Are there Economies of Scale in Wheat Breeding?; Some Comparative Efficiency Measures of CIMMYT and NARS

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September, 1993

Draft note for CIMMYT internal use only.

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Introduction

The aim of this note is to make a general comparison of costs of wheat breeding and productivity measures in CIMMYT and NARS. This comparison is necessarily artificial since CIMMYT does not release varieties, but depends on NARS to evaluate and release varieties. Nonetheless, one of the findings of the impact study is that the proportion of varieties that are released from crosses made by CIMMYT has continued to increase steadily over time, in contrast to rice, where the trend has been away from directly lines from IRRI crosses (Figure 1). Also, studies of costs of wheat breeding programs have shown that about 85 percent of the costs of developing a wheat variety are incurred up to and including the F6 generation, the stage when NARSs take over the testing and evaluation of varieties (Brennan, 1988). Thus by defining varietal origins in terms of who makes the cross, we can in a general sense regard CIMMYT's wheat improvement program as a multinational program that targets megaenvironments, that are the aggregate of more specific environments spread over several developing countries. This note departs from the usual representation of CIMMYT and NARS as complements and disaggregates varietal releases in developing countries into those based on CIMMYT crosses (usually based on testing of advanced lines) and those based on NARS crosses. Using this necessarily crude delineation, we present data on the inputs and outputs of CIMMYT and NARS breeding programs, and compute some crude measures of input-output efficiency. For comparative purposes, we also present information for one industrialized country, Australia, for which relatively complete data are available.

Estimates of Inputs and Outputs of Wheat Research Programs

CIMMYT's Inputs and Outputs

CIMMYT's wheat program produces several types of products, ranging from conservation of genetic resources for human kind, to advanced lines, to crop management information and training. For the purposes of this note, we are interested in its crop improvement (CI) activities aimed at producing superior, relatively finished, genetic materials for release to farmers after evaluation by NARS. We ignore CIMMYT's role in producing intermediate products for use by NARS in their own crossing programs. From a survey of activities of all staff in CIMMYT made in 1991-92 to prepare the Medium Term Plan, we have a detailed breakdown of the time allocation of each senior scientist in terms of activities--genetic resources, crop improvement, crop protection, crop management, economic analysis, training, information, consulting and administration. Of the 30 senior scientists in the wheat program, we estimated that 19.5 full-time equivalent (FTE) staff were engaged

in CI activities, or 65 percent of the staff time.[1] To obtain an estimate of CIMMYT's expenditure on wheat CI, this number was multiplied by the average cost for CIMMYT per senior scientist in 1992 and an estimated overhead of 26 percent was added for services provided by biometry, biotechnology, economics and research administration. Using this procedure, we arrived at an estimate of expenditure on wheat CI of $8.3 million in 1992. This is a close approximation to the method used to calculate the budget of CI activities of NARS.

The above estimates of FTE scientists include only senior international staff. To make comparisons with NARS, we need to include all persons engaged in CI research that have at least a BS degree. To do this, we included associate scientists, post doctorals and *ingenieros*, assuming that, in aggregate, their time was allocated to CI in the same ratio as that for senior scientists. This gave a total of 36 FTE scientists engaged in wheat CI in CIMMYT at an average cost per scientist of $230,000, over double that in NARS.

These costs do not include the costs of NARS's testing and evaluation in later generations of CIMMYT materials. According to Brennan (1988), some 15 percent of the costs of developing a wheat variety are incurred after the F6 generation, the stage when NARSs generally take over the testing and evaluation of varieties. However, the proportion of resources devoted to testing is likely to be higher for an international breeding program, because of the wide dispersal of testing sites. On the other hand, the availability of elite parents from CIMMYT for use in NARS crossing programs, reduces the cost of NARS breeding, so we assumed that this effect offsets the cost of testing services provide by NARS.

Outputs of the CIMMYT wheat improvement program were considered at various levels:

- *The number of crosses made annually :* A rough estimate is that CIMMYT makes 12,000 crosses annually, although this number needs to be refined with better estimates for the Aleppo program.

- *The number of varieties released from those crosses :* In the period, 1986-90, an average of 34 varieties were released annually by developing country NARS based directly on CIMMYT crosses. Of course, many of these varieties were from the same cross and even the same selection history, but released in different countries. However, NARS also frequently release several varieties within a country from the same cross, and often from the same selection history, so this duplication does not presents a major bias in the comparisons.

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[1] We included all of the CI category, one half of the genetic resources category (the other half was assumed to be devoted to conserving resources for humankind), one half of the crop protection activities (in addition to time of crop protection scientists spent directly servicing crop improvement), the time of crop management and physiology devoted to CI, and a prorated share of wheat program administration.

- *The area covered by varieties from CIMMYT crosses:* Here we included only varieties released in the period, 1981-90, to reflect more recent experience and to be comparable with the time period for the cost estimate.

The above measures of CIMMYT outputs are an underestimate since they do not include varieties released from CIMMYT crosses in high income countries. These may add another 20 percent to the area covered by 'CIMMYT varieties' (see below for the case of Australia).

NARS inputs and outputs

The data for NARS costs were taken directly from the 1993 Wheat Facts and Trends. All data are expressed in $1990 Purchasing Power Parity which is considered a better measure of the real costs across countries. If we were to use official exchange rates, the costs of NARS would be about 27 percent less. However, even at the official exchange rate, the cost per scientist in NARS is high relative to scientists' salaries (about eight times), reflecting a relatively large number of technicians and laborers per scientist, and high overheads for administration.

The outputs of NARS's programs in terms of crosses and released varieties were also taken from the 1992 Wheat Facts and Trends Survey. However, in several large countries, the survey sub-sampled breeding programs, so that for country and global estimates, we had to scale up to the national level. This was done by assuming that the number of crosses and varieties released per FTE scientists for the sampled programs (a total of 66 programs) was representative of the population of all wheat breeding programs in developing countries. This probably gave an upward bias to the global totals since it is likely that we sampled the most active programs.[2]

Varieties released by NARS from their own crosses and the area covered by these varieties were computed based on the origin of varieties released in the period, 1981-90, defined in terms of where the cross was made. This information was available from the 1992 Impact Study.

Australian Wheat Research Inputs and Outputs

For comparative purposes, we include data from Australia, an advanced NARS for which we had comparable data on FTE scientists in wheat CI from Clements et al. (1992), cost per scientist from Pardey et al. (1991) and number of crosses and varieties released from Brennan (1986), Brennan (pers. com.) and B. Skovmand (pers. com.). Costs were

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[2] For varieties released, we had an alternative estimate at the country level from the 1990 Impact Study. This estimate corresponded quite well with the estimated total from the 1992 survey of a sample of wheat breeding programs, with the exception of Asia. However, in Asia, the Impact Study did not include most of China, nor did it include Indian varieties released only at the state level.

computed both at the average PPP cost per scientist for all researchers, (to be comparable with NARS estimates), and using actual CI expenditures from Clements et al. (1992).

It should also be noted that Australia has directly released varieties based on CIMMYT crosses. Although these 'CIMMYT varieties' were only 3 percent of all varieties released, they covered 16 percent of the wheat area in 1992. These 'CIMMYT varieties' were subtracted in computing Australian outputs, but were *not* added to the CIMMYT totals.

Descriptive statistics on inputs and outputs of CIMMYT and NARS

The results of these estimation procedures provided the summary data in Table 1. Excluding China for which data were not available on some variables and which was not targeted by CIMMYT until recently, CIMMYT expenditures on CI research account for about 9.7 percent of total wheat CI research in developing countries, compared to CIMMYT's share of FTE scientists of only 4.7 percent. However, our average cost per FTE (including all persons with a BS degree or above) is double that of developing countries, and 50 percent more than in high income countries. This reflects higher costs of fringe benefits as well as travel and support services.

On the 'output' side, CIMMYT accounts for about 25 percent of all crosses made by wheat breeding programs outside of China but these crosses provide almost 50 percent of the varieties released in developing countries.

Comparison of efficiency measures

Table 2 gives various measures of efficiency of resources invested in wheat breeding programs. All of these measures point to considerable cost savings for a global program such as CIMMYT.

- CIMMYT scientists make five times the number of crosses per FTE scientist as the average NARS scientist. These crosses result in ten times more varieties released annually per FTE. Even standardizing the number of varieties released per ten thousand crosses, the output is much higher from CIMMYT crosses (about 5 times). Australian wheat research programs tend to be somewhat more efficient by these measures than developing country NARS, but significantly higher costs than CIMMYT.

- In terms of costs, each cross costs $700 dollar in CIMMYT, much less than the comparable cost for crosses in NARS. The average cost per variety released from a CIMMYT cross is about $245,000 dollar, lower than the average cost of

$500,000-900,000 in Australia and much lower than the average cost of $ 2.6 million for each variety released from NARS own crosses.[3]

- The average area sown per 'variety' is lower for CIMMYT than for NARS. This is in part because many varieties from CIMMYT crosses are disproportionately released by countries with a small wheat area. Also NARS figures are dominated by the success of two varieties derived from Indian crosses.

- Probably the best measure of productivity, is the expenditure per ha of varieties sown by farmers (in this case, varieties released since 1981). For varieties from CIMMYT, these costs are about $0.50 per ha, while for NARS this cost is almost $5 per ha. Australian programs also have a relatively low cost per ha sown to its own varieties, although still above the CIMMYT cost.

- In all cases, these productivity measures indicate that programs in Asia, which are the largest programs are the most efficient, while programs in WANA and sub-Saharan Africa are the least efficient. In the case of Sub-Saharan Africa, the small size of the wheat area is the main factor leading to low efficiency, while in WANA, it is the low number of varieties released and the relatively small area per released variety that explains these differences.

Returns to CIMMYT and NARS research

An overall measure of efficiency of investment in research is the rate of return on research investments. Traxler and Byerlee (1993) have computed the rate of return on investment for spring wheat, using a similar partitioning as above of costs and benefits. They conclude that over the period, 1977-90, investment in CIMMYT provided an overall rate of return of 63 percent, and investment in NARS a return on 50 percent. These differences are less than the implied efficiency differentials presented above, for two reasons. First, at high rates of return, the IRR is very insensitive to large changes in benefits streams, and a difference of 13 percent in the IRR is in fact a significant difference. Second, the lags in the use of CIMMYT products are longer than for the NARS. In particular, it takes an average of five years from the time that CIMMYT has produced an advanced line at about the F10 stage, until it is released by NARS. Since the IRR is very sensitive to the time lag used between when research costs occur and when benefits begin, this long lag in using CIMMYT products reduces its overall IRR.

Concluding comments

These crude comparisons indicate that CIMMYT appears to have a comparative advantage in CI research in wheat, even compared to strong NARS in Asia and Australia.

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[3] This is considerably above the estimate given in Wheat Facts and Trends which includes all released varieties including those based on CIMMYT crosses.

As we emphasized in the beginning of this note, these comparisons between CIMMYT and NARS are necessarily artificial. In particular, we have failed to include the costs of international testing that is borne by NARS as well as the cost of evaluation of advanced lines by NARS before release. And for a donor investing in wheat research, computation of costs at the official exchange rate would by a better measure of that donor's costs. However, even putting both of these factors together, it seems clear that in a perfect world without political boundaries, there would be a strong case for quintessential agricultural research (Winkelmann, 1993). That is, there would be considerable efficiency gains in having one or a very few centralized breeding programs, such as CIMMYT's, linked to small testing programs located at key sites. We do not live in such a perfect world, but it does appear that there is considerable potential to improve efficiency of the present system, through consolidation and rationalization of existing programs.

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Table 1: Descriptive statistics on inputs and outputs for wheat breeding programs, 1992

Region	Total expenditure (in millions of 1990$ PPP)	Total FTE scientists in 1992	Cost per FTE scientist	No. of own crosses (annually)	Total of varieties released	Percent "CIMMYT varieties"[c]	Total wheat area sown to varieties released since 1980 (M ha)	Percent area sown to "CIMMYT-varieties"[d]
Sub-Saharan Africa	3.0	27	112	1,470	3.8	85 %	0.3	45 %
WANA	37.5	283	133	7,490	12.4	55 %	4.3	50 %
Asia[a]	21.9	300	73	26,480	13.2	33 %	13.9	25 %
Latin America	14.4	123	117	20,600	32.8	53 %	5.3	44 %
All Developing countries (using PPP)[a]	76.9	733	105	47,810	62.2	53 %	23.7	34 %
All Developing Countries (at official exchange rate)[a]	48.3		66					
CIMMYT	8.3	36	230	12,000	33.8	100 %	23.7	34 %
Australia (using PPP$)	3.4	42	81	3,600	7.1	3 %	6.8	16 %
Australia(using actual exp.)	6.1		145					

[a] Excludes China.
[b] Number of crosses made in Australia: taken from Brennan (1986, p.6).
[c] Defined by where the cross was made.
[d] Percent of area sown to varieteis released since 1980 derived from CIMMYT crosses.

Table 2: Comparison of various measures of efficiency of wheat breeding programs, 1992

Region	No. of crosses made annually per FTE (program)	No. of varieties released annually per FTE (program)	No. of own varieties per 10,000 crosses	Mill. ha per own variety	Cost (in '000s of $ PPP) per		Cost per ha sown to own varieties released, 1981-1990
					Own cross	Own variety	
Sub-Saharan Africa	54	0.14	4.0	0.27	2.1	5,154	19.20
WANA	26	0.04	7.4	0.39	5.0	6,790	17.31
Asia - without China	88	0.04	3.4	1.17	0.8	2,460	2.21
Latin America	167	0.27	7.4	0.19	0.7	941	4.87
All Developing countries (using PPP)[a]	65	0.09	6.2	0.52	1.6	2,576	4.91
All Developing countries (at official exchange rate)[a]					1.0	1,620	3.09
CIMMYT	333	0.94	28.2	0.24	0.7	245	0.53
Australia (using PPP$)	86	0.17	19.2	0.82	1.0	496	0.61
Australia (using actual exp.)					1.7	883	1.08

[a] Excludes China.

Figure 1 Percent of all varieties in developing countries based on IARC crosses, 1966-90

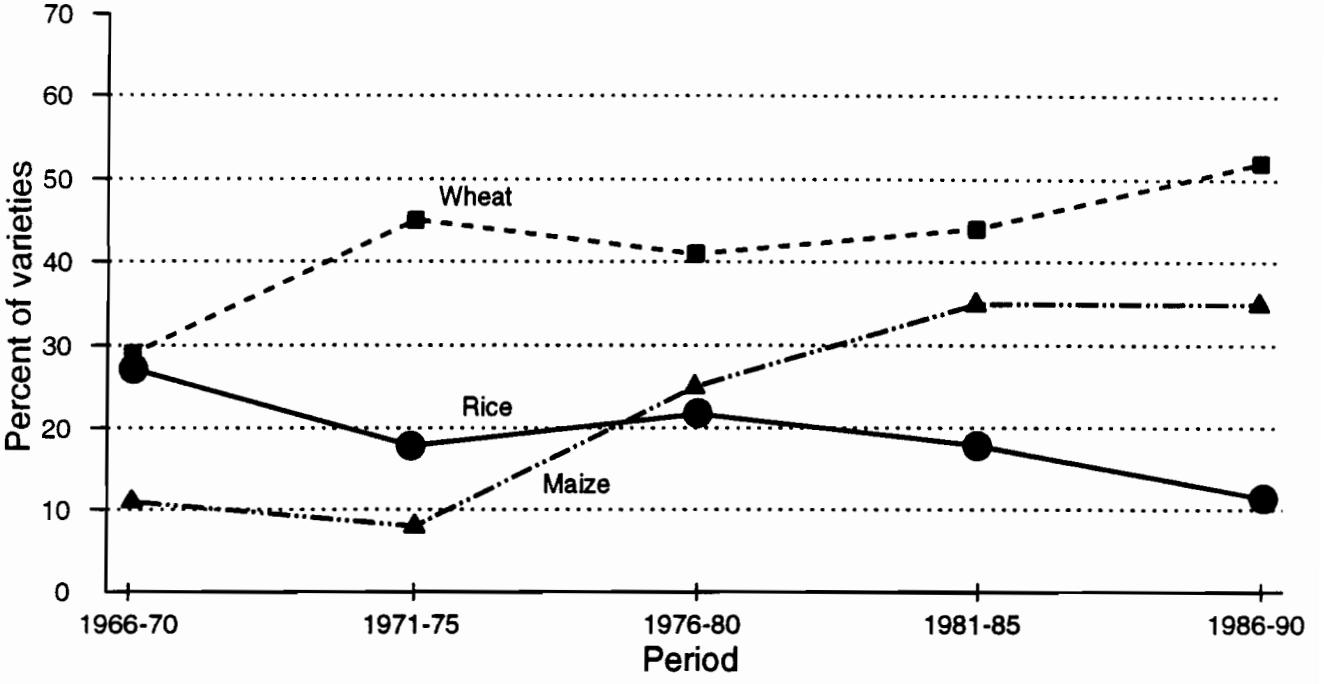
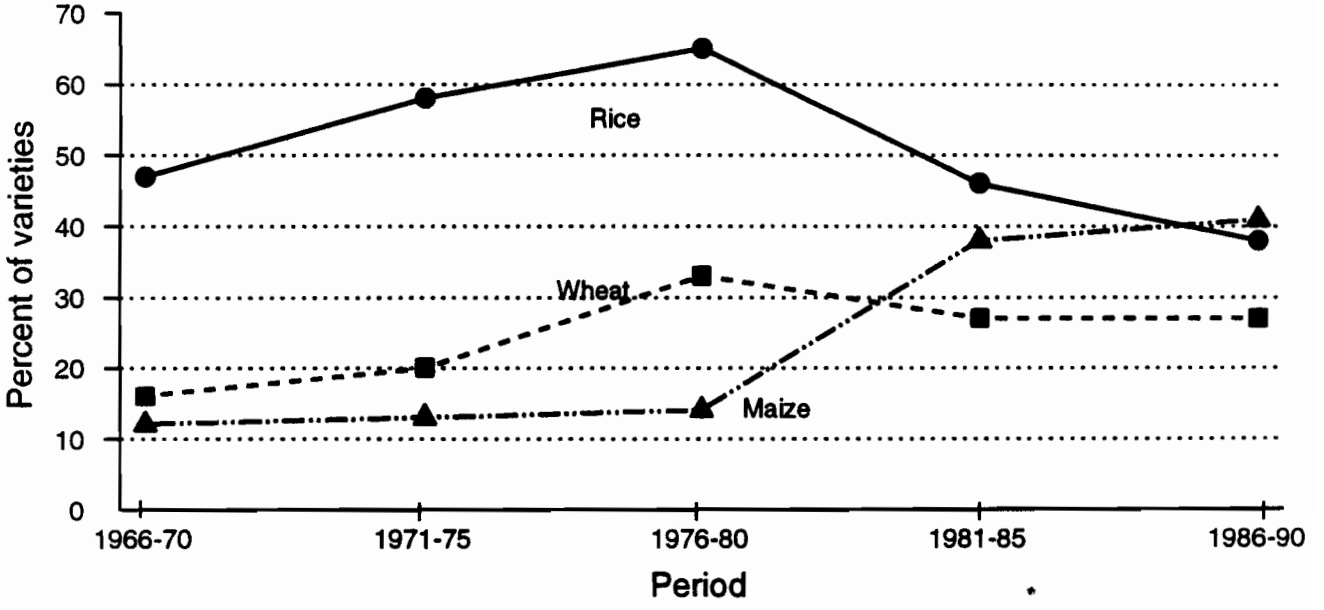


Figure 9b. Percent of varieties in developing countries based on NARS's crosses with IARC parent, 1966-90



All varieties in developing countries outside of China. For maize, IARC crosses are varieties with mostly IARC germoplasm, and NARS crosses, varieties with some IARC germoplasm.

Sources: Byerlee-Moya (1993); Lopez-Pereira and Morris (1993); R. Evenson (pers.comm.)