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potentials for improving production efficiency of cereals

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POTENTIALS FOR IMPROVING PRODUCTION EFFICIENCY OF CEREALS

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1.1 INTRODUCTION

My remarks deal primarily with increasing yields in developing countries, with some discussion of economics as seen by a biologist.

Greater production through greater efficiency in all crops is a primary concern of man today in his search for a way out of the dilemma of feeding, clothing and supplying the increasing population. Let there be no mistake: population control is the overriding problem. But in spite of this, a great deal remains to be done to bring to bear the full agricultural production capacity of the various nations.

The spread between present and potential full production varies in width depending on the degree of sophistication that has been achieved in marshalling the total forces of government research, extension, and producer efforts in the different countries. Thus, in the United States and other developed countries, the spread is much narrower than it is in most of the countries with which we, in CIMMYT, have close collaboration. In some cases we are beginning with a barter level economy, whereas in other the change has moved into monetary commerce and, in still others, export is beginning on a modest scale.

Little additional land is available for crop production in many developing countries. Thus, the need for increasing yield per hectare becomes increasingly critical. The life of these countries depends on it. In the more developed countries, the intensity of need has not reached this critical stage, but if yields per unit area can be raised, more land can be made available for recreation, wildlife, and forest development. In this sense, increase in yield efficiency can be a boon to environmental protection, even though it may be only transitory.

It can be seen that factors leading to yield changes within a country are very involved and touch on many human emotions and endeavours. What are the attitudes of people toward change? What incentives are needed? What effect does change produce in the farmer? What public policy is most effective in effecting change at the planning level? Does the present economic policy of the developed nations fit the situation in countries with large rural populations? How should research and extension be organized to get positive and concrete results? these are questions which we, in CIMMYT, are faced with each day in the countries with which we are concerned.

In the biological sense, yield can be defined as the sum product of genetic, agronomic and environmental factors and the degree to which these are effective is governed by the factors I have referred to above.

In the past eight years I have been concerned with and involved in international agriculture. For seven of those years I was joint coordinator of the All India Coordinated Wheat Improvement Program (AICWIP). In the present paper I would like to make some

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observations on how change in yield is brought about based on experience gained both in India and other countries. I would then briefly refer to the after effects and look forward to some of the biologic possibilities for change we may expect in the next few years. The paper will be speculative, rather than documentative.

2.1 CHANGING PRODUCTION PATTERNS

The farmers in a traditional form of agriculture are generally poor, ill educated, poorly advised, without much hope and hence dispirited -- but they are intelligent. Each day and each generation follows the previous and has the same concern: to exist. How can this cycle be changed?

Basically, the change must come from a teaming together of research, extension, government policy makers and farmers coupled with an esprit de corps among the leaders. This latter provides the fuel. The research scientist must have a product to promote that is superior to existing cultivars, and a set of practices under which it can be successfully grown. The extension worker must demonstrate the product's advantages to the farmer; the farmer must have an incentive. The policy maker must, in sequential steps, devise means to meet growing needs. If these factors are mixed in proper proportions, yield increases and production advances occur.

In most developing countries there are few scientists. Even where a number of good scientists have been trained, they are organized according to disciplines, not in a crop-oriented fashion. Thus, a first step required is to reorganize scientist into a crop-oriented team comprising the various disciplines. This is best done on a national basis, so that policies affecting production are universal and have equality throughout the country. I venture to say that such national orginzation of research would be decidely more efficient than that followed in most developed countries.

Extension in developing countries is normally moribund. This is not intended as a slight to those charged with this responsibility. They are unable to advise the farmer because they are not sure that research results can be duplicated at the farm level. In such a position, it is best to do nothing since unsuccessful action may mean dismissal from service. Therefore, research personnel who are knowledgeable about the possibilities and methods must carry out the first demonstrations on farm fields. If the scientist now has a superior variety and a sound package of improved practices which will give 2,3 or 4 times what the farmer previously was able to produce, the farmer is immediately convinced of the desirability of change. I would like to make the point here that even though the supplies of fertilizer in the country are low, in the beginning a high rate of application must be recommended and used to maximize yield for purposes of demonstration effect. One should not be concerned with economics at this point. This initial demonstration will convince farmers, extension workers, legislators and planners if they are shown the results. A modest increase in yield might be attributed to weather, acts of God, or other phenomena but a two to three-fold increase in yield cannot be explained away in this manner. Farmer tells farmer and the new varieties and techniques spread rapidly to neighbors. A press campaign should now come into play which popularizes the production gains. The farmer on his part will adjust his inputs in such a way that he either maximizes yield or balances his gains against chances of loss, but his new level of yield is much above that previously experienced.

The pressure now is relayed by the farmers to government to provide large increases in input availability. This includes seed production, fertilizer import and production, water development and pesticide import and production. There now comes a period where production gains spread and a marketable surplus from heretofore subsistent farms becomes a reality. In the early agriculture development of North America, increased production led to depressed prices. This mistake must no be repeated if we are to continue the onward progress of change in the developing countries. Thus planners must set a remunerative floor price and announce it before the onset of the sowing season. Setting a price is not enough.

Defending it by setting up procurement facilities is essential; otherwise the market will be manipulated so that at harvest the trader buys low to sell high as stocks are depleted. This procurement and resale to buffer the market protects both producer and consumer. On the producer side, the larger farmer can hold stocks for rising prices whereas the small farmer must sell immediately to get cash - thus the floor price has its greatest meaning for him. The floor set should not be predicated on price levels in the international market when a country has a food deficit but must represent a reasonable return to the farmers in the particular country in question.

The consumer, on the other hand, benefits through greater stability in food prices over the year.

Concurently with procurement there is the need for marketing and storage facilities. Otherwise, grain cannot be procured or stored for later resale.

There follows in this development a period in which the agro-industries begin to prosper as the result of capital generation within the country. Tractors, pump sets, threshers, seeders and some of the field equipment become more generally available. This, of course, increases efficiency, but it is my opinion that the direction which mechanization takes should be carefully considered insofar as government policy is concerned. Tractors have the advantage of replacing animal power. Hence, land otherwise used for feeding draft animals is released to produce human food and animal feeds to enter the human food chain. There is a need for seed drills to ensure good stands. Mechanization of harvesting should have low priority in a country with high population density unless weather is normally poor during this period. Harvesting is a labor-intensive operation and can be a source of income for many people. Threshing should be mechanized since rapid storage of the product is of real concern to avoid losses to insects, rodents and weather. Further, where multiple cropping is practiced, bullocks should be spared this operation in order that they be available for land preparation.

The ability to buy the products of agro-industries reflects the general increase in prosperity. The farmer also uses his increased income for consumer goods, education and other products or services of human value. The transistor radio for example, opens his horizons; enhancing the government's ability to use radio as a tool in further development. The farmer is now a participant in the economy, many for the first time.

At this point, it is fair to say that, for this particular crop, change has occurred. It is now up to the public policy makers to readjust floor prices in such a way as to balance food or fiber needs from other sources. This should not be done on a pricing policy basis alone; instead, research must be stimulated in the alternate crops in order to increase their yield to make them competitive.

While this is being accomplished, it is necessary to build an institutional base that can support the crop program with which we are concerned. Scientists must be trained in the practical aspects of crop improvement; as well as provided with an opportunity to take advanced academic training. It is important that the first group so trained are very carefully screened, since, in the absence of other trained people, they will form the group which will soon take over administrative positions. Here, a poorly motivated individual can be real bottleneck to continued progress. As I have suggested, many of the trained people will be moved to administration from direct research. The training, therefore, must continued for some period until the country's internal educational system can cope with the growing needs for research personnel.

The young scientists drawn from the necessary disciplines must work together as a team, solving problems of that particular crop. This team is the unit that will continue to provide the new varieties, the new techniques, the new protection devices that will ensure the steady forward progress of increasing production. Governments should not forget this group once success has been achieved. Unfortunately, this is often the case and the esprit de corps that motivated their earlier thrust is lost. A production program without infrastructure development in research may make an initially large splash, but cannot be expected to support itself except in the short term.

I have herein outlined a blueprint that we will try to follow, with variations to suit the specific situation vis a vis the country in which we operate, changing direction as pragmatism dictates. These methods have proven workable in a number of situations.

3.1 YIELD INCREASES IN THE RESEARCH SENSE

3.1.1 IMPROVING INHERENT YIELD

I should like now to turn to the more direct aspects of increasing yields by scientific means. This is of more direct concern to the domestic situation in North America.

Let me say at the outset that it is difficult to generate high dedication among scientists who are working on a particular crop where surpluses already exist and where increases in efficiency lead only to greater embarrassment of government. Ths scientific effort is either not recognized or is downgraded for this reason and the scientist tends to settle into a routine that is only partially productive. I speak from personal experience as a wheat scientist in government service in Canada. It is essential, therefore, that the environment provides challenge and a feeling that successful results are appreciated.

Yield in the biologic sense, as I said earlier, comprises the sum effect of genetic and agronomic manipulation in interaction with the environment.

From the genetic standpoint, efficiency can be increased through improving the inherent yield characteristics of the particular crop plant - by providing better protection against diseases and insects - and by developing more widely adapted varieties.

Over the centuries there has been a gradual enhancement of basic yield characteristics in most of the cereal crops. The real quantum jumps have been made, however, in better protection of the crops or fitting the crops to different management techniques. I would place in these categories such historical developments as the introduction of crop rotations, the advent of the use of chemical fertilizers, the control of rusts in wheat and barley, rendering rice and wheat short-strawed to provide better response to higher levels of fertility, and producing hybrid and synthetic strains of maize.

Since I am most familiar with wheat, I should like to use this crop for purposes of example. Essentially, the approaches in this will be similar to those for other cereals if suitable modifications are made.

We now have varieties of wheat which are widely adapted. These have resulted from growing materials at sea level in the desert climate of Northern Mexico (20°latitude) and in alternate generations under cool near-monsoon conditions at 8500 feet near Mexico City (18° latitude). Only those selections doing well in the two locations survived in the selection process. Hence, the varieties which eventually were released by the Mexican Government had a built in adaptation to differing environments. Similar variations in environment are now being utilized on other programs. In this way, their "stability of yield" is more or less guaranteed over a wide area. These varieties are short-strawed, responsive to fertility and are in general insensitive to differences in day length encountered in different latitudes. This latter characteristic is beneficial in most of the countries of the lower latitudes, but can be slightly detrimental under certain conditions in the high latitudes. Some of these varieties have done well both under irrigated and rainfed culture. Varieties such as those described regularly emerge from the collaborative programs, both in Mexico and other nations.

Given this as a base, what must we do to increase yields beyond this point? Heretofore, genetic varietal improvement has been achieved largely on an empirical basis with little consideration given to the basic physiology underlying yield. We must now modify the plant in such a way that it will become a more efficient manufacturing unit, capable of utilizing more soil nutrients and transforming more carbon to carbohydrate. If this is done, we must have "built-in" grain storage capacity in which to place this extra elaboration of food.

In wheat and other small grains, three components of yield have been traditionally recognized. These are: tillering capacity, number of grains per head, grain size and density. It is difficult to increase one of these characters without causing a decrease in one or both of the remaining. This indicates that only so much food is being produced and it makes little difference in which way it is stored.

We must look then to increasing efficiency, We might ask what features of a plant will allow it to utilize sunlight more efficiently? What features will allow it to use water more efficiently? Do some plants have a better system for transport of food to storage than others? These are only a few of the questions we can use as leads to necessary research. Most of these are already under investigation at an academic level. Are there other approaches?

Over the past eight years I have had the opportunity to observe some millions of lines in some hundreds of nurseries in some two dozens countries. In doing so, I have been on the "look out" for certain identities which characterize the more successful variety. These empirical observations have led me to visualize a plant for irrigation and one for very dry conditions that, as yet, do not exist; but for which genes are known in wheat.

Under irrigation or high rainfall this plant should be sufficiently short and strong-strawed to withstand lodging and should have a large number of florets per spikelet combined with the largest possible grain and moderate tillering. The heads of this plant should: be mid-dense to lax, should stand upright on a long peduncle and should be bunched together (the latter the result of a compact, non-spreading crown). The leaves should remain erect or be curled in a spiral shape and the plant should head early but be relatively late in maturity. The roots should remain functional during periods of excessive water application.

Why should these characters be chosen?

Firstly, the seed or sink as it is now called, should be adequate to store all of the elaborated food. Excessive tillering interferes with sunlight penetrance and required food for production of stems; hence greater stress on larger individual heads and grain. Compact heads interfere with seed development. Heads in an upright position and on a long peduncle offer unobstructed photosynthesis on a considerable green area while interfering less with light entering the leaf canopy. The non-spreading crown allows greater light penetration between rows, as does the upright or curled leaf. This penetration of light allows the basal leaves to remain green. Since these leaves have been shown to be responsible for providing nutrition to the roots in rice and some evidence is available for a similar function in wheat, this can prevent the early root senescence that cuts off flow of nutrients and water from the soild to the plant. In addition, an open canopy is less subject to disease and insect attack. Early heading and relatively late maturity provide greater length of time for the plant to develop photosynthate for storage. Similarly, the earlier deposition occurs, the higher the yield at any one time should the plant be subjected to stress by disease or drought.

Under very dry conditions, at the other extreme, a different plant form appears to be successful. The plant appears to be late in maturity; the main tiller forms large grains; other tillers develop leaves but normally do not head; crown should be set deep in the soil;

angle of leaf should be from prostrate at the base moving to upright at the apex of the stem; leaves should be narrow with a limited number of stomate.

Lateness predominates in successful drought resistant varieties in spite of what might be expected. This may reflect the possibility that the late plant can take advantage of temporarily better conditions or a more actively growing root system. The larger grain provides adequate storage without producing more heads. The non-reproductive tillers may be supplying food to the roots and/or the grain developing in the main tiller thus allowing the root to continue its downward growth to moisture reserves. Deep placement of crown favours the development of the secondary root system. After a seed is planted and germination occurs, a crown is formed about 3-4 weeks later. From this crown, root buds appear. If they enter dry soil, there is no further development. Therefore, the deeper the crown is formed, the more chance the buds will enter moist soil resulting in the formation of a secondary root system. Without this, yields will be very low. Genes for deep crown are present in winter wheats. These may be associated also with genes for greater water binding capacity leading to drought resistance of the aerial parts of the plant. Leaves lying prostrate on the ground at the base of the plant will assist in prevention of evaporation during early growth. Upright upper leaves again allow better light penetration. Narrow leaves with few stomata reduce the transpiring surface and are more efficient in water use.

Genes for all of the characters I have outlined exist in our present germplasm pools, but are not present in their entirety in any one variety. I would predict that plants suitable for conditions intermediate between the extremes cited would carry intermediate characteristics for some of these factors.

These are some of the characteristics we are able to see. No doubt many physiologic processes such as enzyme balance, better internal transport of elaborated materials within the plant, more efficient chlorophyll types, and a host of other criteria, will be found to be limiting today's yields.

Certain of these characteristics which I have described for wheat apply equally to the other cereals. Time does not permit dealing with each in turn.

3.1.2 IMPROVING STABILITY OF YIELD

Just as man's crops are a blessing, the diseases and insects which attack them are a curse. The rusts, ubiquitous on all cereals expect rice, are a continuous menace to crop production. The smuts of most cereals, Septoria of barley and wheat, Piricularia of rice and various other destructive diseases continuously and actively attempt to return to a balance with nature that man has bent in his favor. The documents of history point to such recurrent plagues and their disastrous effects on entire populations. Insects viewed as another parasite are part of the same phenomenon.

Probably more research moneys and time have been devoted to the study of these parasitic organisms than to any other part of plant improvement efforts. In spite of this, we have been able to provide only temporary solutions through incorporating genetic resistance. In each disease, resistance has succumbed in our commercial varieties after a varying period of time. In each case the organism has developed a variant capable of overcoming the resistance genes. Various methods have been used, including the placing of several sources of resistance in the variety at the same time and attempting to incorporate the more general type of resistance or tolerance to attack. None of these, thus far, has been entirely successful in the long term.

Another system is present in maize varieties. Because of its out-pollinated character, it has come to an equilibrium with its rust pathogens. For example, some plants in the population are attacked by one race,others by another and so on but intensity of infection is restricted so that large epidemics of the type afflicting wheat rarely or never occur and the effect on yields is of a low order. Such a system does not occur, naturally, in wheat or other small grain cereals except rye, because of their close-pollinated natur In a normal variety the plants are, therefore, all similar in regard to resistance.

A system for wheat designed to simulate that in corn was proposed by Dr. Borlaug and others some years ago. In this system different genes for resistance from many sources are incorporated into a superior variety in separate line. A series of such lines having diverse sources of resistance, but morphologically similar, are then mixed together as a composite variety. In this "multi-line" variety, as it is called, the organism may eventually attack one or two of the component lines. Since the inoculum can only increase on susceptible plants, the mass of spores for further inoculation is restricted in amount, the chances for new variants is reduced, and the crop yield is only partially reduced.

Susceptible components are replaced with other resistant lines as needed. This type of approach is now being pursued for several diseases in the case of one of our most productive and extensively grown varieties.

In the case of insects, losses to wheat stem sawfly, Hessian fly, Sunn pest, corn ear worm, shoofly, stalk borers and virus carrying insect are very significant. It has been found that certain of these insect and mite pests are more easily controlled by chemical than genetic means. For others the reverse is true. Research must continue to pursue ways and means of protecting the crop against these depredations.

In both, diseases and insects, the loss of genetic resistance and development of tolerance to chemicals are identical phenomena. The plant chemical in the cell providing resistance acts in the same way as the chemical applied on the surface. Populations of the parasites are put under pressure and the survivors capable of resisting either become the progenitors of the new generations. No variety of any crop has been produced that has the genetic ability to resist all diseases and insects. To produce it would be exceedingly expensive and its existence only transitory.

The use of chemicals must continue if crops are to be efficiently produced. If we are to eat, a judicious combination of all available methods must be used.

Stability of yield, therefore, is of paramount importance. If we develop varieties with wide adaptation which are able to do well in widely separated geographic areas, the effect of variations in climate from year to year at any one location can be expected to have considerably less effect on yield. Resistance to diseases and insects in such widely-adapted varieties becomes increasingly important. Attacks of these biologic parasites and predators are periodic and cyclical, leading to wide yearly production variations unless resistance is maintained. Increase in yield potential without protection of the manufacturing plant from weather, disease and insect, is no advance but even dangerous.

4.1 AGRONOMIC RESEARCH

Agronomy, as a branch of agricultural science, is given lip service in North America. There are a few, but only a few, true agronomists on this continent. Most of the agronomic work is conducted by soil scientists who very often, although highly trained in their discipline, have minimal training in plant science or the interactions of plants with soils. This has led to a wide schism in research between the two groups.

In certain other countries, agronomy is a special discipline and agronomists are trained for this interaction role alone. It has been my experience that such persons are best able to understand the interrelationships of soils and crops, cultural practices, weed control, plant protection and other factors because they have a foot in several camps.

Agronomy in this sense, therefore, embraces soil science, the use of fertilizers and water, the cultural practices required to conserve moisture, weed control and the overall development of sets of practices for different crops under different conditions. With the true agronomist, the placing together of different crops in rotations designed to maximize yields per hectare per year and the selection of suitable crops for different environmental conditions and fertility regimes, becomes a challenging field rather than an academic exercise.

4.1.1 FERTILIZERS AND SOIL PROBLEMS

In fertility, different moisture regimes require different levels of inputs. Under irrigation or high rainfall, dwarf plant types in most of the cereal crops have responded to high levels of N. whereas the taller plants lodge at such levels. Under low rainfall, moderate levels of N and P_2O_5 have been found to be essential if plants are to become established early and give reasonable yields.

Many soils through long usage or because their parent material is deficient, are devoid of some or all of the major elements. In the subcontinent of India and Pakistan, for example, P_2O_5 is nearly universally deficient and N only present at reasonable levels after legumes or on summerfallow. Potassium, on the other hand, is present in abundance in virtually all of the soils, in some of the Andean soils, P_2O_5 is so deficient that only minimal seedling growth can occur where it is not applied.

Minor elements are again deficient in many significant soil groups throughout the world and must be used if crops are to be grown successfully. In other cases, excess of some elements cause toxicity. In the tropical and subtropical countries cropping is practiced throughout the year. Under such conditions where heavy doses of major elements are used, minor elements may not be supplied from the parent material at a sufficiently rapid rate to supply the succeeding crops. For example, zinc deficiency in India was not recognized earlier. It has now been found a limiting factor over very substantial areas of the north. In Brazil, the acid soils have high levels of free aluminium which are toxic to most wheat varieties. Soil amelioration with lime and development of resistant varieties are raising yield levels in that country. Salt problems afflict very large irrigation projects in different parts of the world. Although attempts have been made to breed for salt-resistant varieties of cereals, yields are relatively low and under such conditions, large scale drainage projects are essential as a permanent solution.

In applying fertilizers it has been found that, in wheat, favourable yield responses are only obtained when the fertility is applied before jointing begins. Any N applied later either by spray or broadcast may increase grain protein level but not yield, except in areas where virtually no N is present. It has also be found that P_2O_5 must be drilled or mixed with the soil at preplanting. Under dryland conditions, deep placement in the soil moisture is desirable for all fertilizer applications.

4.1.2 CULTURAL METHODS FOR MOISTURE CONSERVATION AND WEED CONTROL

Probably more crops are lost each year to weed competition than to any other factor. In very large areas of North Africa and the Middle East where winter cropping is practiced, the normal rotation is wheat-fallow. Unfortunately, in the fallow year, sheep are allowed to pasture the fields after wheat harvest; plowing is delayed until spring. Under this system, non-edible weeds grow unchecked and large quantities of weed seed are deposited on the ground annually. The winter precipatation runs off the unplowed land or is pumped out by deep-rooted weeds. Even after plowing, the land is allowed to remain rough and open to evaporation. The storage of moisture is thus very limited and weeds are not destroyed - the advantage of the fallow year is essentially nullified. As might be predicted, weed growth is heavy in the succeeding crop and should the rains be distributed unevenly, the resulting moisture shortage causes substantial areas to have low yields or fail completely.

Cultural methods designed to conserve moisture and control weeds can, therefore, have a tremendous effect on the increase of yield. Chemical control of certain of the weed species can also be combined successfully with cultural practices to speed up the reduction of weed populations. Another method now being investigated in the Mediterranean region is the annual legume - wheat rotation as presently practiced in South Australia. This has the dual advantage of including animals in the rotation as well as supplying N for the following wheat crop.

In still another way, total yields per hectare per year are advancing rapidly in several countries where year round cropping can be practiced. Thus early maturing wheat varieties, for example, arising from CIMMYT materials, provided a means for effective late sowing of wheat following late-harvested paddy. Similarly, wheat and corn have been put into rotation in several countries. These rotations have moved total cereal production ahead very appreciably in the subcontinent.

These are some of the factors which are now leading toward greater yields.

5.1 CONCLUSIONS

In conclusion, to increase yields throughout the world, several requirements are essential. For most rapid change, the government of the host country requiring assistance must be fully committed and have food deficit as its principal problem. Most governments are short of money. There are innumerable places in which it can be spent. Is it any wonder, therefore, that money is spent on an exigency basis for that which is most urgently required? In our case in point, this applied initially to its desire to place funds in support of production programs, but also to which aspects are first supported within this program. For example, when food imports are high prior to the development of increased production they will not spend money to develop storage facilities in anticipation of need. It is only when storage becomes a limiting factor that moneys will be appropriated. Thus, as the first essential in mounting production programs, I place country need.

The key to success, thereafter lies in reorienting research and building an institutional structure that combines the interdisciplinary play of research coupled with international scientific interchange of ideas, materials and manpower.

The extension service must be activated.

The farmer must be given incentives. This may take the form of providing stable price for the product at remunerative levels within country, irrespective of price levels in international market. Incentive may take the form of subsidies on inputs, but I do not favour this approach personally because of increased bureaucracy and the loss of pride attendant to appearing to receive help from government.

There must be a progressive recognition of the increasing needs of inputs; in the early stages import of fertilizers moving as rapidly as possible to indigenous production; setting up of an adequate seed organization to assure seed availability; increase in marketing, transport and storage facilities; the orderly development of agro-industrial enterprises to supply the increasing demand. As production rises and sufficiency and adequate buffer supplies are achieved, the prices must be monitored and adjusted in such a way that surpluses do not become onerous; acreages must be shifted to other crops but research in those crops must also be fostered early to permit an efficient transition.