Asia after World War II hastened by the "population explosion" ~~obviated~~ (demonstrated) the need for the development of modern technology to enable rice production to keep pace with rapidly growing demand. The dismantling of the colonial research network as the developing countries gained independence left tropical Asia with virtually no legacy of trained research manpower. This led to an international effort to facilitate research and to strengthen research capacity.

The first important international undertaking was the establishment of the International Rice Commission (IRC) in 1949 within the framework of the FAO.[2/] It's working parties undertook several projects such as categorizing and maintaining genetic stocks, japonica-indica hybridization, cooperative variety trials, wide

adaptability tests. The first meeting of the working party of IRC held in Rangoon in 1950 emphasized that the primary aim of rice improvement was increased yield through selection and breeding. However, high yielding varieties that would respond to fertilizer had been virtually eliminated by the tall, leafy varieties adapted to the conditions that prevailed at the beginning of the century. Indentifying short, stiff-strawed varieties in the world collection of typical varieties was like looking for a needle in a hay stack (Parthasarathy, 1972). Coupled with this was the failure of the scientists to identify the plant type that should have been the object of the search. The achievements were disappointing for the indica-japonica hybridization project sponsored by the FAO from 1950-57 and headquartered at the Central Rice Research Institute(CRRI), Cuttack, India. In 1958, the IRC member governments called for an international rice research institute in the tropics not only for achieving the identified objectives of rice breeding, but also for training personnel in the different disciplines.

The history of the development and dissemination of modern rice varieties from the International Rice Research Institute (IRRI) is well documented (Dalrymple, 1978). However, there are a few points worth noting. Neither the founders of IRRI nor the group of researchers who began work at IRRI in 1962 would have been so optimistic as to suggest that a major "breakthrough" could have been achieved in four years. Plant breeding is not such a plannable task. In addition to the experience and insites of some of the best rice scientists from Japan, Taiwan, the United States, and tropical Asia, a stroke of luck was needed to speed the effort. The original two Taiwan semi-dwarf indica varieties were unearthed in the Taiwan collection in 1952 when a program was initiated there to improve the yield of the native indica varieties.[3/] The subsequent discovery by IRRI scientists that these varieties has a single recessive gene for dwarfness greatly reduced the time required to breed for the new plant type.

The first of the IRRI varieties, IR8, released in 1966 was developed from the cross of one of the Taiwan dwarfs, Dee-geo-woo-gen, with the Indonesian variety Peta.

Peta was one of the so-called 40C selections, a non-photoperiod sensitive variety, developed by the Dutch on the eve of World War II. In the tropics the Dutch seem to have been the first to recognize the importance developing varieties with wide adaptability by breeding for non-photoperiod sensitivity. The yield potential of IR8 grown under ideal conditions in tropical Asia has yet to be exceeded.

The enthusiasm that accompanied the initial release of the new varieties led many to assume that it was just a matter of time before the new seed-fertilizer technology disseminated to all parts of Asia. Those who understood the history of the developmen of new rice technology in East Asia knew better. It was soon evident that the adoptio of the new technology was closely associated with the degree of water control.[4/] The unirrigated areas account for over two thirds of the rice growing area in Asia. New varieties even today are seldom found in these areas.

The literature of the "green revolution" suggests that in tropical Asia large farmers and landlords have gained relative to small farmers and tenants as a result of the adoption of high yielding grain varieties. The evidence in the case of rice is mixed.[5/] Small farmers frequently have adopted the new technology as rapidly as large farmers. On a per hectare basis the new technology is energy intensive relative to the old and requires a higher level of cash inputs, but in a per ton basis the evidence is not clear. Traditionally before the adoption of new technology small farmers achieved yields as high as or higher than large farmers, but employed more labor and less purchased inputs per hectare or per unit of output. In those areas where the institutional structure has allowed the affluent easier access to inputs and credit often at lower prices, large farmers frequently use a higher level of input and achieve higher yields with the new technology.

Of far greater immediate concern is the fact that most Asian rice farms are already very small. Farm size is declining and the number of landless and near landless is increasing; a situation that has no parallel in the development of the East Asian rice economies. Additional rice must be produced,

and ways must be found for the landless to participate in the sharing of increased production. This brings pressure to bear on the existing social and institutional structures.

The biases inherent in the institutional structure cannot be overcome by design of "more appropriate" technology. There is, however, latitude in the development of technology for reducing energy and cash requirements and thus increasing availability to small farmers. The development of varieties resistant to insects and diseases eliminating the need for expensive chemical controls, is one example. Research also is underway to improve the efficiency of fertilizer and other chemical inputs through proper timing of application and placing of materials.

In terms of the implication for allocation of resources to rice research, the previously mentioned fact that the technology favors the irrigated over the unirrigated areas is of potentially greater significance than the farm size issue. The regional bias of the technology is discussed in more depth subsequently. In the next section we describe the rice research organization as it has developed overtime in Asia.

The Organization of Rice Research

Throughout this century the level of investment in rice research in East Asia (Japan, Korea, and Taiwan) has been several fold the level in South and Southeast Asia (Table 1). Japan is, of course, the leader. Based on the estimates of Evenson (1978) Japan's research investment since World War II has represented slightly more than half of the world total.

Beginning with the work of Griliches (1958) for hybrid corn in the United States there have been a host of studies on returns to investment in agricultural research. A significant number have dealt with rice (Table 2). Hayami and Akino show that the internal rate of return to investment was greater in the period after 1930 when Japan

shifted from a breeding program based on pure line selection to an emphasis on the development of varieties by crossbreeding. Evenson and Flores (1978) show that in tropical Asia the internal rate of return for national research programs increased substantially in the period after 1966 as national programs were able to lay claim to a major share of the benefits of the new rice technology. The consistantly high internal rate of return found in all studies suggests a chronic state of underinvestment in rice research.

There has been considerable discussion regarding both the accuracy and meaning of these findings (see for example Hertford and Schmitz, 1977 and Ruttan, 1978). Certainly, it would be wrong to conclude that because returns are so high it is unnecessary to worry excessively about the allocation of funds. In fact, just the opposite conclusion seems warranted. Given the scarcity of resources and high potential payoff, more time needs to be devoted to the question of allocation. But it would be difficult to suggest how additional funds should be invested without a clearer understanding of the research organization. In order to achieve efficient utilization of very limited research resources, understanding the structure, organization and administration of research is a matter of great importance.

A typology of rice research systems can be drawn which relates research skills and institutional organization to the stage of development of the system.[6/] A research system passes through three stages of development: (i) the <u>low skilled system</u> dependent primarily on technical and engineering skills and characterized by widely diffused commodity oriented experiment stations, (ii) the <u>intermediate hierarchal system</u> with appreciable scientific skills and substantially economies to be gained by the concentration of these skills in leading institutions, (iii) <u>advanced scientific-based systems</u> characterized by a large supply of conceptual scientific skills and emphasis of the most highly regarded centers on research which does not

have a direct technological objective.

In the first step of development, the low skilled system will depend heavily on the transfer and simple adaption of technology. As the system matures, capacity to develop new technology, given the state of scientific knowledge, is added. In the final stage of the systems development, skills are added which permit basic scientific breakthroughs.[7/]

Japan is perhaps the only country in Asia where the rice research system has passed through all three stages and can today be characterized as advanced scientific-based. The shift from the first to the second stage occurred in 1926 when the build-up of technical and scientific skills resulted in a major reorganization of agricultural research. Under the new "assigned experiment system" the national experiment station was given the responsibility for conducting the initial crosses while breeding centers in each of the eight regions conducted further selections for different ecological conditions. The intermediate hierarchal system that emerged allowed Japan to capitalize on the development and dissemination of crossbred varieties.

Although the same scientific knowledge was potentially available to the experiment stations established throughout the tropics in the early part of the century, the scientific manpower needed to translate this knowledge into new technology did not emerge for the reasons previously noted. The handful of scientists were often caught up in all phases of agricultural service - research, extension, and administration - and became a "jack of all trades" (Masefield, 1972). Rice research started at a single experiment station in most countries, but the great diversity of rice varieties was considered to be due to their narrow adaptability. In most countries, therefore, several stations were eventually established, each in a known ecological area.

In the decade after World War II efforts to encourage agricultural development in the tropics still tended to ignore the potential of research in food crops. Extension received priority over research in part because the benefits promised to be

more immediate, and in part because it was felt that higher production could be achieved with existing technology.[8/]

Beginning in 1954 the extension model was superseded and incorporated into a more comprehensive organizational structure for agricultural development patterned after the land grant university in the United States.[9/] The adoption and promotion of the land grant model was reflected in international aid agency funding of developing country research. This represented 40 to 50 percent of the total investment in the 1950s and about one third of the total in the mid 1960s (Evenson, 1977). In research, export crops continued to be favored over food grains. With one or two exceptions, such as India, the national research programs of tropical Asia could continue to be categorized as low skilled systems. This lag in the development of research organization and scientific skills set the stage for the technological breakthrough that was to follow. The establishment of the International Rice Research Institute (IRRI) in 1962 as the "main station" in an international hierarchal system can be viewed as a temporary departure from the basic developing country research process (Evenson, 1977). However, it has been suggested by Ruttan (1978) that the system of international agricultural research centers be looked upon as a permanent feature of the global agricultural research development infrastructure.

One could have argued, of course, that following in the path of the Rockefeller Foundation country programs in Latin America, the aim should have been to develop the national research main station. However, the investment resources and the indigenous professional skills were not available and are still extremely limited in many countries of Asia today. In the creation of IRRI, the founders gambled that the concentration of a "critical mass" of research skills could result in the development of a technology with a high degree of transferability. The new plant type proved to be transferable across the irrigated rice paddies of tropical Asia,

but only in the Philippines has there been significant acceptance of the modern varieties in the rainfed environment.

The creation of IRRI and the other international centers for biological research has been referred to as the "big science" model (Esman, 1978). After 1965 international aid funding for national research agencies declined as more and more funds were diverted to the establishment of the international agricultural research centers.[10/] The main criticism of this approach is that the new varieties tend to be limited primarily to farmers who can replicate the favorable environmental conditions (e.g. irrigation) and afford the costly inputs. Furthermore, analysis of returns on investment (Table 2) show that returns in national programs are very high. There is an observable high degree of complementarity between the work of the national institutions and international centers. A strong national program can facilitate the spread of new technology by adapting the exotic materials to local conditions. This capacity becomes increasingly important as the easy gain in productivity in the more favorable environments is fully exploited. The establishment of the International Agricultural Development Service (IADS) in 1975, International Service for National Agricultural Research (ISNAR) in 1978, whose main focus is on the strengthening of national research systems, reflects a growing recognition of the need to achieve an appropriate balance of international aid support between international and national programs.

Alternative Methods of Establishing Research Priorities

Although the issue can be debated, there was undoubtedly more agreement among rice research workers in the early 1960s as to the best research strategy for increasing rice production than exists today. The lag in technology development created a gap, but experience with small grains elsewhere suggested the potential to be gained from breeding a short-strawed fertilizer responsive variety. This objective

having been achieved, however, the subsequent steps to increase production were less obvious. Thus, a little more than a decade after the establishment of IRRI, the appropriate allocation of research resources was a matter of considerable debate. Scientific and management staff alike showed increasing concern for the need to develop a clearer perception of research priorities.

Methods and procedures for evaluating agricultural research can be usefully divided into ex post studies and ex ante models.[11/] A primary objective of many ex post studies is to assess the economic returns to research investment. The results of several of these analyses have been discussed previously (Table 2). We will consider only the ex ante approaches in this section. Schuh and Tollini (1978, p. 56) note that the various ex ante methods, or the methods which look to the future, are most appropriate in establishing research priorities. The advantage of these procedures is that they provide a formal means of using pooled judgement. In degree of methodological sophistication, the ex ante models range from the simple scoring schemes to highly complex mathematical programming models. To a greater or lesser degree all such models depend upon the judgement of either the researcher or of knowledgeable individuals concerning the outcome of future events. While the results may be sensitive to these judgements, some of the most important findings are likely to hold under a wide range of sensitivity tests. Three ex ante approaches have been utilized by IRRI.

A wide range of models have been developed which attempt to examine the results of research in terms of expected impact on production and income distribution. One such approach employed by IRRI is closely related to the "gap and trend analysis" undertaken by the International Food Policy Research Institute (IFPRI).[12/] The growing gap between projected demand for food and projected trend in supply reflects the need to achieve a more rapid increase in production. A preliminary study was undertaken to determine the investments required in irrigation, fertilizer, and research to increase Asian rice supplies at a pace in keeping with projected demand

(Herdt, Te, and Barker, 1977). A joint project is now being initiated by the ASEAN rice growing countries (Indonesia, Malaysia, Philippines, and Thailand) in cooperation with IFPRI, IRRI, and the International Fertilizer Development Center (IFDC) to investigate the supply, consumption and trade dimensions of this problem in greater detail. This investigation looks on research as one alternative for shifting the supply function. It is concerned with the total research needs for rice, but not specifically with the allocation or research priorities within rice.

A number of studies have focused on the productivity and income distribution effects of the allocation of research funds among alternative problem areas on commodities. The scoring model was employed to determine the relative research emphasis that should be given to specific problem areas.[13/] Senior scientists were asked to rank the Institutes nine problem areas separately on the basis of twelve questions relating to research expectations. The results were weighted into a single ranking of problem areas. These rankings turned out to be very comparable to the ranking according to budget allocation (Table 3). The only significant discrepancy is in the lower rating by scientists of "machinery development and testing" and the higher rank by scientists given to "soil and crop management." The results are, of course, sensitive to the weightings given to the various questions (e.g. will the research increase the yield of rice?). A further difficulty is that even in an institute as small and homogeneous as IRRI, the average scientist is not and should not be expected to be concerned with the priorities of the entire institute.

A similar and perhaps more useful exercise, is one which administration frequently faces related to the addition (or reduction) in staff. If the institutes could hire one more person, what problem area and what discipline in the problem area should have first priority? If this is carried through several steps in either direction, it can provide clues as to areas that need to be strengthened or reduced. This procedure takes cogizance of the fact that major redirections of research focus are normally accomplished by changes in the research staff.

In the analysis presented in this paper we have used a productivity approach to examine the benefits to be derived from research in different rice-growing environments - irrigated, rainfed, upland, and deep-water rice - in the main rice growing countries of South and Southeast Asia (Fig. 1). (A complete definition of these environments is provided in the next section.) Scientists believe that in large measure the research findings are environment specific, and this is born out by the fact that the new varieties have been adopted principally in the irrigated areas. Thus, we can assume that the four types of rice defined by the different environmental conditions are, from a production perspective, essentially different commodities.

The analysis of production potential in different rice growing environments has implicit implications for income distribution. Many of the rural poor in Asia are located in the unirrigated rice producing regions particularly in Eastern India and Bangladesh. The initial sources of the new rice technology in the irrigated environment has tended to widen the disparity between irrigated and unirrigated regions.

Allocation of Research Inputs to Rice Environments

In this section we first define the rice growing environments. We then present the conceptual framework of the productivity approach. The analysis and results are discussed under three headings: (i) gross benefits, (ii) net benefits for irrigated vs. rainfed rice, and (iii) contribution of research by country.

Definition of Environments

A detailed classification of environmental factors influencing rice production includes soils, characteristics, geographic features, water control, climatic factors, biotic factors, and socio-economic factors. The definitions used in this analysis are based principally on water control. Water control is emphasized because of the previously noted close association between the degree of water control and the adoption of the new technology. The definitions given here have been developed through numerous

discussions with biological scientists. The definitions are as follows:

Irrigated rice - Water is added to the fields from canals, river diversions, pumps, tanks, etc. The degree of water control (both irrigation and drainage) varies considerably from one system to another.

Shallow rainfed - This area has a maximum water debth from tillering to flowering of from 5 to 15 cm. Water is impounded in paddy fields and rice is normally transplanted. Some parts of the area are drought prone, particularly the higher terraced areas.

Medium deep rainfed - This area has a maximum water debth from tillering to flowering of from 15 to 100 cm. Medium deep rainfed rice is found principally in the major river deltas. The area is typically either transplanted or broad cast to traditional tall varieties.

Deep water rice - The maximum water debths exceeds 1 meter. Deep water rice is found in the major river deltas of continental Asia. Fields are usually unbounded and are broad cast to floating rice varieties.

Upland rice - Upland rice is distinguished from rainfed rice in that it is grown as a typical non-paddy crop, with no attempt to impound the standing water in the field by bunding as is normally the case in both rainfed and irrigated fields. The term upland, is a misnomer, as the upland areas are not necessarily at higher elevations. The upland rice is grown under aerolac conditions and is thus subject to water stress.

It is presumptious to assume that we can accurately determine the amount of rice grown under each environment. Nevertheless, rough indications (Fig. 1 and Appendix Table 1) are useful as the analysis will show, and the definition by specific water debth and degree of water control helps to reduce the confusion that has been associated with the use of the above terms. These water debths are associated with plant type, modern semi-dwarf varieties being grown in water debths of 15 cm or less, traditional tall varieties up to one meter in debth, and planting rice in areas where water debth exceeds one meter. However, developing new rice technology for each of these areas involves consideration of a wide range of factors in addition to varietal type.

The Productivity Approach

Theoretically, in order to maximize the productivity of research resources, expenditures should be allocated so that the increase in productivity from an additional amount of funds spent on research in each environment is equated. A model taking amount of time required to solve the problem, probability of success, yield increase, changes in cropping intensity, area affected, direct costs of using the technology, and the investment cost can be formulated.

The yield effect can be formulated as follows:

$$\sum_{m=m'}^{M} P_{(m)} \left(\Delta Q_{m,t} - \Delta C_{p,t}\right) Ai$$

where:

m = the level of yield.

$P(m)$ = the probability of success in achieving $\Delta Q_{m,t} - \Delta C_{p,t}$ in time period t.

$\Delta Q_{m,t}$ = the change in value of output made possible by research leading to an increase in yield in time period t.

$\Delta C_{p,t}$ = the added cost to the farmer of using the technology in time period t.

Ai = the area of the rice environment for which the technology is developed.

The above expression shows the probability of success ($P_{(m)}$) in achieving an increase in income ($\Delta Q_{m,t} - \Delta C_{p,t}$) over a specified rice growing environment (Ai).

The intensity effect can be formulated as follows:

$$\sum_{n=n'}^{N} P_{(n)} \Delta A_{n,t} (Qi - Ci)$$

where:

n = the level of cropping intensity.

$P_{(n)}$ = the probability of achieving $\Delta A_{n,t}$ in time period t.

$\Delta A_{n,t}$ = the change in intensity of cropping pattern in time period t made possible by research investment.

Qi = value of output per hectare of area.

Ci = cost of output per hectare of area.

The above expression shows the probability of success ($P_{(n)}$) in achieving an increase in cropping hectares ($\Delta A_{n,t}$) for a given income per hectare in a specified rice growing environment ($Qi - Ci$).

The investment in research for a given rice environment in a given time period ($K_{i,t}$) produces a stream of benefits over a project life of t years. If the social rate of time discount is r, then the NPV_i of the investment in rice environment i can be written as follows:

$$(1) \quad NVP_i = \sum_{t=t'}^{T} (1+r)^{-t} \{[\sum_{m=m'}^{M} P_{(m)} (\Delta Q_{m,t} - \Delta C_{p,t}) Ai]$$

$$+ [\sum_{n=n'}^{N} P_{(n)} \Delta A_{m,t} (Qi - Ci)]\} - \sum_{t=}^{T'} (1+r)^{-t} K_{i,t}$$

Given this formula, for each type of rice environment it would be optimal to allocate research resources so as to equate the net present value of potential new technology for each environment. Due to lack of adequate data we have modified the above model to assess the benefits for research investment in the five environments specified in the previous section. The modifications incorporates an additional

effect on productivity resulting from the expansion of irrigation.

Gross Benefits

A group of IRRI scientists estimated the anticipated increase in rice yield and cropping intensity that would be possible from "reasonable" research and extension inputs directed at each environment for South and Southeast Asia.[14/] It was assumed that these yields would be realized over a twenty year period. At the outset the probability of success, the direct cost of technology for each area, and the time required to achieve success are assumed to be identical for all environments. Thus the formula for gross benefits can be written as follows:

$$(2)\quad NPBi = \sum_{t=t'}^{T} (1+r)^{-t} \{[\sum_{m=m'}^{M} (\Delta Q_{m,t})Ai] + [\sum_{n=n'}^{N} (\Delta A_{n,t})Qi] + [\sum_{m=m'}^{M} \sum_{r=r'}^{R} (\Delta Q_{m,t})\ (\Delta A_{i,t})]\}$$

The first two expressions in the equation account for the affect of yield and intensity on production and gross returns. These terms are as previously defined. The final expression relates to the increase in production and income that is the net affect of the increase in irrigated area with its higher yields, less the reduction of the returns from the rainfed areas converted to irrigation $(\Delta Q_{m,t})\ (\Delta A_{i,t})$. Cropping intensity is assumed to increase in all environments either by increasing the percentage of the area with more than one rice crop or by increasing the percentage of the area followed by a crop other than rice or both. The expansion of irrigation increases the amount of double cropping of rice in the irrigated areas.

Gains in yield and cropping intensity are shown in Table 4. The first two columns of Table 5 show the change in the proportion of land area in specific categories over the 20 year period due to the expansion of irrigation. Irrigated area was assumed to grow at 1.5% per year. The gross area in the irrigated environment increases by 9 million hectares. The area in rainfed rice declines by 6 million as land was converted

from rainfed to irrigated rice. The net increase of 3 million hectares is due to the increase in the irrigated area double cropped.

The increase in rice production in the 1990s from expansion of irrigated land, assuming no change in the 1970s yield level, is projected to be 17.8 million tons (Table 5). If the value of rice is assumed to be US$100 per ton, the undiscounted benefit in the 20th year will be $1.78 billion, Irrigated rice accounts for 52% and rainfed rice for 38% of the total research and extension benefits that results from an increase in yield. Deep-water and upland contribute the balance.

The impact of crop intensification is shown in Table 6. Undiscounted benefits in the 20th year are $8.10 billion from rice, and $3.40 billion from upland crops, where upland crops have a net value (gross value less cash costs) of $75 per ton (Col. 7 & 8).

The value of discounted benefits incorporating both the yield and crop intensification affect over the 20 year period are summarized in Table 7. The largest share of benefits, 56%, is in the irrigated environment, both because the area is expanding and because the absolute yield gain is larger for irrigated than for rainfed rice. The potential for increasing yields on shallow and medium rainfed areas was assumed to be equal (0.8 t/ha), but the shallow rainfed area is considerably larger than the medium deep rainfed. Rainfed rice accounts for 37% of the total increase in benefits. Upland and deep-water rice account for only 3 and 4% of the total benefits, both because the area is small and the potentials for increase in yield are low.

Net Benefits - irrigated vs. rainfed rice.

Excluding further consideration of upland and deep-water rice we now expand the analysis to compare the benefits and costs and internal rate of return for: (i) investment in research/extension for the irrigated rice environment, (ii) investment in research/extension for the rainfed rice environment, and (iii) investment in new irrigation. The equation expressing the summation of all benefits and investment is as follows:

$$(3)\quad NVPi = \sum_{t=t'}^{T} (1+r)^{-t} \{[\sum_{m=m'}^{M} P_{(m)} (\Delta Q_{m,t} - \Delta C_{p,t})Ai] + [\sum_{n=n'}^{N} P_{(n)} \Delta A_{n,t}$$

$$(Qi - Ci)] - [\sum_{t=0}^{T'} (1+r)^{-t} K_{i,t}]\} + \{[\sum_{r=r'}^{R} P_{(r)} (\Delta A_{i,t} (Qi - Ci)] +$$

$$[\sum_{m=m'}^{M} \sum_{r=r'}^{R} P_{(m/r)} (\Delta Q_{m,t} - \Delta C_{p,t}) \Delta A_{i,t}] - [\sum_{t=0}^{T'} (1+r)^{-t} (I + K_{j,t})]\}$$

where:

t' = 1980

T = 2010

r = 12 percent

m' = level of technology in 1980 = 3t/ha for irrigated rice, 1.5t/ha for rainfed rice

M = level of technology in 2000 to 2010 = 4.1t/ha for irrigated rice, 2.3t/ha for rainfed rice

$P_{(m)}$ = probability of success for yield = 0.75 for irrigated rice, 0.50 for rainfed rice research/extension

$\Delta Q_{m,t}$ = change in value of output in time period t made possible by research

$\Delta C_{p,t}$ = change in farm costs associated with change in value of output in time period t

Ai = area in environment i over which the technology is successful

$P_{(n)}$ = probability of success in cropping intensity = 0.75 for irrigated rice and 0.50 for rainfed rice research

$\Delta A_{n,t}$ = the change in intensity in cropping pattern in time period t

$t=0$ = in 1976

T' = 1985

$K_{i,t}$ = capital investment in new technology for rice environment i in time period t

R = benefits from total new irrigated area = 9 million ha in 2000 to 2010

$P_{(r)}$ = probability of success = 1.0 for new irrigated area

$\Delta A_{i,t}$ = change land area in environment i due to expansion of irrigation in time period t

Qi = value of output per hectare in environment i in 1980

Ci = cost associated with value of output in environment i in 1980

$P_{m/r}$ = probability of success = 0.75 for increasing the yield on new irrigated (and due to research investment) environment

I = annual investment in new irrigated area = $450 million

$K_{j,t}$ = capital investment for new technology in new irrigated area j in time period t

The first three terms of the equation are concerned with the net benefits to capital investment in research/extension for the specified environments irrigated and rainfed rice). Cropping intensity includes only rice. The remaining three terms of the equation show the net benefits to investment in new irrigation and to investment in research/extension which increases returns on newly irrigated area by the same level as for existing irrigation.

The research/extension investment and the benefit streams are shown for new technology in irrigated and rainfed rice environments in Fig. 2. In the year 1976 the annual investment in research and extension in irrigated rice is assumed to be $40 million. It increased at a rate of approximately three million per year reaching $100 million in 1995. Beginning in 1980 yields increase by 55 kg per year on irrigated land or a total of 1.1 t/ha by 2000, yields increase 40 kgs per year on rainfed land or a total of 0.8 tons/ha by 2000. The stream of net benefits (return to rice less fertilizer and labor costs) remains constant after 2000 and is discounted from the year 2010 (Fig. 2).

By the year 2000, 120 kg/ha NPK is required on all 48 million ha of irrigated land while 40 kg/ha NPK is applied to 48 million ha of rainfed land. The fertilizer costs approximately $150/ton or $0.33/kg of NPK. Paddy is $0.10/kilo and the NPK to paddy price ratio is 3.3. Approximately half of the fertilizer is produced

domestically in 12 new urea plants producing 500,000 tons of urea per year and costing $300 million per plant. One of the plants, constructed in 1985 is charged to new irrigation, two plants each constructed in 1980, 1985, 1990 and 1995 are charged to irrigated rice environment, and 3 plants constructed one each in 1985, 1990, and 1955 are charged to rainfed rice environments.

In both irrigated and rainfed environments labor is the current input cost associated with increased production. Thirty days are required to produce an additional ton of paddy and labor is valued at $1 per day.

Beginning in 1976 irrigation is assumed to expand in South and Southeast Asia at a rate of 450,000 hectares annually for 20 years at which time there are 9 million hectares of newly irrigated cropped area. However the increase in commercial area is only 6 million hectares, half of which grow two crops of rice. The capital cost per hectare of commercial area is $1500. The maintenance per cropped area is $11 per hectare per year.

Like the stream of benefits from research/extension, the stream of benefits from irrigation begins in 1980 and increases to 2000 remaining constant from 2000 to 2010. The investment stream, however, is constant at $450 million per year from 1976 to 1985.

The annual undiscounted investments, annual increased output, returns, and cost for the 20th year are shown in Table 8 for new irrigation, and for research/extension investment in irrigated and rainfed environments. The discounted benefits and costs at 12 percent interest and the internal rate of return for the three alternatives are shown in Table 9. In these calculations the benefits that result from yield increase due to investment in research/extension on newly irrigated land are considered as part of the benefits derived from new irrigation.

The initial computations suggest that returns to investment in new irrigation are relatively low. However, returns to investment in research/extension on the irrigated rice environment are high, and they appear to be even higher for rainfed rice. Why then do we find in the plans of many developing Asian economies, increasing emphasis

in irrigation investment, and relatively little interest in research on rainfed rice. The answer is in part associated with the probability of success, the element that we have not yet incorporated in our model. Although the payoff is low, the greatest certainty is associated with increased productivity due to expansion of irrigation land. At the minimum, it is known that the presently available new technology will significantly boost yields on the newly irrigated lands. It is also clear from discussion with scientists, that achieving a 1.1 t/ha yield increase with further research on irrigated lands must be given a higher probability of success than achieving 0.8 t/ha yield increase on rainfed lands.

We assumed that the probability of success in achieving returns on a hectare of new irrigation comparable to that for existing is 100 percent; the probability of achieving a 1.1 ton yield increase from investment in research for the irrigated environment is 75 percent, the probability of achieving a 0.8 ton yield increase from investment in research on the rainfed environment is 50 percent (see equation 3). Using these probabilities, we recalculate the benefits and costs and internal rates of return. While the order of priority remains the same, the difference among alternatives is understandably much smaller. Given these new calculations one might argue that with scarce scientific manpower, it makes better sense to concentrate these limited resources in irrigated rice. In the early 1960s, when the potential for increasing rice production even in the favorable tropical environments was uncertain, the argument seemed valid. However, to see this issue more clearly in the light of the situation existing today, we need to examine the potential benefits from irrigated and rainfed rice research and extension in a country by country bias.

Contribution of Research by Country

We sent questionnaires to a delegation of rice scientists from each country asking them for information on the present area in irrigated, upland, deep-water, and rainfed rice (shallow, intermediate, and semi-deep) and for the present and potential yields in each of these categories. This unofficial data received from each of the

countries was used to compute the potential benefits from research extension in each country following the procedure shown in equation 2. (Benefits due to cropping intensity again were not considered.) The results for each country are shown in Appendix Tables 2-9. The percentage share of the benefits attributable to each rice crop environment are summarized in Table 10.

The results indicate that the countries in Asia fall into two categories: those with high potential benefits from investment in rainfed rice research and those with high potential benefits from investment in irrigated rice research. Bangladesh, Burma, Thailand, and Nepal fall into the first category; Indonesia, Philippines, and Sri Lanka into the second. The exception is India, which shows a distribution of benefits similar to that for South and Southeast Asia. But if we were to divide India, which accounts for almost half of the total rice area, into regions, we probably would observe the same biomodal distribution.

There results do not imply that it would be unprofitable to expand irrigation in the rainfed oriented countries. Rather, they indicate that for those countries, regardless of the rate at which irrigation expands, for some time in the future there will be a substantial portion of total rice produced under rainfed conditions.

Among the rainfed oriented countries, there are four traditional exporters: Burma, Thailand, Vietnam, and Nepal. The first three have large delta-based rice industries. It is useful to compare the research expenditures of the rainfed and more export-oriented countries with those of the irrigated and more import-oriented countries. Table 10 shows the total and per 1000 hectare research investment for selected countries. Both in absolute level and per unit of cultivated rice area, the research investment in general was lower in those countries with a high proportion of rainfed area. IRRI research to date has been of greater benefit to those countries with a high proportion of irrigated area. As previously noted, only in the Philippines is a significant portion of the rainfed area planted to modern varieties.

Implications for Rice Research in Asia

The potential benefits for rice research were discussed in the previous section. Whether or not these benefits are realized in the next two decades will depend upon the ability to: (i) develop a suitable technology, (ii) put the technology in the hands of farmers, and (iii) provide the proper incentives to encourage farmers to utilize the technology. On all three counts the task is more formidable for the rainfed areas than for the irrigated areas. It is becoming increasingly clear, however, that we can no longer afford to bypass the rainfed areas.

Developing a Suitable Technology

There are three principle directions for rice research in the irrigated areas: (i) increasing yield potential, (ii) lowering input costs and (iii) reducing the growth duration of the plant. Basic scientific research will be searching for ways to break the current yield ceiling, and to reduce our dependence on fossill based fuels to achieve high yield. But the time horizon for this research is probably 20 to 50 years. Much of the current effort will be directed toward "maintenance research" which will make available insect and disease resistant varieties to replace earlier varieties. There is also substantial scope for more efficient application of fertilizer and chemicals which would make it possible to achieve the same yield level with significantly lower cash inputs. Whether it is possible to reduce the growth duration of the plant to less than one hundred days (from transplanting to harvest) without significant reduction in yield is questionable. But the potential of the 100 day variety for promoting more intensive crop production has not yet been fully exploited.

Developing technology for the rainfed areas probably will take more time. Lack of water control results in a more heterogeneous environment. The present research effort directed toward rainfed rice is exceedingly small (Table 10). Furthermore, many of the major research stations are not located in typical rainfed environments. IRRI is a case in point. Scientists are forced to use deep-water tanks and green-

houses to simulate the flood and drought conditions of the major rainfed areas. Even where stations are in typical rainfed environments, most of the research plots in the stations are likely to be irrigated. Only recently has emphasis been given to varietal trials under rainfed conditions. During the 1970s, there has been a considerable increase in our understanding of rice production under flood and drought conditions throughout Asia. There are already signs that the current modest investment will pay dividends, but we are not yet confident whether the yield potentials for rainfed rice indentified by the rice scientists are realistic targets.

The technology for the rainfed areas should be yield stabilizing and require a minimum of purchased inputs. For these areas it would be more appropriate to refer to high-stability varieties (HSV) rather than the conventional but misleading term high-yielding varieties (HYV). Farmers should be given the choice of raising varieties that produce a minimum level of yield every year (HSV) and varieties that produce high yields under ideal conditions, but lower yields under unfavorable conditions. Farm level surveys and investigations have shown that even in the less progressive areas, farmers have considerable skill in selecting among several varieties those that are most appropriate for their situation. The international rainfed rice trials, only recently initiated by IRRI in cooperation with scientists in several locations throughout South and Southeast Asia, may help to identify the different traits of varieties that perform well under rainfed conditions. But if more serious attention is given to the rainfed area, it will be necessary to specify the rainfed environment in more detail and to concentrate on that portion of the rainfed area which shows the greatest potential for yield increase. In my judgement, the shallow rainfed areas (5-15 cm maximum water debth) lying in the major flood plains of continential Asia should receive first priority both because of the size of these areas and what appears to be the potential for raising yields. We already know that improved varieties of medium height, such as Pankaj and Maksuri in Eastern India seem to perform better than other varieties in this poorly drained or stagnant water environment. For social rea-

sons, the work in this poorly drained environment should initially concentrate in Eastern India and Bangladesh since this is where problems due to population pressure are most serious.

Perhaps more than anything else, the problem of rainfed rice tends to emphasize the fact that the research establishment in South and Southeast Asia described earlier is a "top-down" organization. Until recently there has been little attempt on the part of research workers to discover why farmers are doing what they are doing, and from thus to ascertain what technology is appropriate to increase production. Part of the reason has been due to the false premise that it is the task of the extension service to provide the communication link between the farmer and the research worker. In the developed countries establishing a link between farmer and researcher has been as much a function of the private sector as the extension service. However, the United States land grant model is clearly inappropriate given the limited resources of the developing countries.

Beginning in 1973, there was a substantial shift in IRRIs budget, with more than a quarter of the research funds devoted to farm based research ("rice based-cropping systems" and "constraints on rice production" in Table 3). A primary objective of this research is to provide a link between the research and the farmer, to feed back information from the farm that would be useful in designing research.[15/] Results of this research consistantly has shown that, input levels aside, many of the cultural practices appropriate for achieving high yield under experiment station conditions are not appropriate for achieving a profitable return under the farmer's environment.

Cultural practices, as well as varieties, will differ for the rainfed areas. For example, the wide variability in cropping patterns from one location to another and even within a given location reflects the extreme heterogeneity of conditions, and the attempt on the part of farmers to stabilize production by providing contingencies for variable weather conditions. Cropping patterns generally vary according to topography, but are adjusted also to annual variation in weather conditions. The

implications of these types of adjustments are important for technology development. Researchers can provide technology components, such as short season varieties, that can be used to adjust cropping patterns and increase production. Because of the extreme heterogeneity of the environmental conditions and the limited capacity of the research-extension network, normally, it must be left to farmers to work out the most appropriate cropping patterns.

Getting Technology into the Hands of Farmers

The input delivery system in general is not as well developed in the rainfed as in the irrigated areas. Seed multiplication and delivery is a major weakness in many areas. For example, we were told recently in Eastern India that from the time of the first cross, it takes about 10 years to release a new variety of rice (Barker, 1977). Even when the variety is released, there is no assurance that it will be made available to farmers. By contrast, varieties typically are available to farmers in the Philippines within 5 years of the first cross. The only modern varieties currently grown on a wide scale in Eastern India are Jaya, IR8, Pankaj, and Mahsuri, all of which were released more than a decade ago. There varieties are grown almost exclusively in the irrigated areas: Jaya and IR8 in the dry season, and Pankaj and Mahsuri in the wet season.

Hargrove's research (1977) suggests that the problem begins with the breeding objectives. Breeders, at least until recently, have not been emphasizing those genetic characteristics required for the drought and flood conditions common to Eastern India. The problem, however, is not only with research. We saw varieties in Eastern India that seemed to be more suitable than what farmers are using now. But the mechanism for testing promising new cultivators to assure their rapid and wide dissemination is not adequate. The seed-delivery system is so inadequately developed that it is difficult to determine whether superior varieties exist that are not being used widely by farmers.

Supply of other inputs must accompany the seed. The distribution and transportation system in the rainfed areas is often such that farmers who live at greater distance from the commercial centers are at considerable disadvantage in the prices they pay for inputs and receive for products. Only the two most progressive of the 12 rainfed villages surveyed in the RURP in Central Luzon, Philippines received a significant amount of Masagana 99 credit and extension support in 1974. The government surmised, perhaps correctly, that given the potential of existing technology in the rainfed area at that time, the irrigated areas would provide a higher return on investment. Factors, such as this, must be taken into account in the design of new technology.

Providing Incentives

Many observers associate farmer incentives with prices. Low rice prices and high input cost will discourage production. However, the disincentives for rice producers extend well beyond the pricing mechanism. Land fragmentation, small size of farms, inappropriate technology, and lack of knowledge on how to use inputs are often noted. A strong research-extension program and efficient input delivery system are among the most important incentives to farm production.

The expansion of irrigation provides another important incentive to production. As an alternative to irrigation expansion, we suggest that strengthening the research-extension system in the rainfed areas may show a higher economic benefit from rice technology. Most countries cannot afford to ignore either alternative. It is a matter of finding the proper balance.

Ultimately, the strengthening of farmer incentives required the strengthening of community leadership and organization. This is perhaps the greatest challenge for social science research.

Concluding Remarks

The evolution of rice research systems in South and Southeast Asia has been accompanied by an extreme shortage of manpower and a chronic underinvestment in research funds. Developed countries have played an important role in establishing the system

that exists today. However, this has involved an extended learning process, as efforts to transfer first technology, and then institutions to the developing countries did not solve the production problem. IRRIs initial success in increasing rice production has been criticized on the grounds that it failed to give adequate attention to the distribution problem.

The potential for increasing production on the non-irrigated areas is still in question. However, it now seems appropriate for social, as well as economic, reasons to concentrate more research resources on the more promising shallow rainfed areas. The success of such a research endeavor will depend much more than in the past on an understanding of the cliental that the research is designed to serve. To design appropriate research for rainfed farmers, it is necessary to understand their present farming system, and the factors that constrain their production. There are already attempts to experiment with this new interactive model. However, increasing rice production in the rainfed areas will require a major research investment and a new philosophy in place of the drive for high yield that prevades most experiment stations. Given these obstacles, it may still take some convincing to persuade the national and international research establishment that the task is worth doing.

FOOTNOTES

1/ The contrast between the indicas and japonicas, the two major subspecies of rice, with respect to fertilizer responsiveness needs further elaboration. The japonica rices are grown principally in temperate zone Asia particular Japan, northern China (North of the Yangtze River) and Korea. The Japanese developed japonica rices suitable to the semi-tropical conditions of Taiwan. Centuries of selection had resulted in distinct differences among these subspecies, the japonicas having been selected to respond to conditions of intensive case and the indicas better suited to the extensive management conditions found in the tropics. The traditional semi-tropical indicas found in South China and Northern Vietnam differed from the tropical indicas in one important respect. They had been selected over centuries for short growth duration (100 days or less from transplanting to maturity) thus facilitating an intensification of production through multiple cropping rather than through higher yields. A sterility barrier had developed between the two subspecies. Lack of resistance to insects and diseases provented the moverment of japonicas to the tropics while lack of cold tolerance provented the movement of indicas to the tropical zone.

2/ A very excellent account of rice breeding research in the tropics in the period prior to the establishment of the International Rice Research Institute in 1962 is given by Parthasarathy (1972). Further details are contained in the annual reports of the International Rice Commission's Working Party on Rice Breeding beginning in 1950.

3/ The first of the semi-dwarf varieties, Taichung Native 1, was released in Taiwan in 1956. The semi-dwarf indicas were developed independently by the Chinese in the late 1950s. The new indica plant type had been disseminated over a substantial portion of South China by the mid 1960s prior to the release of the first IRRI variety in 1966. The Chinese varieties have the same genetic source of dwarfing as those in Taiwan.

4/ In discussing the interaction between seed-fertilizer technology and water control based on the East Asian experience, Ishikawa (1967) and Hsieh and Ruttan (1967) clearly foresaw this result.

5/ For example, Palmer (1976, p. 126) in a study of new rice on four Asian Countries (Indonesia, Philippines, Malaysia, and Thailand) concludes that "over a wide range of reports larger farmers tended to be more intensive adopters of HYVs in the long run, though not necessarily being prominent as initial adopters." But this study provides no data to substantiate such a claim. A 1972 study of 36 Asian villages (IRRI 1978, p. 91) shows that on average small farmers typically adopted yield increasing technology (varieties, fertilizer, and insecticides) as rapidly as large farmers, but that large farmers adopted labor saving technology (tractors, threshers and herbicides) more rapidly than small farmers. The same study (IRRI 1978, p. 96) shows that in 8 of 32 irrigated villages inputs and yields were significantly higher on large than on small farms. Yields and input levels tended to be higher on large farms in the Indian, Indonesian, and Pakistan villages but were the same or lower in Malaysian, Thai, and Philippine villages. This reflects the importance of differing institutional structure among countries relative to the relationship between technology and farm size.

6/ This typology is due to Evenson (1975) developed in the context of developing country research generally, and not with specific reference to rice in Asia.

7/ Drawing the line between the various categories of research ranging from the very basic to the very applied is always difficult, somewhat arbitrary, and therefore confusing. Wortman and Cummings (1978, p. 299-301) define five categories of re-

search and suggest that "countries in a hurry to produce results" should give priority to the more applied levels. Evenson and Binswanger (1978, p. 201) on the other hand conclude from recent research that there is a high degree of complementarity between national capacities in basic and applied research. "The results reported here indicate that policy makers may be persisting in making the same errors as in an earlier period when the emphasis was on direct technology transfer."

8/ Both in the United States and Japan in the earlier part of this century prior to the perfection of the cross-breeding technique, an extension oriented approach, with emphasis on transferring to others what the best farmers were doing, had achieved considerable success.

9/ Esman (1978) discusses the post war research and development phase in terms of four models, reflecting the particular emphasis of the period. These include: (i) the extension model covering the decade immediately after World War II when there was a strong belief that technology could be transferred from developed to developing countries, (ii) the land grant model extending from the late 1950s through the 1960s reflecting the attempt to transfer the land grant system of research and extension to the tropics, (iii) the big science model representing the establishment of the network of international agricultural research institutes in the late 1960s and early 1970s, and (iv) an interactive model, as yet in the formative stage, in which the attempt is to provide appropriate technology to those farmers by-passed by the "green revolution," by strengthening the link between the farmer and the research worker.

10/ For an excellent discussion of issues relating to the development of the international agricultural research institutes see Ruttan (1978).

11/ Two useful review documents on this subject have been prepared at the request of the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR): (i) G. Edward Schuh and Helio Tollini (Oct. 1978), and (ii) International Food Policy Research Institute (IFPRI),(Nov. 1978).

12/ There are in fact several studies that have been undertaken recently which project a widening gap between supply and demand for cereal grains in Asia including the International Food Policy Research Institute (1977), the Asian Development Bank (1978), and the World Bank (Hadler 1976). Despite the difference in approach, all three studies indicate that a gap of between 25 and 40 million tons of food grains will exist between production and demand in the region by 1985.

13/ This procedure and the productivity appraoch presented subsequently are described in detail in International Rice Research Institute (Sept. 1978).

14/ The concept of "reasonable" research and extension is difficult to define, but it should be understood to include a wide range of technology improvements relating to cultural practices, use of inputs, and varietal improvement.

15/ Ruttan (1978) notes that another stated objective of cropping systems research at some international institute is to develop more productive cropping systems, but that this is not a credible objective for these centers since the fine tuning of cropping systems is highly location specific.

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Table 1. Annual investment in rice research and extension: historical series (million 1970 constant US dollars)[a/]

Period	East Asia		Southeast Asia		South Asia		Other Developing Countries		Developed Countries		IRRI Research
	R	E	R	E	R	E	R	E	R	E	
1900-20	0.9	-	-	-	0.1	-	0.5	1.0	1.0	0.5	-
1921-40	2.7	1.9	0.1	0.5	0.3	1.0	1.0	2.0	2.0	1.0	-
1951-55	10.0	3.0	2.1	3.0	1.7	2.7	1.5	3.0	5.0	3.0	-
1956-60	17.5	24.9	2.0	3.7	1.8	2.9	1.8	3.5	5.5	3.1	1.0
1961-65	32.0	7.1	2.7	5.7	3.0	4.8	3.0	6.0	7.0	3.5	1.8
1966-70	45.0	17.1	3.2	7.2	4.0	11.0	5.0	10.0	8.0	4.0	2.9
1971-75	48.2	18.3	3.1	7.2	4.4	11.7	7.1	12.0	11.2	5.5	4.0

Source: Evenson and Flores (1978) as computed from Boyce and Evenson (1975).

a/ Excluding People's Republic of China, R = research; E = extension.

Table 2. Summary of Studies of Rice Research Productivity.

Study	Country	Time Period[a/]	Annual Interest Rate of Return %
Hayami and Akino (1977)	Japan	1915-50	25-27
Hayami and Akino (1977)	Japan	1930-61	73-75
Evenson and Flores (1978)	Asia-national	1950-65	32-39
Scobie and Posada (1978)	Columbia	1957-74	79-96
Hertford et. al. (1977)	Columbia	1957-72	60-82
Flores, Evenson, and Hayami (1976)	Philippines	1966-75	27
Flores, Evenson, and Hayami (1976)	Tropics	1966-75	46-71
Evenson and Flores (1978)	Asia-national	1966-75	73-78
Evenson and Flores (1978)	Asia-international	1966-75	74-102

a/ Refers to period for investments, but not for the stream of benefits.

Table 3. Rankings by IRRI Senior Staff of research problem areas based on specific questions regarding research expectations compared with budget rank.

Research problem area	Percent of 1977 Budget	1977 Budget rank	Scientist's rank
Genetic evaluation and utilization	40	1	1
Rice-based cropping system	21	2	3
Control and management of pests	10	3	4
Soil and crop management	9	4	2
Machinery development and testing	8	5	7
Constraints on rice production	4	6-1/2	6
Irrigation and water management	4	6-1/2	5
Consequences of new technology	2	8-1/2	9
Environment and its influence	2	8-1/2	8

Source: IRRI Long Range Planning Committee Report, September 1978.

Table 4. Estimated changes in yield and cropping intensity attainable in 20 years from reasonable research and extension efforts on rice and its cropping systems for specified rice environmental complexes in South and Southeast Asia, 1970s and 1990s.

Environmental complexes	Yield (t/ha)			Rice cropping intensity			Upland cropping intensity		
	1970s	1990s	Change	1970s	1990s	Change	1970s	1990s	Change
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Irrigated	3.0	4.1	1.1	1.2	1.6	0.4	0.3	0.5	0.2
Shallow RF	1.8	2.6	0.8	0.7	1.0	0.3	0.4	0.5	0.1
Medium deep RF	1.0	1.8	0.8	0.8	0.9	0.1	0.3	0.5	0.2
Deep water	1.0	1.5	0.5	0.9	1.0	0.1	0.3	0.4	0.1
Upland	1.0	1.5	0.5	0.8	0.8	0	0.5	0.8	0.3

Table 5. Estimate of contribution of research and extension to the increase in rice production due to yield increase in specified environmental complexes, South and Southeast Asia, 1970s to 1990.

Environmental complexes	Gross area[a/] (million ha)		Yield increase	Undiscounted benefits from irrigation[b/]	Undiscounted benefits in 20th year from research and extension due to yield		
	1970s	1990s	(t/ha)	(million t)	(million t)	(Billion $)	(%)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Irrigated	27	36	1.1	27.0	39.6	3.96	52
Shallow RF	29	25	0.8	-7.2	20.0	2.00	26
Medium deep RF	13	11	0.8	-2.0	8.8	0.88	12
Deep water	7	7	0.5	0	3.5	0.35	5
Upland	8	8	0.5	0	4.0	0.40	5
Total	84	87		17.8	75.9	7.59	100

[a/] Irrigated area is assumed to increase at 1.5% per annum and gross land area at 0.2% per annum. Land moves out of the rainfed and into the irrigated category.

[b/] Col. 4 equals col. (2-1) x col. 1 of Table 4. Benefits are for the 20th year.

Table 6. Estimated contribution of research and extension to increase in rice and upland crop (UC) production through cropping intensity in specified environmental complexes, South and Southeast Asia, 1970s to 1990s.

Environmental complexes	Area harvested at 1970s intensity[a] (million ha)		Anticipated increase in intensity				Undiscounted benefits in 20th year from research and extension due to intensity			
			Ratio[b]		(million ha)		(Billion $)[c]		(%)	
	1970s	1990s	Rice	UC	Rice	UC	Rice	UC	Rice	UC
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Irrigated	23	30	0.4	0.2	12.0	6.0	4.92	1.85	61	54
Shallow RF	41	36	0.3	0.1	10.8	3.6	2.81	0.70	35	21
Medium Deep RF	16	14	0.1	0.2	1.4	2.8	0.25	0.38	3	11
Deep water	8	8	0.1	0.1	0.8	0.8	0.12	0.09	1	3
Upland	10	10	0	0.3	0	3.0	0	0.38	0	11
Total	98.0	98.0					8.10	3.40	100	100

[a] Computed by adjusting gross area in Table 5 by rice cropping intensity existing in 1970s shown in Col. 4 of Table 4.

[b] From Col. 6 and 9, Table 4.

[c] Converted to dollars where one ton of paddy rice equals $100, one ton of upland crop equals $75.

Table 7. Summary of discounted added benefits from research and extension due to yield increase and cropping intensity for specified environmental complexes in South and Southeast Asia, discounted to present value at 12% interest, 1970s to 1990s.

Environmental Complexes	Benefits (billion $) from			Total Benefits	(%)
	Yield Increase	Rice Cropping Intensity	Upland Cropping Intensity		
Irrigation	10.4	12.9	4.7	28.2	56
Shallow RF	5.2	7.4	1.8	14.4	29
Medium deep	2.3	0.6	1.0	3.9	8
Deep water	0.9	0.3	0.2	1.4	3
Upland	1.1	0	1.0	2.1	4
Total	19.9	21.2	8.9	50.0	100

Table 8. Annual increased investments, returns, and costs estimated in the 20th year, achieved from reasonable research and extension efforts in irrigated and rainfed rice and investments in new irrigation, South and Southeast Asia, 1970s to 1990s.

	New Irrigation	Research and Extension Areas	
		Irrigated	Rainfed
Annual capital investment in irrigation and in research extension ($ million)	675	100	100
New area irrigated (million ha)	9	-	-
Increased outputs per year (million tons)	17.8	88.8	59.4
Contribution to annual growth in national production (%)[a/]	0.5	1.8	1.3
Value of output increase ($ million)	1780	8880	5940
Current operating costs for new irrigation ($ million)[b/]	100	-	-
Added fertilizer cost ($ million)[c/]	180	1896	632
Added labor cost ($ million)[d/]	540	2664	1782
Net benefit ($ million)	960	4320	3526

a/ Output from irrigation includes the yield increase due to research on new irrigated area.
b/ $11/ha/yr.
c/ Price of fertilizer $150/ton. Additional fertilizer applied at 60kg. for newly irrigated area, plus 120kg/ha on all irrigated area, and 40kg/ha on all rainfed area.
d/ Added labor cost $30/ton of paddy rice.

Table 9. Annual discounted investment costs and net benefits, benefit-cost ratio and internal rate of return for alternative rice investments, 1970s to 1990s in South and Southeast Asia.

	New Irrigation[a/]	Research and Extension	
		Irrigated rice	Rainfed Rice
Discounted investment costs	5800	2000	850
Discounted net benefits			
equal probability	5600	13500	11000
unequal probability[b/]	5000	10100	5500
Benefit-cost ratio (12% interest)			
equal probability	1.0	6.7	12.9
unequal probability[b/]	0.9	5.0	6.5
Internal rate of return (%)			
equal probability	12	40	85
unequal probability[b/]	11	35	40

a/ Benefits from new irrigation include the yield increase due to research on new irrigated area.

b/ Assumed probability of achieving production gain from new irrigation = 100 percent, from research/extension on irrigated rice = 75%, from research/extension on rainfed rice = 50%.

Table 10. Estimated percentage contribution of research-extension to growth in rice production by specified environmental complexes for selected countries in South and Southeast Asia, 1970s to 1990s.

Environmental complexes	Share of benefits from research-extension[a]								
	South and Southeast Asia	Nepal	Thailand	Bangladesh	Burma	India	Philippines	Indonesia	Sri Lanka
Irrigated	52	20	22	23	25	45	75	76	79
Shallow RF	26	67	49	41	53	10	11	10	8
Intermediate RF	12	-	20	17		19	1	-	5
Semi-deep RF		-	4	5	19	7	.5	-	4
Deep water	5	-	4	4		4	0.5	6	-
Upland	5	13	1	10	3	15	12	8	4
Total	100	100	100	100	100	100	100	100	100
Implied annual growth in rice production	2.4	3.0	4.1	1.9	3.2	3.6	2.9	4.2	2.4

[a] Benefits are due to yield increase only.

Source: Appendix Tables 2-9.

Table 11. Rice research expenditures for selected countries in East, South and Southeast Asia, 1974.

Country	Total research expenditures (1971 '000US$)	Expenditures per 100,000 ha (1971 US$)
Rainfed oriented-S & SE Asia		
Bangladesh	120	1.20
Burma	40	0.80
Nepal	100	8.10
Thailand	300	3.50
Vietnam	160	3.00
Irrigated oriented-S & SE Asia		
Indonesia	550	6.40
W. Malaysia	1460	252.00
Pakistan	210	17.00
Philippines	500	14.00
Philippines (including IRRI)	2900	80.60
Other		
India	3900	[illegible]
Japan	46000	1688.70
Taiwan	1700	218.50
Korea South	250	35.70

Source: Adopted from Evenson and Flores (1978).

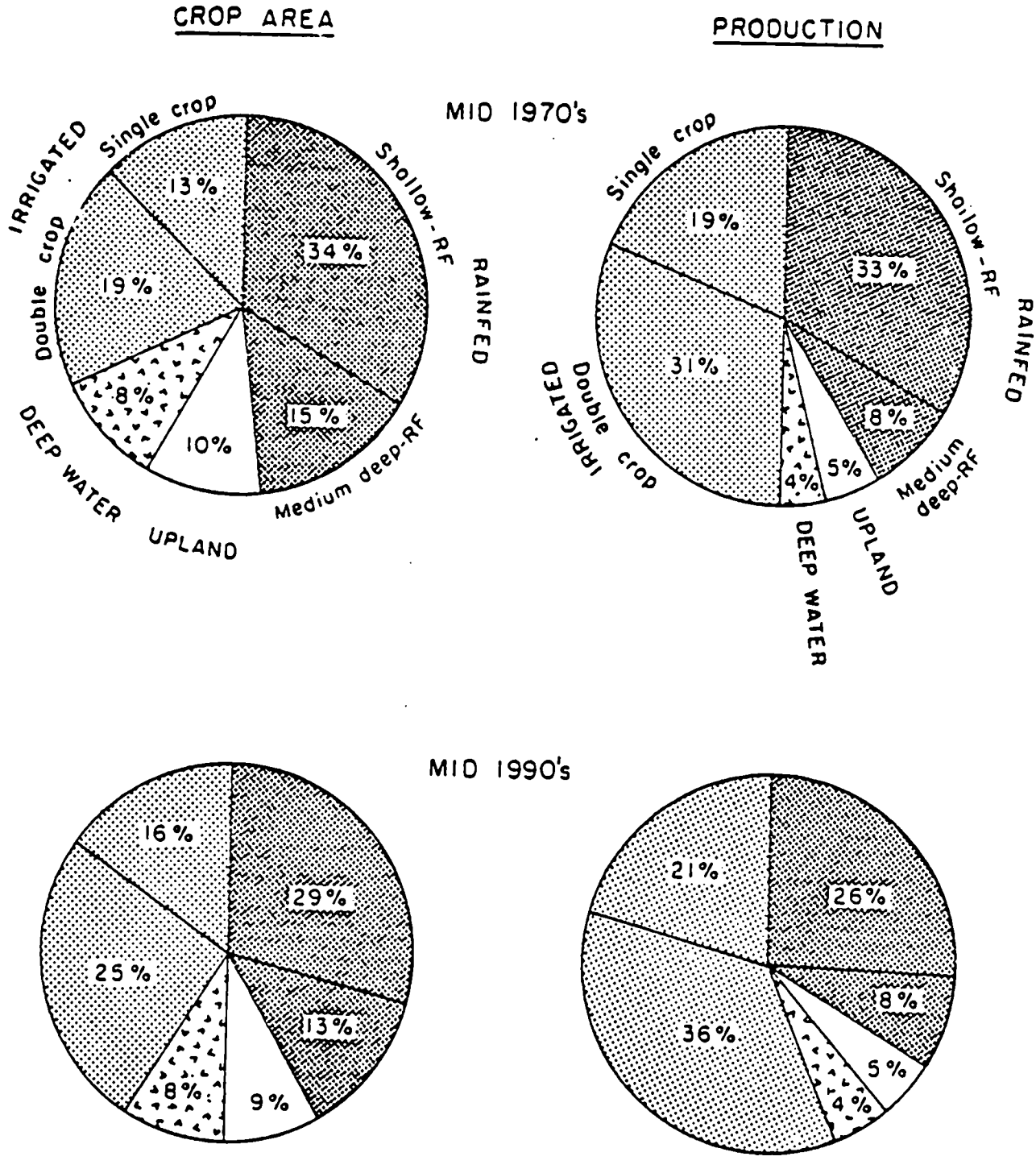

FIGURE 1. ESTIMATE OF THE PERCENT OF RICE CROP AREA AND PRODUCTION BY SPECIFIED ENVIRONMENTAL COMPLEX IN SOUTH AND SOUTHEAST ASIA, MID 1970s AND MID-1990s

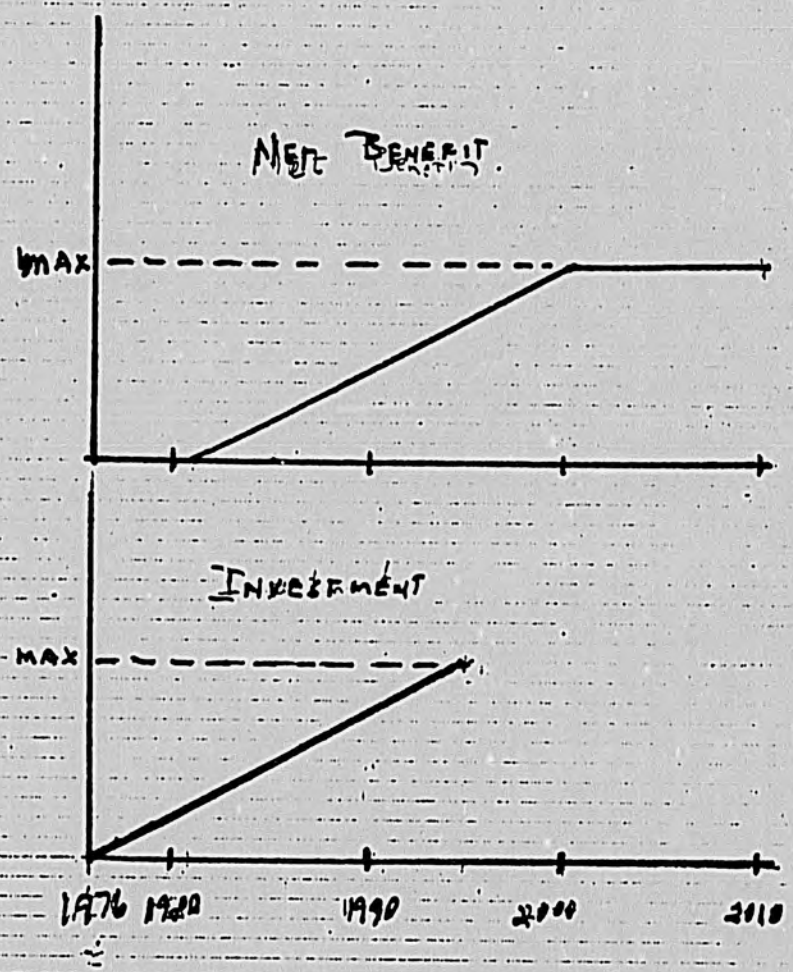

Fig. 2. Time profile of net benefits (B-C) and research/extension investment (K).

Appendix B

Appendix Table 1. Allocation of gross rice area in major producing countries of 5 types of rice culture, 1973-75 av. (million ha).[a]

Country	Total rice	Upland	Deep-water	Shallow RF	Medium Deep RF	Irri-gated	Dry season
South and SE Asia							
India	38.4	2.4	2.4	12.6	6.1	14.9	1.7
Bangladesh	9.5	2.2	1.9	2.2	2.2	1.0	1.0
Indonesia	8.5	1.4	0.4	1.7	1.7	3.3	1.3
Thailand	8.2	0.8	1.7	2.0	1.7	2.0	0.5
Burma	5.1	neg.	neg.	4.1	0.2	0.8	0.1
Philippines	3.5	0.5	0	1.6	0	1.4	0.4
Vietnam (former S)	3.0	0.2	0.3	1.7	0.4	0.4	0.1
Vietnam (former N)	2.3	0.2	0.2	1.3	0.3	0.3	neg.
Pakistan	1.6	0	0	0	0	1.6	1.6
Nepal	1.2	0.1	neg.	0.9	0	0.2	n.a.
Sri Lanka	0.6	0.1	0	0.2	neg.	0.3	0.2
Laos	0.7	0.2	0	0.2	0.2	0.1	n.a.
Malaysia (Peninsular)) Sarawak) Sabah)	0.8	0.1	0	0.2	0	0.5	0.2
Total, S & SE Asia	83.4	8.2	6.9	28.7	12.8	26.8	6.6
Other Asia							
China	34.1	0.7	0	2.7	0	30.7	n.a.
Japan	2.7	0.1	0	0	0	2.6	0
Korea Rep.	1.2	neg.	0	0.1	0	1.1	0
Korea North	0.7	neg.	0	0.1	0	0.6	0
Iran	0.3	0	0	0	0	0.3	0
Afghanistan	0.2	0	0	0	0	0.2	0
Total, Other Asia	39.2	0.8	0	2.9	0	35.5	n.a.
Other Regions							
Brazil	4.8	3.7	0	0	0.6	0.6	n.a.
Malagasy Rep.	1.1	0.2	0	0.3	0.3	0.3	n.a.
U.S.A.	1.0	0	0	0	0	1.0	1.0
U.S.S.R.	0.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Egypt	0.5	0	0	0	0	0.5	0.5
Guinea	0.4	0.25	0	.06	.06	.06	0.4
Ivory coast	0.3	0.3	0	neg.	0	neg.	n.a.
Colombia	0.3	0.1	0	0	0	0.2	n.a.
Sierra Leone	0.4	0.22	0	.05	.05	.05	n.a.
Others	5.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Source: Adopted from R. W. Herdt's report submitted to the Long Range Planning Committee, IRRI, October 1977. See notes on sources of basic data.

[a] See definitions in text.

Appendix Table 2. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Bangladesh, 1970s to 1990s.[a]

Environmental complexes	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	(tons) (8)	(%) (9)
Irrigation-1st crop	0.1	0.1	2.5	4.0	0.25	0.25	0.40	0.15	2.1
Irrigation-2nd crop	1.0	1.5	3.5	4.5	3.50	5.25	6.75	1.50	20.5
Shallow RF	3.0	3.0	2.0	3.0	6.00	6.00	9.00	3.00	41.1
Intermediate RF	2.4	2.4	2.0	2.5	4.80	4.80	6.00	1.20	16.4
Semi-deep RF	1.5	1.5	1.5	1.75	2.25	2.25	2.63	0.38	5.2
Deep water	1.3	1.3	1.25	1.5	1.63	1.63	1.95	0.32	4.4
Upland	1.0	1.0	1.0	1.75	1.00	1.00	1.75	0.75	10.3
Total	10.3	10.8			19.43	21.18	28.48	7.3	100.0

Based on questionnaire completed by M. S. Ahmad, Head of the Division of Rice Breeding and M. S. Nasiruddin, Principal Scientific Officer (Breeding), BRRI, Dacca, Bangladesh (1978).

Irrigated area assumed to grow at 2% per annum and gross land area at 0.3% per annum.

Column 6, 1990s gross area (2) multiplied by 1970s yield (3).
Column 7, 1990s gross area (2) multiplied by 1990s yield (4).

Column 8 is column 7-Column 6.
Column 9 is Column 8 expressed in percentage.

Appendix Table 3. Estimate of contribution of research extension to the increase in rice production in specified environmental complexes, Burma, 1970s to 1990s.[a]

Environmental complexes	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	(million t) (8)	(%) (9)
Irrigation-1st crop	0.8	0.9	3.0	5.0	2.40	2.70	4.50	1.80	19.4
Irrigation-2nd crop	0.1	0.2	3.5	6.0	0.35	0.70	1.20	0.50	5.4
Shallow RF, Intermediate RF	3.5	3.5	2.3	3.7	8.05	8.05	12.95	4.90	52.7
Semi-deep RF, Deep water	0.5	0.5	0.9	2.5	0.45	0.45	2.25	1.80	19.3
Upland	0.2	0.2	1.0	2.5	0.20	0.20	0.50	6.30	3.2
Total	5.1	5.3			11.45	12.10	21.40	9.3	100.0

a/ Based on questionnaire completed by Ohn Kyaw and P. B. Escuro. Deputy General Manager and FAO Rice Improvement Specialist respectively, Rice Division, Agricultural Research Institute, Yezin, Pyinmana, Burma (1978).

b/ Irrigated area assumed to grow at 1.0% per annum and total land area at 0.2% per annum.

c/ Column 6 based on 1990s gross area (2) and 1970s yield (3).
Column 7 based on 1990s gross area (2) and 1990s yield (4).

d/ Column 8 is column 7-column 6.
Column 9 is column 8 expressed in percentage.

ppendix Table 4. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, India, 1970s to 1990s.[a]

Environmental complexes	Gross area[b] (million ha)		Yield[c] (t/ha)		Production[d] (million t)			Benefits from research-extension[e]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	(million t) (8)	(%) (9)
Irrigation-1st crop	11.5	14.5	2.5	3.5	28.75	36.25	50.75	14.50	27.6
Irrigation-2nd crop	2.5	4.5	3.5	5.5	8.75	15.75	24.75	9.00	17.1
Shallow RF	4.5	4.0	1.5	2.8	6.75	6.00	11.2	5.20	9.9
Intermediate RF	7.3	6.8	1.0	2.5	7.30	6.80	17.05	10.20	19.4
Semi-deep RF	2.8	2.8	1.0	2.3	2.80	2.80	6.44	3.64	7.0
Deep water	2.3	2.3	1.05	1.8	2.30	2.3	4.14	1.84	3.5
Upland	8.1	8.1	1.0	2.0	8.10	8.10	16.20	8.1	15.5
Total	39.0	43.0			64.75	78.00	130.48	52.48	100.0

a/ Based on questionnaires completed by S. Biswas, Chinsura Rice Research Station, West Bengal and M. V. Rao and J. B. K. Rao, CRRI, Cuttack (1978).

b/ Irrigated areas assumed to grow at 1.5% per annum and gross land at 0.5% per annum.

c/ Adjusted upward to reflect India's current level of production.

d/ Column 6 1990s gross area (2) multiplied by 1970s yield (3).
Column 7 1990s gross area (2) multiplied by 1990s yield (4).

e/ Column 8 is column 7-column 6.
Column 9 is column 8 expressed in percentage.

f/"...shifting cultivation is practiced....terrace cultivation is common.... (where) rice is sown broadcast or transplanted." Half of difference between total and irrigated to UL and SRF.

g/"only 40% has assured water supply," meaning that 456 of the 739 shown as irrigated is assured of fairly regular water.

h/10% of difference between total and irrigated allocated to UL (Dharwar, Belgaum and parts of Shinoga and North Kanara). Balance allocated equally to SRF and MDRF (coastal areas).

i/Autumn rice is assumed to the beali crop "grown as a purely rainfed crop... dry or upland beali rice is sown broadcast." Difference between total, UL, and irrigated is allocated equally to SRF and MDRF.

k/"There are problem areas in the coastal region where fields are inundated and deep-water rices are grown between June to December. 10% of difference between total and irrig. is allocated to DW, 20% to MDRF rest to SRF.

m/Allocated as for Assam
Irrigated area assumed proportional in all zones. The following allocation relates to the balance of area.

n/Zone I assumed 1/2 SRF; Zone II all SRF; Zone III equal % in UL, DW, SRF, MDRF; Zone IV same as Zone III; Zone V all SRF.

p/Irrigated area allocated proportionally to zones I, II, IV. Zone III assumed 50% DW, 50% MD Balance of zones II, III allocated equally to DW, SRF, MDRF. Balance of Zone IV equally to SRF and UL.

Appendix Table 5. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Indonesia, 1970s to 1990s.[a]

Environmental complexes	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	tons (8)	(%) (9)
Irrigated-1st crop	3.9	5.2	3.1	5.0	7.00	16.12	26.00	9.88	49.1
Irrigated-2nd crop	2.7	3.6	3.5	5.0	9.45	12.60	18.00	5.40	26.9
Shallow RF	1.8	1.3	2.5	4.0	4.50	3.25	5.20	1.95	9.7
Deep water	0.8	0.8	2.0	3.5	1.60	1.60	2.8	1.2	6.0
Upland	1.2	1.2	1.6	3.0	1.92	1.92	3.60	1.68	8.3
Total	10.4	12.1			24.47	35.49	55.60	20.11	100

a/ Based on questionnaire completed by Agronomy Staff, Central Research Institute for Agriculture, Bogor, Indonesia. (1978).

b/ Irrigation increases at 1.5% per annum and gross land area at 0.8% per annum.

c/ Column 6, 1990s gross area (2) multiplied by 1970s yield (3).
Column 7, 1990s gross area (2) multiplied by 1990s yield (4).

d/ Column 8 is column 7 - Column 6.
Column 9 is Column 8 expressed in percentage.

ɔpendix Table 6. Estimate of contribution of research-extension to the increase in rice ield in specified environmental complexes, Nepal, 1970s and 1990s.[a]

ıvironmental ɔmplexes	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	(tons) (8)	(%) (9)
rrigated-1st crop	170	235	2.8	4.0	475	660	1940	280	16.3
rrigated-2nd crop	20	45	3.0	4.5	60	135	200	65	3.8
ıallow RF	925	965	1.8	3.0	1665	1735	2895	1160	67.4
ɔland	165	165	1.2	2.5	200	200	415	215	12.5
ɔtal	1280	1410			2400	2730	4450	1720	100

[a] Based on questionnaire completed by B. B. Shahi, National Rice Coordinator, Parawanipur, Nepal. (1978).

[b] Irrigation increases at 2% per annum and gross land area at 0.5% per annum.

[c] Column 6, 1990s gross area (2) multiplied by 1970s yield (3).
Column 7, 1990s gross area (2) multiplied by 1990s yield (4).

[d] Column 8 is column 7 - column 6.
Column 9 is column 8 expressed as a percentage.

Appendix Table 7. Estimate of contribution of research-extension to increase in rice production in specified environmental complexes, Philippines, 1970s to 1990s.[a]

Environmental complexes	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	(tons) (8)	(%) (9)
Irrigated-1st crop	0.98	1.20	2.2	4.0	2.16	2.64	4.80	2.16	50.6
Irrigated-2nd crop	0.43	0.70	3.5	5.0	1.51	2.45	3.50	1.05	24.6
Shallow RF	1.50	1.15	1.3	1.7	1.95	1.50	1.96	0.46	10.7
Intermediate RF	0.08	0.08	1.0	1.5	0.08	0.08	0.12	0.04	0.9
Semi-deep RF	0.05	0.05	0.8	1.5	0.04	0.04	0.06	0.02	0.5
Deepwater	0.07	0.07	0.5	1.5	0.04	0.04	0.06	0.02	0.5
Upland	0.39	0.39	0.9	2.5	0.35	0.35	0.87	0.52	12.2
Total	3.50	3.64			6.13	7.10	11.37	4.27	100.0

[a] Based on questionnaire completed by Teofilo S. Eugenio, Rice Research Training Director, Maligaya Rice Research and Training Center, BPI, Muñoz, Nueva Ecija, Philippines. (1978).

[b] Irrigation increases at 2% per annum and gross land area at 0.4% per annum.

[c] Column 6, 1990s gross area (2) multiplied by 1970s yield (3).
Column 7, 1990s gross area (2) multiplied by 1990s yield (4).

[d] Column 8 is Column 7 - Column 6.
Column 9 is Column 8 expressed as percentage.

Appendix Table 8. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Sri Lanka, 1970s to 1990s.[a]

Environmental complex	Gross area[b] (thousand ha)		Yield (t/ha)		Production[c] (thousand t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	(million t) (8)	(%) (9)
Irrigated-1st crop	255	295	3.3	4.5	842	974	1328	354	52.1
Irrigated-2nd crop	100	120	2.5	4.0	250	300	480	180	26.5
Shallow RF	110	110	1.7	2.2	187	187	242	55	8.1
Intermediate RF	50	50	1.5	2.2	75	75	110	35	5.2
Semi-deep RF	50	50	1.2	1.8	60	60	90	30	4.4
Deep water	0	0	-	-	-	-	-	-	-
Upland	50	50	1.0	1.5	50	50	75	25	3.7
Total	615	685			1464	1646	2325	679	100

a/ Based on questionnaire completed by M. D. Davis, Team Leader and Crop Protection Specialist, IRRI Sri Lanka (1978).

b/ Irrigation assumed to grow at 1% per annum and gross land area at 0.5% per annum.

c/ Column 6, 1990s gross area (2) multiplied by 1970s yield (3).
Column 7, 1990s gross area (2) multiplied by 1990s yield (4).

d/ Column 8 is Column 7 - Column 6.
Column 9 is Column 8 expressed as a percentage.

Appendix Table 9. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Thailand, 1970s to 1990s.[a]

Environmental complexes	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	(million t) (8)	(%) (9)
Irrigation-1st crop	1.5	1.7	2.5	4.0	3.75	4.25	6.80	2.55	14.9
Irrigation-2nd crop	0.4	0.6	3.5	5.5	1.40	2.10	3.30	1.20	7.0
Shallow RF	3.6	4.0	1.4	3.5	5.04	5.60	14.0	8.40	49.0
Intermediate RF	1.7	1.7	1.8	3.8	3.06	3.06	6.46	3.40	19.8
Semi -deep RF	0.5	0.5	2.0	3.5	1.00	1.00	1.75	0.75	4.4
Deep water	0.5	0.5	2.0	3.5	1.0	1.0	1.75	0.75	4.4
Upland	0.1	0.1	1.0	2.0	0.1	0.1	0.20	0.10	0.5
Total	8.3	9.1			15.35	17.11	34.26	17.15	100.0

a/ Based on questionnaire completed for the International Rice Research Conference, April 1978 by Ben R. Jackson, Sermsak Awakul and Boriboun Somrith.

b/ Irrigated area assumed to grow at 1% per annum and gross land at 0.5% per annum.

c/ Column 6 1970s gross area (2) multiplied by 1970s yield (3).
Column 7 1990s gross area (2) multiplied by 1990s yield (4).

d/ Column 8 is Column 7 - Column 6.
Column 9 is Column 8 expressed in percentage.