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THE DEVELOPMENT AND ADOPTION

of

PRODUCTION TECHNOLOGY

by

M. B. Russell and G. K. Brinegar

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I. INTRODUCTION

The authors were engaged as consultants to AID Mission, India, for a short period, to provide assistance to the Mission in their development of a study entitled "Long-Range Agricultural Adjustment Analysis." The part of the Mission study this report deals with, as a primary concern, centers upon (1) the Indian resource base and potential for food and fiber production and (2) the flow of "on the farm" agricultural technology. Secondary attention is focused upon (3) problems and concerns in optimizing the adoption of agriculturally useful technology and (4) policy implications.

The authors start with the assumption, which they believe to be correct, that the food problem in India is manageable, if population growth levels out by the turn of the century and if but even a small percent of the very able and highly skilled manpower of India has the opportunity to effectively work on and to determine an agricultural policy directed toward increasing Indian food and fiber supply.

This report is divided into several parts. The production potential of India is considered and discussed by soil regions. The level of aggregation used in this study reflected the resources and time available for the study as well as the questions to which answers were sought.

The next section of the report is directed toward identifying the technologies and groups of technologies which can increase food and fiber production both in the near and more distant future. The technologies examined are related to crops, geographical areas of like ecological characteristics and crop rotation systems. In the first go-around a loose concept of "normal and constant" price ratios of inputs and outputs is assumed.

Section IV is directed toward problems and concerns in optimizing the adoption of agriculturally useful technology and spills over into the input and output markets and industries sometimes identified as agri-business. In Section IV the outlook for the likely flow of agriculturally useful technology is evaluated first. Attention is then directed toward the geographical specialization and location of agriculture. Lastly, a number of adjustment problems are examined.

In the concluding section, consideration is directed toward policy implications.

II. THE NATURAL RESOURCE BASE FOR CROP PRODUCTION

The soils and climate of India constitute a resource base, which if properly developed and wisely managed, is capable of supporting levels of production that will meet the nation's food needs for the predictable future. For most of the country, temperature and day length place little or no constraint on plant growth during any season. On the other hand, rainfall is highly seasonal and varies widely in quantity in different parts of India.

The soil serves as a "staging area" for the water and nutrients required by living plants. Soils differ widely in their inherent capacity to perform these functions and it is often necessary to introduce management practices to correct sub-optimum levels of nutrients, improper drainage or physical conditions that impede root development or to supplement the natural soil moisture supply with irrigation.

The Water Supply for Agricultural Production

The basic strategy of water management for maximum agricultural production is to balance for the maximum length of time the supply of water available in the rooting zone with the evapotranspiration demands of the crop. Since the latter is largely a temperature dependent parameter, it exhibits pronounced seasonality in India and is markedly out of phase with the highlyly seasonal distribution of rainfall. Characteristically the water supply equals or exceeds crop demands during some or all of the monsoon season. For the remainder of the year however the evapotranspiration exceeds the precipitation. During the latter period the growing crop is dependent on soil moisture stored in the root zone. It is clear therefore that the capacity of the soil to store water and the depth to which plant roots can penetrate to exploit that reservoir are important factors influencing agricultural water management. When the amount of available water from incident rainfall that can be stored in the root zone is insufficient to meet crop needs, additional water in the form of irrigation is required.

The geographic distribution of annual rainfall, annual potential evapotranspiration and the ratio between them is shown in Figures 1 - 3. From those figures it is clear that except for areas in Assam, Bihar, West Bengal, Madhya Pradesh, the Malabar coast and in the mountains the average annual potential evapotranspiration exceeds the average annual

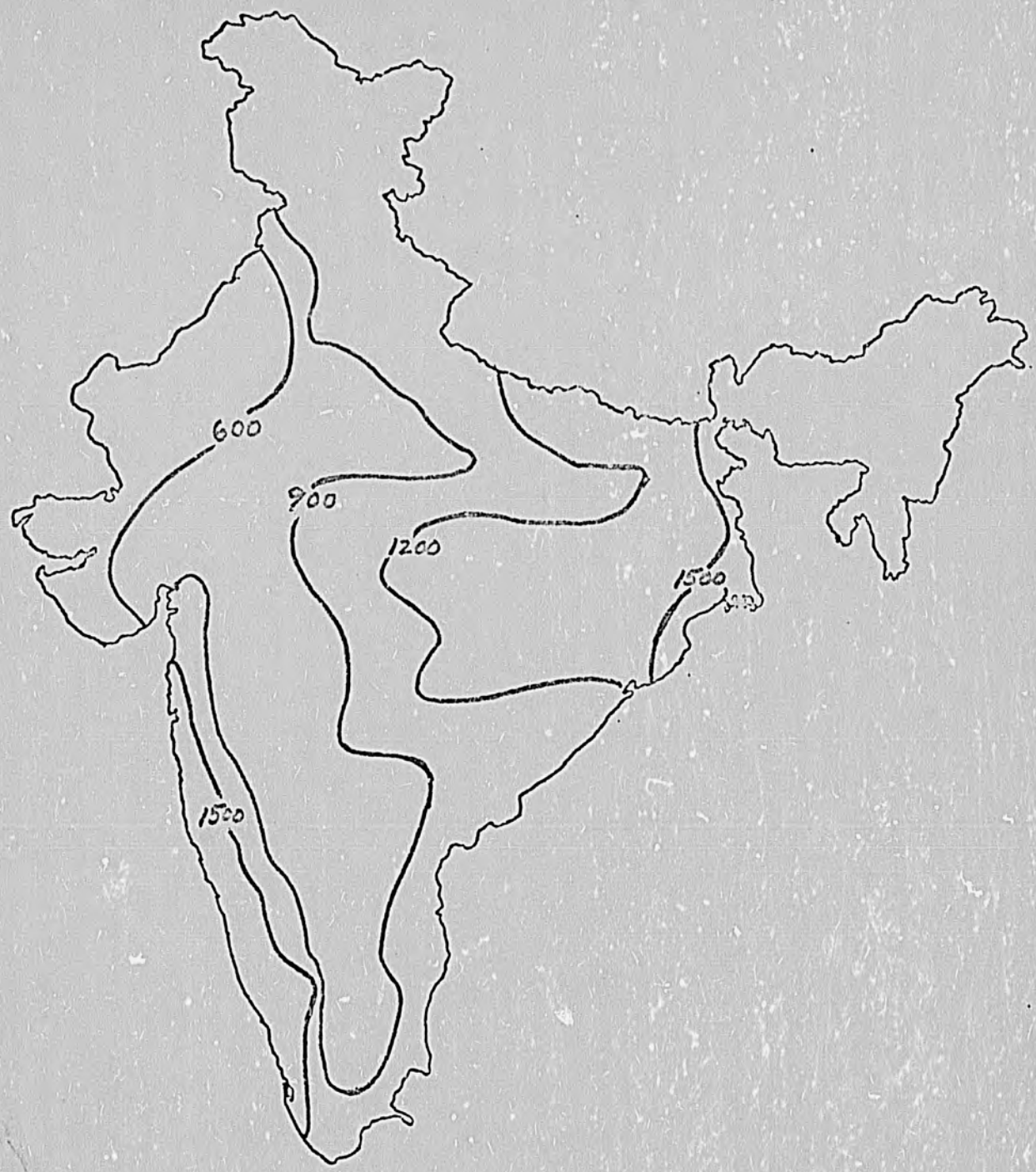


FIGURE 1 -- Annual Precipitation (mm)

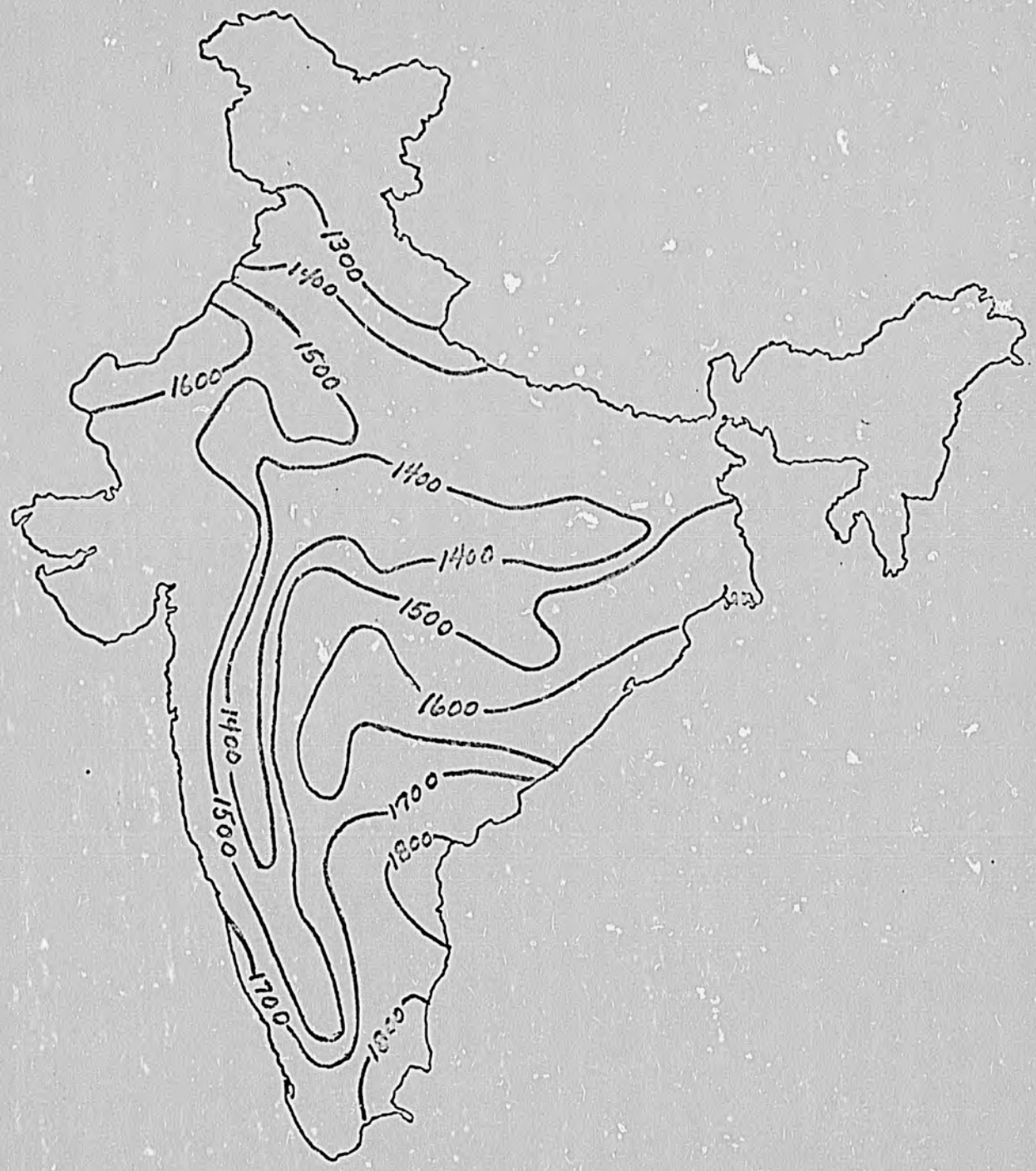


FIGURE 2 -- Annual Potential Evapotranspiration (mm)

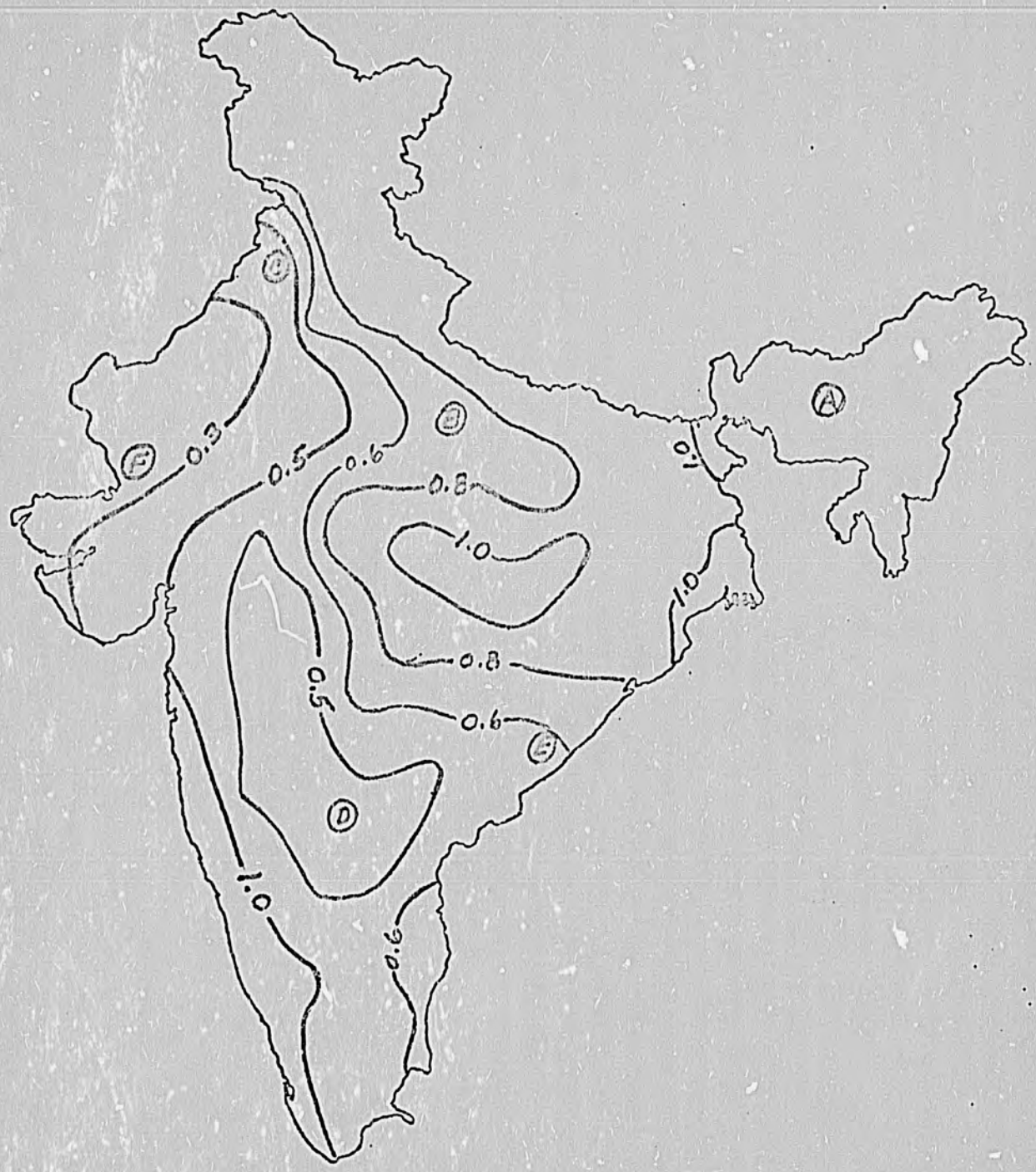


FIGURE 3 -- The ratio of rainfall to potential evapotranspiration.
(Letters refer to curves in Figure 4)

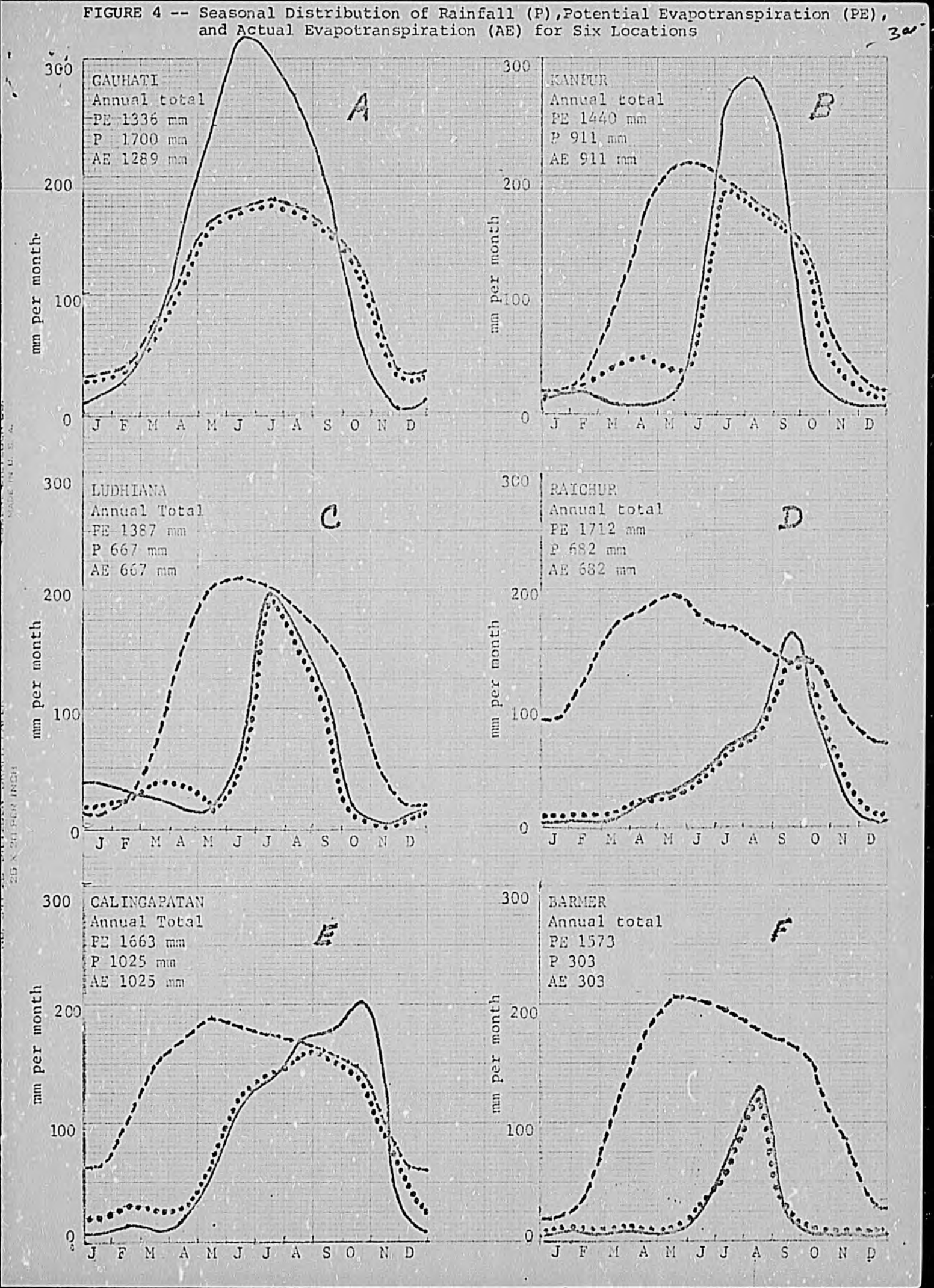
rainfall. This indicates that for most of India it is not possible to meet fully the 12-month evaporative demand of cultivated areas even if it were technically possible to retain on each hectare of such areas all of the rain that falls on it. To meet the crop needs beyond those supplied by indigenous rainfall, it is necessary to supplement the latter with run-off water from other non-agricultural areas. Such "foreign" water may be retained in surface storage reservoirs, in underground aquifers, or may be supplied to the area of use from perennial streams flowing from the catchment area. The more complete utilization for agricultural production of both the rainfall that falls on cultivated area and foreign water from those parts of catchment areas that are not suited for intensive crop production is clearly a problem of paramount importance in programs designed to increase agricultural production in India.

Although the total supply and total potential demand figures are useful in analyzing the limiting physical possibilities of regions for crop production, it is the comparative seasonal distribution of water supply and demand that largely dictate the ways in which regions can be utilized. In Figure 4 are shown the seasonal distribution of rainfall (P), potential evapotranspiration (PE) and the calculated actual evapotranspiration (AE) for six stations whose locations are indicated on Figure 3. The actual evapotranspiration is calculated on the assumption that the soil has a moisture storage capacity of 300 mm and that the actual evapotranspiration will fall below the potential in direct proportion to the fractional depletion of the soil moisture supply. The data in Figure 4 show that the actual evapotranspiration falls far below the potential for several months at five of the six stations. Using similar data from 145 Indian weather stations below 1500 meters elevation, an analysis was made of the seasonal distribution of the $\frac{AE}{PE}$ ratio. The results of this analysis are shown in Figures 5 and 6.

The data show that current rainfall and profile stored water are usually sufficient to meet crop needs for a kharif crop, may be adequate also to meet the requirements for a rabi crop, but only in limited areas are they also sufficient for the high water demands of crops produced in the hot, dry zaid season.

If the PE and P for the latter season (April, May and June) are subtracted from the annual PE and P values, one obtains the potential water

FIGURE 4 -- Seasonal Distribution of Rainfall (P), Potential Evapotranspiration (PE), and Actual Evapotranspiration (AE) for Six Locations



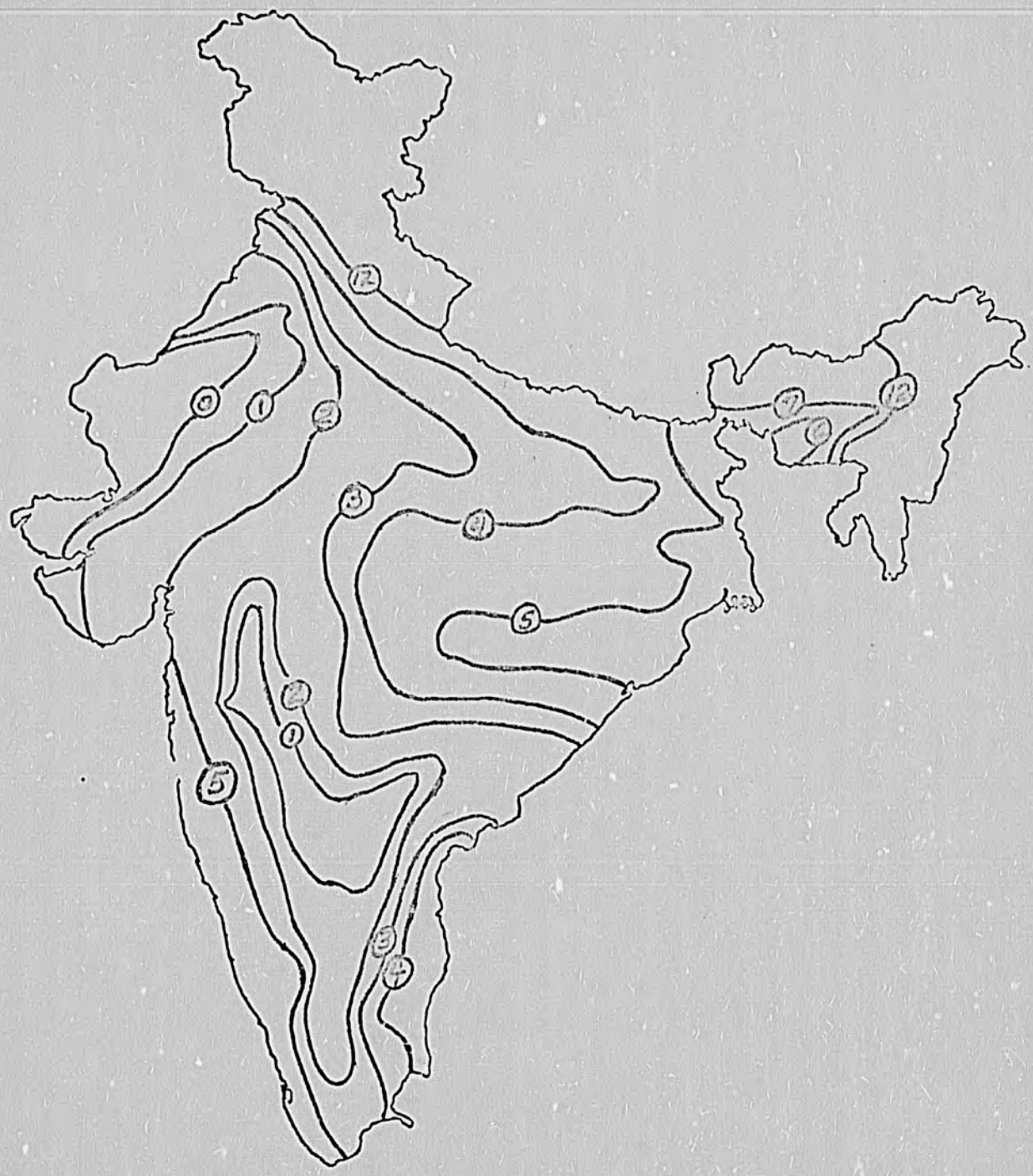


FIGURE 5 -- The number of consecutive months for which the ratio of actual to potential evapotranspiration is >0.90.

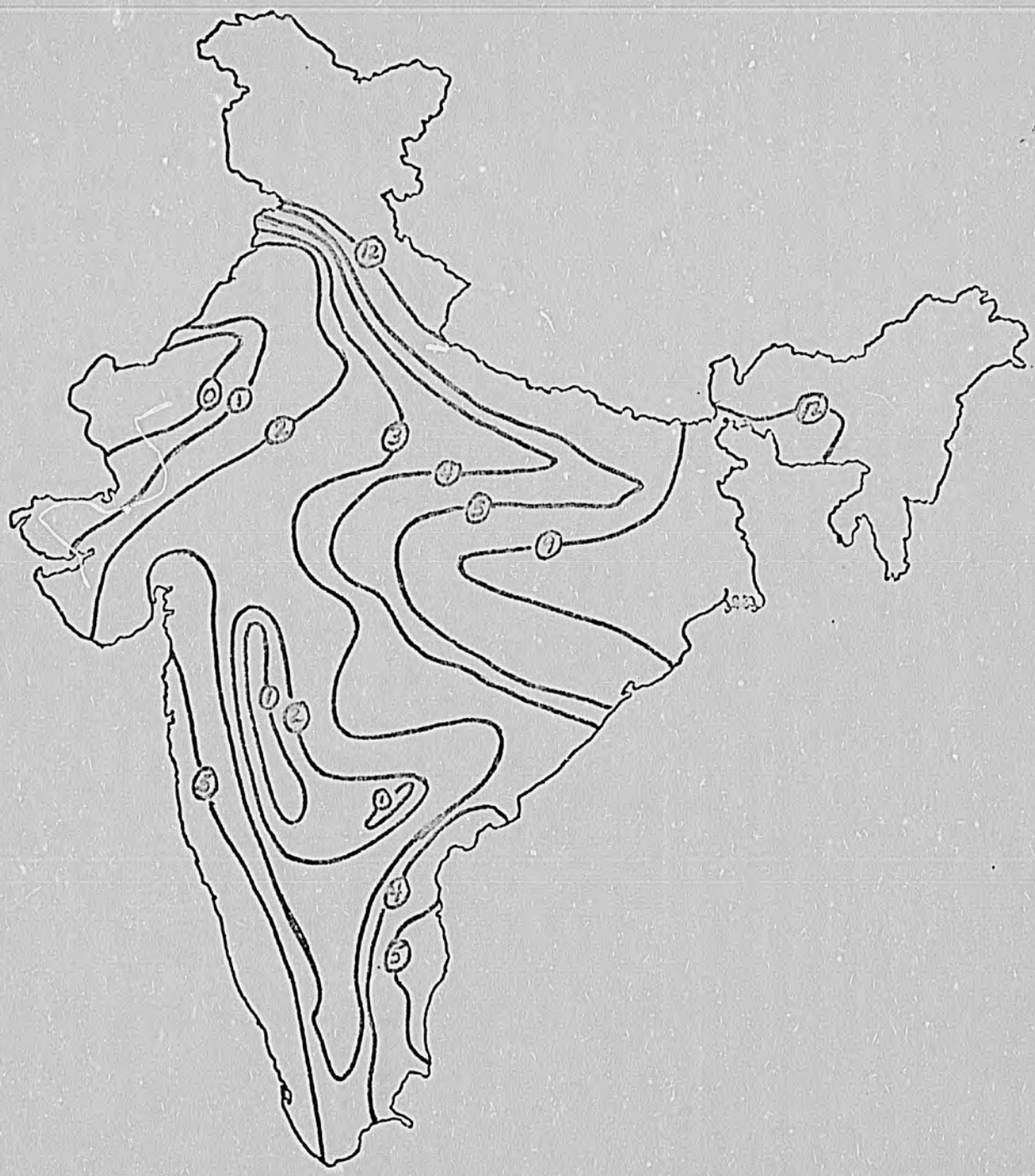


FIGURE 6 -- The number of consecutive months for which the ratio of actual to potential evapotranspiration is 0.75.

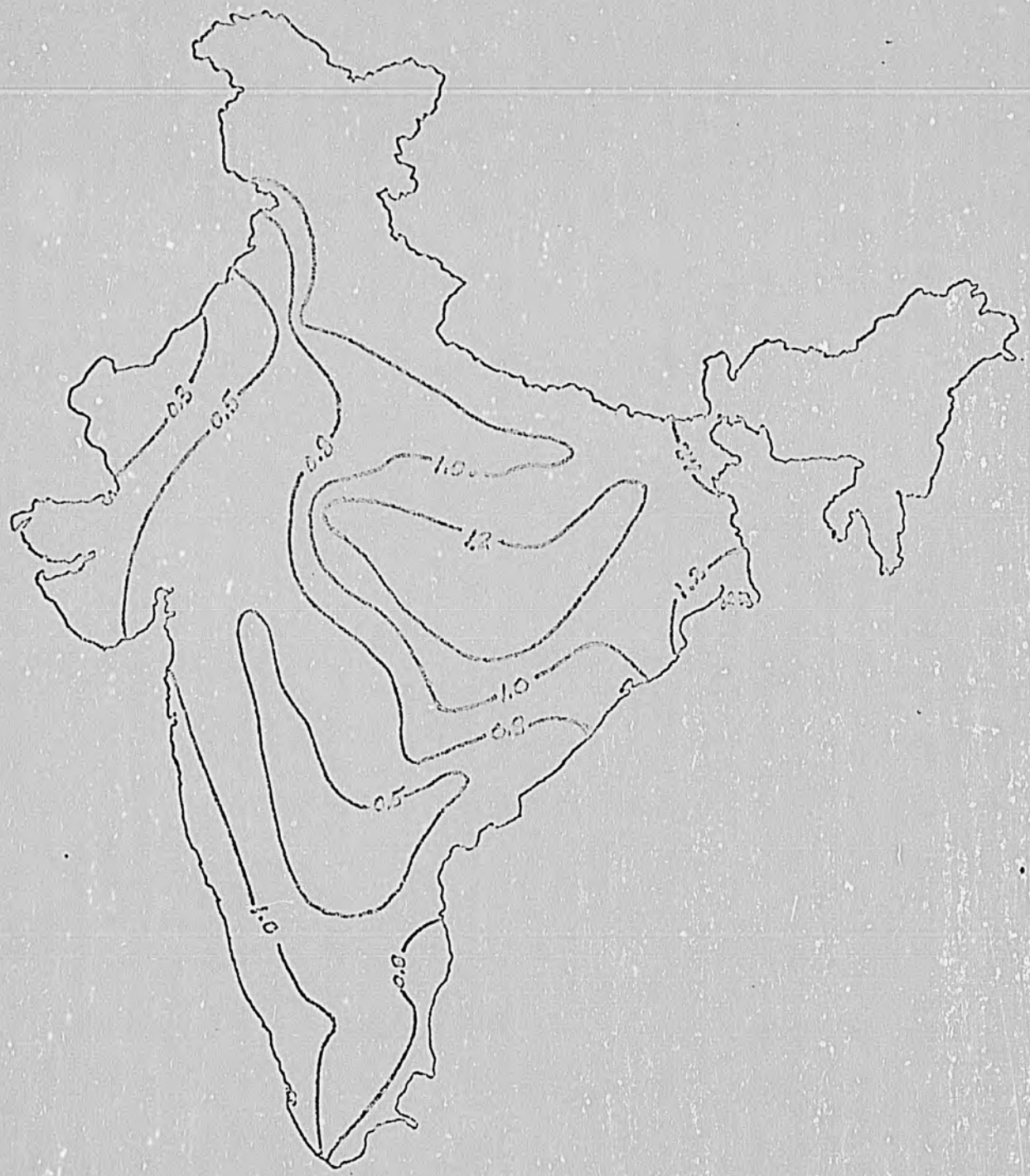


FIGURE 7 -- The ratio of rainfall to potential evapotranspiration for the 8 month period 1 July to 31 March.

demand (PE*) and supply (P*) for the 9-month production season consisting of kharif and rabi crops. Figure 7 shows how the $\frac{P^*}{PE^*}$ varies in India. This indicates that the indigenous water supply is sufficient to meet the potential demands for a double-cropping system for a significantly large part of India. The double-crop water demands for an even larger area can be met if foreign water from those parts of catchment areas not suitable for intensive crop production can be supplied to supplement the indigenous supply of the double-cropped area.

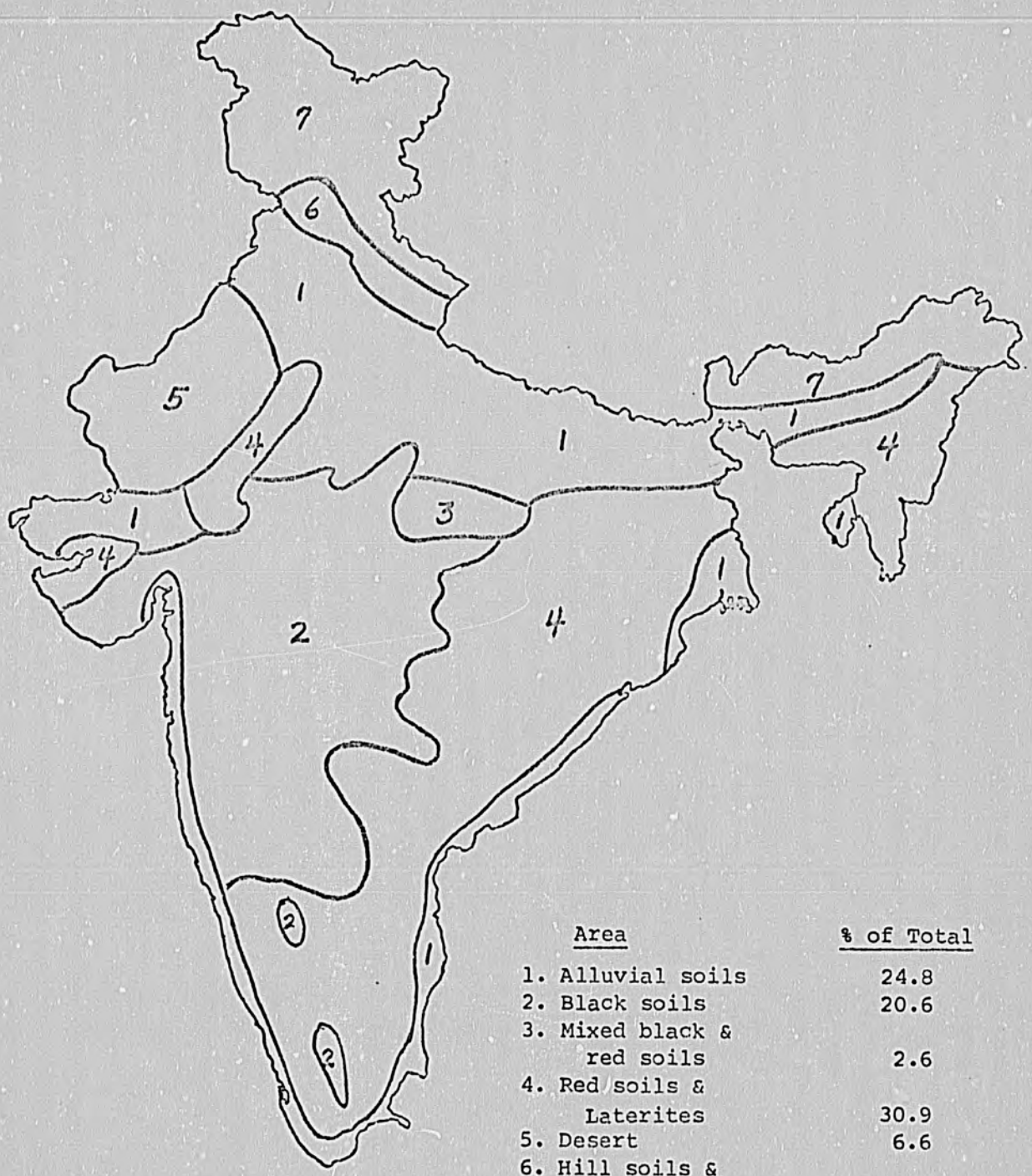
The Soil Resource for Agricultural Production

The basic potential of the soils of the major regions shown in Figure 8 is considered here to be largely determined by the physical capability of the soil and the underlying parent material to provide sufficient storage of water to bring the seasonal supply and demand functions into balance. In most instances the full expression of the physical potential will require the correction through fertilization of the basic inadequacy of nutrients that exist in most of the soils of India.

Alluvial soils represent nearly 25 percent of the total land area of India and perhaps 40 percent of the nation's currently cultivated acreage. These soils have developed on old alluvium of great depth in the Indo-Gangetic plain and on more recent alluvium in the large coastal deltas and adjacent to the major rivers of peninsular India. Because of their extent, favorable topography and general suitability for intensive cropping, the alluvial soils as a class constitute India's most important soil resource.

Characteristically sufficient water is available to permit crop production on a year-round basis on the alluvial soils. Although indigenous rainfall is insufficient to meet the annual evapotranspiration demand in much of the alluvial soil area and surface storage is not feasible because of the nearly level topography, the underground storage capacity, recharge, and withdrawal characteristics are favorable to pump irrigation. Water management in the alluvial soil areas should treat indigenous rainfall, perennial stream flow and underground recharge, storage and withdrawal as a total dynamic hydrologic unit. When considered in this light there seems little reason to doubt the assertion that the water resources are sufficient to permit year around cropping in most, if not all, of India's alluvial soils.

In Assam, and much of West Bengal and Bihar, the major problem of



Area	% of Total
1. Alluvial soils	24.8
2. Black soils	20.6
3. Mixed black & red soils	2.6
4. Red soils & Laterites	30.9
5. Desert	6.6
6. Hill soils & Sub-montane	3.3
7. Mountain soils	11.2
	100.0

FIGURE 8 -- Generalized Soil Map of India

water management is drainage and flood control during the monsoon -- a problem that is greatly intensified by the large volumes of stream flow from other parts of the catchment basins that enter these areas during and immediately following the monsoon. Water requirements for rabi and zaid crops can be met in this area from annually recharged groundwater aquifers.

In central and eastern Uttar Pradesh and the coastal deltas, an extensive acreage of alluvial soils occur in areas of lower annual rainfall. Here too the problem of disposal of excess water during the monsoon, though less severe than those of the areas described above, must be solved if the full potential for kharif cropping of this large and important area is to be achieved. Water requirements for rabi and zaid crops can be met in these areas from the groundwater aquifers that normally will be recharged naturally each year. Although the indigenous rainfall in these regions is sufficient only to meet kharif and rabi season demands, the fact that the areas are traversed by perennial streams and many unlined irrigation canals it is reasonable to assume that the annual recharge of the groundwater will be sufficient to meet the water requirement of a 12-month system of cropping.

In Punjab, Himachal Pradesh, Western Uttar Pradesh and Haryana there are large areas of alluvial soils that receive only limited annual rainfall. The disposal of surplus monsoon rainfall is only a minor problem in this area which traditionally has emphasized rabi season production. The extensive development of canal and tube-well irrigation in this region is dependent on surface water that enters the area as stream and canal flow from the Himalayan watershed. The potential volume of such imported water is such that if the rates of annual groundwater recharge are sufficient a combination of canal and tube-well irrigation could meet the water requirements for 12-month cropping of most, if not all, of the alluvial soils in this important agricultural area.

Large areas of alluvial soil also are located in the deltas and as riverine deposits in the valleys of major rivers of peninsular India. Although the indigenous rainfall in these areas is usually less than that required to meet the water requirements for 12-month cropping, the availability of annually rechargeable underground aquifers and the possibilities for diversion from the perennial streams that traverse these areas suggest that 12-month cropping is feasible for these important alluvial soils.

Protection against flooding during and immediately following the monsoon will be locally important in many of the deltic and riverine alluvial soils.

In summary it can be stated that if indigenous rainfall, exogenous stream and canal flow and the inherent storage capacity of underground aquifers are properly managed, the extensive alluvial soils of the Indo-Gangetic plain, the coastal deltas and the riverine flood plains of the major rivers of peninsular India are capable of producing crops on a 12-month basis. Given existing knowledge, proven production technology and current prices, it is estimated that the total annual agricultural production of the alluvial soils of India potentially can be increased by a factor of ten times the current level.

Red soils as a class are the most extensive in India. They are the dominant soils of the more humid uplands of Assam, West Bengal, Orissa and eastern Madhya Pradesh. They also are the major soils of the drier regions of the eastern part of Andhra Pradesh, Mysore and Madras and of the very dry desert fringe of Rajasthan and Gujarat. The red soils are highly weathered and low in organic matter and plant nutrients. In the more humid regions the red soils of medium to fine texture on level to gently sloping topography have great potential for paddy production. The full expression of this potential commonly requires land leveling and provision for positive water control through drainage and irrigation. On more sloping topography the red soils, given appropriate fertilization and cultural management, are well suited for a wide range of kharif crops including maize, jowar, soybeans, etc. Where the topography is suitable and the water supply adequate the red soils in south India are well suited for production of sugarcane.

In the more humid red soil area the water requirement for a rabi crop can normally be met from water stored in the root zone or from that in tanks and locally recharged groundwater aquifers. Where such water storage facilities are available, production of paddy during the rabi season can be greatly expanded. Where irrigation is not available, other food crops can be produced during the rabi season to augment the kharif paddy crop. Crop production in the zaid season on red soils will be limited to relatively small areas having an assured supply of irrigation water. Because suitable groundwater aquifers are in general not available, such water

must be obtained from surface storage facilities or from perennial streams that traverse the area.

In the drier areas of south India the production potential of the red soils is lower than that of the more humid regions discussed above. The indigenous rainfall for much of this area is sufficient for only the kharif crop, although the more favorable seasonal distribution of the precipitation does permit rabi production in significant parts of this area. Groundwater resources for irrigation are generally not available and storage of indigenous water in tanks is quite inefficient due to high evaporative loss caused by the higher winter temperature of this region.

The red soils of the desert fringe in northwest India have a very low production potential. The rainfall is so low and erratic that even kharif production is limited to short season drought tolerant crops such as the millets. Production in this area is largely restricted to areas where there is some localized accumulation of runoff or where irrigation water can be supplied from outside.

In summary, the red soils although more extensive, do not have as great a potential for meeting India's food needs as do the alluvial soils discussed above. This arises because of their lower capacity for moisture storage in the root zone, lower inherent nutrient status and less favorable topography. The potentials of the red soils for multiple cropping is lower than that of the alluvial soils because of the general lack of adequate aquifers for storage of exploitable groundwater and because extensive irrigation with foreign water is less feasible because of topographic limitations. The red soils, however, are responsive to improved management and as discussed above are in many areas suited for much more intensive use. It is estimated that double cropping could be practiced on 50 percent of the red soils now under cultivation and that 12-month cropping is technically feasible on perhaps 10 percent of the cultivated red soils. Based on this evaluation, it is estimated that with present knowledge, existing technology and current prices, the food production on the red soils could be increased to five times its present level.

Black soils occupy most of the drier western part of the central Deccan plateau. They comprise an estimated area of 60 million hectares and are the dominant soils of central and western Madhya Pradesh, most of Maharashtra, western Andhra Pradesh and northern Mysore. The dark surface layers of these soils are commonly from one to three feet thick,

but despite their color are generally low in organic matter. Characteristically the black soils are fine textured. Their high clay content is reflected in their plasticity and stickiness when wet and their tendency to crack deeply into hard intractable blocks upon drying. Due to this deep cracking characteristic, the black soils undergo considerable natural vertical mixing and are commonly called "self-swallowing" soils. Because they have developed under sub-humid to dry conditions, the black soils are less highly weathered than the red soils and are normally higher in bases and plant nutrients.

The black soils as a class have a high capacity to store soil moisture for use by crops. The full exploitation of this inherent capacity is often prevented because low infiltration rates prevent full recharge of the soil profile during the monsoon or because poor root penetration does not allow the crop to use the water in the deeper parts of the subsoil. The physical management of the black soils is thus the key to their more productive use.

In the more humid parts of the black soil area, kharif paddy can be produced provided suitable land leveling and water control techniques are used. Their high clay content and low profile permeability makes these soils well-suited for paddy production. Problems of seed bed production for transplanted paddy are more easily solved than are those for other crops. On black soils having sufficient slope to permit surface drainage, kharif crops of maize, jowar, soybeans, etc. are feasible. However, existing methods for timely seedbed preparation, planting and weed control, seriously limit the full potential for kharif production of these crops on the black soils.

In the 30-45 inch annual rainfall belt of the black soil region, wheat is the predominant food crop. Seedbed preparation for this rabi crop is done after the end of the monsoon, but at a time when the surface soil has dried enough to have lost its plasticity and stickiness, but not so much as to become hard and intractable. The wheat crop is then produced primarily on the soil moisture stored in the root zone. In the drier western parts of the black soil area where the moisture supply is more marginal for wheat, a rabi crop of jowar or millet may be produced.

Irrigation is not highly developed in the black soil region. Suitable ground water aquifers have not as yet been widely located or developed and large scale irrigation schemes are very limited in this part of India. Because of their inherent low permeability, the black soils present

difficult problems of soil management under irrigation. In the drier areas where soluble salts are present in significant quantities at shallow depths, the application of irrigation water will lead to serious salinity problems unless adequate provision for profile drainage is made a part of the design of the irrigation scheme. Given the low permeability of the black soils, this is usually a difficult requirement to meet.

Because of their inherent moisture holding characteristics and relatively high base status, the black soils have considerable potential for double-cropping. Expansion of kharif crop production in the more humid parts of the black soil region is critically dependent upon the development of suitable high yielding short-season crop varieties and improved technology for seedbed preparation and weed control. Improved methods of harvesting of surplus monsoon rainfall for profile or groundwater storage for rabi crop use, would also increase the food production of the black soils. It is estimated that with present knowledge, existing technology and current prices, the food production of the black soils could be increased to three times its present level. If suitable techniques for tillage and timely seedbed preparation could be developed for the black soils, the productivity of this important area could be increased to five times its current level.

Other soils. As shown in Figure 5, the alluvial, black and red soils discussed above represent about 80 percent of the land surface of India. The remaining 20 percent consists of the desert soils of Rajasthan and the soils of hills and mountainous regions, principally in the northern regions. It is estimated that the cultivated area in these two groups of soil represent not more than 2 percent of India's total.

Food crop production on the desert soils is almost wholly dependent on the development of irrigation. Indigenous water resources are so limited that such development depends on the importation of water into the area from the Indus catchment basin. The desert soils are inherently rich in bases and many have profile characteristics that make them well suited for intensive cultivation if supplied with adequate water of suitable quality. Because desert soils contain large quantities of mobile soluble ions that will accumulate to toxic levels unless suitable profile drainage is provided, it is imperative that both the quantity and quality of the water used to irrigate desert soils be sufficient to maintain a net downward flex of water through the soil profile. Although very large capital investments are

required to develop them, the desert soils if properly managed can make a significant contribution to meeting India's food needs.

The soils of the hills and mountains represent a very heterogenous group. Many are uniquely suited for such crops as tea, coffee and tree fruits. The temperature and moisture conditions are often suited for vegetables or off-season speciality production. Improvements in productivity of these soils will be associated with the development of varieties and cultural practices to meet special needs and will often be dependent on improved off-farm storage, processing and marketing facilities and transportation.

III. THE SUPPLY AND FLOW OF ON-THE-FARM PRODUCTION TECHNOLOGY

Agricultural production involves the interaction of a complex set of physical, biological and economic factors. Since most of them are susceptible to modification by the farm operator, the successful application of a new technology is dependent on the degree to which an adequate level of sufficiency has been achieved in the other factors. Thus the potentialities of a new variety will not be realized if it is inadequately fertilized or supplied with needed water. Recognition of this interaction phenomenon has led to acceptance of the "package-of-practices" concept for the major physical production inputs. Such a systems approach also can be extended to include the interactions arising from marketing and utilization parameters and from off-farm, intersectoral economic and technologic factors. In this discussion we limit our consideration to the on-the-farm production inputs and to annual net income of the firm as the measure of performance of the package-of-practices employed. It is clear that the managerial ability of the farmer plays a key role in determining the effectiveness of any new production technology. It is assumed in the following that a suitable market demand exists for any increased production arising from the new technology.

It is our belief that new production technology will be adopted most quickly by innovators and will spread most rapidly among their neighbors if that technology enables the individual farmer to exercise management control of the maximum number of the production variables that influence his net income. Adoption will be slow and diffusion minimal if the effectiveness of a new technology is critically dependent upon the decisions

and actions of individuals or groups other than the farmer himself. Thus the adoption of new varieties, fertilization and cultural practices for wheat is accelerated by the installation of farmer operated tube-wells which bring the essential irrigation water under his control. Conversely, the lack of adequate on-the-farm control of excess water during the monsoon has impeded the adoption and spread of certain of the high yielding varieties of paddy which are intolerant of marked fluctuations in depth of flooding.

We also postulate that the adoption of such on-the-farm controlled production technology by a significant fraction of the farmers in a village will create awareness of the need for and advantages of group action as a means of achieving even better control of important factors that influence their individual economic well-being but which cannot be achieved by individual action. Thus pest control may be technically very difficult for an individual farmer, but technically and economically feasible if handled on a village-wide basis. Recognition of the need for consolidation of holdings and rationalization of field boundaries may well follow the adoption by a significant number of farmers of improved land forming, drainage or irrigation technology. The benefits associated with economies of scale in threshing, storage or marketing may well become evident following the adoption of yield increasing new technology by a group of farmers. The emergence of such a "grass-roots" kind of need for group action will, in our opinion, result in more viable and effective socio-economic and political institutions than those that are conceived and organized exogenously.

The Research Base and Outlook for Production Technology

It is well established that improved technology is an essential ingredient in programs designed to increase agricultural production. It is equally clear that because there is a high degree of interaction among the major factors of production, the full benefits from technological improvement in one factor will rarely be obtained without concomitant improvements in the other factors. It follows therefore that sustained growth in agricultural productivity requires that improved technology be developed for all of the major factors of production. The present status and outlook for improved technology for each of the major components of the crop production package follows.

Improved varieties. This phase of agricultural research has traditionally received major attention in India. The development of high-

yielding varieties of the major food grains has recently been greatly strengthened by the organization of nation-wide systems for the interchange of breeding materials and uniform testing. These co-ordinated crop improvement schemes are also benefited by their linkage with worldwide crop improvement programs. The plant breeding programs should give increased attention to varieties having higher yield per hectare per day, lower day-length sensitivity and improved responsiveness to higher levels of fertilization and irrigation. Improvements of this kind will not only increase the level of production but will improve the adaptability of the crop into systems of multiple cropping. In addition, the plant breeding programs should give greater attention to improving the insect and disease resistance and grain quality. Care must be taken to maintain a sufficiently broad germ-plasm base for the variety improvement programs to lessen the vulnerability of the crop to rapidly developing epiphytics or other unforeseen hazards of production.

On the whole, the variety improvement research is satisfactory and can be expected to provide an adequate supply of improved varieties of the major food crops required to maintain a steady growth rate of agricultural production. For this potential to be realized, however, more attention must be given to improving the multiplication, production, quality control and efficient distribution of the improved varieties developed by the research program.

Fertilization. It is generally recognized that the inherent fertility of Indian soils is too low to sustain high levels of crop production. The yield responses are particularly dramatic when fertilizer is applied to responsive varieties and where adequate moisture, suitable cultural practices and appropriate plant protection practices are used. Until recently most of the soil fertility research has been of the "some vs. none" type on unimproved varieties and with traditional cultivation and plant protection practices. Soil testing as a means of fertility diagnosis has received considerable attention, but at present is largely ineffectual because of the lack of adequate correlation with field response data. Field experiments to establish the fertilizer response surfaces for the major food crops grown under improved production conditions are urgently needed to provide a basis for the efficient use of the greatly increased amounts of fertilizer that will be required to steadily increase food production in India. In addition, more research is needed on leaching and denitrification losses, on inoculation of legumes, and on the residual effects

of fertilizers, particularly as this relates to multiple cropping systems.

The initial yield increases that will be obtained from the application of fertilizer to responsive varieties is usually so large that the lack of pre-application diagnostic information may not be serious. However as the marginal returns for fertilizer decline, the need for more precise information on the shape of the response surface increases. It is imperative therefore that greater research be directed to the establishment of such response functions if the full benefits of efficient fertilizer are to be realized.

In the immediate future the contribution of fertilization to increased food production will be constrained more by inadequate supply, inefficient distribution systems and by pricing policies, rather than by inadequacy of fertilization technology. Existing technology is not sufficient however to provide for the sustained efficient use of fertilizers under conditions of continued improvements in varieties, cultural practices, water management, plant protection and multiple-cropping.

Plant protection. Diseases, insects and vertebrate pests take a heavy toll of India's food crops. Unfortunately research in this field has received relatively little emphasis by Indian agricultural scientists. As a result there is a great lack of basic knowledge of the life history, population dynamics, epidemiology and host-parasitic interactions. Such information must be obtained if effective methods of plant protection are to be developed. Prompt attention must be given to the organization and operation of disease and insect surveillance systems and in the training of field personnel who can diagnose crop diseases and insect infestations. Close collaboration between entomologists, pathologists and plant breeders in the development of resistant varieties should be encouraged. Special attention to host-parasite interactions is needed for crops receiving higher levels of fertilizer and irrigation and for crops grown in systems of multiple-cropping. A vigorous effort should be made to determine the natural biological controls that operate on the various diseases and insects and to seek ways to augment the effectiveness of such effects. Field evaluation under a range of environmental and production conditions of chemical control agents should be expanded.

The supply of appropriate field evaluated technology for plant protection is inadequate at present and unless vigorous steps are taken to correct this situation promptly, the required progressive increase in food production will be jeopardized.

Cultural practices. The introduction of new varieties, improved fertilization and other production innovations, must be accompanied by improved technology in seedbed preparation, seeding, weed control, harvesting and in the post-harvest conditioning and storage of the crop. Research on problems of this kind is both quantitatively and qualitatively inadequate and shows little evidence of generating the new technology needed to sustain the continued increase in agricultural production. Much more emperical field work on planting dates, plant population, weed control practices and the interaction between such variables and varieties, fertilization and irrigation practices is needed. Such studies are especially needed with respect to the sequence of crops used in multiple-cropping systems. At present little new technology on cultural practices is being generated by the agricultural research system. This deficiency must be corrected if the potential benefits from improvements in other factors of production are to be realized.

Water management. Improvement in the management of water is a key element in increasing agricultural production in India. Despite the fact that the monsoon is the overriding ecological factor in Indian agriculture, the role of water as a factor in crop production has received very little serious or systematic study. Consequently there is an appalling lack of basic climatic, hydrologic and agronomic information on water as a factor in crop production. Quantitative data on ground water supplies and recharge rates, on soil profile, storage and depletion characteristics, on rooting depth of crops and on the response of crops to different moisture regimes is virtually non-existent. Water management is more than irrigation. It also encompasses disposal of excess water and the effective use of indigenous rainfall and water stored in the crop root zone.

Examples of the kinds of research-based technology that are urgently needed are: (1) methods for land forming for more uniform distribution of irrigation water, (2) techniques for increasing the recharge of the soil profile and of increasing the efficiency with which plant roots can utilize such moisture, (3) procedures for minimizing the damage to crops of excess water during the monsoon, (4) field proven methods of reducing evaporation from the soil surface and water reservoirs, (5) more efficient ways of distributing irrigation water so that it is under the management control of the cultivator, and (6) more efficient methods of "harvesting" run-off for subsequent on-site usage, (7) more dependable methods of locating groundwater aquifers and better methods and equipment for installation and operation of farm-scale irrigation wells. There is urgent need for emperical field measurements of the interaction between moisture conditions and all of the other factors of production and for basic and applied research on means of reducing the effects of moisture stress on

plant growth.

Present Status and Outlook for Increased Crop Production

The availability and rate of adoption of yield-increasing technology does not occur uniformly for all crops or in all areas of production. The present status and outlook for each of the major food grains is briefly reviewed. This is followed by a discussion of multiple cropping.

Rice is the major food grain of India. It currently represents about 40 percent of the nation's total food production and occupies 30 percent of the gross acres sown to food crops. The current situation and future outlook for improved high-yielding varieties is good. Lack of proven technology for positive on-the-farm control of water is probably the most important single deterrent to the more rapid adoption of high-yielding fertilizer-responsive varieties. To realize more fully the potential of such varieties and other yield increasing production technology, greater effort is required in land leveling and on-the-farm distribution systems that will bring water under more positive control by the individual cultivator. Encouraging developments in disease and insect resistance and control and in the breeding of photo-insensitive varieties of improved quality suggest that the flow of new varieties and plant protection technology will keep pace with the needs to increase rice production.

As multiple-cropping expands, varieties and production practices designed for particular parts of the 12-month growing season will be needed. In some areas multiple-cropping may be with a mono-culture of rice, probably three crops per year. This may develop as a system in which rice is being planted and harvested during every week of the year. Such a system would level out the seasonal peaks in labor and on the supply and marketing agencies serving the area. It would however make more difficult such problems as water management and the control of insects, diseases and pests by making group action on these problems more complicated.

Although paddy mono-culture may develop in some of the multiple cropping area, the high water demand of paddy will favor its use as a kharif crop in a mixed multiple cropping system. The major technical problem to be solved in such a system is that of quickly converting a paddy field into an adequately drained seedbed for other crops. The bedding technique developed in Taiwan and extended by Bradfield at IRRI is an approach to this problem that shows considerable promise.

Wheat is second only to rice as a food grain in India. It is grown on about 15 million hectares and represents about 18 - 20 percent of the nation's annual food grain supply. Production has shown a sharp response to the introduction of the fertilizer-responsive varieties and the associated set of improved practices. This breakthrough has been most dramatic

in the irrigated wheat producing areas of Punjab, Western Uttar Pradesh and Harayana. For these areas the flow of improved varieties, more efficient methods of using fertilizer, water and plant protection materials appear sufficient to keep the wheat revolution moving. More attention must be given to problems of harvesting, marketing and storage as the size of the wheat crop in this important production area continues to grow rapidly.

The impact of the improved practices on wheat production in the extensive rain-fed areas has been much less dramatic. For these areas, which constitute the major part of India's wheat growing region, further improvements in production technology are needed. Wheat grown in the rain-fed or "baroni" areas is dependent largely on water stored in the soil profile. Therefore increased attention should be given to (1) increasing the intake and retention of water in the rooting zone, (2) increasing the vigor and depth of penetration of wheat roots, (3) improving the physiologic efficiency of the wheat plant under conditions of water stress, (4) development of varieties having shorter growing seasons and (5) improvement of seedbed preparation and planting methods that will permit more timely seeding to maximize favorable early season growing conditions. Because it is unlikely that yields under baroni conditions can consistently match those obtained under irrigation, the set of production practices developed for the rain-fed areas will necessarily be different from those that have been so successfully adopted in the irrigated areas.

Sorghum and millets are important food grains, particularly in the drier parts of India. In 1967-68 they constituted about 25 percent of the acreage and about 15 percent of India food grain production. Progress to date in variety improvement and innovative change in production practices has not been as great as that in rice and wheat. This is due in part to the lack of comparably large reservoir of production technology in other parts of the world on which an adaptive program for India could be quickly developed. Rapid progress is being made, however, to exploit the world-wide pool of germ plasm and to develop suitable production technology for Indian conditions. Varieties and hybrids with greatly improved yield potential, shorter growing season and improved disease and insect resistance have already been developed and field evaluated. Although the major emphasis with these crops is for improving their productivity under rain-fed conditions, they have considerable potentialities for use in multiple-cropping systems under irrigation. This is particularly true for the

sorghums which by "ratooning" can be harvested two or more times from a single planting.

Because the sorghums and millets rank below both rice and wheat in consumer preference, their long-term importance for direct consumption will decline as the production of rice and wheat more nearly meet India's food grain needs. Although there is a small demand for the sorghums and millets for local consumption and speciality food uses, the pattern of use for these grains will, we believe, slowly shift to livestock and poultry feed and to industrial utilization.

Pulses are grown on nearly 20 percent of the land used for food grain production and represent about 13 percent of India's food grain supply. Although the pulses are an important part of the diet and constitute the major source of protein in it, this important group of crops has received very little attention by research and agricultural development agencies in India or elsewhere. There is a serious lack of both basic knowledge and empirical data on even such major pulse crops as gram and tur upon which to build a program for improvement of these crops. Preliminary studies indicate that sufficient diversity exists in gram and other pulses to permit selection for length of growing season, yield, and other agronomic characteristics. It is reasonable to expect that highly significant improvements can be made in variety development. Such efforts to be effective in improvement of pulse production must be accompanied by the discovery and development of a suitable set of production practices that will permit the full expression of the genetic potential of the improved varieties.

Because of the lack of suitable yield-increasing technology, the production of pulses has been slowly declining. This trend probably will continue as the spread of improved technology in other crops proceeds at a faster pace than is likely to occur for the pulses. Although pulse production to meet local consumption may keep pace with that demand, major changes in production technology are needed if the production of these important food crops is to keep pace with the off-farm market demand. A major research and development effort directed at improvement of systems of pulse production is clearly needed and should be given high priority.

Maize represents about 6 percent of India's current food grain production. Except in limited areas, it ranks below rice and wheat in consumer preference. It has been repeatedly demonstrated that hybrid

maize is widely adapted throughout India and, when improved production technology is used, is one of the most productive of the cereals on a per acre per month basis. More rapid expansion of this crop in India is also favored because of the existence in the United States of a large reservoir of basic knowledge and practical experience about the crop and systems for its efficient production. Although hybrid maize was introduced and research and development efforts on its production initiated many years before the introduction of the high yielding wheat and rice programs, it's spread has been limited. It appears therefore that like the sorghums and millets, this crop will not effectively compete with rice and wheat as a major food grain. Maize does have a great potential as a feed grain and for processing for food and non-food uses. Modification of the crop and systems for its production to meet any foreseeable demand for maize could be made rather quickly because of the existing reservoir of knowledge and technology on this crop.

Soybeans are not now produced in significant quantities in India. Research in progress indicates clearly that they are well adapted for kharif production in central and northern India. Commercial United States varieties have been shown to be agronomically suited for these areas, although the performance under farm conditions have not yet been extensively evaluated. The data at hand suggest that this crop can make a major contribution to India's food needs, not as a pulse for direct local consumption, but as a productive source of industrially processed edible oil and protein. It appears that the soybeans will adapt well to a multiple-cropping system in much of the rain-fed wheat producing areas. The development of suitable day-length insensitive varieties may also make feasible the use of soybeans during the rabi and zaid seasons in situations where it would fill a need in a year around multiple-cropping system.

Like hybrid maize, the future of the soybean in India is more dependent on the development of a suitable market demand than on the development of adapted production technology. As a source of edible oil and protein, the soybean has a clear comparative advantage over other alternative pulse and oilseeds being grown in India. It also has the advantage of a large United States reservoir of basic knowledge and practical production and utilization experience on which to draw. Soybeans not only have a great potential as a source of edible oil and protein, but also as raw material for livestock and poultry feeds and for industrial utilization.

Multiple-cropping represents a largely unexploited means of greatly increasing agricultural production in India. With relatively minor exceptions, temperature and day-length place only minimal constraints on 12-month production. Water availability is the major climatic constraint. For large areas of India, however, the indigenous water supply if properly managed is sufficient to meet the need of both a kharif and a rabi crop. In a more limited part of the nation, the availability of water is such that 12-month cropping is feasible. Much of the multiple-cropping now being practiced involves the casual interplanting of a "scavenger crop" to utilize residual moisture and fertility. With the availability of higher yielding varieties and improved production technology, emphasis will shift to a more planned and systematic pattern of sequential cropping. For such systems of production, the total annual return of the sequence of crops, rather than the yield of an individual crop, will become the measure of performance.

Although relatively little research and development effort has been given explicitly to the problems of multiple cropping, much of the work on individual crops contributes to their usefulness in multiple crop systems. Newly innovated methods of seedbed preparation, water control and harvesting, have been developed in Taiwan and elsewhere that can provide ideas and techniques for possible application in India. Successful operation of a multiple-cropping system of production places increased demands on the managerial ability of the farmer and increases his dependence on the supporting infrastructure. It is, however, a powerful multiplier factor in its effects on agricultural production and provides an opportunity to markedly increase both per capita and per hectare productivity of small holdings.

IV. LIKELY PROBLEMS AND CONCERNS IN THE ADOPTION OF AGRICULTURALLY USEFUL TECHNOLOGY

Discussed in this section are several sets of problems that India will face as a part of the process of increasing the production and consumption of food and fiber. The first discussion focuses upon the likely flow of on-the-farm production technology as an output of the scientific community and on the need for such technology and its adequacy measured in terms of likely market supplies and demands for food and fiber. Attention is then directed toward the problems involved in the geographical location of agricultural

production and the agri-business infrastructure, selling to and buying from farmers. Finally, attention is directed to the adjustment problems flowing from the development of a more efficient agriculture.

Major attention is directed toward questions of the geographical location of production and the associated adjustment problems which at this point in history may well be limiting on the rate of productivity increase in agriculture. This statement can be put the other way around by observing that it is likely that the flow of new technology from the scientific community will be so great that much of it will go unused because of uncertainties generated by adjustment and location problems.

Flow of Agriculturally Useful Technology

The flow of agriculturally useful technology is examined with reference to the capability and productivity of the scientific community as well as the needs for new technology as these will likely be reflected in market supplies and demands for food and fiber. In one sense, the need for new technology is unlimited in that the fewer the resources required to produce food and fiber, the better, which in the limit would generate free food and fiber. The concept of need used in this paper is not of this sort--it is one which, loosely put, only asks that efficiency increase fast enough to permit the percentage of national income spent on agricultural commodities to decrease over time.

The scientific community which generates technology useful in agriculture is located in all parts of the world in universities, government agencies, foundations, businesses, etc. From the point of view of any one country or area, in this case India, the key component is the part which draws on knowledge from all sources and incorporates it into technology useful in the specific area of concern.

The world-wide flow of technological information, as shown in earlier sections of this paper, is adequate to make it possible for food production to be greatly increased subject to several "ifs." The first "if" centers upon the ability of the Indians' research system to adopt and adapt technology to Indian conditions. The second "if" centers upon the ability of the Indian research system to fill the technological gaps that are generated by the situation India is in.

The outlook appears to be good on all of these counts. India has under development both the research manpower and the institutions in which they can work to a degree that it seems likly that food production can be increased

several percentage points each year--at least technological know-how does not seem to be the limiting factor. This assumes a high national priority is given in the allocation of resources to the orderly growth of the Indian agricultural research capability and to the complimary development activities needed to translate research findings into production-increasing practices.

The needs for food and fiber in India over the next ten or twenty years can likely be met if the technology that is available and that will be generated during this period is put to work. The definition of need employed is demanding only to the extent that food and fiber production is expected to a bit more than keep up with the birth rate and increases in per capita income. The ex post test of "success" would be for the terms of trade to shift against agriculture over the next decade or two.[1/]

The Location of Agricultural Production and the Supporting Infrastructure

The problem which stands out as probably the most urgent, if the rate increase in the efficiency of Indian agriculture is to be optimized, is to develop a process which will lead to an optimum specialization of production among geographical areas in India. The difficulties involved take several forms and concern:

1. There are no large highly developed high income economies in the tropics which can be used as a model.
2. The macro-ecological conditions in India make it possible and necessary for farm firms to choose among many more, currently more nearly equal, viable cropping pattern alternatives than is the case in temperate zone agriculture.[2/]
3. The variables which determine the optimum location of agricultural production, since they are largely other than macro-ecological, present difficult analytical problems in that they are not highly

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1/ This judgment is based on the assumption that population growth will amount to about 2.5% to 3% per year and that non-agricultural income will increase between 5 and 10 percent per year.

2/ The relatively wide array of near-equal choices that are available to each firm individually does not mean the sum of these choices which defines the structure and location of agriculture is not of major consequence.

stable over time and involve dynamic changes, cumulative effects, population concentration, marketing centers, transportation costs, and the location of non-agricultural industry, etc.

4. An efficient and modern agriculture requires high capital investment, which must be appropriately located geographically if high rates of obsolescence are to be avoided and uncertainty minimized.
5. Geographical concentration and specialization of agricultural production is probably a necessary but not a sufficient condition for a high per capita income society.

Changes in location of agricultural production and the supporting infrastructure are necessary for the replacement of a traditional agriculture with a modern one. A first step in this process involves the discovery and/or the determination of where and when crops will be grown and what long-term investments should be made in such items as land improvement, buildings, water supply, drainage facilities, roads, etc. Associated with the on-farm investment decisions are the investments that must be made in farm labor, the transportation, processing, and the marketing facilities for the distribution of farm products. Similar investment choices must be made if farmers are to obtain fertilizer, seed, machinery, information, etc. Each of these investment choices involves the selection of a specific geographical location at which the investment will be physically located. The choice of optimal sites for investment will accelerate the modernization of agriculture. Additionally, the rate of economic development of the entire society depends to an important degree on the selection of optimal locational choices (involving joint optima) for agricultural production which in turn feeds back into the rate at which agriculture develops. What are the most important variables which affect the optimum location of agricultural production?

In temperate zone agriculture, in contrast to agriculture in the tropics, macro-ecological conditions play a major role in determining where the production of corn, citrus, wheat, etc. is located.[3/] Other variables such as micro-ecological conditions, transportation, population, etc. are also operative. The authors are of the opinion that in India the

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[3/] This is a question of degree, or alternatively stated, of locating points on a continuum rather than of an either-or answer.

macro-ecological variable is much less important, relative to other variables, in bringing about a geographical concentration of agricultural production than is the case with temperate zone agriculture as found in Europe, USA, and Russia, for example.

The strategy for agricultural development is greatly simplified if the location of production of most food and fiber is largely determined by macro-ecological considerations. This flows from the fact that the macro-ecological characteristics of an area in general change little even over long periods of time. The stability in macro-ecological variables stands in contrast to the instability of the other location-determining variables such as political boundaries, transportation costs, the demand for exports, the distribution of income and population, and consumer preferences among foods all of which change over time. Thus, in the tropics it may be much more difficult to optimally direct capital investment into agriculture and the agricultural infrastructure than in the temperate zone, because most of the variables determining the profitability of any investment in any location have short half-lives--thus, generating high rates of obsolescence at worst, or high uncertainty at best.

The agricultural development strategy alternatives available, when the half-lives of the key location variables are short, are examined in two groups. These alternatives are not mutually exclusive in an engineering sense, but they are usually mutually exclusive in terms of scarce resources or cost. The first strategy to consider is to minimize the effects of risk and uncertainty by, for example, making only those capital investments which pay off when high obsolescence rates are built in, of perhaps 25 or 50 per cent per year. The second strategy is to manipulate the location variables, to increase their half-lives, to reduce uncertainty and the rate of obsolescence on investment. In both cases it is assumed the investment decisions made are intended to be yield or profit maximizing, independent of the investor, be it the farmer, the government, or the businessman.[4/]

When the key variables determining the optimum location of agricultural production have short half-lives - when obsolescence may be high - when uncertainty is high - the chances an investor takes of losing his capital are great. The farmers, communities, and businesses that survive will likely

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4/ This is not intended to suggest that the variables that will be taken into account are unrelated to the decision-making entity.

be those that avoid making long-term commitments and thus avoid adopting technologies requiring either long-term or large capital investments in plant and facilities, skills, and education or large-scale operations with high degrees of specialization. The product of following the above type of strategy describes the traditional types of agriculture normally found in the tropics and until recently found in all parts of the world. Thus, it may be no accident that modern agriculture developed first in the parts of the world where the micro-ecological variables were demanding and did not give man the chance of being confused by an array of approximately equal short run alternatives.[5/]

A second alternative, assuming nature has not done it ecologically, is to attempt to stabilize the key variables which determine the optimum location of agricultural production. The variety of possible actions to accomplish this objective is limitless, and most are inefficient, but there are a few choices which may offer sizeable payoffs. Historically, most of these choices have been made for "other" reasons, the "wrong" reasons or more commonly obliviously to the consequences.[6/]

1. Transportation rates for the mass movement of specific commodities can oftentimes be fixed which favor the centering of a particular economic activity in a specific geographical area. This occurred in the United States in the establishment of rail rate structure --

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5/ The case would also need to be established that several alternatives are needed - otherwise Greenland should have developed the first modern agriculture.

6/ Numerous examples of agricultural policy actions can be listed which have had the effect of encouraging the dispersion of agricultural production. In the U.S.A. acreage allotments have reduced wheat production in the wheat belt and have increased wheat production in the corn belt. Wheat produced in the corn belt sells at a discount because not enough of it is grown to use the most efficient technology or to market it efficiently. In India the establishment of food zones has often been criticized because of the resulting distortion of relative prices. While this cost is real, it is likely that this cost is relatively small compared with the costs that result from the encouragement the program gives in spreading food production over wide geographical areas rather than bringing about geographical concentration in the production of individual crops. The gains from concentrating the production of crops geographically are discussed in the next several pages.

or the purpose of generating rail business covering more than marginal cost--with a secondary by-product effect of concentrating production rather than the other way around.

2. A second method used, which has brought about among country geographical concentration of production, results from the establishment of import and export tariffs and subsidies. Again the location effects are usually by-products of policy rather than objectives of policy.
3. The growth of urban centers, specializing in the production of minerals, manufactured goods, etc., has defined the areas of production for specific agricultural commodities by altering the geographical pattern of input prices and creating markets for agricultural outputs.
4. The establishment of price support programs for agricultural commodities can greatly affect the geographical location of the production. This effect is generated by the ratios among the commodity prices for the same commodities among geographical areas and/or quotas which are set.
5. Investments and subsidies (or taxes) on inputs can affect the location of agricultural production. Irrigation projects provide numerous good illustrations.
6. One of the oldest techniques is for the government, the "lord," etc., by force, to requisition or require specific groups in specific areas to produce specific commodities.

<u>The case, if any, for the geographical specialization and concentration of agricultural production</u>: The efficient agricultures of the world tend to be geographically concentrated, specialized, and to sell in markets where the firms within the agri-business complex are faced with relatively stable and elastic demand curves for their goods and/or services. In the above statement the test of efficiency goes beyond a simple fulfillment of first and second order marginal conditions.[7/] The test of efficiency also includes

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7/ First and second order conditions can be fulfilled by a traditional agriculture only capable of generating low per capita income. This would mean that all possible gains have been realized by substituting one output for another, one input for another, and that the factor product relations cannot be improved.

third order conditions which state that no existing technologies that would reduce costs remain unused or that no commodities are unproduced which would be demanded. An additional requirement is also needed--that appropriate amounts of resources be expended on the development and adoption of new technology. The above empirical generalization along with other information is examined in the effort to see how it may provide some help in offering a little insight into efficient approaches in choices designed to speed the modernization of Indian (and tropical) agriculture. This step is taken by comparing the technological alternatives available to farm and agri-business firms serving "large" markets compared with those serving "small" markets. The incentives these firms have in the "large" and "small" market situations are also compared. The differences in the incentives facing firms in the "small" and "large" market situations are examined. First, however, the connections between geographical concentration of an industry and size and stability of markets require explicit treatment.

Size and stability of markets and geographical concentration of production: The size and stability of the market faced by an individual firm, in a multiple firm industry, is greater, the greater is the geographical concentration of the industry.[8/] This statement need not be true for a single industry firm or for the entire industry as a whole but it may be. Thus, other things the same, the higher the geographical concentration of production the more stable and elastic will be the demand curves faced by the firm for its outputs and the more stable and elastic will be the supply curves it faces for its inputs since its own actions will have little or no observable effect on price. The behavioral statement of this relationship is that as production is concentrated geographically in a multiple firm industry, variations in purchases of inputs and sales of outputs by any one firm, the less will the action of any one firm affect price. In more formal terms, marginal revenue will, in the limit, equal price of the output while marginal cost will equal the price of the inputs in the "large" market or "small" firm situation.

8/ An industry may be geographically concentrated with reference to production, consumption, or processing--concentration of any one of these activities increases market size and stability for the firm. This statement refers to degrees of concentration within an industry, other things remaining the same--it does not apply to among industry comparison which are confounded by many other factors.

Incentives for output expansion and the development and adoption of new technology: If a firm has no alternative use or market for any saved inputs or a market for increased outputs the incentives for the development and adoption of new technology are zero. The situation in which the incentives to the firm are at a maximum is found when equally good uses are available for saved inputs and equally good markets are available for additional outputs--the situation found when demands for outputs and supplies of inputs are stable and infinitely elastic which implies that near unlimited quantities can be sold at near constant prices.[9/] Thus, the case for "large" stable market rests to a large extent on the effect it has on incentives for the development and adoption of technology. This case can be put in more rigorous terms by showing the effects of other than stable and infinitely elastic input supply and output demand curves on prices and production.[10/]

The desirable effects on economic development of the "large" market situation compared to the "small" market situation can also be put in the terms of variable proportions and economies of scale. These cases do not require spelling out since it is clear that the firm buying and selling in "large" markets has a wider array of choice among production alternatives (in terms of both kinds of crops and methods of production) than a firm selling in "small" markets.[11/] The range of choices denied the firm buying and selling in large markets is the option to restrict output to increase price to increase profits, which is all to the good if economic development is wanted.

The value of the option for a firm to be able to buy and sell in the "large" market rather than in a "small" one is most difficult to measure, but it is probably by all odds a most important one in stimulating economic growth. The key item is the freedom to choose from a much wider array of technologies than is the case for the "small" firm selling and buying in the "small" market. If the above statement of what is believed to be fact

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9/ The case in which additional inputs can be purchased at a lower price as volume increases has been neglected as is the case of being able to sell a larger amount at a higher price than could a small quantity be sold for.

10/ At least two components of the causal mechanism should be spelled out: (1) the effects of risk and uncertainty and (2) the effects of a sloping input supply and sloping output demand curves on profit maximizing production.

11/ The "large" firm, "large" market alternative is best; the "large" firm, "small" market case is classical public utility or monopoly case; and the "small" firm,"small" market case is hopeless if high per capita income is wanted.

were to be adequately documented, an analysis of all economic history would be required, however, the notion goes back to Adam Smith and the specialization of labor. Moreover, for this fact to be useful in the future, the assumption is required that "new technology" will also be output increasing and/or input saving, resulting in the optimum size of firm tending to increase over time as new technology is developed. Needless to say, this statement should in no way be read to imply that specific plants or firms will not on occasion be "too big" or that bigness is necessarily more efficient.

A number of other advantages are likely to be realized when the production of small sets of commodities tend to be produced in geographically concentrated areas rather than produced over widely dispersed geographical areas. Among the items worth explicit mention are the following:

1. Price stability increases if some areas are always surplus and others always deficit, rather than if areas shift back and forth from surplus to deficit from year to year, or over other time periods.
2. Informational programs by government, universities, and others are less costly to operate and can be more efficiently conducted if the interested audience is concentrated in one or a few places rather than spread over many places.
3. Group activity becomes less difficult when common interests exist. This applies to the formation of farm organizations, cooperatives, political groups, etc. This is the reciprocal analogue of lack of consumer interest in items on which a very small per cent of income is spent.

<u>The case, if any, for the geographical dispersion of agricultural production</u>: The case for dispersion is not the mirror opposite of the case for concentration even though the fact of "too" much or "too" little concentration is always a real possibility. If too much concentration is spoken of as type one error and too little concentration is spoken of as type two error it is clear that the cost of the type two error is much greater than type one error as long as the geographical concentration is not also accompanied by concentration within a small number of firms be they either private or owned by government and if efficient technologies thereby go unused. Adequate proof of the above would again require a full analysis of economic history which cannot be presented there, since this is a question of fact rather than of logic.

The major savings from a geographical decentralization of agricultural production are likely to flow from a reduction in transportation costs and some types of risk and uncertainty associated with the weather. The current trends, over time, is for these terms to decrease in relative importance and this trend will likely to continue.

Effects of Large Markets on Agricultural Development

Historically, the macro-ecology of the tropics has provided few incentives for the geographical concentration of agricultural production--in fact, the incentives have been largely of a type, given the costs of transportation, that encouraged a wide dispersion of agricultural production. This has stimulated the development of an agriculture in the tropics designed to serve local markets with the few notable exceptions such as the spice, tea, and other plantation crops.

Production units which serve "small" local markets face unstable and inelastic demand curves for their outputs and unstable and inelastic supply curves for their inputs. Thus, the profitability of adopting a new technology is minimized and often below zero to the firm. Thus, traditional agricultures in the tropics tend to be what should be expected and while efficient in terms of first and second order marginal conditions, they are not progressive in terms of the adoption of new technology in the absence of a "big" market for increased output.

The development of agriculture in the tropics that can support high per capita incomes in agriculture and stimulate growth in the non-agricultural sector by supplying low cost food will require the establishment of "large" input and output markets for agriculture.[12/] There are many ways in which such markets will or can be developed and thus, the policy question is what combination of methods and techniques to use.[13/] Needless to say, "large" markets, while a necessary condition for highly productive agricultures, are not sufficient conditions--low cost production technologies are also required, and causality between the two flows both ways.

12/ The only economies that can afford low productivity agricultures are those in which agriculture is an inconsequential percent of national income. We neglect this qualification to the "Requirement" of large markets.

13/ When the English adopted a cheap food policy more than 100 year ago, they chose to do it by importing food rather than developing new technology to produce food at home. While this choice was likely correct a hundred years ago for the British Isles it is not a reasonable option for India in 1969.

We explore only a few of the more likely and efficient alternatives by which "large" markets can be generated since an exhaustive list would involve a near infinite number. The following considerations require attention if any positive policy is followed to encourage the development of "large" agriculture factor and output markets:

1. Macro-ecological conditions in India encourage the development of "small" rather than "large" agricultural markets both positively and by not forcing "large" markets.
2. Micro-ecological conditions, for different reasons, also encourage the development of "small" rather than "large" agriculture markets.
3. The higher communication and transportation costs are, the more "small" compared with "large" agricultural markets are encouraged.
4. The development of a relative few large urban centers, in contrast to many smaller ones, encourages the development of "large" markets.
5. "Large" markets require a high geographical concentration of some stage of production or demand--using these terms as an exhaustive classification of the whole production-consumption process.
6. On balance new technology and highly skilled manpower has encouraged the development of "large" rather than "small" agricultural markets and will likely do so in the future.[14/]
7. Increases in the productivity of agriculture increases the productivity of non-agriculture and vice versa and both, on the balance, encourage the development of "large" markets.

The policy question to be faced is what if any action should be taken, in addition to letting current trend generating factors operate, to speed the development of "large" agricultural input and output markets.[15/] Specific answers to this question can only be made if specific action

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14/ The development of multiple cropping may well encourage the growth of "small" markets. There is no question but that a much more sophisticated marketing system is required to effectively distribute agricultural production when a multiple cropping system is followed than when a mono-crop system is followed.

15/ On the balance, all currently operative factors are probably tending to encourage the development of "large" markets, though some factors work strongly in the opposite direction. This question may in the future become unimportant because "large" markets will have been established or because non-agricultural productivity will have become so high that an inefficient agriculture can be treated as a consumer's good for, say, aesthetic reasons.

proposals are presented and analyzed. There are, however, significantly different sets of possibly appropriate actions which are classified as follows:

1. Steps designed to increase the effects of current trend generators encouraging the development of "large" markets.
2. Steps designed to develop new trend generators which will encourage the development of "large" markets.
3. Steps designed to eliminate or decrease the effects of current trend generators which encourage the development of "small" markets.
4. Steps designed to prevent the introduction of new trend generators which will encourage the development of "small" markets.

Attention should also be directed to the fact that most of the factors that effect the size of agricultural factor and product markets have multiple effects--thus, a policy choice, if optional, will require that the net or total effect of the choice be determining, rather than any one partial effect.

The following specifics are suggested as worthy of further investigation:

1. Measures to appropriately increase the geographical concentration of production of specific agricultural crops and other products.
2. Measures to increase the technological efficiency of marketing and markets.
3. Measures to decrease price risk and uncertainty.
4. Measures to stimulate the development of "information" centers in and out of government, universities, institutions, etc., which can adequately predict the secondary effects of the continuation of present trend generating factors and of any new ones being considered or in the development process.

Lastly, it should be added that any measures which increase supply will tend to increase the size of agricultural markets since supply does, at least in part, create its own demand--and it is also correct to observe that any measures which increase demand will tend to increase the size of agricultural markets since demand creates its own supply, at least in part.

The Adjustment Problems Flowing from the Development and Adoption of Technology.

The problems a society faces when new technologies are developed and adopted may be usefully considered under the heading of:

1. Reorganizing production for use of new technologies by the technology adopters (farmers).
2. Reorganizing the input producing and marketing system supplying the technology adopters.
3. Reorganizing the output buying and processing system which obtains the products supplied by the technology adopters.
4. Secondary effects of increased production on:
   a. The sector of the economy adopting the technology.
   b. The rest of the economy
   c. Interrelations between adopting sector and rest of economy
5. Further problems and opportunities.

The first three items center upon actions that are required on the part of farmers as well as the suppliers of farm inputs and the buyers of farm outputs if the adoption of the new technology is to be facilitated. The focus of the fourth item starts with the assumption new technologies have been adopted and that the supply of food and fiber has increased.[16/] The secondary effects of increases of supply are examined with reference to both household and firm consequences. Item five centers upon problems which can be most effectively examined from points of view that do not fit the logical structure of items of one through four.

In the context of this discussion the new technologies of interest are a sub set of all new technologies. Our interest is not in all change but only the changes which offer high returns, or alternatively stated, profitable new technologies---a new technology which is less efficient than an old one should likely be classified as a technological regression---though it must be remembered that changes in prices will change the profitability of various technologies. A more concrete statement of this notion is that a new variety of wheat that is unprofitable to grow is of little interest[17/]--a new variety

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16/ This assumption reflects optimism. Should the food supply not increase faster than the food requirements--due to either ineffectiveness of technology or the birth rate or other reasons---the group of problems to be faced will be accordingly changed.

17/ The interest we have would rest on its likely potential.

which is profitable to adopt and grow is of interest. This notion can also be stated at a much higher level of abstraction in the context of agricultural development. Such a statement is that the process of agricultural development involves, to a large extent, the discovery or the invention of new ways of producing goods and services that are highly efficient and thus highly profitable.

Reorganization of production for the use of new technologies by the adopters: When a farm firm adopts a new technology a number of adjustments, of a farm management type, are usually required. The nature and extent of these adjustments will be closely related to the specific technology involved. The complexity of these adjustments may range from the adoption of entirely new farm management system to something as simple as altering the time of sale of a commodity.

The three major variables which appear to have the most effect on the rate of adoption of such technologies are (1) the potential gains to the adopters, (2) the complexity of the changes required of the adopter, which reflects both the technology and his past behavior, etc., and (3) the extent to which his ability to adopt the technology requires changes in behavior by other farmers, the government, and private agri-business firms.

Variable three is of special significance because of its quantitative importance as well as the measurement (estimating) problems involved and the fact that the incidence of the gains is often other than on the group of which change is required. For example, the profitability to a farmer of producing a crop may depend on the efficiency with which the suppliers of farm inputs or the buyers of farm outputs operate. Profitability may also depend on the efficiency with which such "non-traditional" inputs such as extension information, price reporting, insurance etc., is provided.

Reorganization of the input and marketing systems supplying the technology adopters: When a new production technology is being adopted by farmers, changes in the input system supplying farmers is often required. Moreover, a change in the input system supplying farmers may generate the use of new technologies on the farm in the production of food and fiber. Thus, the flow of causality is in both directions running from the farm to the input suppliers and from the input suppliers to the farm.[18]

18/ The flow of causality is more complex than the above statement suggests in that the buyers of farm outputs may also provide farmers with inputs such as credit or contract specifications defining either what inputs are to be used and/or what the characteristics of outputs will be--nor is this a full statement since disturbances can originate from other sources.

The types of changes that may be appropriate are normally thought of as resulting from potential gains and losses from internal and external economies of scale. A third consideration of considerable importance consists of gains and losses flowing from various degrees of industry agglomeration or concentration. Special attention needs to be paid to the problems flowing from changes in risk and uncertainty which is necessarily generated in the face of high rates of technological change.

Most of the reorganization problems are of the business management type that firms are traditionally expected to deal with. However, many problems will exist which will spill over to or directly involve such items as education, government policy, research, legal procedures, regulation of utilities, etc.

Reorganization of the output buying and processing system which obtains the products supplied by the technology clusters: The problems that arise for this sector of the economy, as well as the problems generated by this sector, are both a close analogue and overlap with the problems identified in the preceding section focusing upon inputs.

The production of new agricultural commodities or the increased production of existing commodities, if they are to be used efficiently, may require changes ranging from relatively small adjustments by a single firm to the establishment of new markets, marketing systems, and/or the construction of new processing facilities and plants. It is also possible that changes and innovations in the markets for and the marketing of agricultural commodities will lead to the production of new agricultural commodities or to an increase in the production of existing commodities.

Secondary effects of increased production of food and fiber: The effects of increases in the production of food and fiber are examined in terms of the firm and household for agriculture and non-agriculture. The characteristics of the markets for food and fiber are of key importance in relation to changes in factor prices, industry organization, and changes in the distribution of income. The single most important facts about the markets for food and fiber in India to keep in mind for this analysis are:[19/]

1. The price elasticity of demand for food and fiber is relatively low, perhaps about -.2 to -.5.

19/ These "facts" involve predictions about the future--if they turn out to be wrong, any inferences based on them will be wrong.

2. The income elasticity of demand food and fiber is relatively low--less than +1.0; probably about +.5.
3. The demand for food and fiber will likely increase at a lower rate than output.
4. The terms of trade favor food and fiber in relation to other goods and services to a higher degree now (1969) than will likely be the case in the future.
5. The ratios in which farmers use inputs in the future will be markedly different than at the present (1969).
6. The geographical locations at which food and fiber produced in India will be processed and consumed in the future will likely be markedly different than at the present (1969).
7. The increased flow of food and fiber to market will largely reflect production increases resulting from the adoption of new technology including multiple cropping.

Nature of the problems to be faced as the production of food and fiber increases: Farm firms, as a result of production increases, will be faced with downward pressures on the prices they receive for the products sold. These pressures will be sufficiently great to cause gross farm income and net farm income to decrease. The extent to which payments to the factors of production on a per unit basis decrease, assuming the total of all payments to be constant, will depend on the number of units each factor of production employed in agriculture. Net income, in the aggregate, received by farm producers for labor and management will decrease.

The risk and uncertainty faced by the suppliers of inputs to agriculture and the buyers of agricultural outputs will increase. On the balance these businesses will expand and likely net income to these industries will significantly increase.

Food and fiber prices to consumers will be lower and thus, farmers and non-farmers will benefit from the lower prices. Two benefits various persons receive will reflect the amounts of their incomes as well as their choices in the use of income.

The magnitude and the specific types of farm problems that are generated by falling food and fiber prices will reflect the responses farmers make in the aggregate and as individuals. The responses of farmers to decreasing output prices which imply lower rates of payment to the factors of production in the aggregate may be to (1) do nothing, (2) increase output per unit of input, or (3) shift out of agricultural production. These choices may, but need not, be mutually exclusive.

In the event all inputs now employed in agriculture remain so employed--the do-nothing alternative--many underemployed resources will remain in agriculture. In more specific terms, the incomes of farm people will be low and the ratios in which inputs are used to produce food and fiber will be relatively inefficient. This will not only mean that agricultural prices will be low but that non-agricultural prices will be higher than otherwise would be the case. It will also likely mean that the range of incomes found within agriculture will increase with some farmers, the ones who use the new technology, having the relatively high incomes.

In the event farmers further increase output per unit of input by producing more of the same commodities or even of different commodities, farm income will decrease by an amount determined by the elasticities of demand for the commodities produced. Analytically, the causal relationships may at times seem confused. It is, of course, not correct to expect to observe negatively sloping supply curves in terms of physical output, commodities marketed, or value productivity. However, the "shock" effect of decreasing prices may cause farmers and others to look harder for opportunities to increase efficiency. In the event, which should be expected, the prices of various agricultural commodities go down by different amounts, the optimum cropping pattern will be changed. When a firm adjusts to a new pattern of relative prices it may also take advantage of introducing additional efficiencies that would have been possible to introduce even though relative prices had not changed.

If the gross income of a sector of the economy decreases because of supply increases, a situation which will result when new technology is introduced by an industry faced with an inelastic demand for its output, the only way per unit returns to inputs can be held the same or increased is for some of these inputs to be transferred to other uses. The specific input pricing problem that will likely generate the greatest amount of trouble is that of returns on income to the people working in agriculture.

The reasons the rate of income payments to farmers will likely be the most difficult problem are several and involve the considerations that:

1. Persons working in agriculture are not highly mobile even in the presence of employment opportunities.
2. Persons working in agriculture amount to over 50 percent of the gainfully employed of India.

3. The rate of increase of employment in the non-agricultural sector of the economy likely cannot provide enough new jobs to meet the increasing supply of labor implied by existing birth rates and to reduce on-farm employment for many years to come.
4. Non-farm income will increase relative to farm income and the range of income distribution within agriculture will likely increase because only some farmers can adopt the new technologies of the Green Revolution.

Thus, the stage is set for an agricultural income situation involving equity and welfare problems among individuals and political problems when individuals act as members of sizable groups.

Action Programs to Meet Problems and Take Advantage of Increased Agricultural Production.

The various types of action programs that may be useful are listed below under six headings. Brief attention is given to each in the effort to indicate a little additional detail in the types of choices that are available.

The matter of the birth rate is one that has long been a matter of concern and will likely continue to be. At this point in history the most that can be reasonably concluded in specific cases is that birth rates in given situations are too high, too low, or about right. No reasonable concepts of optimum populations or rates of change are either generally accepted or intellectually satisfactory. Moreover, there is no reason to believe that the equilibrating mechanisms at work will generate a solution that is at all consistent with usually held notions of what the "world should be like."

Thus, we stop with our discussion of the birth rate problem in India and observe it is too high and action programs to reduce it are likely in order, but that there is little reason for optimism.

The mobility of labor as it relates both to the firm and household has long been recognized as a critical matter. Perhaps the only comment needed here is to emphasize the trade-offs that may be present between increasing the mobility of labor and decreasing the needs for it by treating the location of economic activity as a manageable variable as well as by the development of new technologies which tend to minimize the needs for changes in skills

and physical transfers of people. Programs should be designed to create productive labor-intensive services in the non-farm part of the agricultural sector and in building the physical infrastructure needed for a productive commercial agriculture. Such programs would provide an easier transition for traditional farm labor, would be a means of slowing the migration of the farm laborers to urban centers, and would contribute to increasing the overall productivity of the agricultural sector.

The rate of growth in the nonagricultural sector of the economy has long been considered a key economic policy issue, in the dimension of aggregate resource use and total outputs as well as in terms of output increases with corresponding input increases. The spill-over effects of the rate of growth of non-agriculture on the agricultural sector of the economy are many. The most direct effects show up in the demand for food and fiber in domestic markets and the demand for labor in industrial employment. Indirectly, an increase in the rate of growth of the non-agricultural sector of the economy will decrease the costs and increase the supplies of both consumers and producers goods to farmers. Decreases in the prices of industrial-produced inputs used in agriculture may have important secondary effects on exports of agricultural commodities.

The potential gains from increasing exports can be carefully thought of as a special case of increasing productivity per unit of input. The gains that can be realized are those implied in the usual comparative advantage analysis as well as a second type of gain that takes a bit of forcing to make a part of comparative advantage analysis. The latter type of gain is that which flows from specialization, large scale organization and trade in relatively "large" markets which is implied by international trade, which is operative in the marketing-production system distributing imports. The spill-over effects into the rest of the domestic economy involving the development of ports, population concentrations, transport network, etc., may result in gains that go unaccounted in the usual calculations.

Labor using U.S. labor-saving new technology is an often discussed subject around which much confusion is centered. Much of this confusion results from treating labor as an aggregate taking no account of differences in skill and from a failure to take explicit account of differing periods of time.

The types of new technology that are most useful in the context of the problem discussed in this paper, other things the same, are those which can be adopted with (1) the least time lag and (2) the least change in the behavior, skill, and location of people (labor).

New technology which is labor-saving and capital-using cannot be adopted until the new capital items are produced which may require the expansion of the input industries producing the capital goods, even though the technology may ultimately be labor-using when the entire production process is examined. Moreover, when all time, past and present, is aggregated the differences between capital and labor become confused.

A new technology that requires the use of labor skills that are not available or that can only be made available after long periods of training generate a set of problems not unlike the problems of constructing new physical capital. Thus, a new technology using the existing labor supply with existing location will likely be adopted more quickly than if these conditions are not met.

It is, of course, not likely that a simple choice among new technologies of differing degrees of labor and capital intensity can be made at no cost. However, in an economy short of capital and with a large pool of relatively unskilled manpower it may be possible to estimate reasonable trade-offs and concentrate on the development of technologies that can be put to work rather than left on the shelf or put to work only in other parts of the world.

Identification of likely future centers of populations, markets, and production centers can serve a number of useful purposes. The users of such information would involve both government and private sector firms in making choices among possible geographical locations to center various economic activities.

Research of the type implied by the above needs does not involve planning, though the information generated would be useful in planning by private firms or government agencies. The specific information that would be useful will vary among the types of choices under consideration. Examples of types of information of interest to many potential users includes data and analyses of population, income, raw materials supplies, transportation costs, etc.

V. Policy Implications

An investigation of the sort conducted by the authors of this report is not by its nature capable of generating policy recommendations, since but a small number of the relevant variables determining the appropriate policy mix were investigated. This investigation, we hope, has been designed in such a way that some matters can be highlighted which should be considered when policy choices are made.

The items presented below are, in the authors' opinions, matters that should receive consideration when policy choices are made. The suggestions presented below rest on the assumptions, which we believe are also fact, that the agricultural problem is not one of lack of natural resources--India is favorably endowed in terms of land, water, climate, etc., if her potentials are developed. A second belief is that the people of India are India's most valuable resource and will have no problem in producing all the food and fiber needed, if they can work in an environment that is generous in supplying needed (1) new technologies, (2) economic information to enable producers to make rational choices on how to produce what, when, and where, (3) incentives and freedom to produce food and fiber, and lastly, (4) political stability and an expanding and relatively prosperous non-agricultural sector of the economy from which agriculture can buy and to which it can sell. In short, our belief is that the agricultural production problem is largely one of improved technology, information, incentives, and the opportunity to base behavior on information and respond to incentives.

An effective research strategy to follow is one that will generate the technology and information needed to enable farmers (and the groups selling to and buying from them) to (1) employ new technologies and (2) choose among production alternatives on the basis of predictable price relationships. If the above objectives are reasonable, resources will be required to generate a continuous flow of the necessary technology and economic information. Such a continuous flow of information can be assured only if a research strategy is followed which institutionalizes the needed research effort in various organizations such as universities, institutes, and various units of government. The research strategy should also be broadly enough conceived that provision is made for the training of research scientists and technicians as well as finding solutions to specific research and technological problems.

Likewise, communication among the various research units within India is imperative and highly desirable in relation to other units in various parts of the world.

A second point concerning research strategy relates to the potential uses to which research results can be put at this point in the history. Top priority should be placed on the development of knowledge and technology with early payoffs. An appropriate test which can be applied to research programs and projects is to look at them as capital investment. In an economy with high interest rates of say 10 to 25 percent, results that cannot be obtained and employed in a few years are poor investments since alternative uses of the resources will generate greater returns. A $100.00 return ten years from now is virtually worthless today, if other uses of funds can return 25 percent per year. This is a severe but nevertheless a valid test to apply in making choices among potential research programs to support. Fortunately, in many cases research programs can produce early payoffs and at the same time provide training and contribute to the reservoir of knowledge and experience which will improve the capacity of the individuals and institutions to solve future problems.

Continued strong research emphasis should be given to the development of improved production technology for the major food crops. Because of the great interaction that exists among the various factors of production, attention should be given to development of systems of production rather than to single factor technologies. Such systems should enable the farmer to bring under his management the maximum number of the factors that control the yields that he obtains and the net returns that he realizes.

Of all of the factors of production water is the one that offers the greatest opportunities for improving agricultural production. Improved technology for on-the-farm water management will provide early pay-offs in increased production, is a necessary prerequisite for the exploitation of the potentialities of improved varieties, more adequate fertilization and other improved practices and is the key to the development of systems of multiple cropping. Improved technology is needed for (1) drainage and prevention of flooding, (2) land leveling for more uniform application of irrigation, (3) systems for delivery of water to individual fields, (4) locating and efficient methods of use of groundwater, and (5) improving the use of root-zone soil moisture.

A second focus of attention for research efforts concerns the development of new and the expansion of existing markets. The existing markets for vegetable proteins, including soybeans, can be profitably explored. The further development of export markets may be useful in connection with several crops. As agricultural production becomes more efficient and output increases, the research emphasis on animal agriculture should increase.

A third research program should take into account the need for a continuous flow of information to farmers, the buyers of farm products, and the groups selling to farmers that will be useful in the decision-making process. High on such a list is farm management data and its analogue for agri-business. Market reporting, as well as price and crop outlook data, is useful. The growth of markets in various urban centers along with changes in common preferences, if projected with reasonable accuracy, can assist both farmers and business persons planning long term capital investments. Lastly, studies in comparative advantage will enable the decision maker in both the public and private sectors to more effectively plan for the future in terms of where to locate economic activity as well as to choose the types of economic activity to engage in.