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WATER MANAGEMENT FOR INCREASED PRODUCTION IN THE SEMI-ARID TROPICS[1/]

by

B.A. KRANTZ & J. KAMPEN

1/ Invitational paper presented at National Seminar on Water Resources in India and their Optimum Utilization in Agriculture, at the Water Technology Center, IARI, New Delhi, March 21 & 22, 1973.

WATER MANAGEMENT FOR INCREASED PRODUCTION IN THE SEMI-ARID TROPICS[1]

by

B.A. Krantz[2] & J. Kampen[3]

In the semi-arid tropics, the main factor limiting crop intensity and crop production to its present low level is water. Although the Semi-arid tropics are typified by temperatures favorable to year-around crop production, in most areas only one low-yielding crop is grown, thus utilizing only a fraction of a total crop production potential. In India, about 20% of the crop land is irrigated from large storage reservoirs, diversion dams, small tanks or wells. These areas are usually associated with river basins. The other 80% of the crop area is generally defined as "rainfed". This paper will deal mainly with that portion of the rainfed area which is designated as the "semi-arid tropics". The portion of the tropics which is referred to as semi-arid tropics represents a rather broad range of rainfall conditions, varying from about 500 mm to 1500 mm. According to Troll's classification Gray (1970) the semi-arid tropics are described by classes V3 (Tropical wet-dry) and V4 (Tropical dry) in which rainfall exceeds Potential evapotranspiration (PET) for 2.5 to seven months of the year. Humid and rainy tropics - V1 & V2 - are defined as those regions where rainfall exceeds PET for more than 7 months of the year). Conversely, the tropical semi-desert or desert zones are defined as those areas where rainfall normally exceeds PET for 0 - 2 months during the year. This

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1/ Invitational paper presented at National Seminar on Water Resources in India and their Optimum Utilization in Agriculture". at the Water Technology Center, IARI, New Delhi, March 21 & 22, 1973.

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classification gives a general characterization of the climate of the semi-arid tropics. In time a sharper delineation of the regions involved in the Semi-arid Tropics will have to be made.

The semi-arid tropics have a distinct wet and dry season and the variation in rainfall consists primarily of the amount and intensity of rainfall during the wet season with little or no difference in the length of the wet season (see table 1). Thus, under traditional agriculture, crop production may not be positively correlated with rainfall due to such factors as increased soil erosion and temporary water-logging, particularly in the black cotton soils. The rainfall pattern in the semi-arid tropics is erratic and short-duration droughts may occur during the monsoon (wet) period. Thus, a crop may suffer from water-logging due to excess rainfall or from drought due to scarce rainfall during a single cropping season. The objective of this paper is to examine the potentialities for more productive farming systems through improved water, soil, and crop management. It is recognized that soil management, water development, storage and utilization techniques are determined by site-specific factors. Therefore, only general principles or guidelines will be discussed.

Rainfall Patterns and Soil Erosion Problems in the Semi-Arid Tropics

Before discussing water management methods for increasing crop production, we need to look at the nature of the soil and the rainfall pattern in the semi-arid tropics. Webster and Wilson (1966) pointed out that in most parts of the tropics, much of the rainfall occurs as storms of much higher intensity than is normally experienced in the temperate zone. They also noted that in the tropics, the yearly variation in rainfall is much greater than that experienced in the temperate zone. Thus, in the tropics, average annual rainfall data alone are of limited value to

the agriculturists. However, rainfall intensity has important implications for soil management and conservation practices and the feasibility for intensification of cultivation in a specified area.

Webster and Wilson (1966) stated that in the tropics a large part of the soil erosion occurs during relatively infrequent storms of high intensity. The classical work of Ellison (1944) using high speed photography to show the "bomb craters" caused by each individual rain drop, drew attention to the extreme importance of raindrop erosion on bare soils. Ellison (1952) calculated that the energy in a three inches rain falling in one hour with a drop velocity of 30 feet per second, is equivalent to that required to plough the land 29 times. The battering of the soil surface by raindrops of high intensity storms breaks up soil aggregates and results in sealing of the soil surface with fine soil particles. As a result water infiltration into the soil is reduced and runoff and erosion are increased. In a study of the effect of the raindrop impact on soil erosion and runoff, Hudson (1957) compared the following treatments on land of 4.5% slope in southern Rhodesia. 1) Permanent grass sod giving protection from raindrop impact as well as impeding runoff flow, 2) two layers of mosquito gauze placed on a frame 6" above the soil surface, giving complete protection from raindrop impact but not impeding runoff flow; 3) bare soil, no protection. During a three year period, the bare soil plots lost 350 tons of soil per acre, the grass plots 3.3 tons and the "gauzed" plots only 3 tons. These results further emphasize the importance of the raindrop impact in causing erosion and the primary importance of vegetative cover in erosion control and avoidance of reservoir siltation. The avoidance of raindrop erosion is especially important in clay soils, since suspended clay usually does not settle out until it reaches a reservoir or the sea.

Bhatt et. al. (1971) working on a silty clay loam soil at Dehradun found that the annual runoff soil loss was 49 tons for a wheat-jowar rotation and 291 tons for a "cultivated fallow" system. Thus, the soil loss in the cultivated fallow was about 6 times that of a double-crop rotation. For the permanent grass sod, the soil loss was nil.

In many black soils in Central India, where rainfall ranges from 800 to 1500 mms, it is a common practice to fallow the cropland by cultivation during the monsoon season in preparation for growing a rabi wheat crop. Observations in these areas indicate that the 30 cm deep trench or pit which is excavated during the construction of bunds is usually filled by sheet erosion and sedimentation during the subsequent 3 - 5 years. Calculations based on average trench size and bund spacing indicate that it would require about 90 tons per acre soil loss between the bunds to fill this trench. The total loss would be substantially more since only the coarser sediments would settle in the trench while the fine sediments would be removed from the field by surface drainage and deposited in downstream reservoirs. These observations along with the data of Hudson (1957) and Bhatt (1971) indicate that the fallowing of black cotton soils by cultivation during the monsoon appears to be a highly questionable practice either with or without contour bunding. The nature and amount of vegetative cover is the most important single factor affecting erosion and it should receive primary consideration in the development of any soil conservation program.

In recent years, there has been justifiable concern over environmental pollution. Kanwar (1972) pointed out that runoff and soil erosion is a major cause of pollution and any activities which accelerate erosion also accelerate pollution. Volume wise, the major polluant is soil sediment. These sediments are also the

largest contributors to nutrient loss from the soil and nutrient pollution of reservoir waters.

An Evaluation of Contour Bunding

Contour bunds are used in the black cotton soil region with the aim of decreasing soil erosion, conserving water above the bund, and increasing infiltration into the soil. In order to increase the area of trapped water, the bunds usually have a "hook" at the outlet end. During the spring of 1972, a survey was made by the Madhya Pradesh Department of Agriculture in cooperation with the author of this paper to evaluate the effectiveness of contour bunds in conserving water and increasing yields of the rabi wheat crops. In this investigation, typical bunded areas were studied in two selected blocks of the Vidisha district. The average rainfall in the Vidisha district is about 1300 mms of which about 90% occurs during the monsoon. Most of the fields consist of deep black cotton soils which are normally "fallowed" by plowing during kharif, but are cropped during the rabi mainly to wheat.

A typical cross-section of the bunded area in this region is given at the top of Fig. 1. Since water is the main factor limiting yields in this region it was felt that the wheat crop yields would be the best measure of the effectiveness of contour bunds in increasing the quantity of stored water in the soil. In order to measure crop yields, a two-square meter area was harvested at the following five positions in relation to the bund cross section.

1. 5 meters down stream from the top of the bund;
2. 4.5 meters up stream in the pit or trench section of the bund;
3. 9 meters above the bund;
4. 16 meters above the bund;
5. 35 meters above the bund.

(Positions 3 and 4 were both above the pit but in the area which was submerged during the monsoon season and therefore the yields of these two positions were combined in this graph. Position 5 was well above the submerged area).

The data shown in Fig. 1 give the average wheat yields of the designated positions from 40 contour bunds in the Khamkheda area and 60 contour bunds in the Imalia area. The bunds had been constructed during the 1969-70 season and care was taken to select bunds which had not been breached. (Many bunds follow property lines instead of the contour and are breached, causing additional erosion). Though the general yield level in the Imalia area was lower than that of the Khamkheda area, the yield trend in both locations was the same. From these results, the following observations can be made:

1. Substantial yield reduction occurs in the pit near the bund (position 2) apparently due to the removal of the top soil during the construction of the bund.
2. The yield of positions 3 and 4 is about the same as that of Position 5, indicating that the quantity of water held by the soil was not increased by water trapped near the bund.
3. Thus, when one also considers the area removed from production by the bund (5-10%) plus the reduction in yield caused by the excavation (position 2) the net effect of bunding under these conditions is strongly negative.

A study on the effect of bunding on the yield of kharif crops was conducted in Bellary during the 1960 to 1967 seasons1/. The average annual rainfall in this area is about 500 mm. It was found that contour bunding decreased average yields

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1/ Soil and water Conservation Research 1956-1968, ICAR, New Delhi.

of jowar, cotton and safflower by 25, 30 and 39% respectively. The decrease in yield in these cases was explained by the delay in the cultural operations and crop damage due to stagnant water above of the bund.

It is unfortunate that a practice that is so widely accepted and routinely used in India has had so little recent research and evaluation. The preliminary results obtained at Vidisha and Bellary suggest that contour bunding on many black cotton soils should be replaced by more productive systems of soil and water conservation. The fact that crores of rupees are spent annually on contour bunding on black cotton soils makes the need for additional investigations of alternative practices most urgent. It is recognized that soil and water conservation practices are site-specific. After an adequate research program has been conducted, an action program could be implemented to apply the conservation measures which are best adapted to each of the many specific types of situations which exist in India.

Possibilities of Growing Kharif Crops on Black Cotton Soils

In many black cotton soil areas where rainfall ranges from 800-1500 mms, it is a common practice to fallow the crop land by cultivation to destroy weeds in the monsoon season rather than to grow a kharif crop. Since about 90% of the rain occurs during the monsoon season, it would seem logical to grow a crop during the monsoon period for erosion control as well as for crop production. However, most cultivators avoid cropping for the following three reasons.

1. The difficulties of land preparation and planting in black clay soils during the early monsoon;
2. The relatively low-yield due to damage caused by temporary flooding of kharif crop during the heavy monsoon rains especially in contour bunded areas; and
3. The possibility that the kharif crop will extract too much of the soil moisture from the soil profile at the end of the season and thus reduce the growth of the rabi crop.

During the 1971 monsoon season, Gupta and Krantz (1972) conducted an experiment to obtain information on the three problems listed above and to determine whether or not kharif crops could be successfully grown. The soil used contained about 60% clay and was hard when dry and extremely sticky when wet. The slope of the land ranged from 0.2 to 0.4% and the field used had an adequate drainage outlet. Thus, the excess rain water was readily drained from the flat plots as well as the ridged plots.

Crops were planted using three methods of sowing -- flat sowing, flat sowing followed by ridging, and sowing on ridges. The ridges for the third treatment were formed by using a bullock-drawn sugar cane ridger about three weeks before planting. Planting and fertilization was accomplished on the pre-formed ridges using a bullock-drawn ridge planter with hand seeding and fertilization attachments. The implement used was designed by Swaminathan and Krantz (1972). Flat-sowing treatments were accomplished using a local bullock-drawn planter with fertilizer attachment. Adequate fertilization was provided in all treatments. The rainfall during the 1971 monsoon season was 1337 mms which was 12% above normal. Inspite of the above-normal rainfall, cloudy weather and below normal sunshine, plant growth appeared to be good throughout the growing season, especially in the ridged plots. Grain yields in the ridged treatments were significantly higher than that of the flat-sown plots in both maize and soybeans. The average maize yields for the ridged plot was 42.6 q/ha which was 18% above the flat treatment. The average soybean yield of the ridged plot was 15% above the flat treatment. Even though the percentage increase was not great, it should be noted that with the field slope 0.2 to 0.4%, surface drainage was sufficient so that there was no standing water even in the flat plots. Thus, the growth and yield even in the flat treatment were far better than that observed in the fields

of the surrounding area, most of which have been bunded. Results of this experiment indicate that with proper soil and water management, a good crop can be grown during the kharif season even with the use of bullock equipment only.

Although water harvesting was not included as a part of this preliminary experiment, some runoff measurements were taken late in the season. Water stage recorders and Parshall Flumes were installed in late July and preliminary observations indicate that there was approximately 10 cms of runoff from the plots during August and September.

Water Resources for supplemental Irrigation

Most of the water available for surface or underground storage in the semi-arid and humid tropics comes from rainfed rivers or directly from rainfall on local watersheds (catchments). In some areas of the semi-arid tropics, large irrigation projects are economically feasible. However, in many areas small reservoirs may be more feasible and their potentiality should be further explored, especially in the semi-arid tropics of the world.

In India, tanks (small reservoirs) have been used for centuries as a source of domestic water and water for limited irrigation, especially on rice immediately below the tank. Evans (1967) called tanks, "India's unique tool for irrigation". Sally (1968) states that tanks are more numerous in South India than anywhere else in the world. A 1966 Planning Commission report in India stated that in 1962-63, 4.6 million ha or 17% of all irrigation in India was ascribed to tank-stored water. However, the report further states that the serviceability of many of these tanks has decreased greatly in the last 15 years due to lack of maintenance. Many tanks have lost as much as 50% of their capacity from siltation due to over-grazing and the lack of land conservation practices on the contributing catchment area. Many

tanks have also suffered from over-topping during heavy storms causing erosional damage, or breaching of the embankment. The area acquired by ICRISAT serves as a typical example. It has one large (80 ha) and 3 small tanks. All of these tanks have been badly silted and in all but one small tank, the embankment has been breached.

A sample survey in the Indian States of Mysore, Madras and Andhra Pradesh (1966)2/ showed that the tankbed to ayacut service area ratio was only about 1 to 1.3 due to heavy siltation, heavy evaporation losses during the summer and high water use in rice cultivation. Most of the tanks in these States were constructed in ancient times without the benefit of modern technology. With modern technology, it should be possible to improve the design of tanks, including irrigation and spillway structures. Also, with the better understanding of raindrop erosion control, it should be possible to greatly reduce the amount of sedimentation in the tanks. Thus, we believe that there is sufficient justification for investigation of optimum water utilization through the judicious use of tanks. With integrated use of new technology, these tanks, along with strategically placed wells, could serve as the focal point in the development of watershed-based farming systems. This is particularly important in the semi-arid tropics where water is the major constraint to improved crop production.

In water scarcity areas east of Poona, "percolation" tanks have been constructed. In most of these tanks percolation has been rapid and the wells in the stream bed area below the tank have been benefitted. However, in some of these shallow percolation tanks, water percolates very slowly and remains in the tank into the summer

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2/ All-India Review of Minor Irrigation Works, based on state-wise field studies, Committee on Plan Projects Irrigation Team, New Delhi, June 1966.

season, when the rate of evaporation is very high. These particular tanks are essentially "storage" tanks. Obviously, all tanks provide both storage and percolation. The amount of percolation depends upon the nature of the strata below the tank and groundwater conditions. In water-scarce areas, any surface-stored water that does not percolate into the ground water during the low ET period, should be utilized for early irrigation during the low ET period to avoid the heavy losses of the surface-stored water during the high ET period of the Indian summer season.

Small watersheds as Basic Units for Development

In some areas of the semi-arid tropics, an increasingly larger proportion of the land is coming under cultivation and/or heavy and uncontrolled grazing due to increased population pressures. A recent survey in 84 districts in the semi-arid tropics of India showed that 57.16 percent of the total areas of these districts was cultivated compared to only 44.64 percent for the country as a whole3/. In the present traditional agricultural setting, this intensification of land utilization can become self-defeating. The over-grazing and cropping of sloping lands causes increased runoff, reduced groundwater recharge and severe erosion involving soil deterioration, nutrient losses and lower yields of upland areas; down-stream flooding of heavily cropped and populated lowlands; sedimentation of small tanks and large reservoirs and wastage of precious water to the ocean.

Erratic rainfall patterns and undependability of water supply are major reasons why farmers of the semi-arid tropics generally have not utilized the new high-yielding varieties and capital intensive inputs, such as fertilizers, farm chemicals, farm machinery. Since water is the main constraint, a major breakthrough in overall

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3/ A New Technology for Dryland Farming, Indian Agricultural Research Institute, New Delhi Pg. 5, 1970.

water management is needed to bring the benefits of scientific agriculture to the semi-arid tropics.

In order to achieve such a breakthrough, much research is needed in all facets of the "farming system" including improved water, soil and crop management. Water management research must consider all phases involved from the time precipitation falls on a given watershed until it is either directly used by a crop, "harvested" and used as supplemental irrigation for a crop or removed safely as excess water. Thus, where possible, a small watershed should be thought of as a "closed farming system" unit in which the safely cultivable land is cropped during the rainy season, runoff water from the cultivable land and steep-sloped non-cultivable land is harvested, stored and recycled to improve and stabilize crop production; and drainage water is safely diverted to outlets.

Water harvesting in various forms has been practised since ancient times. However, the term "water harvesting" has only recently come into common usage. Myers (1964) defined water harvesting "as a process of collecting and storing or harvesting precipitation from an area that has been treated to increase runoff of rainfall or snowmelt". In the case of the semi-arid tropics, this definition of water harvesting appears to be too narrow. The authors feel the need for a term to include a broader concept which would include the collection and storage of excess monsoon water for reuse on crops in the donor catchment area during the monsoon and/or post monsoon season. The term "watershed-based farming systems" is suggested which the authors define as follows: "the optimum utilization of the catchment precipitation through improved water, soil and crop management either directly through infiltration of monsoon rainfall or after runoff collection and storage for improvement and stabilization of agriculture on the donor watershed". A watershed (catchment) may consist of one or several farm units.

The amount of runoff that can be harvested and stored from a given watershed will depend upon the amount and intensity of rainfall, the infiltration rate of the soils, the slope of the land and the vegetative cover on the watershed. In a 16-hectare watershed on a cultivated black cotton soil at Bellary Soil Conservation Research Station, it was found that 10% of the rainfall could be captured as runoff. The 5-year average rainfall was 540 mm, thus the average runoff was 54 mm a year. Data compiled by Bhattacharya show an average runoff of 25% in 26 small hilly catchment areas in Central India with 750 mm rainfall. In 16 small catchments in the plains of Central India with an average rainfall of 650 mm, the average runoff was 13%. Krantz and Russell (1971) reported that at Jabalpur with 965 mm rainfall during the 1970 monsoon, the average runoff was 560 mm or 58%. The runoff measurements were made on black clay soils in 61 meter long plots on a 0.75% slope on which maize and soybeans were growing during the monsoon season.

Much more data are needed from small watersheds under a wide range of conditions, but these few data are indicative of the amount of runoff water that might be expected annually for storage in tanks.

To assess the availability of groundwater at any given site, information would be needed on recharge and release rates of water in the shallow groundwater aquifers. For example, how many centimeters of extractable water can be stored in the upper ten meters of soil and regolith? If water recharge in the upper ten meters could be used annually, then a farmer could reduce the amount of tank storage needed. If such ground water cannot be effectively stored, then more emphasis should be placed on improving the efficiency of surface storage, i.e. reducing seepage and evaporation losses.

The development of sound water harvesting, storage and utilization techniques will involve conjuctive use of stored surface water and ground water. The coordinated

research activity of many disciplines will be necessary to generate the proper models for developing integrated approaches toward soil and water conservation, drainage, and efficient use of supplemental irrigation to provide an improved environment for crop production under rainfed conditions in the semi-arid tropics. These models should facilitate the quick assessment of soil, climatic and economic resources of an area and the subsequent development of the most productive and profitable farming systems for the resources available. ICRISAT is intensely interested in pursuing this approach in its research and development program. At least initially in India, emphasis should be placed upon efficient labor-intensive rather than capital-intensive technology.

It is recognized that in many cases the development of farming systems related to small watersheds will ultimately require community action of several farmers, Dandekar (1972). But studies of this factor can come at a slightly later stage. First, we need to develop the necessary watershed-based soil, water and crop research and determine the economics of cropping and farming systems with varying intensities of water development and management. This type of research should provide individual farmers or groups of farmers in any given small watershed with options of various intensities of water development and utilization.

Selective Supplemental Irrigation

Since water, not land, is the most limiting factor for crop production in the semi-arid tropics, all facets of the soil, crop and water management system should be aimed toward maximizing the yields and returns per unit of water. In other words, we should think in terms of "farming" the water that falls in each watershed area.

Thus water, which has been collected and stored, should be applied efficiently and sparingly at the most critical stages of growth. Working with dwarf wheat,

Krantz et. al. (1966) and Bhardwaj and Wright (1967) found the crown root initiation (CRI) stage to be the most critical for irrigation. They observed that regardless of depth of planting, the crown node developed about 2 cms below the surface of the soil (Fig. 2). When the soil zone around the crown node was "dry" at CRI (about 21 days), crown roots did not elongate and very few tillers were produced. Thus, an irrigation at CRI stimulated crown root and tiller development. The importance of timing of the first irrigation was shown in experiments in the All-India Coordinated Wheat Improvement Project (1973). In the average of 24 locations, the highest yield (42.9 q/ha) was obtained when the first irrigation was at CRI (3 weeks). When the first irrigations were made at 4, 5, 6 and 7 weeks after planting the average wheat yields were reduced by 3.2 q/ha per each week of delay after the CRI stage. (Fig.3).

Chauhan et. al. (1970) studied the effect of irrigation timing upon dwarf wheat yields in a sandy loam soil at IARI where a pre-sowing irrigation had been applied to all treatments. The yield with a pre-sowing irrigation alone was only 9.3 q/ha. One irrigation applied at the CRI stage increased the yield to 30.4 q/ha. When a single irrigation was applied at jointing or milk stage, the yields were only 20.6 and 10.5 q/ha, respectively. These data illustrate the beneficial effects of irrigating at the CRI stage in order to establish an effective crown root system for exploiting the soil moisture in the potential root zone. These data and those from earlier experiments show clearly that where the surface 2-3 cms of the soil is "dry" at the CRI stage, irrigation at that stage will increase root development, tillering and wheat yields. Bhardwaj et. al. (1971) found that the flowering and early grain filling stage was the next most critical for irrigation of dwarf wheats.

Cropping Systems for the Semi-Arid Tropics

Cropping patterns to be used in any part of the semi-arid tropics, will depend upon many factors such as crop adaptability, local food preference, population

pressure and other social, economic and market factors. Bradfield (1969) and Bains (1971) working under conditions of ample assured irrigation water have, through "multiple cropping" or "relay cropping", produced four or more crops a year. In the semi-arid tropics of India, where water is usually scarce, the wisdom of growing crops in hot dry months preceding the monsoon is highly questionable. However, by judicious use of harvested and stored water as a supplement to rainfall, it should be possible to consistently grow good crops for 5-8 months during the monsoon and the post-monsoon seasons.

The following items are suggested as criteria to use in arriving at suitable cropping systems for the semi tropics:

1. In most of the semi-arid tropics, water, not land, is the limiting resource. Therefore, all cropping systems should aim toward the most effective utilization of the available water resource. In other words, we are in effect "farming" the water which falls on our land.
2. Where irrigation is available, crops should be planted just ahead of the wet or monsoon period so that vegetative cover would be provided to protect the soils before the high intensity rains occur.
3. Where pigeon peas or other slow-growing, long season crops are grown, an inter-crop using a fast-growing short-season crop can provide early vegetative cover and utilize the radiant energy while the pigeon peas are becoming established.
4. Where possible, crops such as millets or sorghum, which can be successfully ratooned, should be included in the cropping system. By ratooning, additional crops can be produced while providing nearly continuous vegetative cover with a minimum of exposure to erosion hazards.

5. Steep or erosive lands should be planted to grass or productive trees or other perennial crops to minimize the erosion hazards. These areas should be integrated into the watershed-based cropping system as a source of runoff for water collection and storage.
6. Where economically feasible, a combination of legume grains and cereal grains should be used either as an inter-crop or in sequence to provide balanced food and feed requirements and favorable soil tilth.
7. The cropping systems should provide a balanced combination of food, feed and cash crops to fit domestic and market needs.
8. All crops should be harvested as early as feasible (physiological maturity) to minimize bird, insect and weather damage.
9. Immediately after harvest the soil should be tilled to kill weeds and stubble and to conserve the residual subsoil water in the profile for future crops.
10. With the introduction of supplemental irrigation and possible increased intensity of cropping, plant protection problems will need close scrutiny and research during the development of any cropping system.
11. The agronomists, pathologists, entomologists, economists and engineers should work closely with the plant breeder in order to develop tailor-made genotypes which will best fit the desired cropping systems.

Finally, team research efforts of all involved disciplines will be required to develop optimum farming systems for the semi-arid tropics.

SUMMARY

1. Water is the major constraint to increased and stabilized agricultural production in the semi-arid tropics.
2. The rainfall patterns in the semi-arid tropics are characterized by higher intensities, a higher degree of yearly variation in amount and intensity which cause a higher degree of runoff and erosion than those of the temperate zone.
3. Preliminary research and evaluation of data on contour bunding indicates that contour bunding on the black cotton soil appears to be a questionable practice.
4. The approach to development of watershed-based farming systems is discussed. This approach aims at the optimum utilization of the water and soil resources for optimum and reliable agricultural production and profit while conserving the soils and their productivity.
5. Watershed-stored water must be used efficiently to supplement the erratic seasonal rainfall in the semi-arid tropics. More research is needed to determine the most critical stages of growth of various crops and the most efficient and low cost techniques of supplemental water application.
6. Eleven criteria for arriving at a suitable cropping system for the semi-arid tropics are suggested. All cropping systems and soil and water management practices in the semi-arid tropics must be geared towards maximizing the yields and returns per unit of water. In other words we should think in terms of "farming" the water which falls on our watershed.

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Table 1. The comparative monthly, seasonal and annual Rainfall (RF) and Potential Evapotranspiration (PET) at four locations in the Semi-Arid Tropics of India.1/

	Ajmer		Hyderabad		Indore		Jabulpur	
	RF. mm	PET. mm	RF. mm	PET. mm	RF. mm	PET. mm	RF. mm	PET. mm
January	12	55	2	110	8	93	26	70
February	6	77	11	130	1	116	22	89
March	6	130	13	182	4	177	15	135
April	3	174	24	198	4	220	9	165
May	9	243	30	220	13	300	15	203
June	66	229	107	196	147	224	171	173
July	187*	156	165*	140	316*	134	505*	106
August	175*	128	147*	136	266*	119	401*	99
September	71	142	163*	119	221*	123	212*	107
October	16	114	71	123	48	137	50	113
November	4	66	25	104	22	95	17	78
December	2	51	6	99	3	80	5	63
Annual	557	1566	764	1757	1053	1813	1448	1401
July-Sept	403	426	475	395	803	376	1118	312
" " RF PET		-23		+80		+427		+806
June-Sept.% of total	89%		79%		90%		89%	

*Months in which average rainfall (RF) exceeds potential evapotranspiration (PET)

1/ Rainfall data from Climatical tables of Observatories in India (1931-60) India Meteorological Department. Potential Evapotranspiration data taken from "Potential Evapotranspiration of India" by Rao K.N., CJ, George & K.S. Ramasastri, Scientific Report 136 (Prepublished) India Meteorological Department, 1971 (Calculations of PET based on Penman's Formula).

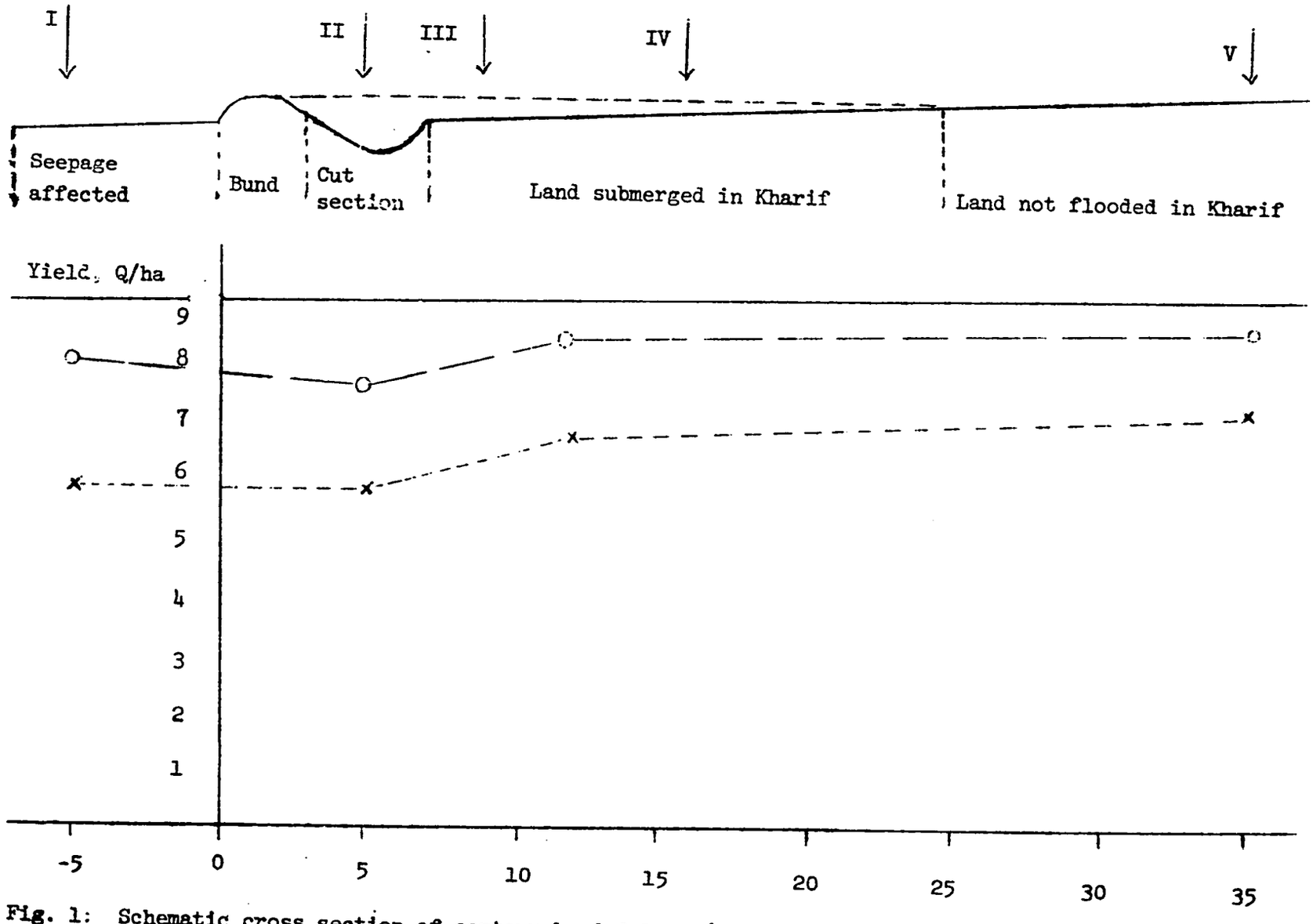

Fig. 1: Schematic cross section of contour bunded land (Hor. scale 1 200· Vert. Scale 1·100) and yields of wheat as a function of distance to contour bunds in Vidisha District, M.P.
x- - - - -x Khamkhed sampling. O——O——O Imalia sampling; ——— Av. Dist. wheat yields.

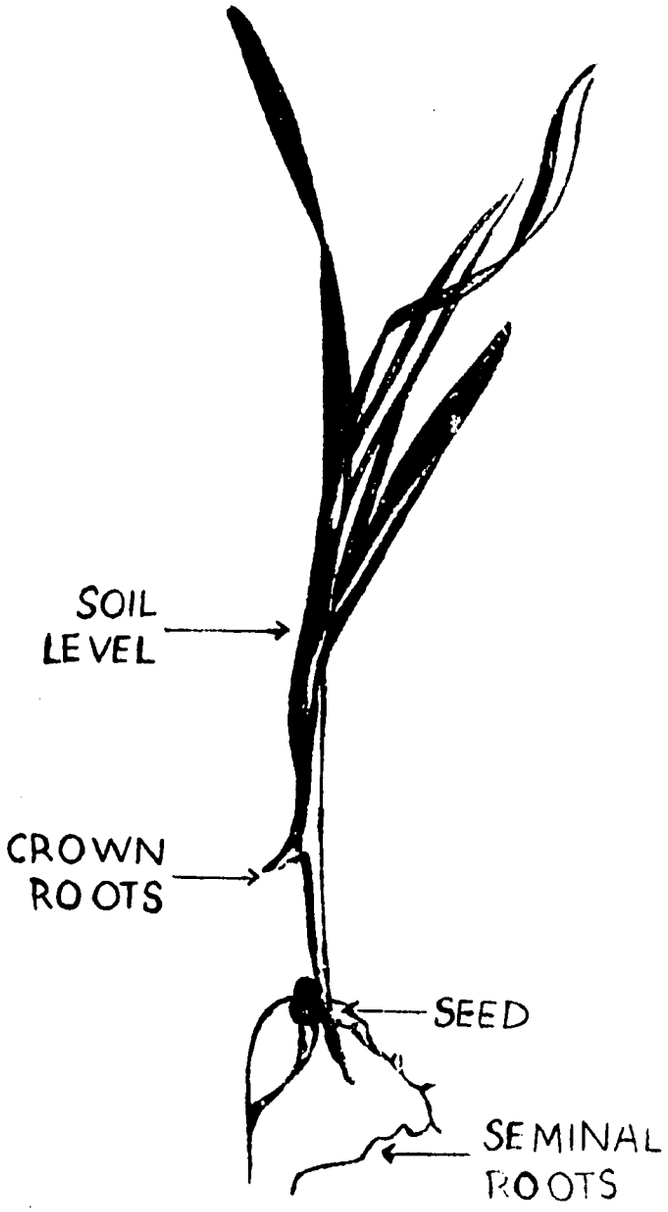

Fig. 2. A wheat seedling at crown root initiation (CRI) stage. Dwarf wheat should be irrigated at the CRI stage if the surface 3 cms of soil is too dry for normal elongation of the crown roots.

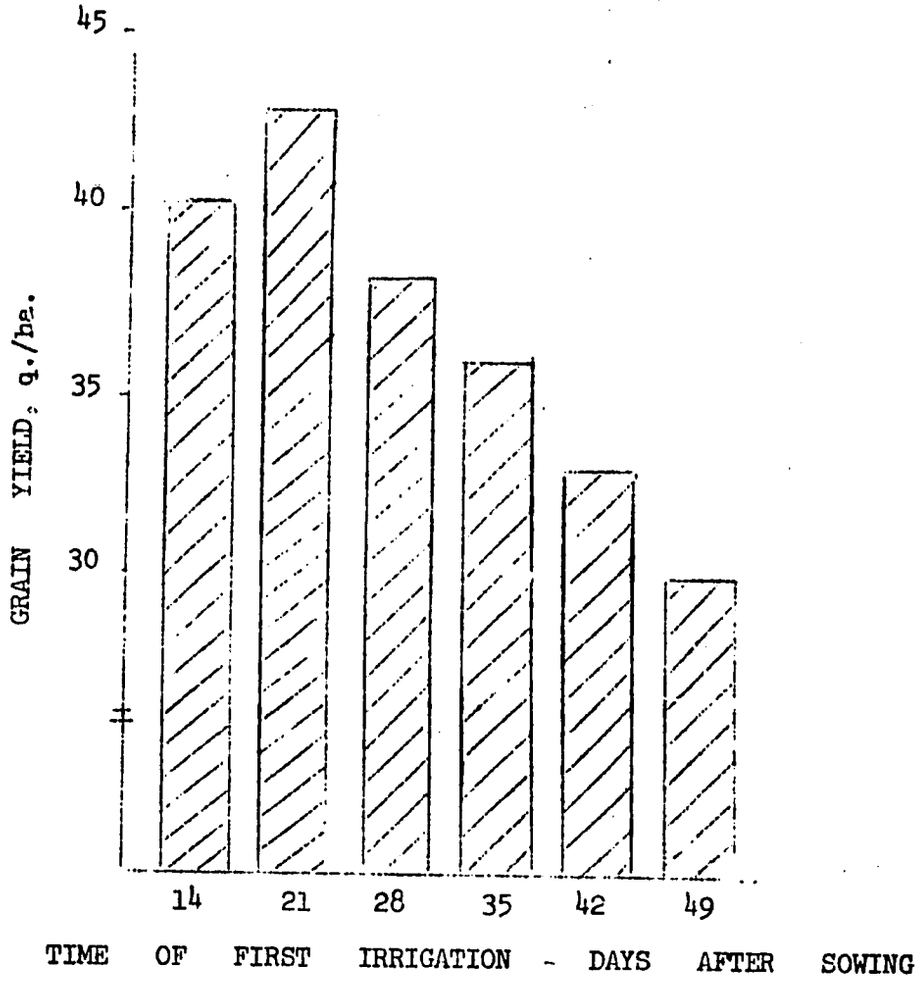

Fig. 3. Yield of dwarf wheat as affected by timing of first irrigation ranging from 14 to 49 days after planting at 7-day (1 week) intervals. Ear bar represents an average of three varieties in the 24 experiments covering 13 locations over the 4-year period (1966-1969). (Taken from "The Agronomy of Dwarf Wheats ICAR 1973 in Press)