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Increasing Crop Yields in Developing Countries¹

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This paper discusses the following two questions: (1) is there unused, proven potential for increasing yields of crops in the developing world? (2) how quickly and dramatically will biotechnology improve the proven yield potential of such crops? The questions have also been phrased: is there "technology on the shelf" for agriculture in the developing countries? Will biotechnology add to the world food surplus? These are such broad questions as to be virtually impossible to answer conclusively, but having agreed to the invitation to do so, I must attempt them.

Crop yields

Lack of attention in this discussion to conditions other than technological change that are necessary for progress in developing countries should not be interpreted to suggest that I view those factors as less important. Indeed, a state of peace, the enforcement of contracts and property rights, education, a functioning capital market, efficiently operating infrastructure, informed and participating citizens and other factors too diverse to enumerate here, are all necessary. But my experience and knowledge enable me to speak most capably about technological change. Therefore, I will stick fairly closely to the assigned topic. To put the question in perspective, I want to begin with

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reflections on a few global criteria that might be used to judge the state of available technology, but then quickly come down to some specific crops and locations.

Unexploited Yield Potential

If one likes to extrapolate from the past, there is ample evidence to suggest the potential for yield increases. Yields in developing countries have increased rapidly over the past 20 years. Between 1964 and 1974, developing country cereal yields increased at an average rate of 2.3% annually and between 1974 and 1984 they increased at 3.1% annually (based on five year averages, centered on the year identified; IFPRI 1987). The corresponding developed country rates were 3.2% and 1.6%, indicating that yields in developing countries have accelerated while those in more developed countries have slowed. Extrapolation would suggest these trends should continue and that the potential for future yield increases is, therefore, greater in the developing than in the developed world.

Comparison of crop yields in the developing world with those in the developed world might be another way to determine the potential for yield increases in the developing world. Table 1 shows such comparisons for 12 important crops. Developing country yields of maize, rice, sorghum, barley, potato and peanut are far below their levels in the developed world, while developing country yields of wheat, sweet potato, beans, and soybeans are similar. Does this mean there is little potential for developing country yield increases in the latter crops? It would appear not, judging from the first criteria -- trend extrapolation -- which showed that wheat yields grew at about 4% annually over the past two decades in the developing world. Thus, the first two global criteria give conflicting indications, in at least some cases.

Large differences between average farm yields and those on experiment stations are a third criteria that might be used to evaluate the potential for yield increases. However, such data must be used with some care. Average farm and experiment station wheat yields in North Dakota show a large and continuing difference for over 50 years (Figure 1). Corn yield data from experiment stations and farmers fields in Illinois show similar patterns (Table 2) as do comparisons of farmers' and experiment station yields of soybeans nation wide (Figure 2). This evidence of a large gap between yields on experiment stations and farmers' fields seems to support the interpretation that American farmers' yields are lagging behind technological potential.

A closer examination of data from Illinois suggests another interpretation. The Allerton Trust Farms consist of a number of farms in Piatt County, Illinois, that are operated by the University of Illinois, not as experimental farms but to "produce maximum income to support the operation and maintenance of the Robert H. Allerton Park and Conference Center" (Swanson, et al 1977). Table 2 shows that yields on the Allerton Farms are 30% below those on the Morrow plots, but only 10% above those of the commercial farms of Piatt County. That is, farms managed by university researchers to maximize profits give yields significantly lower than experiment station yields and only slightly higher than the average of nearby farmers.

Thus, it seems that three reasons combine to account for the observed yield gap--a difference in objectives, a difference in geographic coverage and a difference in technology. Only comparisons having a common objective and a common geographic coverage can indicate differences in technology, and the Illinois data seem to indicate a yield gap of perhaps 10% because of differences in technology.

Another striking feature of the U.S. data is the persistence of the yield gaps over time. Farmers' yields increased over time but experiment station yields also increased, maintaining a gap that widened some years and narrowed others. This bit of U.S. experience seems to indicate that it is "normal" to have a yield gap--at least it has been normal over the past several decades even with rapid growth in farmers' yields.

Some further reflection on the matter might suggest that a yield gap is desirable and that its absence would indicate that there is no "reserve" or "slack" technology for farmers to adopt. Among the available ways of estimating yield gaps, data from agronomic experiments may be the best, although the absolute size of a yield gap can be misleading and must be interpreted carefully. That requires a close examination of the technology available in specific developing countries.

Technology on the Shelf?

The question to be examined is: are there technologies ready and waiting for developing country farmers to put into practice that would give significantly increased yields?

With no limits on costs, sufficiently clever agronomic engineers can increase yields of any crop at any time and place, so the question must be more carefully defined if a meaningful answer is to be given. The most limited way to ask the question is: can farmers in a specific location increase their yields given the seeds, labor, land, power sources and knowledge they have and given the existing set of prices and infrastructure they face?

My reflection on this question after having examined many experiments and surveys of farmer behavior in developing countries convinces me there is little scope for increasing yields or productivity merely by reallocating inputs among enterprises if all factors affecting production are unchanging. That is, to use T. W. Schultz's phrase, farmers are "poor but efficient" when they operate in constant or slowly changing conditions (1964).

The purpose of agricultural development is to speed up the rate of change in the conditions facing farmers to enable them to increase production to meet demand and to raise their incomes. Biological research has the function of raising potential technical productivity, extension has the function of increasing farmers' knowledge, the marketing system has the function of supplying inputs and demanding products, and "society" or government has the function of providing the physical infrastructure and policy environment that enable farmers and the marketing system to meet the demands of consumers for food and other agricultural products.

Focusing on technology per se, and rephrasing the question once more one might ask: is there existing technology that would permit farmers with reasonable levels of knowledge and access to inputs to profitably and significantly increase yields on their farms? For convenience, I refer to this as profitable unexploited yield potential. One might also ask a parallel economic question: is there existing technology that would permit farmers with reasonable levels of knowledge to significantly increase social returns from farming? Here the intention is to focus on profitable unexploited yield potential.

Yield per hectare is recognized as a partial productivity measure but is nonetheless used for practical reasons: data on yields are widely available; yields are quite good proxies for productivity in land short economies; most developing countries are rapidly becoming short of land; and most importantly, there are few data sets that compare total factor productivity of alternative technologies. These are all facts that ought to motivate agricultural economists and agronomists to collaborative examination of potential technologies, but that is a much neglected activity, leaving me little alternative but to focus on yield per hectare.

Rice in Asia

In 1965 Asian rice farmers obtained the first semi-dwarf varieties to be developed at the International Rice Research Institute. Although these varieties had their shortcomings, an important one being their susceptibility to various insects and diseases, they contributed significantly to increases in Asia's food production after their release. Since 1965, a series of newer, much more insect and disease resistant varieties have been produced by IRRI and the rice research programs of Asian countries. These newer varieties have been widely adopted, and semi-dwarf varieties are estimated to cover around half of Asia's rice land area (Dalrymple 1986b). By 1987, newer varieties had largely, but not completely, displaced the first semi-dwarf variety, IR 8, from farmers' fields. A similar story can be recounted about semi-dwarf wheat varieties.

Casual familiarity with these facts has led many observers to assume that the rice and wheat varieties developed in the 20 years since

the first semi-dwarfs were released must be higher yielding than the first ones. However, examination of the available data do not support that supposition. Figure 3 compares experiment station yields of IRRI rices with average national yields in the Philippines.

The rice data, based on experiments in four locations in the Philippines, show a sharp increase in proven yields of the highest-yielding variety from around 3.5 t/ha before 1960 to over 7 t/ha after 1965 when the new varieties became available.³ Experiment station yields declined slowly after 1965, contrary to expectations, for a variety of reasons explored by Flinn and De Datta (1984). This is not to suggest that the newer rice varieties do not have advantages over IR 8. Their yields are much more stable in the presence of insects and diseases than IR 8, and they mature in fewer days, thereby permitting intensification of land use. However, they do not have any higher yield potential than IR 8.

Comparing the national average rice yields in the Philippines with the average experiment station yields makes clear how farmers have been "catching up" with the potential created by the innovation of the 1960s. Still, the difference between the proven potential of 6 t/ha and the national average of 2.5 t/ha suggests a considerable yield gap. The same picture would emerge from a comparison of average farmers' rice yields in other developing countries with demonstrated maximum yields, but such systematic data are not readily available.

3 Yields are averages across 4 stations and for wet and dry seasons at maximum yield fertilizer level for each season.

Direct comparison of rice farmers' yields with experiments on their own farms suggests rather more modest differences than reflected in Figure 3. In 450 experiments conducted over three years in 6 Asian countries, the difference between farmers' average yields and average yield with a high input package was about 33% or 0.9 t/ha in the wet season (Herdt 1979). Of that 0.9 t, about half was contributed by an uneconomically high level of insecticide application. Most of the rest was contributed by a high level of fertilizer application, only part of which could be economically justified. Thus, on average these trials suggest a profitable unexploited yield potential of about 0.2 t/ha, not the 0.9 t measured yield gap.

Wheat in Mexico and Pakistan

The story of semi-dwarf wheat in the developing world closely parallels that of rice. New varieties were released to farmers at about the same time and have spread widely (Dalrymple 1986a). Reported "potential" yields for semi-dwarf improved wheat varieties developed by CIMMYT and the Mexican agricultural research system and released in Mexico since the early 1950s are shown in Figure 4 (CIMMYT 1985). In slight contrast to rice, there is an indication that yield potential has continued to increase since 1965, but the increase has been rather slow, and, in recent years, modest, compared to the sharp increase between 1961 and 1966. As in the case of rice, the difference between national average yields and the potential as measured in the experimental data has been eroding since the middle 1960s.

Research undertaken on farmers' fields evaluating the economics of the yield gap for wheat in Pakistan is summarized in Table 3. The

economic yield potential was calculated taking into account the total cropping pattern (in which wheat often must be planted "late" because of other crops), the available irrigation water and the profitable level of inputs as estimated in on-farm experiments (Byerlee et al 1986). The results show a profitable unexploited yield potential of about 1.0 t/ha, while the total yield gap between farmers' and experiment station yields is about 3 t/ha.

Maize in Africa

The case of maize in Africa is of particular interest at this time because maize is an important food crop in Africa where food production has lagged behind population growth in many countries. Also, developing country maize has received as much research investment as developing country wheat, there has been no "green revolution" proclaimed for maize.

Some of the best informed observers on African agriculture comment that presently there is a backlog of maize varieties on the shelf in the maize belt of the SADCC region (Zimbabwe, Zambia and Malawi), "but technology is not on the shelf in most SADCC countries for the following food crops: white sorghum, millet, summer wheat, rice and groundnut varieties for small farmers" (Eicher and Mangwiro 1987).

The impression generated by their confidence on the backlog of maize technology is strengthened by examination of maize variety trials conducted between the mid-1970s and 1982. In 12 countries of Eastern and Southern Africa the test maizes averaged 5.8 t/ha, in 3 countries of Central Africa they yielded 7.2 t/ha, and in 11 countries of West Africa

they yielded 5.0 t/ha (Gelaw 1986). Average farmers' yields of maize for the same years were 1.3 t/ha in Eastern and Southern Africa, 0.7 t/ha in Central Africa and 0.8 t/ha in West Africa (FAO). Thus, there is a large gap between farm and experiment station yields, with yields of the test varieties far exceeding national averages, leading many to the conclusion that there is a backlog of technology.

With such a large yield gap, it should be easy to demonstrate clearly superior performance of recommended maize technology on farmers' fields in a large number of locations, just as the maize variety trials showed high yields on a large number of experiment stations. The annual research reports from national research services and from farming systems research projects that have been conducting research in African farmers' fields over the past decade are a rich source of data with which to examine this hypothesis, but unfortunately those reports are not widely available. The data that follow, therefore, are illustrative rather than conclusive.

A number of experiments reporting yield response of maize to fertilizer were examined. The experiments all measure the productivity of fertilizer applied to improved maize varieties in farmers' field trials. Fertilizer trials are chosen for a number of reasons. Fertilizer was a crucial component of the seed-fertilizer-irrigation package that was largely responsible for the rapid Asian rice production increases between 1965 and 1980 (Barker and Herdt 1985). Plants cannot give high yields without plant nutrients, either from natural weathering of soil, applied animal manure, plant organic matter, or manufactured sources. Thus, if unexploited yield potential exists, it will most likely show up in fertilizer trials with improved varieties.

Results from a fertilizer and plant population trial on maize at 17 sites across four different agro-ecological regions of an agriculturally important SADCC country were examined (Dept. of Research and Specialist Services 1986). An improved variety that had performed well at all sites in previous trials was grown. As expected, yields were closely correlated with rainfall. However, there was little systematic response of yield to fertilizer or plant population. In 2 of the 17 sites the yield effect of plant population was significant, in 3 of the 17 sites the yield effect of fertilizer was significant. The average yield at 1/4 the recommended fertilizer level was 3.1 t/ha and at the recommended fertilizer level was 3.6 t/ha. Plant breeders' trials at experiment stations in the same country regularly average 8-10 t/ha.

In another set of 8 experiments in one district comparing two planting methods and two methods of weed control, there was little systematic relation of yield to inputs (Dept. of Research and Specialist Services 1985). In 2 of the 8 sites, planting method gave a significant yield difference and in 5 of the 8 sites method of weed control gave a significant difference. Yields averaged 3.6 t/ha overall; the 3 sites that had poor weather yielded 1.5 t/ha and the 4 sites with good weather yielded 5.6 t/ha.

In the same district another trial testing time of fertilizer application and type of fertilizer compound found a significant effect of type of fertilizer in all cases, but in over half the cases the farmers' usual time of application gave a higher yield than the recommended time of application.

In another SADCC country, a large number of agronomic trials were conducted on maize throughout the country (Ngwira et al 1987). The trials were aimed "at developing and selecting the most economic improved management practices for both smallholder farmers and estates to increase maize production per unit area." In a trial testing nitrogen fertilizer levels from 0 to 150 kg/ha, fertilizer level gave a significant yield effect in only 8 out of 15 sites. Maize yield averaged 2.7 t/ha at zero nitrogen and 3.8 t/ha at 150 kg of nitrogen per hectare.

Another trial tested different times of fertilizer application, comparing the recommended timing with farmers' practices. In only 5 of 15 locations was there a significant difference between various timings. Yields averaged 4.1 t/ha overall. In still another trial, 7 levels of fertilizer ranging from 0 to 210 kg/ha of nitrogen were tested on hybrid and local maize at four sites. In this experiment fertilizer and variety gave significant results of the expected kind: the hybrid averaged 3.4 t/ha at 0 N and 5.0 t/ha with 210 N, while the local variety averaged 1.6 t/ha with 0 N and 2.6 t/ha with 210 N.

The maize results from multi-location trials, many on farmers fields, showed considerable variability in response to fertilizer across sites and, within sites, considerable uncertainty about optimal practices. The trials suggest that maximum yields with presently available varieties and management knowledge might average around 3.5 t/ha, not the 5 to 6 t/ha found in the Africa-wide on-station variety trials reported by Gelaw. If these examples represent what is possible for trained agronomists who are not personally bearing the costs and risks

associated with fertilizer use on maize, then the profitable unexploited yield potential for maize in Southern Africa might average the difference between current yields of 1.3 t/ha and a profitable high yield of 2.5 t/ha. Thus, while varieties with the capacity for improved yields exist, there seems to be a need for significantly more research to identify economically optimal management practices for well defined agro-ecological areas.

How does this judgment square with the recent dramatic increase in maize production in Zimbabwe, where in 1985 production was one-third higher than its highest level of the 1970s? A careful study by David Rohrbach of Michigan State University based on farm level research in two communal farm areas of Zimbabwe provides insight on this issue.

Communal farmers' production of maize in Zimbabwe increased from 500 thousand tons in the 1970s to 1.6 million tons in 1985. In Mangwende communal area, located in a relatively favorable agro-climatic region, there was a 450% increase in maize production between 1974 and 1986, caused by a 90% increase in area and a 200% increase in yield. Hybrid maize and fertilizer was used by 95% of the farmers, and the correlation between level of fertilizer application and yield was striking: non-fertilized fields averaged 0.5 t/ha, fields receiving 26kg of N per hectare yielded 1.0 t/ha, while those receiving an average of 100 kg/ha of N gave yields of 2.9 t/ha (Rohrbach 1987).

Chibi, located in a relatively unfavorable agro-climatic area, showed a 270% increase in maize production caused by a 200% increase in area and a 45% increase in yield. All farmers planted hybrid maize but only 12% applied fertilizer. The contrast between the progress in the two

areas is partly due to a more favorable agro-climatic situation in Mangwende, but that difference is complemented by a better infrastructure and the fact that Mangwende is located only 80 km from the capital of Harare while Chibi is located some 370 km away.

One of the main reasons for the difference between yields on research stations and on communal farms is that low resource farmers often plant maize late because of limited power and competing demands from other crops. Late planted maize may not have sufficient time to mature before rainfall or temperature becomes too low (Blackie 1988). Low rainfall areas (Chibi or lower) make up 74% of Zimbabwe's communal agricultural area while areas with rainfall like Mangwende (or better) make up only 9% (Rohrbach 1987). In lower rainfall areas the variability of the beginning date, ending date and duration of rainfall are relatively greater. Delays in weed control and fertilizer application, traceable to labor shortages, limitations in the marketing system and other reasons compound the problems of late planting.

The record of maize production increases in Zimbabwe is impressive, but one should be clear what happened. Communal areas in the better agro-climatic regions accounted for much of the increase by greatly increasing the area planted and by moving from extremely low yields to low yields: in Mangwende yields increased from 0.6 t/ha to 1.8 t/ha and in Chibi from 0.5 to 0.8 t/ha. In contrast, breeders' multi-location maize variety trials in Zimbabwe average yields of 8-9 t/ha. Thus, there is a huge yield gap, but its size is not indicative of the opportunity for profitable yield increases by communal farmers. The on-farm experiments and the experience of communal farmers in Zimbabwe suggests that in

relatively favorable agro-climatic conditions current maize technology has a profitable yield potential of perhaps 3.5 t/ha, and in relatively unfavorable areas perhaps 2 t/ha. These represent large gains from the investment in research and fertilizer application, but they are far more modest than suggested by the top yields achieved by plant breeders. Thus, there is a modest profitable unexploited yield potential, but if Africa is to achieve the increases reflected by these modest yields, soil fertility levels will have to be raised, and much additional agronomic research will be needed to identify where and how fertilizer can be profitably applied.

Raising Potential Yields Over the Longer Term

Heretofore the discussion has been about increasing farmers' yields by exploiting proven potential. A further question remains: what is the possibility of increasing the proven potential? Does plant biotechnology hold out the prospect for dramatic new yield breakthroughs? If so, will these breakthroughs come in the next 5, 10 or 25 years? Will innovations designed for the industrialized world have transferability to the developing world? These are difficult questions to answer, especially because knowledge is just now being converted into technology and it is unclear what the limits of the technology will be.

It is clear that all biotechnology directed at plant improvement depends on the identification of a method or "strategy" by which genetic transformation of some organism can be used to overcome a production limitation. There is a disagreement among plant scientists over the extent to which further increases in yield potential can be achieved through such genetic transformations of plants. H. K. Jain has examined the record of wheat, rice, barley and sorghum yield increases during the

past 80 years of crop breeding and concluded that most of the yield gains come from redistribution of dry matter between vegetative and reproductive plant parts and that "there is little evidence to show that biological yield or the dry matter production has seen a significant increase during this period" (Jain 1986). He sees little possibility for further gains from this source and so concludes that the prospects are bleak. Other authorities do not agree. After enumerating five physiological routes to greater productivity, Evans concludes that he "can still envisage many possible avenues to greater yield potential in wheat, and there is no reason to suppose that it is near its limit" (1987).

The reason for the disagreement seems to rest in the assumptions about what can be changed and how it contributes to productivity gains. Jain identifies past gains in productivity with plant height and biomass partitioning. The genes controlling this character have long been recognized, can be manipulated by plant breeders and could be manipulated using genetic engineering. The potential sources of productivity gains identified by Evans are much more complex traits like photosynthesis, timing of the reproductive cycle, and growth regulation. Many genes affect these processes and only a few have been isolated, so the route to their manipulation will likely be much longer and will require improved understanding of the basic underlying plant processes.

In contrast to complex physiological traits, resistance to insect attack and to damage from certain plant diseases is much easier to recognize, in many cases is controlled by a single gene and sometimes can be introduced through a gene from an entirely different species (i.e. alien or novel genes). These traits will be relatively easy to transfer

into a crop using genetic engineering, if genetic engineering is perfected for the crop. One well know example of the use of novel genes is the transfer of the gene for the toxin produced by Bacillus thuringensis. It occurs naturally in certain soil bacteria and it has been inserted into tobacco and tomato where it has been shown to protect the transgenic plants from insect larvae.

Protecting plants from adverse soil characteristics such as acidity, salinity, alkalinity and drought is a more complex challenge, similar to changing a crop's physiological traits. Plants have many characteristics that enable them to cope with drought conditions, but the relative contributions of each and the genes that control each is poorly understood. Some authorities hold that whole plant characters like root length and leaf surface coatings are important while others hold that the production of enzymes in the plant tissues are important. Thus, more basic research to understand why some plants are well adapted to hostile environments and others are not is needed before the tools of biotechnology can be brought to bear in transferring genes useful for this purpose.

Biotechnology's Potential

Biotechnology provides new ways to genetically improve plants and animals and new products with which to treat plants and animals. But biotechnology applications must be specifically designed for the target organism, and may require intensive research to perfect many separate techniques required by a process. For those reasons a significant amount of resources are required to bring new production technologies to farmers via biotechnology research.

The impact of biotechnology is likely to be modest in the developing world over the next 10-15 years for a number of reasons. The simplest is that few resources are being devoted to biotechnology research on crops of importance for the developing world. Aside from the rice biotechnology program being funded by the Rockefeller Foundation (Toenniessen and Herdt 1988), there is little research being done to develop the knowledge and tools of biotechnology for crops that are important mainly in the developing country (rice, cassava, sorghum, millet, yams, etc.). Secondly, even for crops which are important in both the developed and the developing world (maize and wheat) there is likely to be little contribution to the developing world from ongoing developed country research because of the location specific nature of most agricultural biotechnology applications.

In the case of rice, where there is a program aimed at the developing world, the prospects, over the next 5 to 10 years, for genetically incorporating the capacity to resist the attacks of specific insects or plant diseases, and for genetically engineered products like biological insecticides to lower production costs are relatively bright and will, in aggregate give large output gains and high economic returns to the research investments being made (Herdt, 1987). However, the prospects for dramatic increases in yield potential or for engineering plants to endure adverse environmental conditions are modest in the next 5 to 10 years. The prospects for incorporating nitrogen fixation capacity or increasing photosynthetic efficiency are even more remote: they are extremely complex characteristics that involve many genes and are often poorly understood at the molecular level.

These differences in outlook arise from what biotechnology is and therefore what it can do. There are biotechnology tools to clone or reproduce segments of DNA, tools to determine whether a particular sequence of DNA exists in a particular organism and tools to insert segments of DNA into organisms. These tools can help speed the genetic improvement of crops, but the determination of what genetic characteristics will increase the productivity of a crop, the isolation of the genes for those characters, and the identification of a segment of DNA with a gene all require the growing of crops in the conditions for which they are intended and determining how they perform. In other words, using biotechnology to make improved plants requires much more sophisticated and intensive inputs from plant breeding and the complementary disciplines of entomology, pathology, biochemistry and plant physiology. One eminent plant scientist puts it this way:

"At present, however, our attempts to engineer plants can be likened to those of an electronic engineer who attempts to modify a computer for which there is no circuit diagram. He or she might know how parts of it worked, but would have no way of understanding how it is functionally integrated. There are far too many gaps in our knowledge of biochemistry and physiology to make it feasible to think in terms of planned and directed changes in all but the simplest of plant characteristics (Arnold 1987)."

Conclusions

Farmers in Asia, Africa and Latin America, like their counterparts in the United States generally adopt technologies that increase the productivity of their total farming systems. "Improved" technologies that are not adopted by farmers usually turn out to require either higher prices, unavailable inputs, additional knowledge, lumpy capital, a non-existent marketing system or some other requirement beyond farmers' means.

Where infrastructure, knowledge, capital, or markets are limiting, their development will likely induce farmers to use new

technologies if such are available. Determining whether such technologies offer profit or productivity gains requires economic evaluation of agronomic research conducted under farmers' conditions.

Examination of available data suggests that developing country farmers, at least those in Mexico and the Philippines, are "using up" the profitable unexploited yield potential created by research on wheat and rice as fast or faster than that potential is being created -- the unexploited potential is falling. There is no large backlog of unused technology -- that which is appropriate gets adopted relatively rapidly. On communal farms in Southern Africa there is some, I believe, limited profitable unexploited yield potential for maize, which could be realized if fertilizer were available. Plant breeding research to improve the genetic characteristics and agronomic research to guide the utilization of that potential is needed.

Biotechnology is unlikely to lead to dramatic gains in potential yields of crops important in the developing world in the coming 10-20 years. Some protection of present potential yield levels will be obtained from biotechnology research to incorporate resistances to important diseases and insects of rice, and perhaps of other tropical crops as a spin-off of temperate country research.

Thus, there is little reason to be confident that the present level of investment in research and other productivity increasing investment in developing country agriculture is likely to lead to the required levels of production. On the contrary, there is a need to redouble efforts to improve the technology available to developing country farmers to maintain the rate of increase of output as close to that of demand as possible.

Table 1. Yields (t/ha) of Major Crops 1981-83, Three Regions of the World.

	<u>North America</u> 1981-1983	<u>Europe</u> 1981-1983	<u>All developing</u> 1981-1983
Wheat	2.32	3.77	2.16
Maize	6.37	5.05	1.98
Rice (paddy)	5.26	5.07	2.90
Sorghum, millet	3.59	1.45	0.92
Barley	2.69	3.41	1.28
Potato	29.17	19.02	11.46
Sweet potato	13.57	10.67	13.61
Dry beans	1.58	0.58	0.52
Chickpeas	n.a.	0.58	0.65
Soybeans	1.96	1.26	1.44
Peanuts (in shell)	2.49	n.a.	0.99

Source: FAO, World Crop Statistics: Area, Production and Yield 1948-64 (Rome 1966) and FAO Production Yearbook 1983 (Rome 1984).

Table 2. Experiment Station, University Farm, County and State Average Corn and Soybean Yields, Illinois.

	Experiment station (Morrow Plots) ^{a/}	Allerton Trust Farms	Piatt County	State Average
Metric tons/ha				
<u>Corn yields</u>				
1955 to 1959	6.7	5.4	4.8	4.1
1965 to 1969	9.4	6.3	5.3	5.8
1973 to 1976	9.4	8.0	8.0	6.4
<u>Soybean yields</u>				
1966 to 1970	3.8	2.7	2.4	2.1
1972 to 1976	2.9	2.5	2.4	2.1

a/ Yields from Plot 4, MLP + LNPk treatment, a rotation of corn-oats from 1955 to 1966 and corn-soybeans from 1967 to the present. Each point is the average of 3 years of observations rather than 5 because corn was alternated with the other crop on this plot.

Sources: Morrow Plot data from University of Illinois (1982), other data from Swanson et al. (1977)

Table 3. Estimated Yield Gap for Wheat Considering Total Productivity of Cropping Pattern and Irrigation Water Availability.

	Cropping region and system		
	Punjab rice/wheat	Punjab cotton/wheat	NWFP ^{a/} maize/wheat
Farmers' average yield (t/ha)	1.8	2.2	2.8
Economic yield potential (t/ha) ^{b/}	3.0	3.0 - 3.5	4.0
Yield gap (t/ha)	1.2	0.8 - 1.3	1.2
(%)	40%	27% - 37%	30%

a/ North West Frontier Provinces

b/ Based on results of on-farm experiments

Source: Byerlee et al 1986.

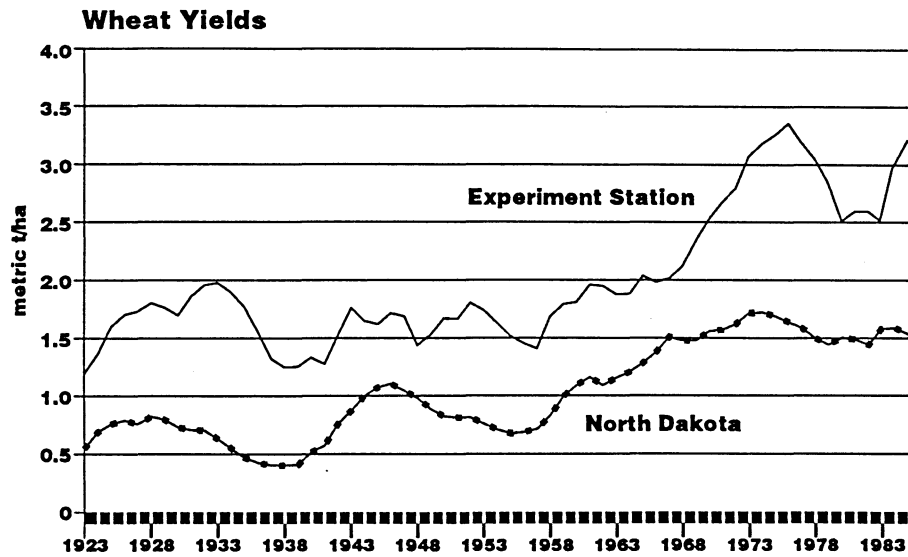


Figure 1. Experiment Station and Average Farm Wheat Yields, Five Year Averages, North Dakota (Sources: Fargo AES 1986; North Dakota Crop and Livestock Reporting Board; USDA, Agricultural Statistics).

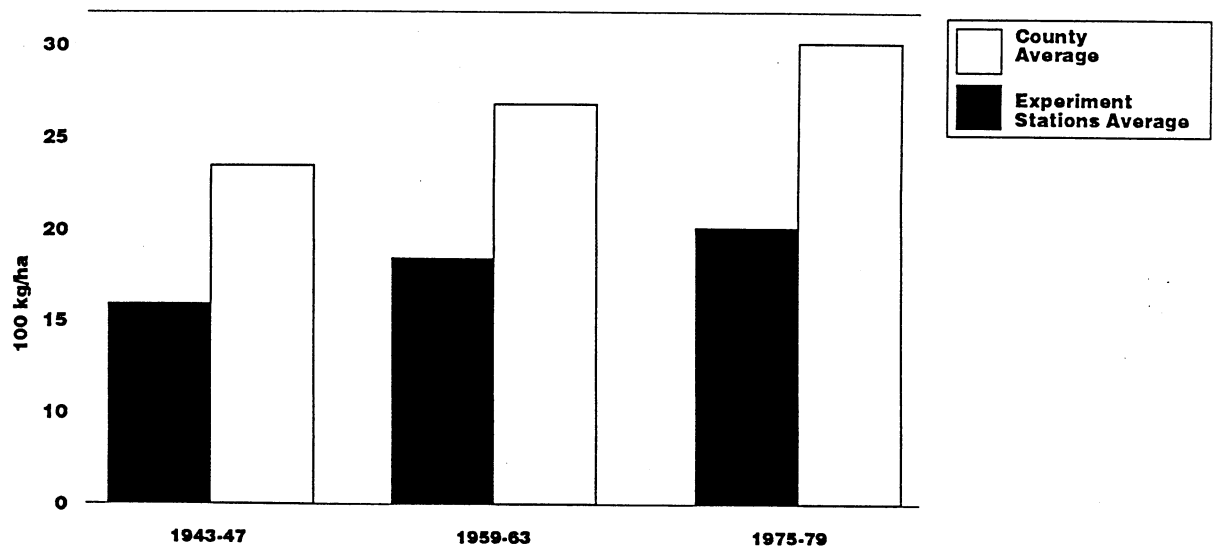


Figure 2. County Average and Experiment Station Yields of Soybeans from 63 Locations in the United States (Source: Rutan and Schoeneck, 1982).

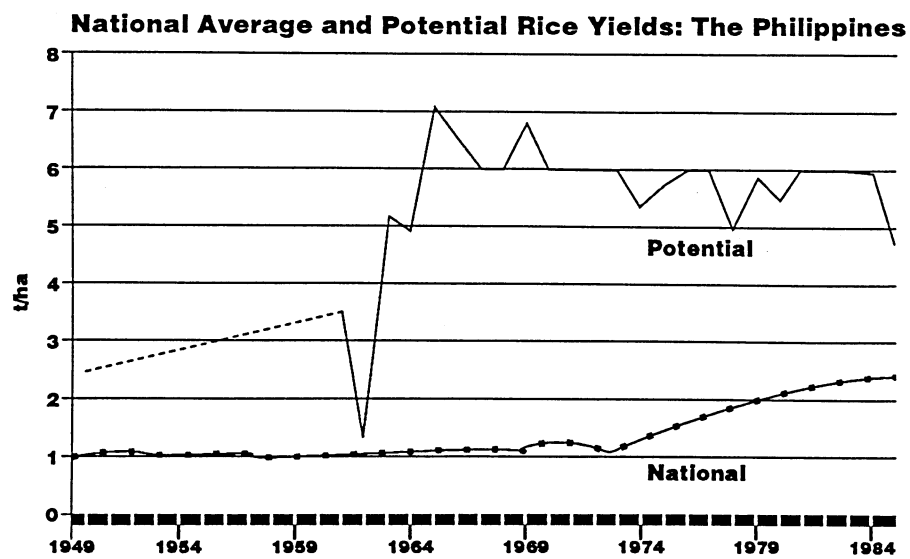


Figure 3. National Average and Potential Yields on Newly Released Rice Varieties, Philippines (Sources: adapted from Flinn and DeDatta 1984; CIMMYT 1984).

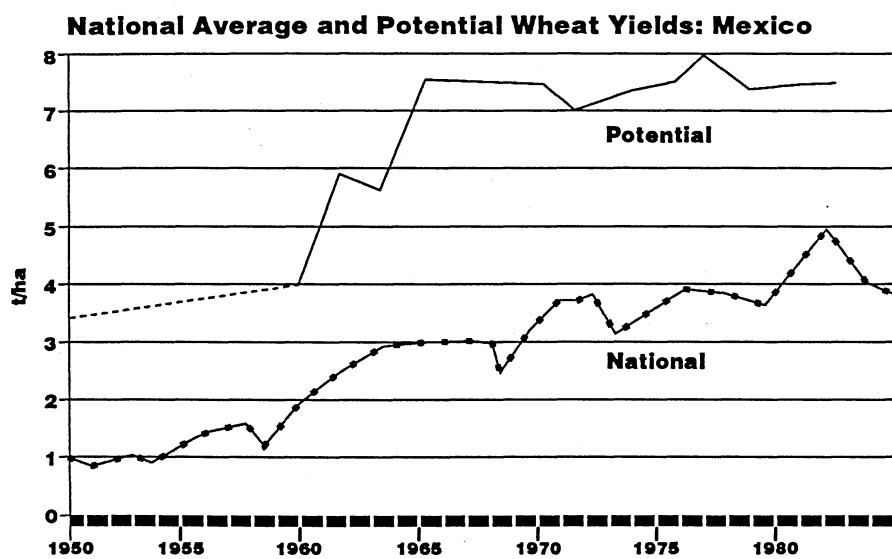


Figure 4. National Average and Potential Yields on Newly Released Wheat Varieties, Mexico (Sources: adapted from CIMMYT 1984).

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