Agricultural Research—Progress, Problems and Prospects

BY

M. S. SWAMINATHAN

Indian Agricultural Research Institute, New Delhi

(With four text-figures)

LANDMARKS IN AGRICULTURAL EVOLUTION

Taking world agriculture as a whole, the selection of plants suitable for domestication from the extensive wild flora and their subsequent improvement through conscious or unconscious breeding, the conversion of geological deposits into soils and planned efforts to conserve and provide water to crops have been the major components of progress until the 17th century. The next significant advance came with the introduction of cereal-legume rotations and addition of nutrients in the form of fertilizers in the 18th and 19th centuries. The beginning of this century marked the re-discovery of Mendel's laws of inheritance and the use of the principles of genetics in the tailoring of plants adapted to the changing physico-chemical, biological, technological, economic and social components of the environment. This development in turn triggered rapid progress in industrial activity related to agriculture, particularly those relating to fertilizers, pesticides and other agricultural chemicals, machinery and post-harvest technology. A few of the significant landmarks of this recent evolutionary phase are indicated in Table 1 (adapted from Witwer 1969). Countries which have taken advantage of these scientific developments are today faced with the problem of surpluses of farm and animal produce, while those which neglected them are fighting for food self-sufficiency.

FACTORS CONTRIBUTING TOWARDS COMPARATIVE STAGNATION IN AGRICULTURAL PRODUCTIVITY IN INDIA

During the first half of this century more and more food and milk were being produced respectively from less and less land and cow population in several countries of the world. In contrast, productivity remained stagnant in many of our important food crops during this period, although a rise in total production occurred due to an increase in the area both under cultivation and under irrigation. Organised

TABLE 1

SOME SIGNIFICANT MILESTONES IN AGRICULTURAL ADVANCE IN THE 20TH CENTURY

Milestone	Approximate year of widespread use
Hybrid Maize ..	1933
Chlorinated hydrocarbons for insect control ..	1945
Minimum tillage ..	1945
Foliar feeding ..	1945
Direct application of anhydrous ammonia ..	1947
Hybrid Sorghum ..	1957
Chemical weed control ..	1958
Systemic biocides ..	1959
Dwarf wheat ..	1961
Dwarf rice ..	1965
Opaque-2 Maize ..	1965
Gossypol-free cotton seed ..	1969
Hybrid barley ..	1969

scientific efforts in agriculture began with the establishment of the Indian Agricultural Research Institute in 1905 at Pusa in Bihar Research, however, did not make an appreciable impact on production except in crops like sugarcane, largely due to the absence of the developmental substrate essential for research results to strike roots. Research, particularly in the fields of plant breeding and plant protection, did, however, help to minimise the fluctuations in production, excepting those caused by the weather, in crops like wheat and rice. Developments in the post-independence era such as the initiation of the Community Development programme, national extension net-work, irrigation projects, fertilizer factories, and finally the Intensive Agriculture District programme provided the stimulus for a radical reorientation of agricultural research policies and goals. The High-yielding Varieties programme and the National Demonstration programme generated the feed-back relationship between agricultural scientists on the one hand and extension agencies and farmers on the other, which is vital for a dynamic research programme.

REORIENTATION OF RESEARCH GOALS

Half of a scientist's difficulties are over once the problem needing solution is clearly formulated. The widespread awareness now in evidence of the role of science in promoting agrarian prosperity has in turn led to a re-examination and reorientation of research programmes. For example, the following are some of the major research goals in cross breeding set for themselves by the scientists of the Indian Agricultural Research Institute:

(*a*) Enhancement of the content of oral contraceptive principles like Diosgenin present in some plants, so as to help in population control programme.

(*b*) Combining yield with the genetic upgrading of the quality and quantity of proteins present in cereals, pulses, tuber crops and other food as well as fodder and feed crops, so as to contribute towards the elimination of protein-calorie malnutrition.

(*c*) Development of varieties suitable for increasing the income and employment potential of farms of small size through a series of multiple and mixed cropping systems, based on choices and alternatives from an economic standpoint and on sound principles of ecology from the scientific standpoint.

(*d*) Achieving stability of production as well as improvement in yield in areas characterised by low and uncertain rainfall and adverse environmental problems such as flood or alkalinity or salinity.

(*e*) Development of strains in the major agricultural and horticultural plants which would help to achieve the yield potential theoretically possible under a given environment.

(*f*) Breeding varieties of crops which can stimulate the development of industries in areas characterised by poverty and population pressure, such as the monoculture rice belts.

(*g*) Upgrading the quality and yield of industrial crops such as fibre, sugar and oilseed crops.

(*h*) Development and use of genetic techniques for accelerating the pace of breeding for better yield and quality in perennial crops such as fruit and forest trees, plantation crops such as tea, coffee, rubber and pepper, and palms like coconut and arecanut.

(*i*) Tailoring varieties in appropriate plants to the specifications of the food industry and of the export market.

(*j*) Collection and conservation of gene pools.

Development of high-yielding varieties

Exploitation of F_1 hybrid vigour as in mainze, *Sorghum* and pearl millet, the introduction of a plant type possessing a dwarf and non-lodging habit and photo-insensitivity as in wheat and rice and population improvement procedures as in maize and *Sorghum* have been the major genetic mechanisms employed so far in developing crop varieties which respond well to good soil fertility and management. In many of the currently available high-yielding varieties, the total dry matter production is similar to that of the earlier tall varieties, but the harvest index (i.e., the ratio of grain to total dry matter) is far better resulting in higher yield. A further improvement in yield potential can come about if a substantial improvement in total dry matter production together with a high harvest index can be achieved. For achieving this, conceptual models of different crop plants (termed 'ideotype' by Donald 1968) based on a synthesis of knowledge from morphology, physiology, biochemistry, climatology, ecology and pathology would have to be constructed and used in plant breeding programmes

Some of the selection criteria that will form the basis for the development of new varieties in the future are given in Table 2. In

TABLE 2

CHARACTERISTICS OF CROP IDEOTYPES

1. Hybrid vigour or additive gene action.
2. Early Maturity.
3. High photosynthetic ability.
4. Low photorespiration.
5. Photo-insensitivity.
6. High response to nutrients.
7. Multiple resistance to insects and diseases.
8. Better protein quantity and quality.
9. Synchronised development of inflorescences.
10. Crop canopies that can retain and fix a maximum of CO_2.

our country endowed with abundant sunlight, a major criterion of new varieties should be improved phytosynthetic capability, which can be achieved through selection of plants having better light-receiving systems, leaf surface characteristics most conducive to CO_2 uptake, low perogisome or CO_2—phororespiration and low CO_2 compensation points. The ideotypes drawn up for wheat by Donald (1968) and Asana (1970) are given in Fig. 1.

HOW HIGH CAN BE THE YIELD OF HIGH-YIELDING VARIETIES?

During a 12-hour day length, about 500 calories/Cm^2 of radiation are received on earth. Of this, only 222 Calories/Cm^2 are in the visible part of the light spectrum and thus useful for photosynthesis. If all this energy is converted into dry matter by plants, 77 g/m^2/day can be obtained, which is equivalent to 770 Kg/ha/day (Loomis, Williams & Duncan 1967). Theoretically, therefore, there is a possibility of producing 281.0 tonnes/ha. of dry matter during a year, provided the photosynthetic rate is not limited by other factors like carbon dioxide, water and nutrition. If a harvest index of 0.5 can be reached, we can get an economic yield of about 140·5 tonnes per hectare per year. The potential yield per day, the highest yield obtained in any National demonstration or trial and the average yield of some of the major cereals, millets, pulses, oilseeds and tuber crops are indicated in Figs. 2 to 4. The data used for constructing these figures are given in Table 3. It would be obvious from this data that while we work towards realising the theoretical potential, we have a long way to go before our average yield attains a respectable relation-

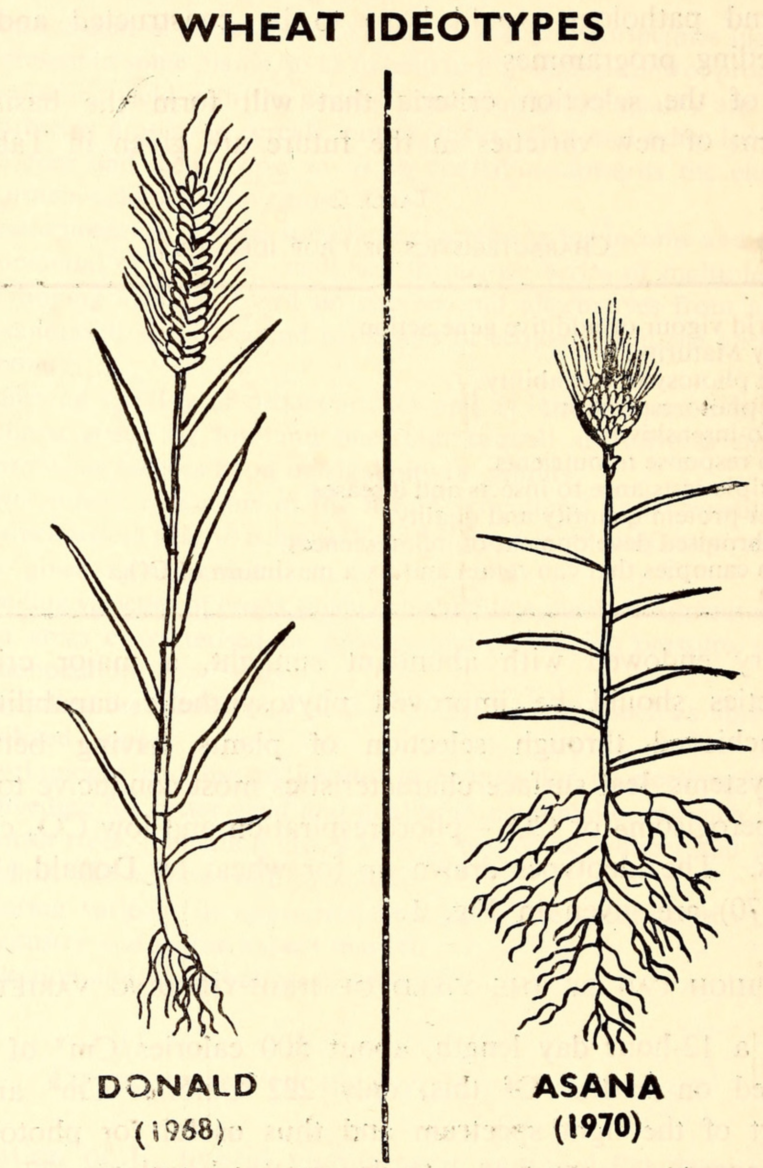

FIG. 1. Conceptual models of the wheat plant developed by Donald (1968) for maximum production and by Asana (1970) for unirrigated conditions. Donald has suggested a uniculm habit with leaves which will not shade each other, while Asana has proposed horizontal leaves for intercepting and retaining dew, a branched ear and a deep root system. Such ideotypes are based on considerable research in production physiology.

ship with the highest yield already reached in the country. The potential for the future is immense, since the maximum yield of the economic product obtained so far in any multiple cropping system is only about 20 tonnes per hectare per year in contrast to the theoretical possibility of about 140 tonnes/ha/year. The scope for research on enhancing the production potential is particularly great in pulses, oilseeds and tuber crops (Figs. 3 & 4).

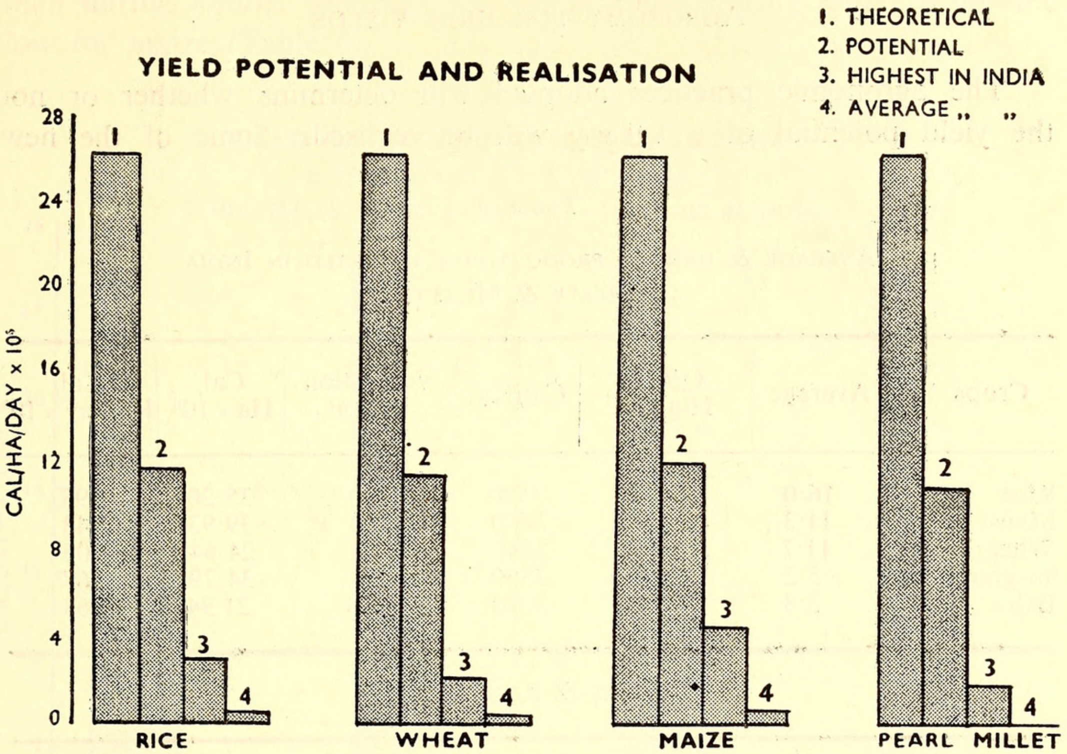

FIG. 2. The actual and potential yields in rice, wheat, maize and pearl millet.

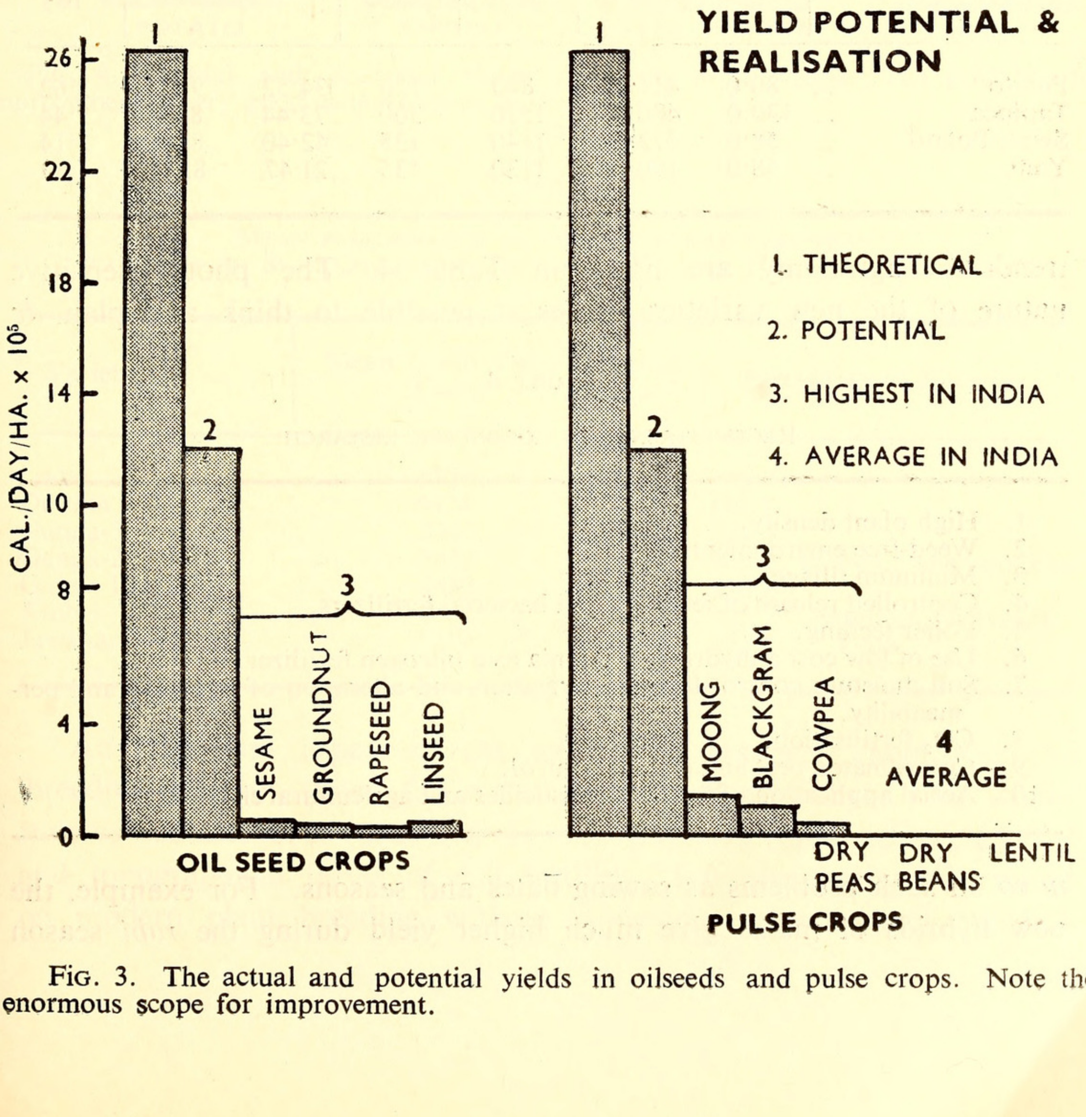

FIG. 3. The actual and potential yields in oilseeds and pulse crops. Note the enormous scope for improvement.

Agronomy for high yields

The agronomic practices adopted will determine whether or not the yield potential of a variety will be realised. Some of the new

Table 3

Average & highest productivity reported in India
Cereals & Millets

Crops	Average	Q/Ha. Highest	Cal/Kg.	Vegetation Period	Cal/ Ha × 10^6	Cal/ Ha/day × 10^5
Rice ..	16·0	100·00	3520	120	35·20	2·93
Maize ..	11·3	110·00	3630	90	39·93	4·43
Wheat ..	11·7	71·63	3440	120	24·64	2·05
Sorghum ..	5·2	98·00	3550	130	34·79	2·67
Bajra ..	3·8	67·10	3270	130	21·94	1·68

Tuber & Root Crops

Crops	Av.	Q/Ha. Highest	Cal/Kg.	Veg. Period	Cal/Ha × 10^6	Edible	Cal/Ha Day × 10^5
Potato ..	80·0	411·00	840	120	34·52	95%	2·62
Tapioca ..	130·0	480·00	1530	300	73·44	85%	2·44
Sweet-Potato ..	58·0	372·00	1140	135	42·40	85%	3·14
Yam ..	58·0	190·00	1130	135	21·47	85%	1·59

trends in agronomy are listed in Table 4. The photo-insensitive nature of the new varieties makes it possible to think and plan *de*

Table 4

Recent trends in agronomic research

1. High plant density.
2. Weed-free environments.
3. Minimum tillage.
4. Controlled release of fertilizer and bacterial fertilizers.
5. Foliar feeding.
6. Use of low cost anhydrous ammonia as a nitrogen fertilizer.
7. Soil moisture control through irrigation and alteration of structure and permeability.
8. CO_2 fertilisation.
9. Co-ordinated pest and disease control.
10. Aerial application of fertilizer, pesticides and agricultural chemicals.

novo on such problems as sowing dates and seasons. For example, the new hybrids of maize give much higher yield during the *rabi* season than during *kharif*, wherever the temperatures during *rabi* are not too low for maize (Table 5).

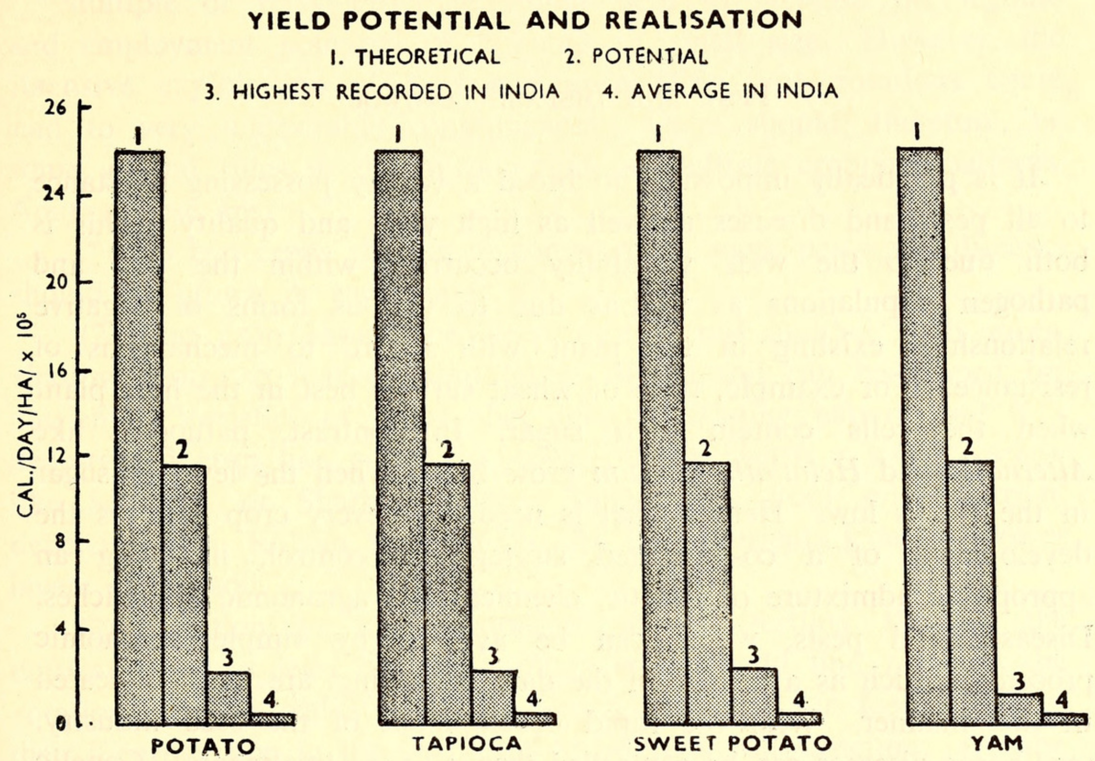

FIG. 4. Actual and potential yields in some tuber crops. The potential for improvement is very great in these crops also.

TABLE 5

MEAN PERFORMANCE OF CERTAIN MAIZE VARIETIES DURING RABI & KHARIF SEASON OF 1965, 1966 AND 1968 AT HYDERABAD

Variety	Mean Grain Yield Kg./Ha *Kharif*	*Rabi*	Percentage of Kharif	
Local ..	5359	5181	96·7	
Deccan ..	5624	7848	139·5	
Ganga-3 ..	5745	7169	124·7	
Ganga-2 ..	5642	5937	105·2	Based on one year data
Ganga 101 ..	4632	5872	126·8	Based on two years Data
Amber ..	4881	8577	175·7	
Jawahar ..	5219	8280	158·7	

An important aspect of the agronomic practices should be the 'breeding' of soils suited for sustained high productivity. This would involve simultaneous attention to the physical, biological, chemical and topographical facets of soil fertility. Intensive agriculture based on modern plant breeding without coincident steps in soil breeding would result ultimately in agricultural disaster than agricultural progress. Unfortunately, there has been little realisation of this position so far.

Pest and disease control

It is practically impossible to breed a variety possessing resistance to all pests and diseases as well as high yield and quality. This is both due to the wide variability occurring within the pest and pathogen populations as well as due to various forms of negative relationships existing in the plant with regard to mechanisms of resistance. For example, rusts of wheat survive best in the host plant when the cells contain high sugar. In contrast, pathogens like *Alternaria* and *Helminthosporium* grow better when the level of sugar in the cell is low. Hence, what is needed in every crop plant is the development of a co-ordinated strategy of control, involving an appropriate admixture of genetic, chemical and agronomic approaches. Diseases and pests, which can be avoided by simple agronomic procedures such as a change in the date of sowing, are best eradicated in this manner. With the rapid development of the seed industry, seed-borne diseases can be controlled through seed treatments. Genetic control will be the method of choice, where usable sources of resistance are readily available and where a disease or pest is very widespread in its occurrence. The approaches likely to give the best

Table 6

Co-ordinated disease & pest control in *Sorghum vulgare*

Disease/pest	Casual Agent	Strategy of Control		
		Genetic	Chemical	Agronomic
Sugary disease	*Sphacelia sorghi*	—	+	+
Downy mildew	*Sclerospora sorghi*	+	—	+
Grain smut	*Sphacelotheca sorghi*	—	+	—
Loose smut	*Sphacelotheca cruenta*	—	+	—
Leaf rust	*Puccinia purpuria*	+	+	—
Leaf blight	*Helminthosporium turcicum*	+	—	—
Shoot fly	*Atherigona varia soccata*	—	+	+
Stemborer	*Chilo zonellus*	+	+	—
Midge	*Contarinia sorghicola*	—	+	+

results in *Sorghum* are indicated in Table 6. Such exercises will have to be done in each crop.

Development of an ecology-cum-economics based multiple cropping 'Cafeteria' system

Multiple or relay cropping would help to increase the income and employment potential of holdings of small size. However, the intensive exploitation of land and unscientific crop rotations could lead to very undesirable consequences. There should, therefore, be some ground rules in the introduction of multiple cropping patterns. Among these are:

(1) No two crops sharing in common the same pests and diseases should be grown in succession.

(2) One crop should be deep rooted and another with more shallow roots, so that different layers of the soil can be tapped for nutrients. Varieties of crops also differ in rooting pattern and if a deep-rooted crop like cotton is grown during *kharif*, a wheat variety like Sonalika or Sharbati Sonora suffers less from micro-nutrient deficiency than Kalyan Sona which also taps nutrients from the lower layers of the soil.

(3) Attention to the restoration of soil fertility through the cultivation of at least one leguminous crop should find place in the rotation. If the stalks of maize are not needed for feeding cattle, their incorporation in the soil helps to improve soil structure. On the above lines we should evolve for each agro-climatic areas, a multiple cropping 'Cafeteria' with a wide choice of alternative crops from which the farmer can choose an appropriate combination suited to his needs and input-mobilizing potential and the demands of the market (Table 7).

Table 7

Breeding varieties for a multiple cropping 'cafetaria' at Delhi

Mid-April/Mid-June	Late June-Sept.	October-December	Late December/ Mid-April
Green Gram (Pusa Baisakhi)	*Maize* (Ganga-5 Jawahar Hi-Starch)	*Potato* (Kufri Alankar Kufri Chamatkar)	*Wheat* (Sharbati Sonora, Sonalika)
Cow Pea (Phalaguni)	*Sorghum* (C.S.H.1)	*Vegetables* *Mustard* (Suphala DS-17 M)	*Barley* (K 15/96-1, BDH-4)
	Pearl Millet (H.B.1, H.B.4)		*Oats* (Kent Early Russian)
	Cotton, Fodder Crops Rice (B.C.5 and B.C.6)		*Vegetables*

Multiple cropping is a very potent instrument for improving the economic position of a farmer with a small holding and for banishing under-employment and unemployment. Studies in the Agricultural Economics Department of the Punjab Agricultural University have clearly shown that the employment potential of agriculture can be greatly enhanced by double cropping in lands with irrigation facilities. Studies have also revealed that in the Ludhiana District, there has been an appreciable increase in real income among all classes of farmers, big, medium and small, as well as among landless labour. This is not true in many other I.A.D.P. districts where the farming technology has not become as advanced as in the Punjab. In as much as 69 per cent of our work-force will depend upon agriculture for employment even by 1981, the social significance of a technological upgrading of the employment potential of our cropping systems is obvious.

In addition to the economic and sociological advantages of multiple cropping in irrigated areas this tool, if deployed scientifically, can also become a powerful method of minimising the incidence of pests and diseases. Examples of a multiple cropping system based only on economic considerations and of one on the ecology-cum-economics concept and analyse their biological implications follow. With water becoming available in many of the River Valley Projects, there is a great temptation to grow two or three crops of rice one after the other. Even in summer, paddy cultivation is becoming popular but already it is clear that where summer paddy is grown pests like jassids become serious in the succeeding *kharif* paddy crop, as was observed in parts of Bihar last year. Conversely, in some parts of Bihar where a mono-culture of tobacco was formerly adopted there was a serious incidence of *orabanche*. When tobacco was introduced into a multiple cropping system involving crops like wheat and maize, the *orabanche* menace began to reccede.

Enhancing the yield and income of unirrigated agriculture

Recent research has shown that apart from the limitations imposed by low and uncertain moisture levels, the missing links in elevating and stabilizing yields of rainfed agriculture have been the non-availability of crop varieties of suitable duration and growth rhythm, poor plant population, absence of attention to rectifying the defects in soil structure, improper tillage, lack of application of nutrients and plant protection procedures and poor storage and marketing. In addition, problems like fragmentation of holdings and lack of organised supply of inputs made the few steps taken in the past in the field of soil and moisture conservation even less effective than they might have otherwise been.

Much progress can be achieved in rainfed farming if a new technology is introduced, comprising of the following components: (1) land consolidation and soil conservation, (2) improvements in tillage leading to better soil structure and root penetration, (3) addition of organic matter in the form of plant residues with a view to improving the physical and biological characteristics of the soil, (4) adoption of water-harvesting procedures resulting in storing as much of the precipitation as possible for the use of crops, (5) addition of plant nutrients through deep placement of fertilizers and foliar feeding, if necessary by aircraft, (6) improving the biological fixation of nitrogen through the use of efficient strains of rhizobia, particularly those which are tolerant to salt and use of pelleted bacterial cultures for buffering the bacteria against acidity and alkalinity, (7) the introduction of photo-insensitive and quick maturing crops which are less affected by drought, (8) replacement of a single long duration crop with a series of double and mixed crop rotations from which the farmer can be advised to adopt the one which is most suited to the likely weather pattern during a season and to giving him the maximum income, (9) popularisation of crops like Soyabean, high-protein maize, macaroni wheat, short-duration varieties of castor and cotton and perennial crops like cashewnut, oil palm and dates which can form the base for small scale food industries and export earnings, (10) popularisation of high-yielding fodder grasses and high protein bajra, and (11) genetic upgrading of the non-descript cattle population by an extensive programme of artificial insemination using superior breeds particularly European breeds, acclimatised in the tropical parts of Australia. While the above would constitute the major ingredients of an immediate action plan, a systematic survey and development of ground water resources should be continued so as to further increase the income potential of agriculture in the dry areas. A book entitled A NEW TECHNOLOGY FOR DRY LAND FARMING has been published recently by the Indian Agricultural Research Institute, which gives details of the research carried out in this field.

BANISHING MALNUTRITION

The major contributions of agricultural research in this field are the following:

(a) *Genetic upgrading of protein quality in staple grains:*

It is now possible to upgrade the quality of proteins in cereals, millets and other food crops very considerably by genetic techniques.

Composite varieties of maize possessing protein properties nearly similar to that of milk are now under multiplication (Table 8). High protein varieties of rice and wheat as well as a highly nutritive new cereal, *Triticale*, are under development. A great merit of this approach is

TABLE 8

IMPROVEMENT OF THE AMINO-ACID COMPOSITION OF MAIZE BY THE INCORPORATION OF OPAQUE-2 & FLOURY-2 GENES OF AMINO-ACID/100g. PROTEIN

	Ganga-3	Yellow Opaque-2	Yellow Floury-2	White Opaque-2
Protein% ..	10·3	10·6	11·6	11·5
Glutamic Acid ..	23·3	20·6	19·9	18·3
Lysine ..	1·6	3·5	4·1	4·2
Leucine ..	17·2	11·4	11·6	10·7
Isoleucine ..	3·9	4·0	3·6	4·3

that a dent on the malnutrition problem can be easily made without any special educational effort.

(b) *Increasing the production of pulse crops:*

New short-duration and high-yielding varieties of the major pulse crops such as *Cajanus cajan, Phaseolus aureus* and *Phaseolus mungo* have been developed, so that pulse crops can find a place in the rotations in irrigated areas. Much of the area under pulses is rain-fed and for these areas both better varieties and suitable methods of applying rhizobial cultures have been developed.

(c) *Increasing vegetable and fruit production:*

These crops have received very little scientific attention so far. In recent years, several new varieties and hybrids have been developed and released in vegetable crops. If these are grown with an integrated schedule of pest control, the production can go up substantially. Research on fruit tree improvement through the development of good rootstock, new varieties and better management practices is now receiving serious attention. The new mango varieties developed at IARI offer great promise. A Demonstration orchard with plants raised on dwarfing root stocks and dwarf hybrid varieties is being developed at the IARI to show how the new plant type can facilitate good orchard management. Though the demonstration plot has been named 'Orchard of the 21st Century', it is hoped that such orchards will become common in our country by 1980.

(d) *Increasing animal production:*

It is well known that India is the largest reservoir of under-utilised cows in the world. The problem of improving animal productivity has two aspects, one relating to increasing the production of fodder and feed and the other to the genetic upgrading of the milk-yielding potential of our breeds and more particularly of non-descript cows and buffaloes. With regard to the fodder problem, the main emphasis should be on the development of high-yielding-cum-high quality fodder crops, so that the supply of concentrates to animals, becomes unnecessary. Maize and millets should also be increasingly used as animal feeds.

A new approach to the rapid genetic upgrading of the milk yielding potential of cows is the use of 'tropicalised' versions of European breeds in our artificial insemination programmes. The value of this approach has become apparent from the results of the cross-breeding experiments carried out at IARI between Sahiwals and Friesians from Australia. India should sponsor a Collecting Team of Animal Genetics to the tropical parts of Australia, Latin America and Africa, for collecting European breeds introduced 2 to 3 centuries ago and which have undergone selection for adaptation to tropical climate. The expense involved in sending such a 'Tropicalised European breed Collecting Expedition' will result in a big pay-off.

Need for exploiting synergetic interactions

If agricultural research is to be effective in canalising the powerful tools of modern science for eradicating hunger and poverty, the most important need is achieving synergetic interactions among scientists working in different disciplines on the one hand and among scientists, extension workers and political and administrative leaders on the other. Synergy or the mechanism which makes the whole something very much more than the sum of the parts, has been the most potent principle involved in evolutionary advance and is the only mechanism which can help a poor Nation to realise its economic aspirations. To cite one example of the use of this principle in evolution, our important cereal, breed wheat, has three parents, *Triticum monococcum*, *Aegilops speltoides* and *Aegilops squarrosa* which are individually poor plants but collectively make the king of cereals. Harnessing and maximising such synergetic effects should be the primary goals of our agricultural research and development policies.

ACKNOWLEDGEMENTS

The data in Figures 2, 3, & 4 were constructed with the help of Dr. S. K. Sinha, Plant Physiologist, IARI. Data on the seasonal influence on maize yield are from All-India Co-ordinated Trials, while the data on amino-acid content in maize were provided by the Quality Laboratory of IARI headed by Dr. A. Austin.

REFERENCES

ASANA, R. D. (1970) : A New Technology for Dry Land Farming—*Indian Agricultural Research Institute, New Delhi.* pp. 55-63.

DONALD, C. M. (1968) : The design of a wheat ideotype. *Proc. 3rd International Wheat Genetics Symposium, Canberra.* pp. 377-387.

LOOMIS, R. S., WILLIAMS, A. W. & DUNCAN, W. G. (1967) : Community Architecture and the productivity of terrestrial plant communities. In harvesting the Sun, Photosynthesis in Plant Life. pp. 291-308.

WITWER, S. H. (1969) : Agriculture for the 21st Century. Proc. 19th Annual National Potato Utilization Conference, Michigan. (In Press).