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Returns to wheat breeding research in Nepal

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Abstract

Returns to investment in wheat breeding research in Nepal were estimated for two periods: (1) the Green Revolution period (1960–1990), when modern semidwarf wheat varieties first appeared and spread throughout the country, and (2) the post-Green Revolution period (after 1990), when first-generation modern varieties will be replaced by newer materials. Major benefits of the Nepalese wheat breeding program have included maintenance of disease resistance and faster dissemination of exotic germplasm. Attractive rates of return to investment in wheat breeding have been due in part to Nepal's ability to capture spillover benefits from neighboring countries and from international agricultural research centers.

1. Introduction

During the late 1960s and early 1970s, high-yielding semidwarf wheats developed in Mexico (referred to here as modern varieties, or MVs) were introduced into a number of the world's most populous developing countries. When grown with increased levels of fertilizer and an assured water supply, MVs performed significantly better than older materials, making possible dramatic increases in wheat production and higher incomes for the millions of farmers who adopted the technology.

The highly visible production increases associated with the introduction of MVs for many years ensured a steady flow of resources to national wheat breeding programs. This situation changed beginning in the late 1980s, when a combination of economic and political factors reduced the availability of funding for agricultural research. As budgets ceased expanding in real terms, research administrators in many countries were forced to pay greater attention to the efficiency with which resources were being used. Research priority-setting procedures were often amended by the introduction of requirements that proposed research projects be subjected to formal economic analysis, with the goal of generating quantitative profitability measures to facilitate selection among alternative investment opportunities.

One country in which there is a need carefully to assess the returns to wheat breeding research is Nepal. Even though agriculture represents the predominant sector in Nepal's economy, the overall level of public-sector support to agricul-

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tural research remains relatively low, averaging only 0.08% of agricultural GDP during the past two decades, as compared to 0.41% for a group of 92 developing countries (Pardey, Roseboom and Anderson, 1991). Because Nepal's limited research resources are used to support a wide range of research activities, there is a need to ensure that funds invested in the National Wheat Research Program (NWRP) generate attractive returns compared to alternative investment opportunities.

This paper reports the results of a recent study carried out to estimate the returns to wheat breeding research in Nepal. The study had two main objectives: (1) to estimate the returns to past investment in wheat breeding in Nepal, and (2) to estimate the likely future returns to wheat breeding in Nepal under a range of plausible assumptions about key technical and economic parameters. The primary goal of the study was to generate information for use by Nepalese policy makers and donors in deciding an appropriate level of future funding for the national wheat breeding program.

2. Estimating returns to agricultural research: Conceptual issues

The rate of return to investment in agricultural research is frequently estimated using the economic surplus approach, which posits that an outward (downward) shift in the supply function attributable to technological change leads to an increase in the economic surplus accruing to producers and/or consumers. [1] Although early work using the economic surplus approach was based on simplistic assumptions about the supply and demand functions, over time the procedures used have been refined substantially. [2] Subsequent extensions of the conceptual framework have made clear that the size and distribution among producers and consumers of the increase in economic surplus depends upon the shapes of the supply and demand curves, as well as the nature of the supply curve shift – parallel, pivotal, or convergent – resulting from technological change (Voon and Edwards, 1991). Government price policies have also been shown to be important in determining the distribution of research benefits (Alston, Freebairn and Edwards, 1988; Renkow, 1993).

3. Application to a plant breeding program

Following Brennan (1992) and Byerlee (1990), the economic surplus approach can be adapted to a plant breeding program. First, the benefits of the breeding program are estimated as follows:

$$B_t = gY_tA_tW_t \tag{1}$$

where B represents benefits from the breeding program, g is percentage yield gain per period attributable to the breeding program, Y yield, A area affected by the breeding program, W price of the commodity, and t period.

Next, the internal rate of return to the research investment is calculated as the value which drives the discounted stream of costs and benefits to 0:

$$\sum\left[(B_t - C_t)/(1 + \text{IRR})^t\right] = 0 \tag{2}$$

where IRR represents the internal rate of return, B benefits from the breeding program, and C cost of the breeding program.

This simplified approach, which uses the change in the value of production attributable to research as an approximation of the change in economic surplus, has two underlying restrictive assumptions. First, it implicitly assumes a perfectly elastic demand function, since research-induced shifts in the supply function do not result in endogenous price changes. For a tradable commodity in an open economy (such as wheat in Nepal), this is a reasonable assumption. Second, it implicitly assumes a perfectly inelastic supply function, so that an outward (implicitly parallel) shift in the supply function is directly translated

[1] For useful reviews of the literature on evaluating returns to investment in agricultural research, see Schuh and Tollini (1978), Scobie (1978) and Norton and Davis (1981).

[2] Progressive refinements of the basic method appear in Griliches (1957, 1958), Peterson (1967), Schmitz and Seckler (1970), Fishel (1971), Akino and Hayami (1975) Hayami and Herdt (1977) Lindner and Jarrett (1968) Rose (1980) Wise and Fell (1980) and Norton and Davis (1981).

into a proportional increase in the value of production. While this second assumption may be overly simplistic in some cases, it probably does not greatly distort the estimated benefits of wheat breeding research in Nepal, where the supply function for wheat is fairly inelastic because Nepal's intensive cropping systems limit farmers' ability to adjust wheat production in response to changing price incentives. [3]

Most previous applications of the economic surplus approach to wheat breeding have estimated research benefits as the product of the yield gains attributable to adoption of MVs times the area over which adoption takes place (for example, see Norton et al., 1981; Nagy, 1983; Byerlee, 1990). [4] However, in the case of the Nepal, this conventional approach is inappropriate. To understand why this is so, it is useful briefly to review the history of wheat in Nepal.

4. History of wheat in Nepal: a Green Revolution in three stages

Official statistics on wheat area, yield, and production in Nepal extend back only to 1967/68 (Table 1). However, despite the lack of a more extensive data series, testimony from Nepalese scientists who have been active in wheat research since the early 1950s suggests that the history of wheat in Nepal can be divided into three stages:

Pre-Green Revolution period (before 1965).
Up until the mid-1960s, wheat was a minor crop in Nepal grown primarily to provide grain for home consumption and straw for animal feed. Most of the varieties used were tall-statured Indian varieties, along with local land races. Area planted to wheat fluctuated around 100000 ha per year, and yields were low, averaging under 1 t/ha.

Table 1
Trends in wheat area, yield, and production in Nepal, 1967/68–1989/90

	1967/68	1989/90	Annual % growth
Wheat area (1000 ha)			
Mid-hills	71.4	244.1	5.75
Terai	94.7	320.2	5.69
Wheat yield (t/ha)			
Mid-hills	1.24	1.25	0.03
Terai	0.87	1.56	2.69
Wheat production (1000 t)			
Mid-hills	88.5	305.1	5.79
Terai	82.4	499.5	8.53

Source: Nepal Ministry of Agriculture.

Green Revolution period (1965 to 1990).
Nepal's wheat sector changed dramatically beginning in the mid-1960s with the introduction of semidwarf MVs. [5] These early-maturing materials, which could be harvested in 115–120 days as compared to the 125–135 days required by the older, tall-statured varieties, enabled Nepalese farmers to switch from the traditional rice-fallow rotation to an intensive production system in which rice and wheat were double-cropped within the same year. As a result, wheat area began to increase rapidly, rising to 600000 ha by 1990.

Three MVs in particular are associated with Nepal's Green Revolution in wheat. Lerma Rojo 64, the first MV grown on a large scale, was introduced from Mexico in the mid-1960s and soon spread to occupy over 70% of total wheat area. Beginning in the late 1960s, Lerma Rojo 64 was replaced by another early-maturing semidwarf, RR21, which had been selected by Indian wheat breeders from a Mexican cross. By the late

[3] Estimation of the price elasticity of supply for wheat in Nepal is made difficult by the lack of reliable time series data for wheat production and farm-level prices.

[4] Depending on the approach, the yield gain may be modeled either as a one-off yield gain associated with adoption of a specific MV, or as an average annual yield gain achieved over time as the result of periodic replacement of older varieties by newer varieties.

[5] Strictly speaking, some of the wheat varieties grown in Nepal prior to the mid-1960s were also 'modern varieties' in the sense that they were improved products of the Indian and Mexican breeding programs. However, these older MVs can be distinguished from the semidwarf MVs introduced beginning in the mid-1960s, which enabled a sharp break in the historical rate of productivity growth.

1970s, RR21 had become susceptible to foliar diseases, and farmers began to replace it with UP262, a more resistant MV developed by Indian breeders from Mexican parents.

Post-Green Revolution period (after 1990).

The years from 1990 onward are expected to become the post-Green Revolution period in Nepal, when first-generation MVs will be replaced by newer MVs with increased yield potential and superior disease resistance. Area expansion is expected to level off during this period, so the main benefit of the wheat breeding effort will consist of improved genetic potential.

5. Selection of an appropriate period for analysis

Two periods were selected for analysis: (1) the Green Revolution period (1960–1990), corresponding to the years when MVs first appeared and spread rapidly throughout the country's major wheat-growing zones, and (2) the post-Green Revolution period (1990–2020), when the original MVs will be replaced by second-and third-generation MVs. While the economic surplus framework was used to analyze both periods, it is important to note an important distinction: returns to wheat breeding during the Green Revolution period were estimated ex post (so that most technical and economic parameters could be estimated from historical data), whereas returns to wheat breeding during the post-Green Revolution period were estimated ex ante (so that technical and economic parameters had to be predicted).

6. Returns to wheat breeding during the Green Revolution period

Calculating the returns to wheat breeding in Nepal during the Green Revolution period is complicated by two factors. First, at the time of their release, the early MVs did not always significantly outyield the varieties which farmers were already growing. Although Lerma Rojo 64 outyielded the older, tall-statured materials which it replaced, when they were first released RR21 and UP262 did not significantly outyield Lerma Rojo 64. [6] Despite the lack of a clear initial yield advantage, RR21 and UP262 were rapidly adopted by farmers because of other desirable characteristics – early maturity, bold grain type, and white grain color in the case of RR21, and disease resistance in the case of UP262. Only later when older materials became susceptible to foliar diseases and suffered declines in genetic potential did yield differences emerge, most noticeably between UP262 and RR21. Second, the MVs which revolutionized wheat production in Nepal probably would have been adopted eventually even had there been no national wheat program. Because Nepal's principal wheat-growing area is contiguous with a climatically similar wheat-growing belt in India, and because many Nepalese farmers have frequent contacts with Indian farmers (often they are related), wheat seed regularly crosses the border. Thus, even if the NWRP had not been active in evaluating, releasing, and promoting Mexican and Indian materials, many of these materials probably would have entered Nepal anyway through farmer-to-farmer seed exchanges.

Because of these unusual features of the Green Revolution in Nepal, it was necessary to devise unconventional methods for estimating two key parameters required by the economic surplus approach: yield gains attributable to wheat breeding, and area affected by wheat research.

Yield gains attributable to wheat breeding

Since at the time of their release the MVs associated with the Green Revolution in Nepal did not always significantly outyield farmers' current varieties, genetic gains due to breeding cannot be calculated using the conventional 'vintage model' approach, which assumes that newly released MVs outyield the older materials they are designed to replace. Instead, genetic gains realized as a result of MV adoption must be esti-

[6] For evidence on the relative performance of these early MVs at the time of their introduction, see Basnyat (1967) and CIMMYT (1970, 1971, 1972).

mated as *yield losses foregone*, under the assumption that yields in farmers' fields would have declined as a result of increasing disease pressure had the older susceptible varieties not been replaced. [7]

The yield losses foregone in Nepal because of varietal replacement (specifically, replacement of RR21 by UP262; Lerma Rojo 64 was dropped from NWRP varietal trials in the late 1960s because it had largely disappeared from farmers' fields) were estimated using 15 years of trial data from six agricultural research stations. [8] The following function was estimated using OLS regression techniques:

$$\ln Y_{ijt} = a + bT_t + dD_i + gD_iT_t + \sum m_jS_j + u \quad (3)$$

where Y represents yield of variety i (RR21 or UP262), T time trend, D intercept-shifting dummy variable on variety UP262, DT slope-shifting dummy variable on variety UP262, S dummy variables for sites j, and u error term.

The following results were obtained (standard errors in parentheses):

$$\ln (Y_{it}) = \underset{(0.094)^{a}}{8.48} - \underset{(0.008)^{a}}{0.068T_t} - \underset{(0.116)}{0.169D_i} + \underset{(0.011)^{b}}{0.025D_iT_t}$$

$$- \underset{(0.080)^{c}}{0.02S_1} - \underset{(0.087)^{c}}{0.16S_2} - \underset{(0.080)^{c}}{0.01S_3} + \underset{(0.081)^{c}}{0.05S_4} + \underset{(0.080)^{c}}{0.11\,S_5}$$

$n = 444$ $R^2 = 0.48$ $F = 16.92$

[a] Significant at level 0.01.
[b] Significant at level 0.05.
[c] F ratio for group of S_j dummy variables significant at level 0.01.

These results are noteworthy in several respects. First, the coefficient on the time trend (T) is negative and highly significant, indicating that over the past 15 years, yields of RR21 declined at an average annual rate of 6.8% (Fig. 1). This striking rate of decline appears to be due to increasing leaf rust and *Helminthosporium* leaf blight susceptibility, as well as crop and resource management problems on the research farms where the trials were conducted. [9] Second, the coefficient on the intercept-shifting dummy variable (D) is not significantly different from zero. This confirms that at the time of its introduction, UP262 offered no significant yield advantage compared to RR21. Third, the coefficient on the slope-shifting multiplicative dummy variable (DT) is positive and significant, indicating that over the past 15 years yields of UP262 have declined approximately 2.5% per year more slowly than yields of RR21. Since the two varieties received identical management in the experiment-station trials from which the yield data were drawn, the only explanation for the faster rate of yield decline of RR21 is its higher level of susceptibility to foliar pathogens.

Area affected by wheat research

Under the economic surplus approach, the area affected by a plant breeding program can be measured either indirectly (in the form of a shift in the supply curve, which implicitly reflects changes in area planted) or directly (by estimating the rate of adoption of MVs and applying this rate of adoption to the area planted to the crop). A direct approach was used in this study. However, use of the conventional method would have understated the impact of the Green Revolution in Nepal, where the introduction of early-maturing MVs in and of itself spurred a significant expansion in wheat area which would not other-

[7] The idea that MVs offer increased protection against diseases runs contrary to the conventional wisdom, which suggests that traditional wheat varieties provided superior resistance (for example, see Shiva, 1991; Conway and Barbier, 1990; Berg et al., 1991; Hobbelink, 1991). In fact, prior to the Green Revolution losses to diseases were often substantial in many major wheat-growing areas of South Asia (Byerlee, 1994). The MVs associated with Nepal's Green Revolution in wheat greatly reduced the risk of disease losses by incorporating resistance genes identified over the course of more than 20 years of research in Mexico and elsewhere.

[8] Use of farm-level yield data would have been preferable, but unfortunately such data were not available over an extended period. Use of experiment-station data is justified by the fact that varietal trials in Nepal are conducted using levels of key inputs (e.g., fertilizer and irrigation) similar to those used by farmers.

[9] Nepalese wheat scientists, extension agents, and farmers report that a similar declining yield trend has also been observed in farmers' fields. However, this effect is masked in national average yield data because farmers, unlike researchers, have been applying increasing amounts of fertilizer and other inputs to compensate for declining genetic potential.

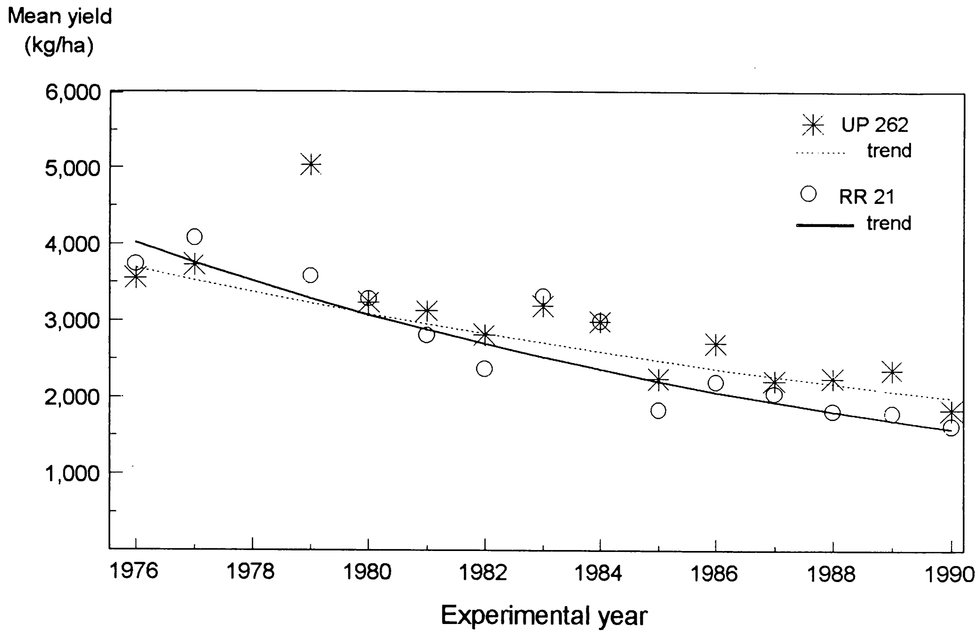

Fig. 1. Mean yields of RR21 and UP262 in six sites in Nepal, 1976–90.

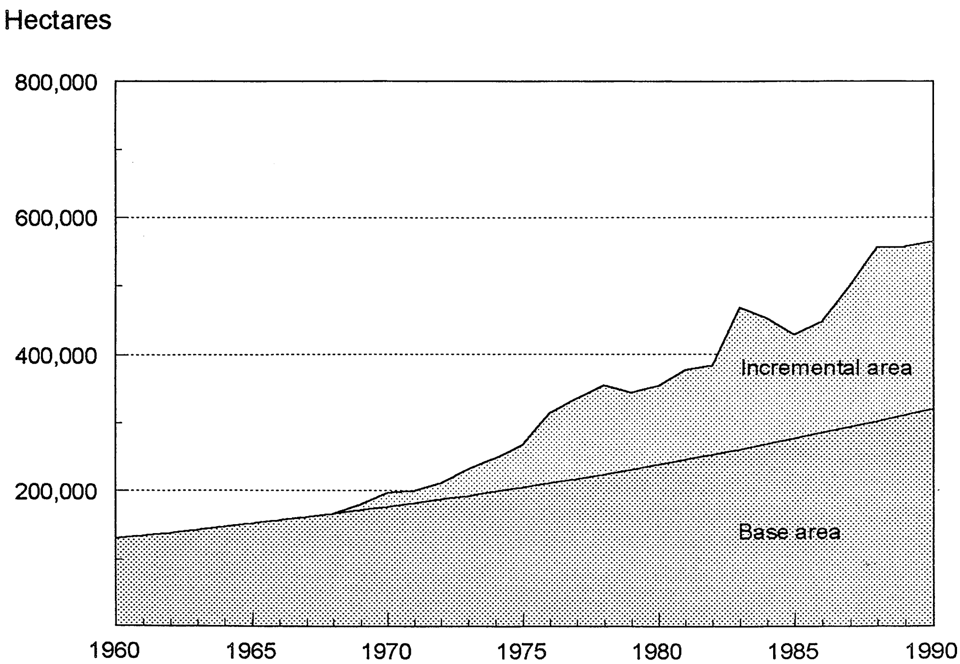

Fig. 2. Expansion in wheat area in Nepal following introduction of modern varieties (MVs).

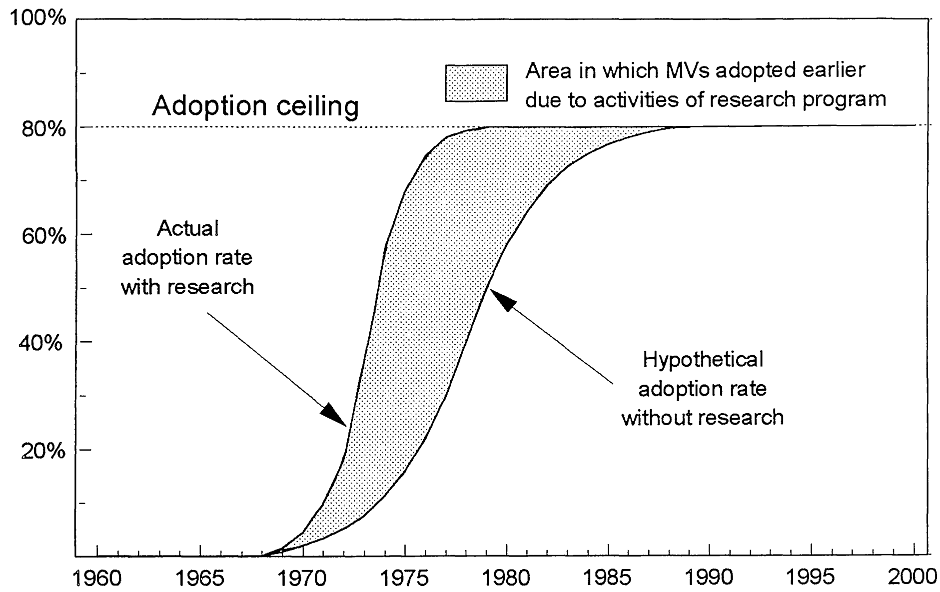

Fig. 3. Acceleration in the rate of MV adoption attributable to wheat research.

wise have occurred. Therefore, Nepal's wheat area was disaggregated into two components: a 'base area' which probably would have been planted to wheat even if early-maturing MVs had not been introduced (estimated by applying a 3% annual long-term growth rate to the area planted to wheat prior to 1968, the year in which wheat area began to expand rapidly), and an 'incremental area' which was planted to wheat only because of the appearance of MVs (Fig. 2).

Different methods were used to estimate the benefits of breeding research in each of the two areas. Since the incremental area by definition was not planted to wheat prior to the appearance of MVs, the benefits to wheat breeding over the incremental area could not be estimated in the same way as for the base area (i.e., based on the difference between the yield of old varieties and MVs). Because the appearance of MVs made wheat production possible on land which previously had been left fallow, a different measure of value-added was needed to estimate the benefits. Thus, the benefits on the incremental area were estimated as the net returns per hectare of wheat production (defined as gross returns minus fixed and variable costs). No opportunity cost was deducted from the net returns figure to compensate for the displacement of competing crops, since farmers expanded wheat area by using land previously left fallow. [10]

Insufficient data were available to allow separate calculation of net returns to wheat production in every year throughout the period of analysis (1960–1990), so it was necessary to make the simplifying assumption that net returns have remained constant in real terms over the past three decades. [11] Net returns per hectare of wheat production were estimated for 1982–83 based on crop budgets published by the Nepal Ministry of Agriculture and projected back over the life of the research program. Expressed in 1990 Rupees, net returns averaged Rs 2000/ha for improved,

[10] Although it probably would have been desirable to adjust the net returns figure to account for long-term costs possibly associated with the intensification of the cropping system (e.g., accelerated rate of soil fertility decline, increased pressure on ground water resources), this was not done, since it was not known how to quantify such costs.

[11] It is important to note that this is not the same as assuming that the price of wheat remained constant throughout the period – which it did not.

partially irrigated wheat in the Mid-hills and Rs 2500/ha for improved irrigated wheat in the Terai). [12]

Benefits over the base area were estimated using the conventional method of multiplying the genetic gains attributable to MVs (in this case, the yield losses foregone) times the area planted to MVs. [13] However, as pointed out earlier, even had there been no national wheat program in Nepal, MV adoption probably would have occurred anyway as the result of farmer-to-farmer seed exchanges along the India-Nepal border. Since the real impact of the NWRP was to accelerate the rate of adoption, the area affected by the Nepalese wheat breeding program was modeled as the difference between the actual historical MV adoption pattern and the hypothetical adoption pattern which likely would have prevailed in the absence of the NWRP (Fig. 3). Parameters of the actual historical adoption pattern (modeled as a logistic curve) were estimated based on information provided by knowledgeable Nepalese wheat scientists about the spread of MVs, supplemented by data from producer surveys carried out during the past three decades. [14] Parameters of the hypothetical 'without research' adoption pattern were estimated based on the rate of adoption of Indian varieties which were never released in Nepal but which came in over the border. Separate adoption curves were estimated under both 'with research' and 'without research' scenarios for the two main wheat-growing zones, Terai and Mid-hills, with adoption taking longer in the Mid-hills due to the lack of transportation and communication infrastructure. Ceiling adoption levels were conservatively assumed to be 80% for both zones, even though recent surveys suggest that the adoption of MVs in the Terai is now approaching 100% (Harrington et al., 1992).

Other parameters used in the ex post analysis

Average annual wheat prices at the farm level, adjusted for inflation, were used in valuing the research benefits (both the extra production attributable to accelerated adoption of MVs over the base area, as well as the production from the incremental area).

Three categories of research expenditures were included on the cost side: (1) the NWRP budget, (2) the budgets of the eleven research farms where wheat research takes place, and (3) wheat research costs of scientists working in the disciplinary divisions in the Ministry of Agriculture. The three categories were disaggregated into breeding and breeding support costs, seed production costs, and other research costs (e.g., crop management research costs).

Based on estimates made by NWRP breeders about the length of time involved in screening, selecting, testing, and releasing a new wheat variety, a research lag of eight years was assumed, meaning that eight years of research costs were incurred prior to the release of the first MV.

Using the parameters summarized in Table 2, the IRR to wheat breeding in Nepal during the Green Revolution period (1960–1990) was estimated as 84%. This figure includes returns to wheat breeding and breeding support activities, as well as to seed production activities carried out

Table 2
Parameters used in the ex-post rate of return calculations

Parameter	Mid-hills	Terai
Yield losses foregone due to research (% per year)	2.5	2.5
Pattern of adoption of modern varieties		
(a) with wheat research:		
– time to full adoption (years)	15	10
– adoption ceiling (% of wheat area)	80	80
(b) without wheat research:		
– time to full adoption (years)	25	20
– adoption ceiling (% of wheat area)	80	80
Wheat area growth without research (% per year)	3.0	3.0
Research lag (years)	8	8

[12] For information on the procedures used to calculate measures of net income, see Nepal Ministry of Agriculture (1991).

[13] Since genetic gains were expressed as a percentage of average yield, in absolute terms the yield gains associated with MV adoption were estimated to be larger in the Terai than in the Mid-hills.

[14] For details, see Morris, Dubin and Pokhrel (1992).

Table 3
Summary of returns to investment in wheat research, selected studies

Study	Year	Country	Period	Rate of return (%)
Ardito-Barletta	1971	Mexico	1943–63	90
Eddleman	1977	USA	1978–85	46
Hertford et al.	1977	Colombia	1927–76	11–12
Kislev and Hoffman	1978	Israel	1954–73	125–150
Pray	1980	Bangladesh	1961–77	30–35
Sundquist et al.	1981	USA	1977	97
Yrarrazaval et al.	1982	Chile	1949–77	21–28
Zentner	1982	Canada	1946–79	30–39
Nagy	1983	Pakistan	1967–81	58
Ambrosi and Cruz	1984	Brazil	1974–90	59–74
Furtan and Ulrich	1985	Canada	1950–83	29
Norton et al.	1987	Peru	1981–2000	18–36
Evenson and da Cruz	1989	Brazil	1979–88	110
Byerlee	1990	Pakistan	1978–87	16–27

Source: Echeverria.

on agricultural research stations by staff of the wheat breeding program. This estimated IRR, while high by conventional investment criteria, falls within the range of IRRS reported in other recent studies of the of returns to investment in wheat research (Table 3).

7. Returns to wheat breeding during the post-Green Revolution period

As Nepal enters into the post-Green Revolution period, Nepalese policy makers must decide an appropriate level of funding for future wheat research. Although past investment in wheat research in Nepal has generated attractive rates of return, several of the key parameters which contributed to large benefits in the past can be expected to change. In particular, the rapid expansion in area planted to wheat resulting from the introduction of early maturing varieties can be expected to slow as remaining arable land is brought under cultivation. In addition, as average wheat yields continue to rise, future rates of yield gain can be expected to decelerate.

Unlike ex post analysis, which is based on historical events, ex ante analysis requires making predictions about the future. Given the uncertainty inherent in predicting what is going to happen in farmers' fields, returns to investment in wheat research in Nepal during the post-Green Revolution period were estimated under a set of extremely conservative baseline assumptions concerning likely future yield gains, varietal adoption rates, and increases in wheat area. These assumptions were then systematically relaxed, and sensitivity analysis was carried out to determine how the returns respond to changes in the parameters. Key parameters used in the baseline ex ante analysis are described below.

Area affected by wheat research

As Nepal enters the post-Green Revolution period and opportunities for further intensification are exhausted, expansion in wheat area can be expected to slow. In the baseline scenario, future wheat area was assumed to remain constant at current levels of 250 000 ha in the Midhills and 350 000 ha in the Terai. The latter assumption in particular is very conservative, since currently only about one-third of the rice area in the Terai is rotated with wheat. As infrastructure improves (especially irrigation), wheat area in the Terai will likely increase substantially. Under the conservative assumption that no further expansion in area will occur, the area affected by wheat research will be the area planted to MVs sooner than would have occurred in the absence of a Nepalese wheat research program. This area was calculated as the difference between the same 'with research' and 'without research' adoption curves used in the ex post analysis.

Expected future growth in wheat yields

Although past yield gains attributable to adoption of MVs were estimated as 2.5% per year, there is no reason to assume that a similar rate will necessarily be achieved during the post-Green Revolution period. Therefore, instead of simply extrapolating past genetic gains into the future, potential future yield gains were estimated based on the performance of germplasm which is currently in the pipeline – MVs which have been tested, selected, and released for distribution to farmers, but which have not yet been widely adopted.

The potential rate of future yield gains was estimated through use of a vintage model using data from varietal trials carried out at six research stations in the Terai during 1978–1990. Eight varieties representing six vintages were included, representing the currently dominant variety (UP262), as well as all subsequent releases for which trial data are available. [15] Because the data set was unbalanced, the residual maximum likelihood (REML) estimation method was chosen in order to improve the precision of the estimates. [16,17] The vintage model was specified as follows:

$$Y_{ijt} = m + v_i + y_t + (s/y)_j + u \qquad (4)$$

where Y_{ijt} is yield of variety i in site j in trial year t, m grand mean, v_i fixed effect for variety i, y_t fixed effect for trial year t, $(s/y)_j$ random effect for site j, and u random error term.

Predicted mean varietal yields were then regressed against year of release (vintage) using a log-linear formulation to estimate the average annual rate of yield gains in varieties released since 1978 (Fig. 4). This rate was estimated as $g = 1.25\%$, which may be interpreted as the potential future rate of yield gains. In the baseline scenario, future wheat yields were projected from current levels of 1.25 t/ha in the Mid-hills and 1.6 t/ha in the Terai using this annual rate of increase. In the sensitivity analysis, several alternative future rates of yield increases (both higher and lower) were considered.

Other parameters used in the ex ante analysis

In the baseline scenario, the future real price of wheat was assumed to remain constant at current levels of 5000 Rs/t. The marketing margin was also assumed to remain constant at current levels of 25% of the consumer prices. In the sensitivity analysis, changes in both the retail price and the marketing margin were considered.

In the baseline scenario, future investment in wheat breeding research was assumed to remain constant in real terms at current levels of 1.2 million Rupees. It was assumed that Nepalese wheat scientists spend an average of eight years screening and selecting imported materials between the release of each successful variety. In other words, eight years of research costs are incurred before the realization of benefits through adoption. In the sensitivity analysis, changes in the length of the research lag were considered.

Using the parameters summarized in Table 4, the IRR to future investment in wheat research in Nepal was estimated as 49%. [18] This figure includes returns to wheat breeding and breeding support activities, as well as seed production activities carried out on the research stations by staff of the wheat breeding program. This projected IRR is lower than the past rate of returns for two reasons. First, the dramatic expansion in wheat area attributed to the introduction of MVs during the Green Revolution period is projected to slow. Second, future rates of yield gain attributable to the replacement of older MVs by newer MVs is expected to be more modest than in the past.

Sensitivity analysis

In order to assess the robustness of the projected rates of return, the values of many of the key parameters used in estimating the baseline

[15] The number of varieties is greater than the number of vintages because in several years more than one variety was released.

[16] This frequently-encountered problem results from the way varietal yield trials are carried out: promising new varieties are periodically added to a trial, retained for some variable length of time, and eventually dropped when they no longer perform as well as later introductions. Although one or two check varieties may be retained throughout the duration of a trial, observations for most of the varieties will be available only for a limited number of years, resulting in an unbalanced data set unsuitable for OLS estimation procedures.

[17] The vintage model was estimated using the Residual Maximum Likelihood (REML) software package developed by the Scottish Agricultural Statistics Service at the University of Edinburgh.

[18] Research costs and benefits were projected for the period 1990–2020. Beyond 30 years into the future, the present value of costs and benefits becomes negligible due to the effects of discounting.

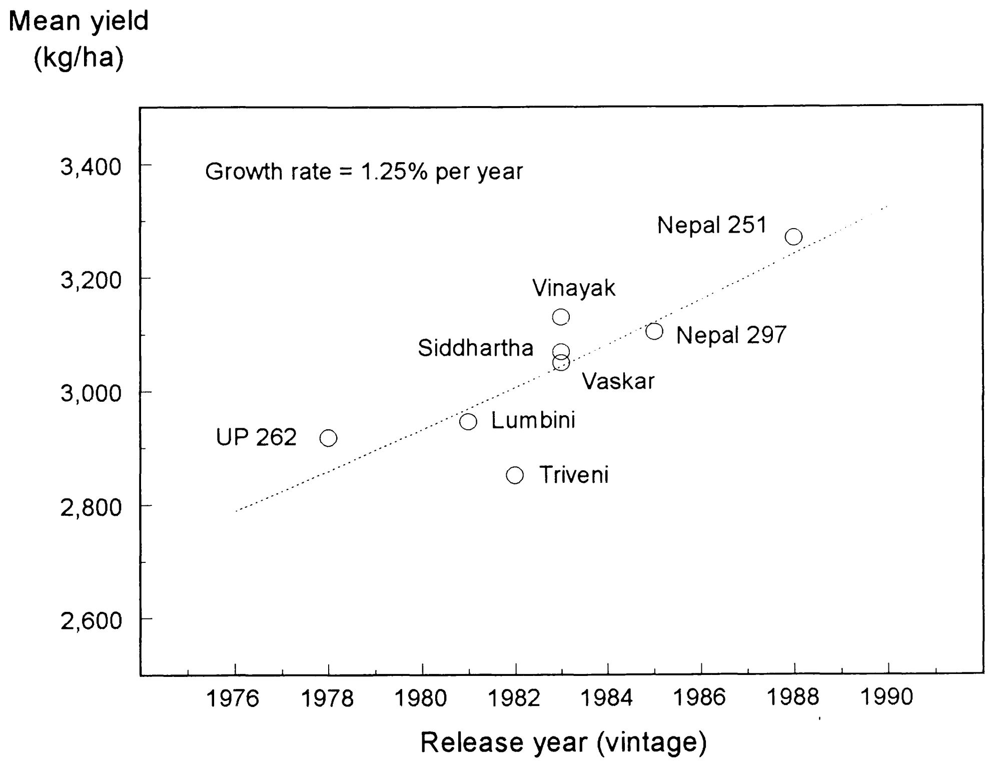

Fig. 4. Genetic gains in wheat varieties released in Nepal, 1978–88.

scenario were systematically varied. The results of the sensitivity analysis (Table 5) suggest that future returns to investment in wheat breeding research will be much more sensitive to some parameters than to others. Relatively large changes in the projected price of wheat and in the size of the marketing margin will have modest effects on the projected IRR, indicating that returns to wheat breeding will not be highly sensitive to changes in the world price of wheat. Similarly, the projected IRR is relatively insensitive to changes in the projected rate of growth in wheat area, the projected rate of growth in wheat yields attributable to research, and to the projected adoption ceiling. On the other hand, the projected IRR is moderately sensitive to the research lag (i.e., the length of the period of research investment preceding the release of each successful variety).

Table 4
Parameters used in the ex-ante rate of return calculations

Parameter	Mid-hills	Terai
Wheat yield growth due to research (% per year)	1.25	1.25
Rate of adoption of modern varieties		
(a) with wheat research:		
– time to full adoption (years)	15	10
– adoption ceiling (% of wheat area)	80	80
(b) without wheat research:		
– time to full adoption (years)	25	20
– adoption ceiling (% of wheat area)	80	80
Wheat area growth (% per year)	0.0	0.0
Research lag to initiation of adoption (years)	8	8
Wheat producer:consumer price ratio	0.75	0.75
Wheat consumer price (Rs/t)	5000	5000
Wheat research investment (million Rs)	1.2	1.2

8. Discussion

Investment in wheat breeding in Nepal has generated an internal rate of return of about 84%

Table 5
Sensitivity of projected returns to wheat breeding research to changes in key parameters

Retail price of wheat (Rs/t)	IRR (%)	Producer : consumer wheat price ratio	IRR (%)
3000	43	0.55	45
4000	46	0.65	47
5000 [a]	49	0.75 [a]	49
6000	51	0.85	50
7000	53	0.95	52
Annual growth in wheat yields (%)	**IRR (%)**	**Annual growth in wheat area (%)**	**IRR (%)**
0.50	37	0.00 [a]	49
0.75	42	1.00	50
1.00	46	2.00	52
1.25 [a]	49	3.00	54
1.50	51	4.00	55
1.75	54	5.00	57
MV adoption ceiling (%)	**IRR (%)**	**Research lag (years)**	**IRR (%)**
0.60	45	12	40
0.70	47	10	44
0.80 [a]	49	8 [a]	49
0.90	50	6	54
1.00	51	4	58

[a] Value used for the baseline scenario.
Source: Calculated by the authors.

during the past three decades. This attractive rate of return is explained by the relatively modest cost of the Nepalese wheat research program in relation to the substantial benefits it generates. On the cost side, NWRP has been able to take advantage of close links with the Indian wheat research program and with CIMMYT in capturing substantial benefits in the form of exotic germplasm which is generally well adapted to production conditions in Nepal; by screening and selecting superior materials coming out of these programs, Nepalese wheat scientists have been able to release several highly successful varieties while managing to avoid a substantial portion of the expenses involved in their development. On the benefit side, two main factors can be identified as having contributed to the success of the Nepalese wheat research effort. The first generation of MVs released in Nepal, particularly RR21, fueled a dramatic increase in wheat area due to their early maturity, which made possible double-cropping of wheat and rice in areas where farmers had previously been restricted to one crop per year. Subsequently, the replacement of RR21 by UP262 and other newer varieties enabled farmers to avoid yield losses due to a breakdown in disease resistance. Experimental data suggest that failure to replace RR21 would have resulted in disease-related yield losses of 2.5% per year.

Although expansion in wheat area can be expected to slow in coming years, returns to wheat breeding research in Nepal will remain attractive under a wide range of plausible economic and technical parameters. Under a baseline scenario in which future investment in wheat breeding is assumed to remain constant (in real terms) at current levels, the IRR is projected to reach 49%. Significantly, expected future benefits from wheat research are based exclusively on the improved yield potential already present in recently-released materials, i.e., assuming no future benefits from disease resistance. To the extent that regular varietal replacement will enable farmers to continue to avoid yield losses due to the breakdown in disease resistance of older varieties (the main source of benefits in the past), future returns could be considerably higher.

These findings can be taken as a strong endorsement for continued investment in wheat breeding research in Nepal. Although future returns cannot be expected to attain the spectacular rates achieved in the past, they will remain extremely attractive by conventional investment criteria. However, the desirable balance between breeding and crop management research will probably change over time. While the benefits realized during the Green Revolution period resulted mainly from the adoption of improved germplasm, evidence of declining yields both at the farm level as well as on experiment stations suggests that crop and resource management problems will assume increasing importance in the future.

More generally, the results of this study indicate that it may be rational to establish plant breeding programs for commodities planted over limited areas if such breeding programs can assist farmers in capturing research spillovers emanating elsewhere (e.g., neighboring countries, international agricultural research centers, the private sector). Although supporting a fully-developed breeding program may not be warranted in cases where benefits are expected to be modest, maintaining the ability to speed the selection and dissemination of imported germplasm can be highly desirable on economic grounds (Brennan, 1992; Maredia, 1993). This conclusion would appear to be particularly relevant for smaller countries which are struggling to maintain fully developed breeding programs for major crops in the face of declining levels of funding for agricultural research, as well as for larger countries which must decide what to do about minor crops.

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