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RICE VARIETAL IMPROVEMENT AND INTERNATIONAL EXCHANGE OF RICE GERMPLASM

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Abstract

Rice is the most important food grain in developing countries. Rapid population growth in developing countries during the 1950s and 1960s presented a massive challenge to rice producers. Rice production would have to be expanded at historically unprecedented rated to maintain per capita rice consumption levels. That challenge was met. Rice production expanded more rapidly than population. The challenge was met primarily by increased yields per hectare of land. This paper documents the role of varietal improvement and of genetic resources in achieving yield improvement. It shows that varietal improvement was international in character with the International Rice Research Institute in the Philippines playing the leading role. More than 100 national rice breeding programs contributed to the pool of approximately 2,000 rice varieties constituting the "green revolution" in rice. Access to and the international exchange of genetic resources in the form of farmer selected "landraces" was vital. More than ninety percent of the green revolution rice varieties were developed from genetic resources originating in more than one country.

KEY WORDS: Rice Production, Genetic Resource Evaluation, Rice Productivity

Rice Varietal Improvement and International Exchange of Rice Germplasm

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Varietal improvement occupies center stage in rice research programs. Rice breeding programs are maintained in the International Rice Research Institute (IRRI) as well as in national agricultural research systems (NARSs), and many NARSs also maintain regional (subnational) breeding programs. Rice breeding programs are directly supported by *ex situ* germplasm collections at IRRI and in NARSs. They also receive considerable support from research in plant pathology, entomology, and agronomy, which places considerable emphasis on achieving host plant resistance to insects and disease and host plant tolerance to abiotic stresses.

Genetic resources in the form of original landraces, wild species, and related materials have been exchanged freely and readily between breeders at IRRI and in national research programs. The international rice germplasm collection (IRGC) is a large collection that includes duplicates of materials in national rice germplasm collections (NRGCs). Much of the IRGC collection has been evaluated for agronomic traits, and this information and the genetic resources themselves have been readily available to rice breeders in NARSs.

"Advanced" genetic resources are also exchanged internationally. These materials consist of advanced breeding lines and varieties, the descendants of original landrace and related genetic resources, which have been crossed (and recrossed) for many generations. Some of this germplasm is exchanged under the aegis of IRGC and NRGCs. The development in 1975 of the International Network for the Genetic Evaluation of Rice (INGER), a system of specialized rice nurseries, provided a vehicle for exchanging as well as evaluating advanced genetic resources.

This paper reviews economic studies of rice research programs and attempts to identify the contributions of rice varietal improvement to changes in rice productivity. I also report some new work specifically addressed to the contributions of genetic resources (and thus of IRGC, INGER, and plant breeding programs) to the production of rice varieties. The paper begins with a discussion of how varietal improvement research is organized, what breeding strategies are used, and how the varieties are produced. Next, general rice research studies are reviewed, followed by an overview of rice "trait value" studies and new evidence from India and Indonesia on how qualitative trait breeding has contributed to the productivity of rice. This is followed by a description of a recent study of the INGER system. The concluding section of the paper discusses the implications of biotechnology tools for future varietal improvement.

Rice Improvement Organizations and the Production of Rice Varieties

Gollin and Evenson (1995) studied releases of *indica* and *japonica* rice varieties over 1962-91. A total of 1,709 releases were classified according to releasing country and release date. The genealogies (parentage) of each release were analyzed, which enabled breeding strategies and the landrace complexities of these releases to be characterized further.

Table 1 summarizes these varieties by releasing country. Note that IRRI made a number of the crosses from which these varieties were selected, but officially released only a few varieties. India, with 26 rice breeding programs, led all countries in number of releases (643). Varieties from more than 100 breeding programs were released. Approximately 20 varieties were released each year in the early green revolution period; this number rose to nearly 80 per year in 1976-80 and has remained steady at around 75 per year since.

Appendix table 1 provides an indication of the scope of the international exchange of varieties by comparing the location of the breeding program where a cross was made with the location of the program that released varieties based on that cross. Panel I of Table 2 summarizes these data, which show that IRRI was an important producer of the crosses from which releases subsequently were made. In the early green revolution period, 1966–70, IRRI made 25% of all crosses leading to varieties. This percentage has declined to 12% in the most recent period, but IRRI's plant breeding program remains a potent contributor to varietal development. Appendix table reports instances in which the releasing unit first obtained a cross via an INGER nursery. As mentioned earlier, the INGER nursery system was introduced in 1975; by the 1980s, more than three-fourths of the crosses from IRRI and other NARSs that led to released varieties were obtained through INGER.

Appendix table 2 reports comparable data for varietal parents (summarized in Panel II, Table 2). Here we see that IRRI produced the crosses from which 24% of varietal parents were selected. Other NARSs produced the crosses from which an additional 18% of varietal parents were selected. By the 1980s, INGER was the source for 80% of IRRI-based parents and more than half of NARSs-based parents.

Further data on breeding strategies in Panel III, Table 2 show that the most frequent (successful) breeding strategy over this period can be described as "one parent from IRRI, one from the NARS." The importance of international exchanges in rice breeding is shown by the relatively low percentage of varietal releases for which all parental material came from national sources (most of these releases were made in India).

The landrace content of released varieties has increased: the average number of landraces in a given release has risen from under 3 to around 8, although some recently released varieties contain more than 25 landraces in their genealogies (Panel IV, Table 2). More than 70% of these landraces were brought into the genealogies through an IRRI ancestor.

Panel V of Table 2 shows another dimension of IRRI's role in breeding by reporting the number of new landraces introduced into the landrace pool by period and by originating source. Here we note first that genetic resources consisting of an impressive number of new landraces (and one or two wild species) have been introduced into the pool of successful varieties. The fact that the 1,709 releases included 838 landraces that were not contained in the landrace pool prior to 1965 shows that genetic resource collections have been valuable to breeding programs.

Second, the data in Panel V reveal that IRRI has actually introduced very few landraces into the pool. Only 80 of the 838 new landraces were introduced via IRRI crosses. By contrast, all of the landraces in released varieties, roughly 70%, were introduced via an IRRI cross. This is the result of two factors. First, IRRI's powerful breeding lines incorporate many landraces that were first brought in through a NARS cross. Second, the widespread use of IRRI crosses as breeding lines multiplies the use of the landraces they contain.

Gollin and Evenson (1993, 1995) have noted that a small set of landraces were built into IRRI breeding lines possessing the original semidwarf plant design. To date these lines have served as the basis for much of the varietal development research described here. IRRI, which had excellent access to genetic resources, did not invest heavily in efforts to exploit more landraces and was not highly successful in doing so, partly because the combinability and use of new landraces was limited by the "narrowness" of the original plant design. The national research systems, even though they had poorer access to genetic resource collections, had somewhat broader plant design bases and were somewhat more diligent in searching for landrace-based traits.

Instead, IRRI devoted much of its effort to packaging high-powered breeding lines using NARS-developed materials and often using INGER to provide access to those lines. The long delay before IRRI began to develop a new plant design is related to this packaging strategy (discussed in the concluding section).

Gollin and Evenson (1995) have traced the routes by which varieties were released (Table 3). These routes are defined as mutually exclusive categories, so each variety in the data set falls into exactly one of 13 categories (see box).

Routes of Varietal Release

Borrowed varieties

1. IRRI line, borrowed through INGER (IRRI/INGER).
2. IRRI line, borrowed independently of INGER (IRRI/No INGER).
3. Variety from another national program, borrowed through INGER (Other national/INGER).
4. Variety from another national program, borrowed independently of INGER(Other national/National/No INGER).

Nationally developed varieties, borrowed parents

5. At least one parent from IRRI, borrowed through INGER (IRRI parent/INGER).
6. At lease one parent from IRRI, borrowed independently of INGER (IRRI parent/No INGER).
7. No IRRI parents, but at least one parent borrowed from another national program via INGER (Other national parent/INGER).
8. No IRRI parents, but at least one parent borrowed from another national program independently of INGER (Other national parent /No INGER).

Nationally developed varieties and parents, borrowed grandparents (OTHER)

9. At least one grandparent from IRRI, borrowed through INGER (IRRI grandparent/INGER).
10. At least one grandparent from IRRI, borrowed independently of INGER (IRRI grandparent/No INGER).
11. No IRRI grandparents, but at lease one grandparent borrowed from another national program via INGER (Other grandparent/INGER).
12. No IRRI grandparents, but at least one grandparent borrowed from another national program independent of INGER (Other grandparent/No INGER).

Nationally developed varieties, parents, grandparents

13. All parent and grandparents from country of release (Pure national).

The data in Table 3 show several additional features of rice varietal development. They show, for example, that whereas IRRI crosses produced 17.2% of the varieties, they were planted on 23.5% of the rice area. Exchanged or borrowed NARSs varieties accounted for 5.7% of varieties but 8.7% of the area.

IRRI varieties, parents, and grandparent materials have the highest landrace content. The "rare trait" index (Gollin and Evenson 1995) is the ratio of landrace content in all ancestors to landrace use in parental crosses. It reflects the breeding strategy of incorporating a landrace to achieve a single trait and replicating that landrace in more broadly used breeding materials. IRRI clearly pursues this strategy to a greater degree than do NARSs.

Later in this paper, I will return to the data on routes in reviewing estimates of the impact of IRGC, international rice plant breeding, national rice plant breeding, and INGER programs.

Traditional Studies of Rice Research: Evidence for Varietal Contributions

This section reviews 15 studies that might be considered traditional "returns to research" studies. Seven of the studies utilized varietal variables, usually measured as the percentage of area planted to modern varieties (MVs). The studies used a productivity decomposition framework, either treating rice yields as a productivity index or modeling an area-yield system (see below for a version of this framework). Three studies (India, Thailand, and the Philippines) utilized a duality-based system of rice supply and factor demand. A study for Indonesia utilized a rice total factor productivity (TFP) measure.

Variables used in these studies to measure determinants of productivity (at the district or regional level -- all studies used secondary data) included:

- **Rice research**, measured as a "stock" designed to be proportional to the flow of productivity improvements in farmers' fields. This stock took into account both timing and spatial spillin dimensions.
- **High-yielding varieties,** measured as the percentage of rice area planted to modern or high-yielding varieties (HYVs) of rice. This variable was usually treated as endogenous at the farm level but exogenous at the district level (see the next part of this paper for an endogenous treatment of the HYV variable).
- **Extension supply,** usually measured as the ratio of extension staff to the farm population potentially to be served.
- **Infrastructure** and related variables such as roads and market variables.

Table 4 summarizes results of the 15 traditional studies surveyed. All reported statistically significant coefficient estimates except for the TFP (upland rice) research estimates for Indonesia in 1995. The estimates of marginal value products are calculated as the estimated benefits per marginal dollar invested at the peak period from a timing perspective (i.e., spending in time t is estimated to generate benefits in periods $t+1$, $t+2$, etc., rising to a maximum in $t+n$. The marginal product is the benefits in period $t+n$. The estimated marginal internal rate of return is the interest or discount rate of this flow of benefits that sets its present value equal to one (i.e., to costs in time t).

As can be seen from Table 4, most estimated marginal products are high, as are the estimated marginal internal rates of return. For comparison, results of studies of research on other commodities are also included in Table 4; of all of these commodity studies, rice research studies report the highest estimated marginal internal rates of return.

The coefficients reported in the studies where a varietal variable was included as a determinant are at least suggestive of the relative importance of varietal improvement. Suppose that over the 15 years from 1970 to 1985 the HYV percentage increased from 10 to 60. This would have produced a productivity increase of 50 x C_{HYV}, where C_{HYV} is the HYV coefficient. Over the same period, the contribution of research unrelated to varietal improvement would have been R^* x C_{RES}, where R^* is the percentage increase in the research variable over the 15 years as a result of nonvarietal rice research. If nonvarietal research is roughly half of total rice research, R^* would be roughly 100% (i.e., a doubling). Using these calculations, one would attribute from one-third to two-thirds of the productivity growth induced by rice research to varietal improvement.

Hedonic Trait Value Studies

This section reviews five hedonic trait valuation studies. Three studies (for India) use rice yields in farmers' fields as the measure of productivity. The fourth study (for Indonesia) uses both crop loss and TFP measures. The fifth study (also for India) developed a model in which traits influenced adoption of MVs.

The hedonic specification is characterized as follows:

$$V_{ij} = F(T_{1ij}, T_{2ij}, \ldots, T_{nij} Z_{ij}, \tag{1}$$

where:

V_{ij} is a measure of economic value of a variety i in location j;

T_{1ij}, T_{2ij}, etc., are trait content indexes for the variety I; and

Z_{ij} is a vector of economic and ecological conditions that influence economic value and trait adoption.

Measures of economic value, V_{ij}, include yields, total factor productivity, crop losses, and pesticide use (Evenson 1994).

Trait content variables include:

- insect resistance traits;
- disease resistance traits;
- ecological stress tolerance traits (tolerance to flood, drought, etc.); and
- agronomic (grain) quality traits.

Plant breeders have rated varieties in India and Indonesia according to the presence or absence of these traits.

The Z_{ij} variables include variables measuring climate, soils, and other factors. Ideally a variable measuring the natural incidence of insect and disease problems should be included in the specification. The absence of such data on pest and disease pressure has biased most trait value estimates utilizing crop-loss or yield data (see Evenson 1994).

Trait Value/Yield Studies for India

The first trait value study of this type for rice was reported in Gollin and Evenson (1990). The study made use of data on actual varieties planted in farmers' fields to construct actual proportions of area planted to varieties with particular sets of traits. District rice yields (with some control for prices and input use) were regressed on these proportions for the years for which data were available. The study found that when varieties incorporating tolerance to abiotic stress and agronomic characteristics were made available to farmers, yields were higher. (This was not the case for disease and insect resistance.)

Gollin and Evenson (1990) also found strong positive impacts when the number of landraces (from both national and international sources) incorporated in varieties was associated with higher yields. This was evidence of the value of genetic resources, as Gollin and Evenson argued that the size and evaluation of the germplasm collections enabled more materials possessing rare traits to be built into modern rice varieties.

Two further studies for India (Evenson 1994a, 1994b) were based on yield data by variety. The first Indian varietal data set was compiled by the Indian Council of Agricultural Research (ICAR) for selected districts and years. The Council reported yields for the three "highest yielding" varieties in farmers' yield trials in each district/year combination for irrigated and unirrigated *kharif* (summer season) and *rabi* (winter season) rice crops. Fertilizer use was measured and yields reported for a sample of farms in each district. Each variety was assigned trait characteristics (noted by breeders) and yields were related to these characteristics. This data set encompassed the years 1977-89 and covered some 45 districts.

The second Indian varietal data set was based on state-level data reported by state Departments of Agriculture for different years. For each state/year combination, all important varieties planted were included in the data set. Data on yields (from farmers' crop-cut estimates) and area planted were reported. For these data, one can use the yields of other varieties in the state and year as a reference group. Thus, for a given year, yields of varieties with trait *x* can be compared with the yields of all varieties in the state. Problems related to weather, insects, diseases (and so forth) were assumed to have affected all varieties equally. Five states were covered: Punjab, Haryana, Andhra Pradesh, Tamil Nadu, and Karnataka. The estimation equation utilized the standard productivity relationship including research, extension, and infrastructure.

Table 5 reports coefficients and significance levels for trait variable coefficients for both data sets. Two specifications are reported for the district data. The first specification included all trait variables. In this specification, three trait coefficients had marginally significant negative coefficients. This probably reflected unmeasured natural vulnerability to disease and insect problems. In the second specification, these three variables were dropped. In the state regressions, no varieties with resistance to bacterial leaf stripe were included in the data set.

The estimates are reinforcing. In both data sets, varieties with insect resistance show better performance in the field, although neither data set shows that resistance to brown planthopper has value. The estimates for disease resistance, on the other hand, are much weaker. Both data sets show yield effects for sheath blight resistance; the state data set shows a blast resistance effect and a positive, nonsignificant effect for rice Tungro virus.

Economic calculations using the district data show a 2% yield gain for disease resistance and 3% for insect resistance. The estimate for varieties at the state level, on the other hand, shows a 4.5% yield gain from disease resistance and a 6.9% yield gain from insect resistance.

The nature of the data argues in favor of the state estimate as the more reasonable of the two estimates. Adoption of varieties incorporating the traits mentioned earlier is quite low, with only a few traits covering 20% of the area, at the mean of the data set. By 1996 these adoption levels had become higher by a factor of 1.5 to 2. I would thus consider it a reasonable (and conservative) estimate that in India conventional breeding for disease resistance has produced a 7-10% yield gain, and conventional breeding for insect resistance has produced a gain of 10-14%. Further conventional breeding is likely to increase these levels further -- perhaps doubling them in another 20 years.

Note that these "traits" were generally based on specific landraces.

Crop Losses, Pesticide Use, and Total Factor Productivity in Indonesian Rice Production

The Indonesia study (Evenson 1994c) was the first to utilize crop loss and pesticide use data in a trait value study. It was also the first to use TFP at the crop level as a productivity index.

The Indonesian Ministry of Agriculture has measured crop losses by type (insect and disease) for each province and year. Data on varieties planted and trait ratings by variety were also available by province and year. Thus it was possible to compute the percentage of area planted in each region and period with specific traits.

Specification (1) does not deal explicitly with several econometric problems. The first problem, noted for the Indian study, is that there is a natural incidence factor for pests and diseases, which may vary by both location and time period. If a good measure of this factor were included in Z_{ij}, (1) could be regarded to be a "technical" relationship between losses and traits. The traits, i.e., the adoption of varieties with the traits, may be endogenous (e.g., it may be a response to the Z_{ij} vector, and economic factors can be set aside if the Z_{ij} vector is complete and controls for differences in the natural incidence of pests and diseases). But if that incidence is not well measured, endogeneity cannot be set aside.

A related problem lies behind this specification. It is that reduced crop losses (as measured by percentage of the crop actually lost) may be a poor measure of the value of a trait. The use of chemicals such as pesticides and herbicides, along with other farming practices, can be and are used to reduce crop losses. The incorporation of traits may reduce the costs of these chemicals and practices. These traits may also have the effect of enabling the adoption of modern high-yielding varieties (i.e., with high yielding quantitative traits) to be adopted in locations where they otherwise would not be adopted. The ecological stress tolerance traits would be particularly likely to have this effect.

For Indonesia, sufficient data exist on inputs by crop to enable the calculation of TFP indexes that take into account the use of conventionally measured inputs.

"Modern" rice varieties in Indonesia have undergone considerable change within the modern variety class. Darwanto (1992) has defined four "generations" of rice varieties. *Generation 1* includes IR5, IR8, IR20, and C463, which are the first semidwarf varieties developed in the Philippines (IR5 and IR8 at IRRI, C463 at the University of Philippines). This generation of MVs also includes Pelita 1/1 and Pelita 1/2, the first Indonesian-bred varieties. These varieties were generally subject to brown planthopper (BHP) and Tungro virus attacks. *Generation 2* includes the varieties IR22 and IR34 from IRRI as well as several varieties from Indonesian programs, all developed in response to the insect and disease problems afflicting the first generation of MVs (BPH and Tungro virus). *Generation 3* includes both IRRI (IR32–38) and Indonesian varieties that incorporate multiple resistance and tolerance traits. The IRRI varieties were the result of its Genetic Evaluation Unit (GEU) program in the 1970s. *Generation 4* includes other MVs incorporating more location-specific and related traits. These varieties (mostly Indonesian varieties) were released in the 1980s.

Each of these MVs was rated by plant breeders for resistance to three diseases (bacterial leaf blight, Tungro virus, and grassy stunt virus) and two insect pests (BPH and gall midge). It was possible to construct a data set for eight regions for 1971–90. Table 6 provides a definition of each variable used in the analysis and indicates whether it is endogenous or exogenous.

The endogenous variables include each of the five crop loss variables, pesticide use, and a cumulated index of rice TFP. The pesticide variable is treated as an independent determining variable. Thus a simultaneous equations estimation procedure is required. A two-stage least squares (2SLS) procedure was used.

Table 7 reports 2SLS coefficients and asymptotic "t" ratios for each of the five crop loss equations (Table 8 reports the sixth equation, predicting the pesticide use variable that was estimated). Three specifications are estimated. The first includes varietal resistance variables and excludes generational variables. The second includes both resistance and generational variables. The third includes only generational variables.

The *a priori* expectations are that an increased area planted to varieties resistant to an insect or disease problem should reduce crop losses. It would also generally be expected that pesticide use would reduce crop losses. Research on rice, holding varietal characteristics constant, is a measure of nonvarietal research findings, and it too is expected to reduce crop losses.

An examination of the estimates indicates that there probably is a problem with the fact that the natural susceptibility to crop losses varies by region and year. A region with high natural susceptibility is likely to have more resistant varieties, more pesticide use, and more losses. This will create a positive bias in the trait coefficients offsetting the expected negative resistance and pesticide use impacts. All equations included dummy variables for regions, but this did not fully control the problem.

The coefficients for pesticide use are marginally significant and negative only in the insect loss cases. They do not show strong effects for disease losses (except for grassy stunt virus).

Varietal resistance traits are also not consistently significant in their effects on losses. There is some evidence for insect loss reduction.

When generational variables are included with trait variables (version two), trait coefficients are effectively reduced to zero. These generations are expected to have different effects. We do not expect generation 1 to have strong effects, and we find strong impacts only for grassy stunt virus losses. We expect stronger negative impacts from generation 2, and we find these for bacterial leaf blight. The strongest impacts should show up for generation 3, and we do find negative impacts in all cases but rice Tungro virus (found in generation 4). In other cases, generation 4 varieties do not reduce losses, given that generation 3 has already reduced them to some degree.

Interestingly, nonvarietal research appears to have loss-reducing impacts for BPH, bacterial leaf blight, and grassy stunt virus. There is also some evidence that larger farms have lower crop losses per hectare for these same pests and diseases.

Table 8 reports the pesticide use and rice TFP index equations. Pesticide use, holding all natural factors constant, should be reduced by expanded resistance in the varieties that farmers plant. This is not the case for most estimates reported in Table 8. Some positive effects are found, suggesting a bias due to unmeasured natural susceptibility. Inclusion of the generation variables (version two) suggests some generation 3 impacts on pesticide use, holding specific resistances constant (enough to cut pesticide use by half).

Nonvarietal research and extension did not appear to reduce pesticide use.

The TFP equation included crop inputs (including pesticide) as an independent variable to provide some control for mismeasured factor shares. This variable, along with the intensification, farm size, and roads variables, contributed little to explaining TFP growth.

The chief variable determining TFP growth in rice is the research stock variable. It has high statistical significance in all specifications.

There is some additional explanation to be had from the traits and generational variables, however. When the traits are included, three of the five appear to be significantly positive, and the sum of the five coefficients is positive and approximately equal to one, indicating that a 1% expansion in every trait would produce a 1% expansion in TFP.

When generational variables are added, four of the five trait variables become negative and the sum of coefficients becomes negative (-.12). The generational variables are positive and quite high. They suggest that full generation 4 expansion may contribute to a doubling of TFP relative to the traditional varieties.

However, when the resistance variables are dropped from the equation, the generational coefficients fall to about 30% of their level in specification 2. These results then appear to be an indication that the trait variables are subject to some natural susceptibility bias, and the negative coefficients in specification 2 suggest that area planted to resistant varieties is responding to natural susceptibility and thus to some extent controlling for it, allowing for stronger generational impacts to be measured. Dropping these control variables reduces the size of the generational effect.

It is relevant to note two conditions affecting the economic interpretation of the estimates. The first is that the values of traits are confined to those environments where disease and insect pressure is greatest. The second is that the trait values included in this study are incomplete. A new variety may have several traits and each has value. Since this study only covered two insect resistance and three disease resistance traits, it probably underestimates the full value of all traits.

Specification (1) indicates that if all varieties had resistance to BPH, losses from this pest would be reduced by 2%. Approximately the same can be said for gall midge (GM) resistance. In actuality, only 60% of the varieties have BPH resistance and roughly 40% have GM resistance.

Thus by these estimates, actual losses are only about 1% lower because of these two traits. But if we consider other insect pests and a further expansion of trait area, we could conclude that conventional plant breeding has reduced crop losses by 3-5% (considering these two insect pests to represent one-third to one-half of all insect problems). There appears to be future potential for another 3-5% reduction if biotechnology methods enable a more complete incorporation of insect resistance traits.

For disease resistance traits, the evidence is less clear. Only Tungro virus resistance shows an indication of reducing crop losses, and that is only one-third of one percent. Even with some expansion to other diseases, it is difficult to say that disease resistance has contributed much more than 1% to reducing crop losses to date.

The pesticide use estimates from specification (1) (Table 8) indicate that the total set of traits reduces pesticide use by 20% (the sum of coefficients is 4,570, and this is 80% of mean pesticide use). This amounts to roughly 1% of crop value.

Finally, the TFP equation can be utilized to calculate trait values. If we leave in the negative value for BPH, we obtain a coefficient of .46 for insect resistance and a combined coefficient of .53 for disease resistance. Multiplying these coefficients by adoption levels, these estimates imply that TFP indexes (yields) are higher (average costs are lower) by roughly 11% because of insect resistance and by 3% or so because of disease resistance traits.

The TFP-based estimates are higher than the combined crop loss and pesticide estimates. With an expansion factor to cover other diseases and insects, the TFP evidence suggests that 15% of current TFP levels is the result of these five traits. The generation 3 evidence (specification 3) indicates a 25% generation 3 gain. This is more than double the contributions suggested by the crop loss and pesticide reduction estimates. These estimates, however, can be reconsidered by noting that TFP (yields) may incorporate a synergistic effect (that is, the sum is greater than the parts, and in this case it is greater than the crop loss pest parts).

It may thus be reasonable to conclude that, to date, rice yields in Indonesia are roughly 15% higher because of these traits and that with synergism they may be 25% higher. It should be noted that this synergism is really the result of quantitative trait improvement. Conventional plant breeding methods have allowed considerable gains to be realized in Indonesia and more are in the offing.

Modern Varieties, Traits, and Rice Supply in India

As in Indonesia, in India the class of MVs has not been static through time, and several generations of varieties, each incorporating new traits, have been produced.

Traits have two means by which they contribute value. First, they may result in higher rice yields, because of reduced losses from pests and disease (or they may result in higher value). But they also contribute value if they enable high-yielding, quantitative plant types to be grown in rice ecologies where they were previously unsuited. In light of the dual nature of trait value (i.e., affecting both yield and MV adoption), a model of MV adoption, supply, and factor demands is required for full trait value analysis.

Farmers respond to changes in technology as well as to changes in prices. Their ultimate objective is net revenue or net profits. They will compare net revenues from one crop with net revenues in another crop. They then formulate expectations by observing MV availability and adoption as well as prices. The profits function model implies cross-equation restriction on net revenues. Hence both MV or technology terms and prices will have these restrictions.

The adoption of MVs itself should be treated as an endogenous choice variable (previous studies have argued that aggregation alleviates this endogeneity; see Evenson et al. 1995). The logic of the discussion about traits suggests that profitability and the *availability* of traits, along with farmer characteristics and extension, will govern MV adoption. One of the concerns in this specification is to measure trait availability so as to achieve "exogeneity" for trait availability while allowing for endogeneity of MV adoption itself. In the India study, this was accomplished as follows.

1. The profitability of MVs for rice is proxied by state area ratios of MV rice yields to yields of traditional (unirrigated) rice. Dummy variables for districts are interacted with this variable to allow for proportional differences among districts. This variable reflects trait values to some extent.

2. Data were collected for "leading" rice varieties in India from 1978-92. In selected districts, yield traits for the three leading rice varieties were collected from farmers. The set of such varieties for each major agroclimatic region then constitutes a collection of ultimately successful varieties. For this set of varieties, it is possible through genealogical analysis and breeders' ratings to compute area traits in the set of such varieties and to date them according to the date of release of the ultimately successful varieties. It is argued that these availability data are exogenous to farmers in that they represent breeders' success.

The model suggested by these considerations is:

$$\begin{array}{ll}
\begin{array}{l}\text{modern}\\ \text{varieties}\end{array} & \left\{\begin{array}{l}\text{MVR}: Y^{*}_{1}, I, TR^{*}_{1}, T_{1}\\ \text{MVW}: Y^{*}_{2}, I, TR^{*}_{1}, T_{2}\end{array}\right. \\[2ex]
\begin{array}{l}\text{acreage}\\ \text{decision}\end{array} & \left\{\begin{array}{l}\text{A1}: \text{MV1}, \text{MV2}, \text{MV3}, P_{1}, P_{2}, P_{3}, R_{1}, R_{2}, R_{3}, T_{1}, T_{2}, T_{3}, I, F, A_{Rt\text{-}1}\\ \text{A2}: \text{MV1}, \text{MV2}, \text{MV3}, P_{1}, P_{2}, P_{3}, R_{1}, R_{2}, R_{3}, T_{1}, T_{2}, T_{3}, I, F, A_{Wt\text{-}1}\end{array}\right. \\[2ex]
\begin{array}{l}\text{demand}\\ \text{for}\\ \text{factors}\end{array} & \left\{\begin{array}{l}\text{X1}: \text{MV1}, \text{MV2}, \text{MV3}, P_{1}, P_{2}, P_{3}, R_{1}, R_{2}, R_{3}, T_{1}, T_{2}, T_{3}, I, F, A_{1t\text{-}1}\\ \text{X2}: \text{MV1}, \text{MV2}, \text{MV3}, P_{1}, P_{2}, P_{3}, R_{1}, R_{2}, R_{3}, T_{1}, T_{2}, T_{3}, I, F, A_{2\text{-}1}\\ \text{X3}: \text{MV1}, \text{MV2}, \text{MV3}, P_{1}, P_{2}, P_{3}, R_{1}, R_{2}, R_{3}, T_{1}, T_{2}, T_{3}, I, F, A_{3t\text{-}1}\end{array}\right. \\[2ex]
\begin{array}{l}\text{yield}\\ \text{outcomes}\end{array} & \left\{\begin{array}{l}\text{YR}: \text{A1}, \text{MV1}, T_{1}, P_{1}, R_{1}, R_{2}, R_{3}, I, W, TR\\ \text{Y2}: \text{A2}, \text{MV2}, T_{2}, P_{2}, R_{1}, R_{2}, R_{3}, I, F\end{array}\right.
\end{array} \tag{2}$$

The model has three blocks. The first is a set of equations determining modern variety adoption for each crop. State yield ratios Y^{*}_{1}, etc., and technology (research) T^{*}_{1} variables are determinants of adoption. The infrastructure and skill variables are included in this (and other blocks) as well. For rice, trait availability data (TR^{*}_{1}) are included.

The second block covers area (acreage) decisions. These equations include all (endogenous) MV variables, prices, and research variables (T) as well as I and F variables. Cross equation restrictions hold for the MV variable (e.g., $\delta A1/\delta MV2 = \delta A2/\delta MV1$) for the price variables and for the research variables. Acreage decisions are treated as subject to Nerlovian cost adjustment (A_{t-1}).

Desired acreage planted to crop i in period t is specified to be a function of relative prices of crop i and other infrastructural variables Z_t in (4).

$$A_t - A_{t-1} = \beta(A^{*}_{t} - A_{t-1}) \tag{3}$$

Costs of adjustment, however, prevent farmers from fully moving from last period's acreage to desired acreage in year t. Equation (3) states that the fraction β of the change will be made.

If acreage response is a linear function:

$$A^{*}t = a + bP_t + cZ_t\ , \tag{4}$$

then

$$\begin{aligned} A_t - A_{t-1} &= \beta[(a + bP_t + cZ_t) - \beta A_{t-1})] \\ A_t - A_{t-1} &= \beta a + \beta bP_t + \beta cZ_t - A_{t-1} \\ A_t &= \beta a + \beta bP_t + \beta cZ_t + (1-\beta)A_{t-1}\,. \end{aligned} \tag{5}$$

Equation (4) is typically estimated with some kind of error specification to account for the lagged dependent variable specification. Technology variables could be incorporated in Z_t, provided they were exogenous. Adoption of MVs is typically a choice variable and thus endogenous, although some features of MVs -- e.g., the availability of traits, may be considered the product of research programs and thus not a choice variable to farmers.

The third block includes the yield equations. These include only the "own" areas, MV, price, and research variables. They also include the *I* variables and weather variables, *W*. For rice the trait values are also included.

This system then constitutes a complete supply-factor demand system based on profit maximization in MV adoption decisions, acreage decisions, and yield (supply) outcomes. One can compute the implicit shadow prices for the policy variables, *I*, *T*, *F*, and *TR* (traits). These are evaluated as impacts on farm revenue.

Table 9 summarizes and defines the variables. Expected revenue variables were estimated from district data and state yield comparisons (Evenson 1995). Variables are characterized as exogenous and endogenous. The system estimates are reported in Table 10.

These estimates show that the price and revenue terms affect the acreage decision as expected. They also affect the MV decision.

The PHYVRICE equation clearly shows that traits affect the adoption of modern rice varieties and that they drove MV expansion beyond the original first-generation levels. The three variables AGRQUAL, ABIOSTRESS, and DISINS increased PHYVRICE by 27% over first-generation levels. An increase in NLR of 2 also increased PHYVRICE by 6-7%. We can conclude that the addition of these traits probably expanded PHYVRICE by roughly one-third, from 40% of area to 60% of area by 1984. By 1995 this had increased further to 75%.

The effects of traits on average yields are negligible when the negative NLR coefficient is considered.

Thus we can approximate the value of third- and fourth-generation traits as an expansion of modern rice area of 15-20% times the yield effect of PHYVRICE. This indicates a yield increase of roughly 1 t/ha (a 65% increase).

Modern varieties also increased input use per hectare by about 10%, so the net productivity increase was probably on the order of 50%. The trait values associated with third- and fourth-generation breeding then added 8-10% to national income. This estimate is roughly double the earlier Gollin-Evenson estimate based on yield effects only.

The Breeding Production Function Study

Gollin and Evenson (1996) report a breeding production function study for rice. The dependent variable in the study was the production of rice varieties that meet official release standards in the locations for which they were produced. Observations were for NARSs over 1965-90. Varietal releases were categorized by the "route" or pathway from origin to release. These routes were described earlier.

The key endogenous variables to be "explained" are R1-R9, the annual varietal releases by route. This set of varieties by route is "jointly" determined by the set of explanatory variables.

The explanatory variables include variables measuring the international rice germplasm collection (IRGC), the international rice plant breeding program (IRPB), and INGER activities, national demand, and national plant breeding activities (NPB). Of these, the most complicated is the measure of INGER activities, NING, the number of nurseries in a country. Since this is chosen by the country, it cannot be treated as an exogenous or predetermined variable. It must be modeled as simultaneously determined along with the other endogenous variables.

The variables measuring IRGC and IRPB, on the other hand, can be considered to be predetermined and thus exogenous to the national level variables. The IRGC, the cumulated number of catalogued IRGC accessions (with passport data), is considered to be a determinant of the number of INGER nurseries undertaken in a participant country. The IRPB activities are measured by the cumulative size of the internationally contributed landrace pool, POOLRI.

Other exogenous variables include the cumulated landraces, both international and national, which are measures of national plant breeding activity. In addition, the area planted to rice in a country should be governing genetic resource flows because it reflects demand.

Table 11 reports coefficient estimates and "t" values from the third stage of a 3SLS estimate of the system of 10 equations. The intercept and country dummy and time dummy variables coefficients are not reported, because they do not generally enter into the policy implications of the results.

The first equation is the equation determining the number of INGER nurseries that the host country chooses. The nurseries have expanded over time and the time dummies reflect this expansion. The rice area variable also explains why countries add more INGER nurseries. We find as well that countries respond positively to their neighbors' decisions to conduct INGER nurseries and, most important, that as the catalogued accessions in IRGC expands, the number of INGER nurseries expands. The INGER nurseries do not respond to the number of materials placed in trials by IRRI and have actually declined as the total landrace pool has expanded, given the response to IRGC. Thus we find a number of factors influencing the number of INGER nurseries placed in different countries. The 3SLS model treats this number as endogenously determined in the nine route or pathway equations.

The "model" underlying the Table 11 estimates is one in which the "flow" of varietal releases through each route or pathway responds to four governing variables in addition to rice area, country, and time effects. Two of these variables measure international plant breeding activities (CILR and POOLRI), one measures national plant breeding activities (CNLR), and the fourth, NING, is the outcome of both international (IRGC) and national activities. We expect each of these activities to have different impacts on each flow. In particular, the introduction of INGER is expected to increase the likelihood that a released variety has passed through INGER. We are, however, interested in the total impact, i.e., the sum of the flow of impacts, because this tells us whether the activity caused expansion in the total number of varieties released.

The two variables measuring the IRRI plant breeding program, CILR and POOLRI, clearly indicate that it is the size of the IRRI origin landrace pool that is important and not the cumulative stock. In other words, what seems to be important is the introduction of new landrace material into the pool, not the replication of those landraces, which is largely the contribution of national programs. Each landrace added to the pool by IRRI contributes .045 varieties annually in each country as indicated by the statistically significant sum of the coefficients.

Now consider the INGER impact. The expansion of INGER diverted varietal flows away from NO INGER routes (R2 and R4) to INGER routes (though this diversion was not highly significant). For parental materials, INGER has a positive impact on all routes, including stimulus of NO INGER routes (R6 and R8). This suggests that the INGER nurseries stimulated more international searching for genetic resources. It also reflects the fact that INGER nurseries actually include parent and grandparent cultivars that were not initially introduced through INGER.

The F tests tell us that the NING has a significant positive impact on the total flow of varieties released The coefficient .0295 indicates that one additional INGER nursery is associated with .0295 additional released varieties. Thus the addition of 34 nurseries (a nursery is counted in each location in each year) adds one released variety. If the INGER program were to end (to be stopped at its level of 900 to 1,000 nurseries each year in recent years), the recent annual flow of released varieties would be reduced from 80 per year to around 60 per year. This indicates that INGER has added to the production of released varieties by roughly 25%. This is a large impact.

Each landrace added from IRRI sources causes approximately .68 added varieties to be released in each future year. (This coefficient is based on replication in 15 countries.)

The IRGC also has an impact on released varieties, because it induces the addition of INGER nurseries. The addition of one accession to IRGC causes (.000875 × 15) = .0013 INGER nurseries. This, in turn, means that (.0295 × .0013 × 15) = .0058 more varieties are produced. Thus adding 1,000 accessions to IRGC causes 5.8 added released varieties in each future year.

Evenson and David report estimates of the impacts of MVs for India, Pakistan, Bangladesh, Philippines, Thailand, Indonesia, and Brazil. These range from a relatively high value for India to lower values for the other countries. The approximate value of MVs in 1990 in *indica* rice regions was US$ 3.5 billion. If we consider this to be the cumulated contribution of the first 1,400 MVs, we obtain an average value of a released variety of US$ 2.5 million per year, and this annual value continues into perpetuity because we are considering varietal improvements to be additive.

Using this estimate, Gollin and Evenson computed the economic effects of INGER, of one added IRRI landrace, and of added accessions to IRGC. First consider the consequence of ending the INGER program. Gollin and Evenson estimate that this would reduce the flow of released varieties by 20 varieties per year. There is a time lag between a material's appearance in INGER and production. Suppose this to be five years. Then further suppose that the INGER effect lasted only 10 years -- in other words, that INGER speeded up the release of varieties that would have been released an average of 10 years later. The present value of the 20 varieties over the sixth and fifteenth year, discounted at 10%, is US$ 1.9 billion. At a 5% discount rate, the value rises to US$ 6 billion. This is clearly a large contribution relative to the costs of operating the system, and much of this value is due to genetic resource collections.

The present value of a landrace added to varieties by IRRI was US$ 86 million, discounted at 10% (US$ 272 discounted at 5%). For landraces added by NARSs, this value was US$ 33 million (US$ 104 at 5%).

Gollin and Evenson also computed the present value of adding 1,000 catalogued accessions to IRGC. Using the estimated coefficient for the impact on INGER nurseries (which was quite small), they computed the value of adding .52 nurseries to be roughly US$ 100 million, discounted at 10% (US$ 350 million discounted at 5%), assuming a 10 year lag between accessions and economic impact.

Future Varietal Developments

This paper has examined the impacts to date of varietal development based on conventional breeding. However, models have indicated that conventional breeding is ultimately subject to diminishing returns (Evenson and Kislev, Lee, Evenson 1996). The remainder of the paper will address four questions related to the possible future impact of conventional breeding strategies:

1. Is there evidence for a slowdown in rice productivity gains driven by varietal development (in other words, is conventional breeding exhaustion setting in)?
2. Will new plant types or designs enable a "recharge" of conventional breed gains?
3. Will early-generation tools of biotechnology (wide crossing and hybridization) recharge breeding productivity?
4. Will more advanced, "transgenic" tools of biotechnology (gene transfer and marker-aided breeding) recharge breeding productivity?

We have sufficient experience to address the first question. The data in Table 12 show slower rates of both area and yield growth for most countries in 1983-92 relative to 1962-

82. Rosegrant and Evenson (1995) attributed the slowdown in yield growth to breeding exhaustion. They based future projections of production on the slower growth rates.

The answers to questions 2, 3, and 4 above can be based on a considerable amount of experimental evidence, but little field evidence (except for hybridization). The new plant type developed at IRRI shows promise (Khush 1996), but its full impact on breeder productivity has yet to be realized. Hybrid *indica* rice materials have now reached the commercialization stage. In India they show some success to date, but their full potential has yet to be shown. Wide crossing techniques have been used to introduce genes of wild species into *Oryza sativa*, and *Oryza nivara* is a widely used source of host plant resistance to grassy stunt virus. Again, the full potential of these techniques has not been realized. Transgenic *indica* rice plants have been available for several years, but are only now reaching the testing stage.

A recent priority setting study for rice was carried out as part of a Rockefeller Foundation study conducted with IRRI and the Economic Growth Center at Yale University. A rating exercise was done with 18 senior rice scientists (nine from IRRI, nine from NARSs). For each set of research problem areas and research techniques, four ratings were elicited for alternative research techniques: managerial research, conventional breeding, wide crossing and hybridization, biotechnology (transgenic rice and market-aided selection). Ratings were on a scale of 1-5 and were calibrated to percentage achievements of economic potential: (1) a rating of achievement to date; (2) a rating of potential achievement; (3) an estimate of the number of years required to achieve 25% of the difference between achievement to date and potential (Y25); and (4) an estimate of the number of years required to achieve 75% of the difference between achievement to date and potential (Y75). In developing their estimates, scientists were asked to assume that in future periods both international and national research programs would continue to be supported at the levels of the past decade.

The specification of two ratings, one for achievement to date and one for potential achievement, forced respondents to focus on "remaining potential." Ratings of potential minus achievements to date were summarized and converted to percent accomplishments (note that scientists were given the ratings -- the percent achievement relationship -- but were asked to rate using the 1-5 scale). The scientists' estimates are reported in Table 13.

Rosegrant and Evenson developed projections of the public rice research contribution by period using the timing estimates of the 25% achievement and the 75% achievement levels to "distribute" economic gain achievement by subperiod. Scientists' estimates indicated that management (agronomy and related research) gains would be realized at a roughly constant rate over time. Conventional breeding gains were projected to decline as Mendelian combinations of genetic resources within the species were exhausted. The wide crossing/tissue culture technologies were expected to reach their maximum contribution around 2010. The contribution of biotechnology (transgenic plants and marker-aided selection) grows over time, with the major contribution coming after 2010.

Rosegrant and Evenson then applied crop loss and potential yield data to develop projections for rice productivity gains. These are summarized for South Asia in Table 13. (Other projections for Southeast Asia and other regions are reported in Rosegrant and Evenson.) The public research component is based on the probability-based (and crop-loss-based) estimates. These estimates indicate that the expansion of gains from wide crossing, hybridization, and transgenic breeding will offset conventional breeding exhaustion but that gains will not return the level seen during the "green revolution" of 1962–82.

Other sources of productivity growth include extension, schooling, research in the private sector, and markets and infrastructure. These are based on productivity studies in several countries.

This exercise is based on judgments, but they are informed judgments by the rice scientists best qualified to make them. They show that varietal improvement is likely to continue to be the centerpiece of rice productivity gains.

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Table 1. Numbers of varieties included in the data set, by country of release and time period of release.

Country/region	Pre-1965	1966-70	1971-75	1976-80	1981-82	1986-91	Total
Africa	3	7	8	17	26	42	101
Bangladesh	1	7	8	11	4	33	34
Burma	0	4	6	21	37	8	76
China	0	1	8	30	31	12	82
India	10	67	136	139	125	166	643
Indonesia	1	2	5	21	10	9	48
Korea	0	5	11	35	40	15	106
Latin America	7	9	48	32	43	100	239
Nepal	0	0	1	10	4	2	17
Oceania	0	1	4	1	0	0	6
Pakistan	0	4	2	3	3	0	12
Philippines	3	4	13	23	8	2	53
Sri Lanka	3	14	4	8	21	3	53
Taiwan	0	3	0	3	0	0	6
Thailand	1	2	4	8	5	3	23
USA	2	5	18	17	3	6	51
Vietnam	0	16	6	16	16	5	59
Other Southeast Asia	2	1	8	7	6	5	29
Other	0	7	15	15	15	19	71
Total	32	150	284	394	377	378	1,709

Table 2. Flows of international genetic resources, by time period

	Pre-1965	1966-70	1971-75	1976-80	1981-85	1986-91	Total
I. Released varieties, percentage based on:							
IRRI cross (through INGER)	3	25	19	22	18	12	17
	(0)	(0)	(2)	(13)	(14)	(11)	(8)
Other NARS cross (through INGER)	16	7	6	6	6	5	6
	(0)	(0)	(0)	(2)	(4)	(3)	(3)
Own NARS cross	81	68	75	72	76	83	77
II. Parents of released varieties, percentage with one or more parents:							
IRRI cross (through INGER)	0	24	29	33	23	19	24
	(0)	(0)	(0)	(9)	(20)	(15)	(10)
Other NARS cross (through INGER)	27	25	21	15	18	20	18
	(7)	(2)	(5)	(9)	(15)	(15)	(10)
Own NARS cross	73	51	50	52	59	6	58
III. Frequency of parental/cross, percentage with no foreign genetic resource:							
All NARS parents	24	11	8	6	7	10	8
IV. Landrace content of released varieties, parent greater than:							
4	10	31	47	67	62	56	55
9	0	3	13	39	34	32	27
15	8	0	3	21	18	18	14
Average number of landraces	2.55	4.01	5.29	8.15	7.49	7.23	..
Percentage from IRRI	3	3	59	79	74	71	68
V. Landrace introduction:							
Number from IRRI	0	16	14	21	11	13	80
Number from NARSs	21	87	126	146	171	180	758

Note: IRRI = International Rice Research Institute; INGER = International Network for the Genetic Evaluation of Rice; NARS = national agricultural research system.

Table 3. Routes of varietal release: descriptive statistics.

Route	Number of varieties	Percentage of varieties	Total area (million ha)	Percentage of area	Average number of landraces		Average number number of landraces independent of IRRI		Average number of landraces with rare trait index >5.0
					Pre-1976	Post-1976	Pre-1976	Post-1976	
IRRI/INGER	146	8.5	5,177	13.3	na	13.2	na	0.0	12.55
IRRI/No INGER	148	8.7	3,959	10.2	5.4	12.4	0.0	0.0	7.66
Other/INGER	37	2.2	411	1.1	na	4.2	na	2.1	3.35
Other/No INGER	59	3.5	2,954	7.6	4.4	5.2	2.5	1.6	4.14
IRRI parent/INGER	214	12.5	6,570	16.9	na	10.4	na	1.2	9.55
IRRI parent/No INGER	313	18.3	5,589	14.4	5.6	9.5	1.7	1.4	6.53
Other parent/INGER	208	12.2	4,283	11.0	na	2.9	na	2.5	1.52
Other parent/No INGER	151	8.8	3,228	8.3	3.4	4.8	3.4	3.8	2.68
IRRI grandparent/INGER	14	0.8	670	1.7	0.0	7.2	0.0	3.0	6.00
IRRI grandparent/No INGER	94	5.5	1,436	3.7	7.4	10.7	4.6	3.6	8.93
Other grandparent/INGER	0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.00
Other grandparent/No INGER	180	10.5	1,482	3.8	4.4	4.1	4.3	3.8	2.04
Pure national	145	8.5	3,121	8.0	3.2	2.6	2.7	2.2	1.10

Note: na = not available; IRRI = International Rice Research Institute; INGER = International Network for the Genetic Evaluation of Rice.

Table 4. Rice research impact studies: a summary.

Study	Estimated coefficients			Estimated marginal products			Contribution		Estimated marginal IRD	
	Research	HYV	Extension	Research	HYV	Extension	Non-HYV	HYV	Research	Extension
India (McKinesy and Evenson)										
Yields	.034	.549	.083	11.3	na	16.5	.04	.26	155	215
India (Evenson 1993)										
Yields	.178	.257	.035	20.0	(.278)	4.9	.18	.14	80	82
Area	.115	.241	na	na	na	na	na	na	na	na
Indonesia (Solmon 1988)										
Yields	.014	na	.050	nc	na	nc	na	na	151	nc
Indonesia (Evenson 1995)										
TFP (irrigated)	140	.015	.011	.91	na	1.0	.14	.01	337	0
TFP (upland)	neg	na	.109	neg	na	10.9	na	na	0	173
Indonesia (Evenson et al. 1994)										
Yields (irrigated)	.0028	na	1.307	101	na	na	na	na	100+	na
Area (irrigated)	-696	na	na	na	na	na	na	na	na	na
Yields (upland)	.0020	na	2.09	20	na	na	na	na	100+	na
Area (upland)	-526	na	na	na	na	na	na	na	na	na
Pakistan (Azam et al. 1991)										
Yields (irrigated)	.016	.109	na	22.4	(.109)	na	.02	.06	84	na
Bangladesh (Dey and Evenson 1994)										
Yields (irrigated)	.048	na	.0203	36.4	na	2.9	na	na	165	45
Philippines (Sardide and Evenson)										
Yields (irrigated)	2.13	na	.016	30	na	3.0	na	na	90	50
Thailand (Setboonsarng and Evenson)										
Yield (irrigated)	.050	.068	.05	1.8	na	1.0	.05	.04	35	15
Brazil (Evenson at al.)										
Yields	.020	na	.059	1.6	na	4.9	na	na	43	86
10 Asian countries (Evenson)	.075	na	.192	na	na	na	na	na	59	780

Note: nc = not calculated; na = not available.

Table 5. Hedonic trait value estimates.

	District 1	District 2	State
Trait for resistance to:			
Blast	–.134	..	.184**
Bacterial leaf blight	–.007	–.069	–.134**
Bacterial leaf stripe	–.065	.173	..
Rice Tungro virus	–.146*	..	..
Sheath blight	1.48**	1.49**	..
Brown planthopper	–.151*	..	.033
Green leafhopper	.037	.052	.123**
White-backed planthopper	.309**	.309**	.377**
Gall midge	.091	.102*	.174**
Stem borer	.155*	.029	.141*

Note: * indicates "t" between 1.5 and 2.0; ** indicates "t" greater than 2.0.

Table 6. Variables: Indonesia study.

I. Dependent variables

Crop–loss variables (percentage of crop)	.0072
Brown planthopper	.0014
Gall midge	.0016
Bacterial leaf blight	.00016
Grassy stunt virus	.00047
Rice Tungro virus	8
Pesticide costs per ha (rupials)	.5585
Rice total factor productivity (index)	1.432

II. Independent variables

Pesticide costs per ha (rupials) treated as an exogenous variable

Rice inputs index	1.150
Intensification program (percentage coverage)	.67
Farm size (ha)	1.224
Roads (proportion of villages with 2 km of all-weather roads)	59.10
Research (stock; see Evenson 1991)	5.53
Extension (staff per farm)	.00016
Varietal resistance (percentage of area)	
Brown planthopper	.56
Gall midge	.30
Bacterial leaf blight	.55
Grassy stunt virus	.05
Rice Tungro virus	.07
Generations of modern varieties (percentage of area)	
Generation 1	.097
Generation 2	.083
Generation 3	.357
Generation 4	.154

Table 7. Crop–loss determinants.

	Farm size	Rice research	Pesticide use	Varietal resistance	Breeding generation				
					1	2	3	4	R^2
Brown planthopper									
(1)	–.0692	–.0078	.72	–.0213	..	..	..	..	..
	(2.26)	(1.51)	(.90)	(2.11)	..	..	..	..	(.45)
(2)	–.0273	–.0023	–.89	.010	.038	.022	– .0150	.001	..
	(.86)	(.68)	(.83)	(.27)	(2.07)	(.01)	(.40)	(.03)	(.52)
(3)	–.0189	–.0074	–1.92	..	.036	.030	–.010	–.019	..
	(.57)	(.12)	(1.26)	..	(1.97)	(1.76)	(.70)	(1.01)	(.52)
Gall midge									
(1)	.0076	.0033	–.82	–.0193	..	..	..	..	..
	(.36)	(1.07)	(1.24)	(3.28)	..	..	..	..	(.22)
(2)	.0045	.0025	–1.08	.0054	–.005	.006	–.022	.05	..
	(.20)	(.64)	(1.42)	(.33)	(.38)	(.57)	(1.24)	(1.17)	(.24)
(3)	.0028	.0021	–.76	..	–.003	.007	–.16	.003	..
	(.12)	(.52)	(.72)	..	(.26)	(.58)	(1.61)	(.22)	(.23)
Bacterial leaf blight									
(1)	–.0012	–.0002	.40	.0002	..	..	..	..	..
	(1.78)	(2.09)	(2.35)	(1.11)	..	..	..	...	(.21)
(2)	–.0016	–.0003	.07	.0001	– .0004	– .0007	– .0002	.0002	..
	(2.18)	(2.18)	(.90)	(.09)	(.94)	(1.61)	(.27)	(.36)	(.25)
(3	–.0014	–.0002	.10	..	– .0004	– .0007	– .0002	.0003	..
	(1.95)	(.93)	(.29)	..	(1.05)	(.74)	(.67)	(.87)	(.25)
Grassy stunt virus									
(1)	–.0016	–.00024	.008	–.0001	..	..	..	..	..
	(1.45)	(1.74)	(.15)	(.09)	..	..	..	..	(.20)
(2)	–.0017	–.0003	–.05	.0001	– .0019	– .0003	– .0010	.0001	..
	(1.35)	(1.08)	(.90)	(.12)	(2.67)	(.43)	(1.79)	(.19)	(.37)
(3)	–.0009	–.0001	–.15	..	– .0022	– .0003	– .0014	.0008	..
	(.62)	(.43)	(2.30)	..	(2.83)	(.38)	(2.27)	(.95)	(.27)
Rice Tungro virus									
(1)	.0042	.0004	–.010	–.0033	..	..	..	..	.
	(1.19)	(.90)	1.10)	(1.19)	..	..	..	..	(.25)
(2)	.0072	.0010	.035	–.0007	.0004	.0025	.0003	– .0044	..
	(1.68)	(1.35)	(.19)	(.18)	(.18)	(1.07)	(.15)	(1.34)	(.27)
(3)	.0068	.0010	.069	..	.0005	.0024	.0064	– .0044	..
	(1.59)	(1.29)	(.35)	..	(.20)	(1.07)	(.20)	(1.74)	(.30)

Table 8. Pesticide use and rice total factor productivity (TFP) determinants.

	Pesticide use (ha)			Rice TFP index		
Determinants	**(1)**	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
Rice research	1,355	1,300	1,629	.2787	.2654	.2678
	(1.28)	(1.26)	(1.31)	(6.44)	(6.48)	(5.40)
Rice inputs						
Extension	865	349	888	..	..	..
	(1.05)	(.38)	(.88)	..	..	..
Intensification program	–32	–23	–69	–.0014	–.0017	–.0021
	(1.49)	(1.09)	(2.95)	(1.35)	(1.87)	(2.02)
Farm size	4,630	4,226	5,318	.152	.054	.223
	(1.36)	(1.27)	(1.48)	(.98)	(.36)	(1.24)
Roads	62	64	51	.0032	–.0004	.0011
	(2.41)	(2.49)	(1.68)	(.27)	(.33)	(.84)
Varietal resistance to:						
Brown planthopper	2,048	5,896	..	–.127	–.507	..
	(1.20)	(1.30)	..	(1.37)	(2.60)	..
Gall midge	–4,342	627	..	.591	.619	..
	(2.71)	(.26)	..	(8.03)	(5.74)	..
Bacterial leaf blight	1.257	6,290	..	–.184	–.672	..
	(.59)	(1.67)	..	(1.89)	(4.23)	..
Grassy stunt virus	10,622	7,550	..	.543	.482	..
	(4.96)	(3.22)	..	(5.48)	(4.61)	..
Rice Tungro virus	–5,015	–6,985	..	.172	–.048	..
	(1.87)	(2.35)	..	(1.39)	(.37)	..
Breeding generation						
1	..	326	–.247	..	.067	.128
	..	(.17)	(.12)	..	(.81)	(1.31)
2	..	–2,571	4,136	..	.406	–.105
	..	(.55)	(1.93)	..	(2.06)	(1.16)
3	..	–12,324	–1,248	..	.812	.254
	..	(1.84)	(.78)	..	(2.87)	(3.46)
4	..	–5,081	8,303	..	.986	.125
	..	(.71)	(4.37)	..	(3.25)	(1.45)
R^2	.90	.98	.87	.94	.96	.94

Table 9. Definition of variables for Indian supply study, North Indian Districts, 1959–88.

Variable	Definition	Mean
1. Endogenous		
MYVRICE	Percentage area planted to modern rice	.28
MYVWHT	Percentage area planted to modern wheat	.39
ARICE	Area planted to rice (000 ha)	64.6
AWHEAT	Area planted to wheat (000 ha)	169.6
Qbullock	Quantity -- bullock power	150.4
Qtractor	Quantity -- tractor use	89
Qlabor	Quantity -- labor	2,879
Qfert	Quantity -- fertilizer	65.94
YRICE	Yield -- rice	1,428
YWHEAT	Yield -- wheat	2,709
		1.502
		1.631
2. Exogenous		
A. Prices		
RTR/RMR	Ratio: Expected revenue TRAD rice/MV rice	.89
RTW/RMR	Ratio: Expected revenue TRAD wheat/MV rice	1.21
RMW/RMR	Ratio: Expected revenue MV wheat/MV rice	1.14
RTR/RMW	Ratio: Expected revenue TRAD rice/MV wheat	.84
RMR/RMW	Ratio: Expected revenue MV rice/MV wheat	.74
RTW/RMW	Ratio: Expected revenue TRAD wheat/MV wheat	.94
B. Technology		
LGCRICE5	Rice research stock	19.75
LGCWHT5	Wheat research stock	7.37
EXT	Extension days/farm	7.80
LITERACY	Percent literate farmers	.300
C. Infrastructure		
IROADS	Index of changes in roads	1.813
NIANCA	Net irrigated average/net cropped area	..
D. Weather		
YEARRAIN	Rainfall -- year	782
JUNERAIN	Rainfall -- June	90
JUARINA	Rainfall -- July, August	436
E. Rice traits		
AGRQUAL	Proportion of leading varieties with agronomic quality traits	
ABIOSTRESS	Proportion of leading varieties with abiotic stress tolerance	
DISINSRES	Proportion of leading varieties with specific disease and insect resistance traits	
NOLR	Number of land races in leading varieties	

Table 10. Estimates: traits-based duality system, Indian District data, 1956–89.

Dependent variables	PHYVRICE	PHYVWHT	ARICE	AWHEAT	YRICE	YWHEAT
I. Endogenous						
PHWRICE	..	..	..	27.62**	..	..
PHWWHT	..	..	-8.18	39.34**	.987	.502**
ARICE(2)	..	..	10.75**	..	..	..
AWHT(2)	..	..	8.65	.804**	.008*	.0004
II. Prices						
RTR/RMR	1.086**	..	..	..	..	..
RTW/RMR	.121*	..	..	..	..	..
RMW/RMR	.128*	.841**	..	.503*	-1.73	..
RTR/RMW	.809**	..	..	..	..	..
RTW/RMW	-1.423**	..	..	..	..	..
III. Technology						
LGCRICE5	-61.2**	..	-30.1**	0.36	..	..
LGCWHT	-132.4*	..	-168.2*	-.997**	..	..
EXT	.023**	-.016**	1.988	1.358**	.023**	.066**
LITERACY	.191**	.413**	-50.07	6.40	-.580*	.225
IV. Infrastructure						
IROADS	.076**	.022**	3.036**	.628*	.282**	.048**
NIANCA	.128**	.209**	-.529	22.62**	.823**	.556**
V. Weather						
YEARRAIN	..	..	..	..	.0008**	-.0001
JUNERAIN	..	..	..	..	.00006	-.0004**
JUARAIN	..	..	..	..	.00005	.00001
VI. Rice traits						
AGRQUAL	.073**	..	..	.0145	..	..
ABIOSTRESS	.0156*	..	.0252	..	..	..
DISINSRES	.0065**	..	..	..	.0049	..
NOLR	.0330**	..	..	..	-.0439**	..

Table 11. Estimates of International Network for the Genetic Evaluation of Rice (INGER), international rice germplasm collections (IRGC), international rice plant breeding (IRPB), and national plant breeding (NPB) impacts (3SLS estimates of 10 equation system).

	Independent variables								
Dependent variable	**OING**	**IRGC**	**ENTRIES**	**POOLR**	**NING**	**CNLR**	**CILR**	**POOLRI**	**AREA**
NING	.0588 (7.85)	.000875 (2.17)	–.00007 (.04)	–.0999 (2.60)	.. ..	.. ..	.. ..	.. ..	.0319 (16.59)
R1 IRRI/INGER	.. ..	.. ..	.. ..	.. ..	.00037 (.16)	–.0034 (2.57)	.0021 (4.42)	.00013 (.05)	.0001 (1.09)
R2 IRRI/No INGER	.. ..	.. ..	.. ..	.. ..	–.0078 (3.16)	.0013 (1.00)	–.0008 (1.70)	.00628 (2.38)	.0002 (2.38)
R3 Other/INGER	.. ..	.. ..	.. ..	.. ..	.0010 (.74)	.0002 (.30)	.0006 (.57)	.00036 (.24)	–.00003 (.93)
R4 Other/No INGER	.. ..	.. ..	.. ..	.. ..	–.0002 (.13)	–.0001 (.09)	.0001 (.20)	.00389 (2.89)	–.00007 (1.44)
R5 IRRI parent/INGER	.. ..	.. ..	.. ..	.. ..	.0036 (1.05)	.0054 (2.89)	.0010 (1.47)	–.00416 (1.10)	–.00004 (.58)
R6 IRRI parent/No INGER	.. ..	.. ..	.. ..	.. ..	.0053 (.89)	.0036 (1.13)	–.0032 (2.69)	.0254 (3.86)	–.00000 (.00)
R7 Other parent/INGER	.. ..	.. ..	.. ..	.. ..	.0087 (1.72)	.0040 (1.43)	–.0002 (.22)	.00062 (.11)	–.0004 (1.82)
R8 Other parent/No INGER	.. ..	.. ..	.. ..	.. ..	.0121 (3.56)	–.00068 (.35)	–.0005 (.92)	.0124 (3.42)	–.00051 (3.86)
R9 National	.. ..	.. ..	.. ..	.. ..	.0065 (1.25)	.0068 (2.38)	.0010 (1.00)	.00015 (.03)	–.00006 (2.21)
Sum of coefficients	..	..	..	..	.0295	.0173	–.0003	.0451	..
F test on sum	..	..	..	..	4.75	5.26	.014	8.35	..
Prob > F	..	..	..	..	.037	.021	.903	.004	..
System $R^2 = .54$									

Table 12. Rice: growth rates (%) in area and yield.

	Area		Yield	
	1962-82	**1983-92**	**1962-82**	**1983-92**
World	1.00	0.40	1.91	1.43
USA	3.30	1.54	0.74	1.65
European Community 12	0.59	2.47	0.39	0.69
Other Western Europe	..	..	..	..
Japan	-1.95	-1.41	0.72	-0.47
Australia	9.59	-1.04	-0.69	3.62
Other developed countries	-1.00	0.00	3.68	0.00
European Economic Community	1.14	-5.01	0.59	-5.66
USSR	7.67	-8.85	2.55	-1.14
Argentina	3.07	0.34	-0.35	1.93
Brazil	2.56	-2.59	-0.44	3.37
Mexico	0.66	-6.77	2.31	1.46
Other Latin America	2.36	0.94	3.18	0.44
Nigeria	5.19	13.11	3.12	-0.86
Other Sub-Saharan Africa	2.47	2.43	0.01	0.87
Egypt	0.58	1.71	0.43	3.73
Other West Asia and North Africa	0.66	2.80	1.37	1.00
India	0.70	0.46	1.62	2.87
Bangladesh	0.69	0.19	1.03	2.81
Pakistan	2.42	0.80	3.22	-0.68
Other South Asia	1.56	-0.25	0.43	1.49
Indonesia	1.36	1.48	3.81	1.52
Philippines	0.67	0.43	3.31	1.60
Thailand	2.05	-0.33	0.24	0.39
Malaysia	1.32	0.57	1.82	1.79
Other Southeast Asia	-0.24	1.20	1.88	1.13
China	1.08	-0.25	2.64	1.29
South Korea	0.20	-0.31	2.38	-0.33
Other East Asia	4.46	1.55	1.19	-3.57
ROW	15.04	-33.32	4.27	-28.85

Table 13. Rice nonprice yield (base) projections (expressed in %), South Asia.

	1995-2000	2000-2005	2005–2010	2010–2015	2015–2020
Public Research					
Management	.216	.216	.216	.216	.216
Conventional breeding	.763	.654	.436	.327	.218
Wide crossing, hybrids	.100	.200	.300	.250	.150
Biotechnology	.158	.316	.474	.682	.790
Total public research	1.237	1.386	1.426	1.425	1.374
Extension – schooling	.470	.570	.597	.593	.569
Private research	.100	.150	.200	.200	.200
Markets – infrastructure	.150	.150	.200	.200	.200
Total base case	**1.957**	**2.256**	**2.423**	**2.418**	**2.343**

Appendix table 1. Matrix of varietal exchange

Releasing country	Source of varietal cross																			
	Other	Latin America	Oceania	Bangladesh	Africa	Burma	USA	China	India	Indonesia	IRRI	Korea	Southeast Asia	Nepal	Pakistan	Philippines	Sri Lanka	Taiwan	Thailand	Vietnam	Total
Other	9	7	0	0	0	1	0	5 (2)	16	3 (2)	18 (9)	6	5	0	0	0	0	1	0	0	71 (13)
Latin America	3 (1)	185 (2)	0	0	1 (1)	0	5	0	2 (2)	0	39 (15)	1	0	0	0	2	1 (1)	0	0	0	239 (22)
Oceania	0	0	1	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	6 (0)
Bangladesh	0	0	0	17	0	0	0	1	4 (1)	0	11 (3)	0	1	0	0	0	0	0	0	0	34 (4)
Africa	1	1 (1)	0	0	69 (1)	0	0	0	1 (1)	0	26 (12)	0	0	0	0	1	2 (2)	0	0	0	101 (17)
Burma	2	0	0	1 (1)	0	33	0	1 (1)	1	1 (1)	18 (5)	0	2 (1)	0	0	1	2 (2)	0	12 (6)	2 (2)	76 (19)
USA	0	1	0	0	0	0	48	0	0	0	2 (2)	0	0	0	0	0	0	0	0	0	51 (2)
China	0	0	0	0	0	0	0	66	1	0	13 (8)	1	0	0	0	0	1 (1)	0	0	0	82 (9)
India	5	0	0	0	1	0	0	0	573	0	53 (33)	0	1	0	1	1	4 (3)	2	1 (1)	1	643 (37)
Indonesia	0	0	0	0	0	0	0	0	0	29	18 (13)	0	0	0	0	1	0	0	0	0	48 (13)
Southeast Asia	0	0	0	0	0	0	0	0	1	0	7 (2)	0	21	0	0	0	0	0	0	0	29 (2)
Korea	0	0	0	0	0	0	0	0	0	0	1	105	0	0	0	0	0	0	0	0	106 (0)
Nepal	0	0	0	0	0	0	0	0	0	0	5 (2)	0	1	8	0	0	1 (1)	0	0	0	17 (3)
Pakistan	0	0	0	0	0	0	0	0	0	0	7	0	0	0	5	0	0	0	0	0	12 (0)
Philippines	0	0	0	0	0	0	0	0	0	0	25 (15)	0	0	0	0	26	0	0	0	1	53 (15)
Sri Lanka	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	51	0	0	0	53 (0)
Taiwan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	6 (0)
Thailand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	23 (0)
Vietnam	0	0	0	0	0	0	0	0	0	0	44 (27)	0	0	0	0	0	0	0	0	15	59 (27)
Total	20	194	1	18 (1)	71 (2)	34 (0)	53 (0)	73 (3)	601 (4)	34 (3)	294 (146)	113 (0)	31 (1)	8 (0)	6 (0)	32 (0)	62 (10)	9 (0)	36 (7)	19 (2)	1,709 (183)

Note: Numbers in parentheses represent borrowings through the International Network for the Genetic Evaluation of Rice (INGER); IRRI = International Rice Research Institute.

Appendix table 2. Matrix of parental borrowing

Releasing country	Source of parental cross																				
	Other	Latin America	Oceania	Bangladesh	Africa	Burma	USA	China	India	Indonesia	IRRI	Korea	Southeast Asia	Nepal	Pakistan	Philippines	Sri Lanka	Taiwan	Thailand	Vietnam	Total
Other	28 (2)	2	0	0	0	1	1	0	42 (23)	4	48 (13)	1	7	0	0	4 (3)	0	2 (1)	2	0	142 (42)
Latin America	116 (26)	73 (20)	0	0	4 (3)	0	22 (3)	0	62 (58)	3 (5)	161 (68)	4	0	0	0	8	6 (3)	5 (2)	10 (3)	4 (3)	478 (198)
Oceania	0	0	0	0	2	0	2	0	5	0	0	0	0	0	0	0	0	1	2	0	0 (0)
Bangladesh	4 (1)	0	0	1 (1)	0	0	2	1	18 (11)	2	34 (9)	0	2	0	0	2	0	1 (1)	0	1 (1)	68 (24)
Africa	33 (20)	3 (2)	0	0	34 (13)	0	0	2 (2)	57 (51)	6 (4)	42 (24)	0	6 (3)	0	0	3	3 (3)	5 (1)	5	3 (3)	202 (126)
Burma	26 (15)	0	0	0	0	1	0	1	68 (68)	5 (1)	38 (29)	0	1	0	0	7 (5)	0	2	0	3 (4)	152 122
USA	28	2	0	0	0	0	47 (1)	0	15 (15)	0	6 (4)	0	0	0	0	0	1	1	2 (4)	0	102 (24)
China	42 (13)	0	0	0	0	0	0	20 (7)	27 (29)	1 (2)	72 (52)	0	0	0	0	0	1	1	0	0	164 (103)
India	150 (32)	1	0	3 (2)	4 (4)	0	2 (1)	10 (3)	637 (101)	14 (7)	351 (174)	0	23 (13)	0	0	15 (6)	10 (4)	57 (14)	7 (4)	0	1,284 (365)
Indonesia	11 (3)	0	0	0	0	0	0	1	22 (12)	22 (1)	35 (14)	0	1	0	0	2	0	0	2	0	96 (32)
Southeast Asia	0	0	0	0	0	0	0	1	9 (5)	3	17 (7)	0	9 (1)	0	0	3 (2)	0	2	2	0	58 (20)
Korea	0	0	0	0	0	0	0	0	3 (3)	0	49 (15)	74 (8)	0	0	0	0	0	0	0	0	201 (29)
Nepal	9	0	0	1	1	0	0	0	7 (4)	1	10 (4)	0	2	0	0	1	2 (2)	0	0	0	34 (14)
Pakistan	1	0	0	0	0	0	0	2	6 (3)	0	12 (4)	0	0	0	0	1	0	0	2	0	24 (8)
Philippines	20	0	0	0	0	0	4	0	11 (2)	5 (1)	45 (13)	0	2	0	0	18 (2)	0	0	0	0	105 (18)
Sri Lanka	24 (3)	0	0	0	0	0	1 (1)	1 (1)	4 (3)	3 (1)	22 (4)	0	0	0	0	0	50 (5)	1	0	0	106 (18)
Taiwan	2	0	0	0	0	0	0	0	3 (2)	0	5	0	0	0	0	0	0	2	0	0	12 (2)
Thailand	12 (5)	0	0	0	0	0	0	0	12 (11)	2	7 (5)	0	0	0	0	1	0	1	11 (1)	0	46 (22)
Vietnam	11 (1)	0	0	0	0	0	0	3	34 (22)	3	63 (23)	0	1	0	0	1	0	0	0	2	118 (46)
Total	603 (132)	81 (22)	0	5 (5)	43 (20)	2	81 (6)	43 (13)	1,039 (423)	74 (22)	1,022 (462)	79 (8)	54 (17)	0	0	66 (22)	72 (17)	81 (19)	45 (14)	13 (11)	3,404 (000)

Note: Numbers in parentheses represent borrowings through the International Network for the Genetic Evaluation of Rice (INGER).

Table 1: Genetic Resource Diversity Collection and Utilization by Commodity

		Diversity (% in collection		Collections					Utilization
Commodity	**Area**	**Landrace (000)**	**Wild Species**	**In situ**	**Ex situ accessions (000)**	**% CGIAR**	**% Dup**	**% LR % WS**	**Distribution**
Bread wheat		(95)	24 (60)	few	24 784	16	50	17 2	
Durum wheat		150 (95)	24 (60)	few	7 20	14	32	53	high
Triticelo		(40)			5 40	38	66	- -	
Rice	149	140 (90)	20 (10)	few	20 420	26	75	25 1	high
Maize	130	65 (90)	(15)	few	22 277	5	80	16 0	high in LDCA
Sorghum	43	45 (80)	20 (0)	few	19 169	21	42	18 0	low
Millets	38	30 (80)	(10)	none	18 90	21		33 2	low
Barley		30			16 484	5	23	9 1	
Oats					20 222	0		1 4	
Rye					8 287	0		8 0	
Food Legumes									
Beans		(50)	(70)	few	15 268	15	76	21 1	low-medium
Soybeans	66	30 (60)		none	23 174	0	?	2 1	low-medium
Chick pea			(75)		13 67	41	75	29 1	
Lentil			(95)		5 26	30	95	30 3	
Fava beans			(25)		10 29	33	35	42 0	

Commodity	Area	Landraces (000)	Wild Species	In situ	Ex situ Accession (000)	% CGIAR	% Dup	%LR %WS	Distribution
Pea			(0)		18 72	0	-	4 0	
Groundnut		15	(28)		16 81	18	28	15 1	
Cowpea			(30)		12 86	19	30	19 2	
Pigeon pea			(22)		4 25	52	22	50 2	
Lupin					10 28	0	-	12 16	
Root Crops									
Potato	19	30 (95)	(30)	few	16 31	20	100	13 5	high
Sweet potato	10	5 (50)		few	7 32	21	93	16 6	medium
Cassava	16	(35)	29		5 28	30	90	23 2	low-medium
Yam		3			2 12	25	20	24 0	
Sugarcane		20 (70)							

Table 3: Bio-diversity in Livestock and Poultry

	Breeds by Region (at Risk) [Extinct]						Breeders Global Total		
Mammalian Species	**Africa**	**Asia/Pacific**	**Europe**	**Latin America**	**Near East**	**North America**	**Number**	**At Risk**	**Now Extinct**
Buffalo	2 (9)	57 (1)	2 (0)	4 (1)	7 (0)	- -	72 (150)	2	
Cattle	120 (9) [17]	190 (12) [10]	305 (94) [37]	62 (13) [17}	62 (1) [2]	48 (6) [1]	787 (1260)	135 30	84
Yak	- -	6 (0)	- -				6	0	
Goat	34 (1)	126 (6) [1]	113 (33) [8]	13 (10)	55 (1) [1]	10 (3) [1]	351 (600)	44	11
Sheep	73 (3) [4]	226 (15) [6]	226 (15) [31]	23 (2)	129 0 [11]	47 (17) [3]	920 (1100)	119 72	55
Pig	13 (0)	157 (15) [11]	129 (40) [22]	24 (8) [1]	2 (1)	28 (5) [10]	353 (680)	69 30	44
Ass	6 (0) [1]	17 (1)	16 (7)	5 (0)	28 (0) [1]	5 (1)	77 (44)	9	2
Horse	31 (1) [4]	72 (17) [4]	185 (85) [20]	24 (3)	31 (5)	41 (9) [5]	384 (60)	120	33
Dromedary	12 (1)	9 (0)	- -	- -	29 (1)	- -	50 (21)	4	
Bactrian Camel	- -	5 (1)	- -	- -	2 (6)	- -	7 (3)	2	
Alpaca	- -	- -	- -	4 (0)	- -	- -	4	0	
Llama	- -	- -	- -	3 (0)	- -	- -	3	0	
Guanaeo	- -	- -	- -	2 (0)	- -	- -	2	0	
Vicuha	- -	- -	- -	3 (0)	- -	- -	3	0	
Total Mammalian	291 (15) [26]	865 (68) [32]	1172 (341) [118]	167 (27) [18]	345 (9) [5]	179 (41) [20]	3019	501	229

Avian Species	**Africa**	**Asia/Pacific**	**Europe**	**Latin America**	**Near East**	**North America**	**Number**	**At Risk**	**Now Extinct**
Chicken	57 (1)	72 (26 [4]	406 (236) [20]	35 (1)	26 (6)	10 (4)	606 (12000)	274	24
Dom. Duck	9 (6)	15 (1)	32 (25) [1]	4 (1)	1 (6)	- -	62 (680)	29	(1)
Turkey	6 (2)	5 (1)	14 (7)	4 (10)	1 (0)	1 (1)	31 (250)	11	
Muscavy Duck	1 (1)	8 (4)	21 (0)	2 (0)	1 (0)	- -	14	5	
Dom. Goose	5 (2)	8 (2)	40 (23)	5 (0)	- -	1 (1)	59 (500)	28	
Guinea fowl	16 (4)	1 (0)	1 (0)	2 (0)	2 (0)		22	4	
Partridge	2 (6)	7 (0)	2 (0)	1 (0)	- -	- -	11	0	
Pheasant	- -	7 (0)	2 (0)	- -	- -	- -	8	0	
Quail	- -	3 (0)	8 (4)	- -	- -	13 (12)	24	16	
Pigeon	5 (0)	5 (0)	6 (2)	- -	2 (6)	- -	19	4	
Ostrich	4 (2)	1 (1)	2 (1)	- -	- -	- -	7	3	
Total Avian	105 (12)	131 (37)	516 (297)	53 (2)	33 (6)	25 (18)	863	372	25