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ANALYSIS OF CONSTRAINTS TO INCREASED PRODUCTIVITY OF DRYLAND AREAS

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Abstract

The drylands of semi-arid and arid areas of subtropical regions. contribute significantly to the world's food production, particularly of coarse grains, cereals, pulses, and oilseed. Although present yields of these crops are low, they have excellent production potential in dryland conditions.

In the seventies, a number of concepts and techniques have been developed that can substantially improve the productivity of many of these drylands. But they have yet to be exploited extensively and intensively. There are good indications that the new farming practices can bring about a breakthrough in production in deep Vertisols, which occupy many million hectares in India. An analysis of constraints to productivity and production in drylands shows that, besides environmental and socio-economic constraints, technological constraints also seriously limit productivity in many of these areas.

Water is a limiting factor in drylands and provision of water for only "lifesaving" irrigation (i.e.. the minimum to prevent total crop loss) can stimulate a favourable chain reaction. However, even without irrigation, appropriate biological technology coupled with fertilisers can enhance productivity manifold. Fertiliser-responsive genotypes with higher yield potential and stability against yield reducers are becoming a catalyst of change in drylands. Such genotypes are available in the case of sorghum, millet, and maize, but not yet for pulses and oilseeds.

Dryland farmers are becoming interested in the use of fertilisers' for dry-farm crops, but their first preference is for high-value, market-oriented crops, high-yielding cereals and for lands with better moisture-storage capacity capable of giving stable yields and assured returns. The unirrigated lands of the semi-arid tropics (SAT) in India are at present given less than 18 kg of NPK per hectare, while irrigated fields in the same area receive about 58 kg per hectare annually. It is concluded that the rate of growth of fertiliser use in both these situations is commensurate with the technology and the infrastructure but there is considerable scope for increase.

This suggests a need for intensive research on the loss and efficiency of notrogenous and Phosphatic fertilisers under dryland conditions and the development of implements for seeding and fertiliser application at proper depth in relation to soil moisture. To avoid shortfalls in production of coarse grains, pulses, and oil seeds and to substantially increase their productivity, intensified support for research and development of dryland agriculture is needed. Investment in dryland agriculture should be considered a cast of social justice and equity to prevent an increasing gap between the disadvantaged populations of these poor areas and the rest of the world.

Introduction

The countries most burdened with subsistence agriculture lie mainly in the world's least reliable rainfall regions. Yet they are also the world's main regions of high population growth. With a high percentage of their population living below the poverty line, they are referred to as the less developed countries (LDCs).

The food supplies of the developing world are dependent on erratic rainfall and seasons within the intertropical convengence zone and in the dry zones that border it, Wright 1970. cited Dudal's findings that in 29 per cent of the soils of the world, moisture, stress is the limiting factor, and in 22 per cent mineral deficiency is the major constraint. There is no doubt that these constraints together produce compounded effects.

Extension of the area under agriculture and expansion of irrigation have been time-honoured ways of increasing food production. But the scope for the both these practices is rather limited for many reasons. Only in Africa, Latin America, and Oceania is there considerable scope for area expansion (Table 1), but in these countries there are many problems of a technological, social, and economic nature. Out of 1457 million hectares of cultivated land in the world only 204 million hectares (14 per cent) is irrigated and the rest is rainfed. Nearly 55 per cent the world's area receives less than 500 mm and 20 per cent has from 500 to 1000 mm rainfall.

World projections indicate that the maximum potential of irrigation is for 470 million hectares, but whether this can be realised in this , century is doubtful Thus, rainfed agriculture is most important, particularly in the drylands that occur in the semi arid and arid regions of the world. According to Troll's classificatiqn, the dry semi-arid tropics (SAT) have 2 to $4^1/_2$ humid months and the arid region less than 2 months when precipitation exceeds evapotranspiration. The extents of these areas in the world is quite large and can be conveniently divided into three climatic categories,

1. Arid and semi-arid tropics
2. Mediterranean arid and semi-arid
3. Continental arid and semi-arid

Table 1—Irrigated area in the world (1970)

Region	Cultivated (million ha)	Cultivated land as percentage of potentially arable land*	Irrigated (million ha)	Percentage irrigated area (%)
World	1457.0	44	203.6	14.0
Europe	145.0	88	12.3	8.5
Africa*	214.0	22	6.3	3.0
USSR	232.6	64	11.1	4.8
North America (US-Canada)	236.1	51	16.2	6.9
Oceania**	47.0	10	1.6	3.4
Asia	463.0	83	145.7	31.5
Latin America**	118.9	11	10.4	8.S

Source : Adopted from Wortman and Cummings (1978), pp. 59, 60.

*Based on the calculations of U. S. President's Science Advisory Committee, 1965.

**Regions with scope for expansion of cultivated area

This paper is restricted *to* discussion of drylands of arid and semi-arid areas, tropics which have a high climatic demand for water.

Indian Scene

In India, of the 143 million hectares cultivated area, 34 million hectares (24.5 per cent) are irrigated. Projections show that by the year 200C, irrigation will be extended to 77.6 million hectares (Swaminathan, 1979), about 55 per cent of its agricultural area. Even if India is able to develop its irrigation potential to the maximum extent, a large percentage of area will remain rainfed and dry farming will continue to be a very important form of agriculture.

Using Troll's classification system, Virmani et al., (1978) found that 60 per cent of the area in India falls in the dry semi-arid belt (Fig. l) with 2 to $4^1/_2$ wet months, and about 19 per cent of the area has less than 2 wet months. Assuming most of the present irrigation is also in these areas, the remaining nearly 55 per cent of India's total area still falls under dry farming and is seriously affected by the vagaries of monsoons.

According to Chowdhury (1979), 83 per cent sorghum, 81 percent pearl millet, 92 per cent pulses, and 90 per cent oil seed production in India comes from the unirrigated drylands. Thus the key to increased-production of these commodities lies in the dry lands.

Food Situation

Besides Indian subcontinent, the dry lands of arid and semi-arid regions occur extensively in Africa, the Near East, Latin America, and

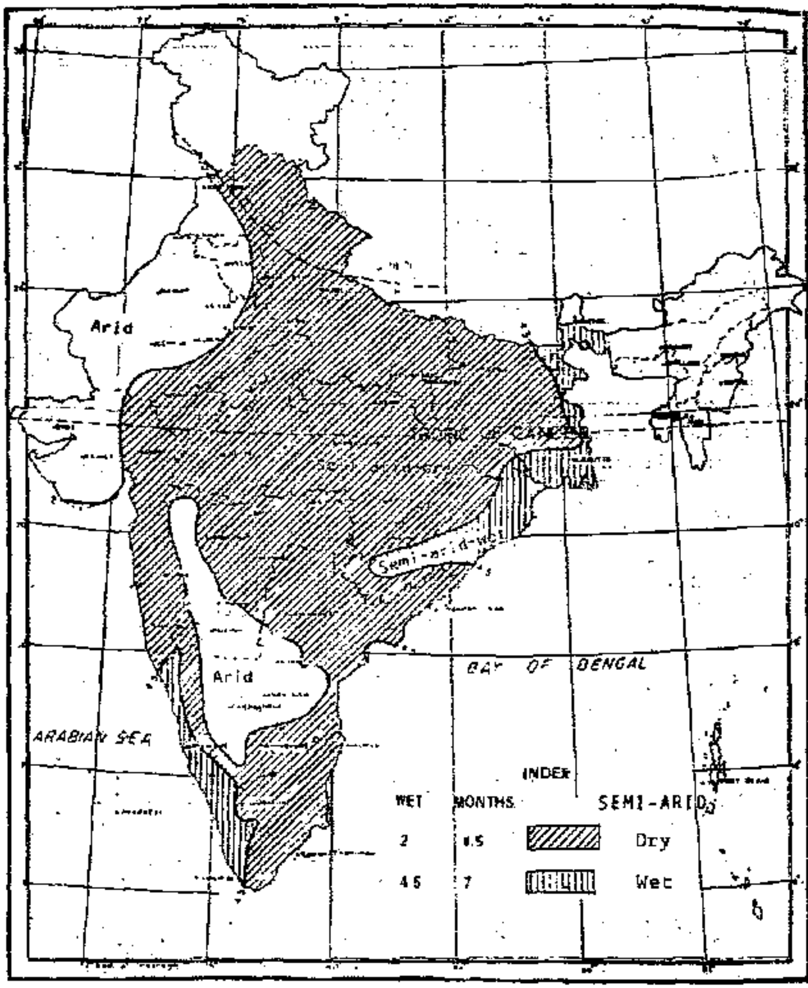

Fig. I—Arid and semi-arid areas in India

Oceania. Sorghum, millet, maize, pulses (pigeonpea, chickpea, green-gram, lentil, beans, etc,), oilseeds (groundnut, rape and mustard, safflower, etc.) are important. Dryland wheat and upland paddy are also important crops of these regions under certain conditions However, in all these crops the gap between the actual average yield and potential yield is very wide. Of 72 sorghum-producing countries, 34 have a yield under 1000 kg/ha and likewise of 65 millet-producing countries 41 have a yield less than 1000 kg/ha (IADS Report, 1978). There also wide variations in yield from country to country, region to region, and front season to season

The average yields of some important crops of the SAT and the potential yields obtainable with improved technology and inputs under rainfed conditions (Table 2) illustrate the wide gap that exists between research results and the farmer's fields (Kanwar, 1979).

Table 2—Average yield of crops in SAT and potential yields with new technology

Crop	Average yield (kg/ha) in SAT (30 years average)	Yields (kg/ha) obtained ICRISAT center, Patancheru (India) under rainfed condition*	
		Low fertility average management	High fertility good management
Sorghum	842	2627	4900
Pearl millet	509	1636	3482
Chickpea*	745	1400	3000
Pigeonpea*	600	1000	2000
Groundnut	794	.1712	2573

Source: * ICRISAT Progress Report 1979. The 1977-78 figures are from comparable situation.

The All India Coordinated Research Project for Dry Land Agriculture (AICRPDA) has also shown (Chowdhury, 1979) that where with traditional technology average yields of wheat, barley, maize, sorghum, and pulses ranged from 550 to 1280 kg, with improved technology the average yields ranged from 1770 to 2800 kg, indicating a three-to five-fold increase. The most disturbing feature of this scene is not only the low yields on farmers' fields but the great fluctuation in total production from year to year. Ryan (1974) calculated the coefficient of variation of sorghum yield in SAT 11.7 per cent and 14.7 per cent in millets (Table 3). There were also great variations from region to region. He concluded that the projected compound growth rate of five major crops of the SAT of LDCs show dismal production trends (Table 4).

In SAT the gap between food production and demand is rapidly widening- A projection of world demand for cereals (Table 5) shows that by the turn of the century the world must produce more than twice as much food as it did a decade ago.

Table 3—Coefficient of variation of yield of sorghum and millets in SAT

SAT region	Coefficient of variation of yield (%)	
	Sorghum	Millets
India	9.4	22.2
Other Asian region	9.S	14.1
Africa South of Sahara	11.5	14.9
South and Central America	17.0	12.4
Near East and North West Africa	2.3	11.6
Average SAT	11.7	14.7

Source: Ryan (1974).

Table 4—Annual compound growth rate of five major crops in SAT countries (based on 1964 to 1974 data).

Crop	Area	Yield	Production
Sorghum	0.71	2.08	2.81
Millet	0.04	1.20	1.24
Chickpea	—1.29	1.46	0.15
Pigeonpea	—0.08	0.83	0.75
Groundnut	—0.40	0.02	—0.38

Source: Ryan (1978)

Table 5—World demand for cereals

Particulars	Food (million tonnes) 1970	2000
Wheat	332.5	601.3
Coarse/grain	572.5	1186.6
Rice	346.7	633.6

Source: Adapted from Aziz (1976).

Aziz (1976) estimated that the projected demand trend is 3.23 per cent for millet and sorghum whereas the production rate increase is 12.4 per cent for millet and 2.81 percent for sorghum. According to Wortman and Cummings (1978) in the case of pulses a shortfall of 50 per cent is projected by the year 2000 and for oilseeds the expected shortfall is about 40 per cent. India and Africa are likely to have the highest deficits. This is an . alarming situation.

The International Food Policy Research Institute (IFPRI) has concluded that by 1990, the food-deficient LDCs will be importing 120 to 145 millon tonnes of food grains (Wortman and Cummings, 1973). No doubt serious efforts are being made to bridge this gap by expanding the area under cultivation and by developing irrigation but as already stated, this strategy has serious limitations because of socio-economic political, and technological constraints. Many of these underutilized lands are not evenly distributed or are distant from the areas of population and require huge investment on irrigation and soil reclamation, thus making their cultivation an impractical proposition. Thus the main plank of a strategy for meeting the food callenge in the year 2000 must be to increase the productivity of the land already under the plough.

The problem of increasing productivity of dry lands has important socio-political implications because the gap between farmers' yields in the irrigated areas and the dry farming areas is widening and the latter are more prone to suffer from natural calamities, such as droughts.

Constraints to Productivity

To critically examine the possibility of increasing the productivity of drylands, the constraints to productivity must be understood. These can be classified into three major categories : socio-economic, environmental and technological.

Socio-economic constraints

Most farmers of the drylands have meagre resources, small holdings, and low availability of capital. In the Indian SAT there are 1.7 person per hectare whereas in the African SAT there is 0.14 person per hectare (Ryan and Binswanger, 1979). Thus human and animal-power-based technology, is labour-intensive but land-saving, is more suitable for the Indian SAT, while the reverse may be true in case of some African countries. The Indian drylands are predominantly operated by small farmers.

The small farmers may be resource poor but they are certainly economic minded and rational. Although they are severely constrained in their use of capital-intensive technologies, they are willing to take risks if the rewards are attractive. But lack of marketing facilities and market incentives for the crops that are predominantly grown on these drylands is a serious constraint to increasing their productivity and production.

What these farmers need for increasing productivity of their lands are innovations, initiative inspiration, aspiration, and appropriate incentives (Ryan and Binswanger, 1979).

Environmental constraints and their management

(a) *Climatic constraints—Dry* areas are characterized by low precipitation that is highly variable both in space and time, thus making regional crop planning a difficult proposition. The mean annual temperature exceeds 18°, the climatic water demand is high, and cropping season short.

The seasonal variations of rainfall influence the water availability, to crops and affect their growth and development. Water is the more limiting factor for agricultural productivity and stability and makes the use of high input-based technology risky.

The agricultural climatologists working at ICRISAT in cooperation with the National Weather Bureaus have carried out extensive analysis of rainfall data of over 70 years in India and in some West African countries. This study has helped to quantify the risk and delineate reliable periods of rainfall on a short-term basis. Based on these data, it is now possible to determine the more suitable crop cultivars and cropping systems for different areas (Virmani et al. 1978). For example, the latitude and total rainfall of Hyderabad and Sholapur are comparable but ther rainfall probabilities and patterns of distribution are different, which makes kharif cropping risky in Sholapur but generally successful in the Hyderabad situation. Such information is useful in developing optimal cropping strategies for different Alfisol and Vertisol regions of SAT India.

Quantification of the risk of rainfall probabilities associated with soil moisture availability for meeting crop demands has been studied for a few typical locations in Vertisols of SAT India. Binswanger et al. (1980) showed that in somewhat similar rainfall regimes the probability of success of meeting crop water needs at the same important phenological stages is different (Table 6). The water supply to crops is considerably modified by the soil moisture holding and release characteristics. The soil depth, rate of intake, texture infiltration, and the presence of root-restricting layers, etc., modify the effect of rainfall.

Table 6—Reliability of a 90-day kharif crop on Vertisols {Probability expressed in per cent years).*

Location/ Soil	Annual rainfall (mm)	Probability of seedling survival	Probability of good growing conditions throughout	Probability of adequate soil moisture for rabi sorghum	
				After kharif crop	After fallow
Sholapur — Deep Vertisols	742	49	33	60	80
Hyderabad — Deep Vertisols	761	76	62	50	83
Akola— Medium deep Vertisols	840	80	66	NA	NA

* Available water holding capacity of deep Vertisols is assumed to be 230 mm and of medium deep Vertisols 120 mm.

NA = The water holding capacity is far too low to meet rabi sorghum water needs.

In a study of the length of the crop-growing period, based on long term, single-day rainfall and three simulated soil moisture storage capacities, Virmani et al. (1977) showed that deep Vertisols at Hyderabad provide a favorable moisture regime for crop growth for 26 weeks, whereas the shallow Alfisols have a growing season of only 18 weeks (Table 7). Such information is useful in crop planning and tailoring varieties to suit the environmental conditions.

Intercropping and climatic constraints

Intercropping can be used as a strategy against the tremendous variability in rainfall and soils by optimizing resource use in dry lands of the SAT. The results from ICRISAT's Farming System Research Programme have conclusively shown that intercropping of maize/sorghum and pigeonpea is more reliable in the deep Vertisol regions of peninsular India than in shallow Alfisols or Vertisols. Yields from these two crop combinations exceeding 3000 kg/ha have consistently been achieved in operational scale watersheds, irrespective of the vagaries of rainfall over the last several years. The system is significantly weatherproof.

Table 7—Length of the growing season in three soils having different available water storage capacity

Probability	Available water storage capacity					
	50 mm (shallow Alfisols)		150 mm (medium Vertisols)		300mm (deep Vertisols)	
	Period	Weeks	Period	Weeks	Period	Weeks
90 per cent	35 June - 30 Sept	14	25 June - 21 Oct	17	25 June - 18 Nov	21
75 per cent	25 June-7 Oct	15	25 June - 4 Nov	19	25 June - 2 Dec	23
Mean	25 June-28 Oct	18	25 June-18 Nov	21	25 June - 23 Dec	26

Source : Virmani et al. (1977)

A study by Rao and Willey (1979), based on the results of 89 experiments available on sorghum/pigeonpea intercrop, showed that the associated risk of crop failure to produce Rs 1000/ha was once in 36 years. The relative risk of failure for sole sorghum was once in 8 years and for sole pigeonpea once in 5 years.

Considerable evidence is available that the productivity of inter-cropping systems can be greatly improved by manipulation of appropriate plant population, genotype, and soil and water management practices. In sorghum/pigeonpea intercropping, using a broadbed-and-furrow system, and increased pigeonpea population from 40,000 to 70,000 plants/ha in a 2:1 row arrangement gave a yield advantage of nearly 70 percent as measured by the land equivalent ratio (Natrajan and Willey, 1979).

Similarly, Reddy and Willey (1979) observed that an intercrop of millet/groundnut produced a yield advantage of 26 per cent in a 1 millet:3 groundnut row arrangement in Alfisols. Averaged over three experiments and two arrangements, the advantages were relatively greater under moisture stress (28 per cent) than under no stress (18 per cent) conditions. Studies have also shown that the medium to tall hybrids of millet are preferable to short dwarf hybrids because of their better competitive ability. It is no wonder, therefore, that Indian dryland farmers invariably put greater emphasis on intercropping systems. Jodha (1979) observed that in some of the SAT villages, intercropping was as high as 90 per cent.

ICRISAT studies have also shown that the success of growing crops on the heavy deep Vertisols during the rainy season is dependent upon the early establishment of good crop stands. Dry seeding techniques coupled with preparation of the seedbed in the dry season have been found useful. Climatological studies using long-term weather data show that in deep Vertisol areas east and south Sholapur, Jalgoan, Sangli, and Ahmedabad (Fig. 2) dry seeding of sorghum in anticipation of rainfall- is practicable and has a low risk of failure. For dry seeding of crops, seedbed preparation must be done much earlier and the broad-bed-and-furrow system renders itself more suitable for this purpose. Introduction of the dry seeding practicle alone can considerably increase the productivity of many million Hectares of deep Vertisols.

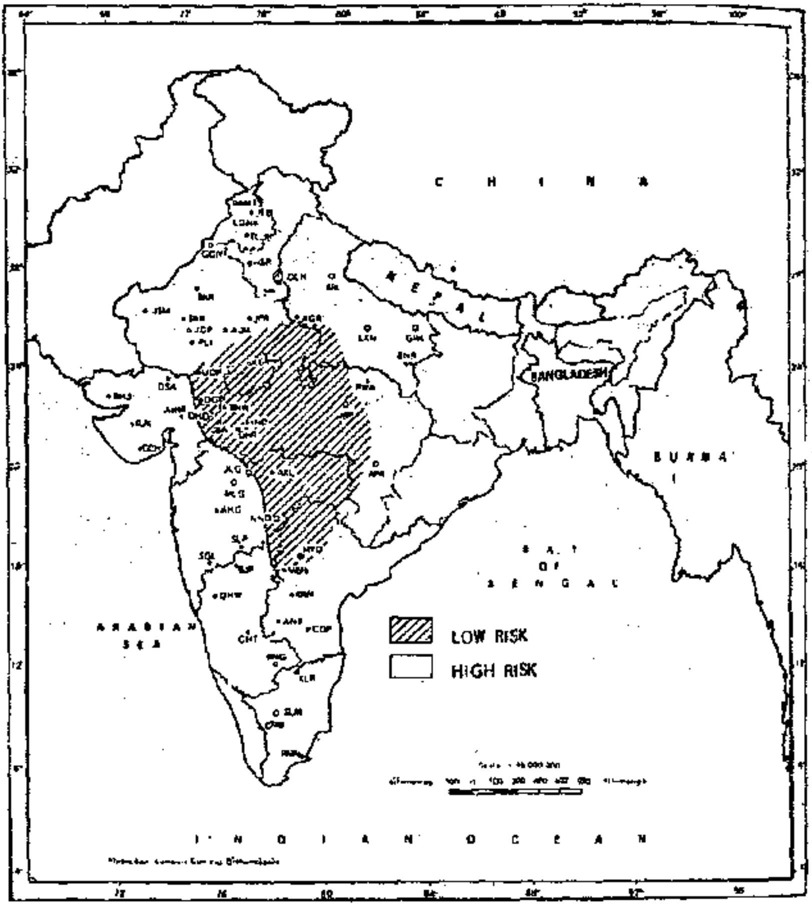

Fig. 2 — Possibilities of dry seeding in Vertisol

(b) *Water constraint and its management :* In all dry lands, water is the basic limiting factor and an all-out effort is needed to exploit every drop of rain water. There is considerable loss of water through runoff, particularly from storms of high intensity. AICRPDA data reported by Chowdhury (1979) show that the loss of rain water in many dry lands of India varies from 9.7 to 39.4 per cent in ICRISAT experience, the runoff loss of water in Alfisols, on an average, may be more than 25 per cent in Vertisols less than 10 per cent. The average runoff loss of water from the watershed experiment at ICRISAT centre is given in Table 8.

The Vertisol watersheds were cropped in the monsoon as well as the post-monsoon season and crops were generally sorghum/maize + pigeon-pea or chickpea. The land treatments were graded broadbeds and furrows or conventional flat systems. The much higher runoff from

Table 5—Runoff in three soils at ICRISAT Centre under field-scale magnagement trials. (1976-79) on watersheds in Alfisols and Vertisols*

Surface Treatment 1	Runoff expressed as percentage mean rainfall of 4 years		
	Shallow Vertisol	Deep Vertisol	Alfisol
Flat	3.1	12.4	21.7
Broadbed and Furrow	4.0	9.6	34.2

* Excluding runoff of one heavy storm on 14 and 15 Aug 1978

Alfisols indicates the possibility of successful water harvesting and recycling in Alfisols to increase the cropping intensity and productivity. In deep and shallow Vertisols the lower runoff loss indicates greater intake of water in the soil, which could be available to the crop or lost through downward drainage.

Three options are open to exploit this valuable resource of water that would otherwise go waste and might even cause erosion and floods :

1. Store as much water in the soil as possible.
2. Harvest the excess of runoff water for life-saving irrigation.
3. Mine the runoff water from low spots where it has enriched the aquifers.

Generally a combination of all these possibilities is operative in a given situation. To increase the efficiency of every drop of water, whether stored in the soil, harvested from runoff, or mined from the aquifers, is the best strategy for removing the constraint of water from rainfed agriculture.

The concept of small watersheds and the broadbed-and-furrow system for increasing rainwater-use efficiency in situ and harvesting runoff water by storing it in tanks and using it for life saving irrigation is an excellent one and needs extensive trials in India and elsewhere.

No doubt water is a limiting factor in dry lands, but this does not mean that all the available water resource potential of dry land areas has been exhausted. In the semi-arid areas of Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu, and Karnataka more planned and intensified effort is needed to develop these water resources in the form of tanks, wells, and minor irrigation works. The emphasis should shift from major irrigation projects to development small watershed resources.

It is a historical fact that in the whole of the Deccan Plateau, the runoff water that is being harvested and stored in tanks or mined from tube wells is mostly used for growing rice No doubt there is a locational advantage in growing rice, but whether this is the most efficient use of water compatible with social justice and equity is questionable. The same water could be used for lifesaving irrigation of many times more acteage of sorghum/maize, groundnut, and other crops that have lower water requirements. Thus we must consider how to transfer the benefits of irrigation water to resource-poor farmers in drylands.

If water were available for lifesaving irrigation for even a small percentage of the total area farmed by a farmer, it would catalyze a series of changes in the outlook of the farmer on investment, cropping system and cropping intensity. Experience suggests that even traditional small farmers who without water, were using the intercropping system as the main system of farming rapidly change to sole cropping and more intensive cropping systems, thus increasing the productivity of land manifold.

However, it hardly needs to be emphasized that water alone is not enough; unless water use is combined with fertilisers, high-yielding seed, and good soil and crop management systems, the desired goal cannot be reached.

(c) Soil constraints and management: Some of the important soil constraints that affect productivity of dry lands are as follows:

i) Low fertility.

ii) High erodibility.

iii) Shallow depth.

iv) Low moisture storage capacity, particularly of Alfisols.

v) High crusting that leads to poor crop stands in many Alfisols.

vi) Management problems with Vertisols which have a high moisture storage capacity but remain uncropped during Kharif because of the difficulty of tillage when too wet or too dry.

Techniques are now available that can convert the deep Vertisols under medium and high rainfall from a single cropped to a double cropped situation, thus enhancing production. The graded broadbed-and-furrow system and associated technology that has been designed by the Farming Systems scientists at ICRISAT may provide opportunities to bring many million hectares of deep Vertisols from single cropped to double cropped lands, thus increasing their productivity substantially- It is estimated (Binswanger et al, 1980) that this change alone may ultimately result in many million tonnes of additional grain production in India from millions of hectares of deep Vertisols*. However, for this additional production, besides the improved varieties and improved soil and water management systems, an application of about one million tonnes of nitrogenous and phosphatic nutrients is also essential-

It is beyond the scope of this paper to discuss all these factors but a detailed discussion of soil fertility and fertiliser use is warranted as it is one factor that markedly increase productivity as well as add to total production in dry lands.

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*Assuming 2 tonnes average increase in yield as observed in Steps-in-Technology experiments at ICRISAT. On such soils, 10 million hectares can produce 20 million tonnes more grain.

Soil Fertility and Fertiliser Use in Drylands

If one were to consider only one factor that can substantially improve productivity of drylands without irrigation, it is the use of fertilisers and manures. Voluminous data are available with the AICRPDA and with the All India Coordinated Crop Improvement Projects that clearly establish the importance of fertilisers in increasing productivity and total production from drylands (Venkateshwarlu, 1979).

After reviewing 7 years' research results, Chowdhury (1979) concluded that all the dryland crops respond to nitrogen, but the most economical results are obtained with low to medium doses varying between 40 to 80 kg. For phosphorus also, the most remunerative results are obtained at lower levels.

Kanwar (1978) critically examined the experimental data from a number of sources and concluded that the available high-yielding varieties of sorghum and pearl millet give a significant response to fertilisers, but in the case of pulses and groundnut high yielding and highly fertiliser-responsive varieties are not available. Thus technological limitations are evident. FAO (1980) has published the results of fertiliser responses obtained from hundreds of trials during 1961 to 1977 in many developing countries. The mean responses in grounndut, sorghum, maize, and millets (Table 9) showed that with modest application of fertiliser the yields were almost doubled.

Table 9—Mean responses in groundnut, sorghum, millets, and maize in Less Developed Countries (LDCs)

Crop	No. of trials	Control yield (kg/ha)	Fertilised crop yield (kg/ha)
Millets (4 countries)	1,354	565	950
Sorghum (9 countries)	2,236	926	1,881
Groundnut (14 countries)	4,385	1,084	1,642
Maize (26 countries)	2,060	1,864	3,108

Source : FAO (1980). Weighted averages by number of trials

The responses to fertilisers are modified considerably by the moisture status of the soil profile (Ranjodh Singh et al., 1975).

The synergistic effect of improved varieties, fertiliser application, and the soil and water management system to improve the soil moisture status have been demonstrated in Steps-in-Technology experiments at ICRISAT for many years. The average yield increases in both Alfisol and Vertisol soils are given in Table 10 (Saharawat et al., 1979). These results clearly show the effect of soil management in improving the fertiliser efficiency with traditional as well as high-yielding varieties.

Table 10 —Effect of improved varieties, fertilisation, and soil and water management on yield of sorghum on an Alfisol

Fertiliser	Sorghum yield (kg/ha)	
	Traditional variety	Improved variety
Control	330	640
NPK	1,240	1,750
NPK and soil and water managment	1,930	3,430
LSD (0.05) = 4.9		

Source : Adapted from Sahrawal *et al.,* (1979)

Thus the available evidence shows that fertiliser is no doubt the key factor for increasing yield under dry farming but its effect is considerably influenced by soil and crop management, moisture storage in the soil, and choice of variety. The technique for improving the efficiency of nitrogenous fertiliser needs intensive investigation. The methods and depth of placement of nitrogenous fertilisers, use of nitrogen inhibitors, granule size of fertilisers, time of application of fertilisers, and moisture status of soil, all influence the efficiency of nitrogenous fertiliser considerably. But the data on this aspect of fertiliser use in dryland conditions are rather meagre. It is hoped that the IFDC-UNDP projects at ICRISAT and ICARDA which are aimed at the study of such factors, will develop techniques for improving the efficiency of nitrogenous fertiliser in dry lands.

There is some evidence that in C_4 plants of sorghum and pearl millet there are considerable genotypic differences in the ability to fix atmospheric nitrogen as measured by nitrogenase activity. Whether the geneticists and microbiologists can exploit these traits in reducing nitrogen requirements of these crops is yet to be researched.

Another fascinating area of research that has considerable scope for practical application is the use of mycorhizal fungi to increase the solubility of soil phosphorous and thus reduce the need for application of phosphate. Intensive research in the eighties is needed to develop these possibilities

These are no doubt distinct possibilities, but it is very unlikely that in the eighties, they will become practical realities for use by farmers. Thus main emphasis will continue to be on the use of fertilisers and manures for increasing production under rainfed conditions of drylands.

Status of fertiliser use in drylands : To understand the present status of fertiliser use in drylands, we may examine the situation in India. Ac ICRISAT, Jha and Sarin (1980) made extensive studies on fertiliser use in the Indian SAT and found that:

(a) 192 semi-arid tropical districts in India accounted for nearly 66 per cent of the gross cropped area of the country and consumed 73 per cent nitrogen, 75 per cent phosphate, and 70 per cent potassium of the entire fertiliser consumption in the country during 1977-79.

(b) Over 62 per cent of the total fertiliser used in the SAT was consumed on 35 per cent of the cropped irrigated SAT area, thus indicating great disparity in fertiliser consumption between irrigated and non-irrigated areas.

(c) The average consumption of fertiliser per hectare of cropped area was 57.5 kg in irrigated and 18.5 kg in unirrigated SAT districts (Table 11).

Table 11—Average level of fertiliser consumption in kilogram per hectare of gross cropped area, 1977-79

Ferti-liser	Irrigated SAT (78 districts)	Unirrigated SAT (114 districts)	Total SAT (192 districts)	All India
N	40.0	11.6	21.5	18.9
P	11.6	4.5	7.0	5.9
K	5.9	2.4	5.6	7.2
NPK	57.5	18.5	32.1	28.5

Source : Jha and Sarin (1980)

(d) In 48 of 114 unirrigated SAT districts, the consumption was less than 10 kg/ha, but in 12 unirrigated districts it exceeded 40 kg/ha. However, in the latter case most of the consumption was in cotton, groundnut, chillies, and tobacco.

(e) The low fertiliser consuming districts are concentrated in Madhya Pradesh, Maharashtra, Rajastan, and Gujarat.

(f) The consumption of fertiliser in drylands started mainly in the sixties, and the growth rate in the seventies also showed considerable upward trend. The unirrigated districts contributed considerably (Table 12) to fertiliser consumption growth rate in the seventies (1970-78). It was also observed that, during this period, in 57 per cent of the unirrigated districts the annual rate of increase in consumption of nitrogen, phosphate and potassium per hectare of cropped area was less than 1 kg, but in 10 per cent of them it exceeded 5 kg/ha (Table 13). In the latter case the fertiliser did not necessarily go to cereals, pulses, and oilseeds; some of the unirrigated commercial crops like cotton, chillies, tobacco, and even groundnut claimed the greatest share of fertiliser in these areas.

(g) The authors concluded that irrigation and assured rainfall, market incentives or high-value crops, and technological changes govern the rate of growth of fertiliser consumption in the semi-arid drylands. Thus viable technology holds the key to the spread of fertilizer. The profitability of fertiliser application and assurance of response have been the major forces motivating fertiliser use in SAT.

Table 12—Contribution of SAT districts to fertiliser consumption in the period 1970-78

Fertiliser	Per cent of total growth accounted for SAT (1970-78)	
	Irrigated districts	Unirrigated districts
Total NPK	59	41
N	62	38
P	55.	44
K	53	47

Table 13—Rate of annual increase per cent in consumption of fertilisers (kg/NPK/ha) in cropped area in SAT districts between 1970-79

Rate of increse	Irrigated SAT districts	Unirrigated SAT districts
0-1 kg	8	57
1-3 kg	42	33
3-5 kg	35	8
>5 kg	15	. 2

Source : Jha and Sarin (1980)

The study of Jha and Sarin (1980) thus clearly illustrates the importance of SAT districts in fertiliser consumption, but the biggest climants for fertiliser continue to be irrigated districts, irrigated crops, commercial crops, and highly responsive varieties of crops. The authors expressed concern that traditional varieties of cereals, pulses, and oilseeds that occupy the bulk of the area under rained conditions of drylands are not usually fertilized. The impediment to fertiliser use in these drylands is not the conservatism of farmers but the lack of highly remunerative technology or of more fertiliser-responsive varieties capable of giving good yields under restricted moisture conditions.

Even in areas of low rainfall and unirrigated conditions the farmers prefer to fertiliser soils with high moisture storage capacity. Further, fertiliser consumption in these areas was greater in wet years or good seasons and less in dry years or uncertain seasons. The nature of the cropping system (sole cropping versus intercropping), timeliness of sowing, soil type, and season and rainfall also influence farmer's decisions on use of fertilisers for crops in dry lands. Lack of implements for fertiliser application at the right depth is a serious handicap for the dryland farmer. Availability of fertiliser at the time of sowing is more serious for dry land crops, as the farmer must follow the rain and cannot delay his operations. Many of these technical and organisational problems were discussed at an FAI seminar in 1979 (FAI Seminar, 1979).

There is a general notion that small farmers are less inclined to use fertiliser than the big farmers. Under comparable situations with irrigated and commercial crops like sugarcane, cotton, chillies, tobacco, etc., Small farmers are as inclined to use fertilisers as big farmers, but in urirrigated conditions small farmers are more selective, preferring to use fertilisers on high-yielding and more fertiliser-responsive varieties (Jha and Sarin, 1980).

Use of fertilisers for intercropping: Fertiliser use is generally lower for intercropping systems (which are a strategy against aberrant weather and uncertain production) than for sole cropping, which is preferred under more favourable soil and microclimatic conditions.

The data in Table 14 from the study of fertiliser use in the Indian SAT by Jha and Sarin (1980) clearly show that under unirrigated SAT conditions the sole-crop-based system received more fertilisers than the intercrop-based system. This may be partly because the responses obtained in cereals like sorghum per unit of nitrogen applied are lower in intercropping than in sole cropping, and partly because of the prevailing notion that legumes in cereal/legume intercropping may benefit the cereal by transferring nitrogen fixed from the atmosphere. Some recent experimental -evidence from the sorghum/pigeonpea combination (Willey, personal communication) raises some doubts about such a nitrogen transfer in this case.

Table 14—Fertiliser use in intercropping and sole cropping systems under unirrigated conditions in Akola district

Crop	Variety	Crop percentage-area devoted to intercropping	Rate of application of fertilisers (kg/ha)					
			sole crop			intercropped		
			N	P	K	N	P	K
Sorghum	Local	*91*	20	3	1	11	6	4
	HYV	27	30	16	10	19	0	0
Groundnut		72	45	17-	31	9	10	6

Source : Jha and Sarin (1980)

Technological and Biological Constraints

Often one is likely to overemphasize the role of socio-economic factors and overlook the fact that lack of a viable technology is the biggest constraint to increasing fertiliser use in drylands. The evidence gathered in the last two decades confirms the lack of a viable technology that could inspire dryland farmers to improve productivity. This is not to undermine the importance of socio-economic factors but to emphazise that a higher priority should be given to removing the following biological constraints:

A. Lack of appropriate biological technology:

1. Lack of genotypes capable of giving high and stable yields despite aberrant weather and yield reducers such as pests, diseases, and drought discourages the use of high input technology because of the inherent risks.

2. Lack of fertiliser-responsive varieties, especially in the case of pulses and oilseeds.

3. Lack of a more remunerative cropping system than toe existing ones to meet aberrant weather conditions.

It is only in the seventies that the importance of drylands and the lack of appropriate technology for improving their productivity has started attracting attention at the national and international agricultural research level. Investment in dryland research is still inadequate to match the size of the problem and to meet even the most urgent needs. Sustained basic research is needed to open up new avenues for achieving breakthroughs.

The major research effort in the world has been and continues to be for the development of technology for irrigated and assured rainfall conditions; this has serious limitations in its applicability to dryland agriculture.

The pest and disease problems of intercropping systems commonly followed in many drylands differ in several respects from the sole cropping system and have not been adequately studied.

A technology that is based only on use of pesticides is also not likely to be attractive to the dry land farmer because of the cost benefit relations and the greater risks involved. Disease and pest resistance, if suitably incorporated in the varieties, should prove more useful.

Weeds are serious competitors for nutrients and moisture in dryland farming, and not much attention has yet been paid to the development of an integrated and viable technology for their control and management. Use of weedicides involves many technological and economic problems, but these can be solved if a national policy is developed for supplementing manual labour with chemical and mechanical weeding for effective weed control.

B. Lack of appropriate resource management technology:

Not only is biological technology not available, but even soil and water management and appropriate engineering technology for increasing production in dryland environments are lacking. Lack of suitable implements for use by small farmer for seeding and fertiliser application at the proper depth and in proper amounts is a serious handicap to obtaining a proper crop stand. The concepts of present-day common conservation practices were developed in the temperate regions under different socio-economic conditions and have serious limitations in their applicability in semi-arid and arid regions of tropical areas. The location-specificity of many dryland farming techniques is another serious handicap to their extension on a large scale.

In recent years, two international centres, ICRISAT and ICARDA have started work on developing technologies that would suit the conditions of the semi-arid subtropical and the arid mediterranean regions. The other international agricultural research centres will also be giving more attention to this problem in the eighties. In India, AICRPDA is endeavouring to tailor technology to meet the conditions of Indian dryland fanners. The new concepts being developed by these organizations need to be evaluated on farmers' fields and, with appropriate modifications, introduced under similar soil and agroclimatic conditions.

It must be recognized that interest in dryland research and development is very recent, that the task is gigantic, and that the resource inputs are not commensurate with the magnitude of the problem. It should not be overlooked that water can become a catalytic agent for change. All encouragement should be given to accelerate the farmers' capability to provide lifesaving irrigation or store more moisture in the soil, which can start a chain reaction for development of agriculture.

Potentialities and Prospects

From the foregoing analysis of constraints and technologies, it follows that for a real breakthrough in productivity and production of crops in the dry lands of the arid and semi-arid regions of the world, for which I have used India as an example, the following priorities emerge:

1. Development of a viable technology that can assure better returns on investment, create greater stability of production, and blunt the effect of aberrant weather. Fertiliser-responsive and management-responsive varieties of sorghum, millet, and maize are now available, but research has just begun in pulses and oilseeds.

2. Improvement of irrigation capability, particularly for lifesaving irrigation, to catalyze change towards use of input-based technology.

3. Development of better infrastructure for supply and use of inputs, marketing of produce, credit availability, incentives and motivation to farmers to produce coarse grains, pulses, and oilseeds.

4. Inducement to use fertilisers and to apply land and water management techniques in drylands is essential for improving returns to dryland farmers.

I do not wish to go into detailed discussion of these aspects as I have referred to them elsewhere. However, I want to emphasize that viable and remunerative technology is the basis for increasing productivity and total production from drylands and that fertilisers are the linchpin of this strategy. Water can act as a catalyst, but even without irrigation the additional moisture stored in the soil can produce spectacular results with fertilisers and superior genotypes. This is not to undermine the importance of development of supplemental irrigation, but to emphasize that in many situations development of lifesaving irrigation should be considered a long-term investment and assurance against calamities. There are a large number of situations, particularly in the SAT, where minor irrigation source development looks promising and needs high priority. When a farmer has control of the. source of irrigation, the system will be more productive and efficient. Rain water should be retained on the farmer's own lands so far as possible instead of allowing runoff which can create erosion and flood problems. The SAT dry lands have tremendous potential. Even with the technology developed in the seventies, production can be more than doubled. However, farmers need a compact area approach and a viable package of practices including crop varieties, cropping system fertiliser, and soil and water management.

The small farmer in dry areas is not in any way less responsive to new technology than the large farmer, but he has his options rationally set in relation to his meagre resources, and given higher priorities to more remunerative crops, varieties, and fields so as to maximize his returns and reduce his risks.

The future of dryland agriculture is bright, but there is a need for greater support to research and agricultural development in these areas. There is also a need to consider whether some development costs in the framework of social justice because of the harsh climates and unfavorable environments of dryland farmers. Conventional economic standards may not be adequate to break the stagnant system of farming in drylands.

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