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Water Conservation and Dryland Crop Production in Arid and Semi-Arid Regions

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Abstract In this paper, the work on rain water conservation, harvesting and its appropriate use in dryland crop production, carried out by various dryland centres located in hot arid and semi-arid regions of India receiving annual rainfall up to 750 mm, has been reviewed. The generated technology of water conservation and its productive use is capable of greatly improving and stabilizing dryland crop production. This requires selection of short duration and low water requiring crops/cropping systems, effective moisture conservation measures, establishment of crops under ridge-furrow system and farm pond for harvesting runoff for providing life saving/critical irrigation. Further research is required on refinement of the technology for pond water harvesting and water budgeting under bare and cropped conditions with different crops. For rapid diffusion of the technology costume-hire services for deep tillage, ridge furrow cultivation and recycling of water harvested in farm pond is required.

Key words Water conservation, water harvesting, ridge-furrow system, farm pond, water-yield function

Out of 328 Mha geographical land area of India, about 143 Mha is under cultivation. More than 70 per cent of the cultivated area is under rainfed crops. Assuming the full utilization of the available surface and ground water resources for irrigation, about 50 per cent of the land area will still continue to remain under rainfed agriculture. Therefore, for sustainable agriculture and for reducing the imbalances between irrigated and dry farming regions, dryland areas must continue to receive priority in development programs.

According to the Indian Agricultural Atlas (Anonymous 1971) the dryland areas include the zones having an annual rainfall upto 750 mm (Fig.1). Such areas fall within the arid and semi-arid climates of the tropics and cover parts of the States of Punjab, Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh. About 51 Mha land area of India falls under this category (Shafi & Raja 1987) and produces most of the coarse grains, pulses, oilseeds, cotton and dry fodder. With traditional farming, the production of these commodities is, however, low and risky. With the new dry farming technology, generated by various dry land research centres (Fig. 1) in different agroclimatic zones, it is likely to at least double the production from its present level.

Constraints in Dryland Crop Production

Out of several constraints of crop production in the dryland areas, the erratic and undependable nature of limited rainfall is the most important single factor limiting crop yield. Usually, the amount and distribution of rainfall does not synchronize with the water requirement of crops, particularly at critical stages. Therefore, the crops suffer due to water stress of varying magnitudes. In order to mitigate the adverse effects of water stress efficient conservation of rainfall *in situ* is of utmost importance. The conserved water in the soil profile and the harvested rainfall runoff water in a farm pond are the only solutions for meeting the water needs of the crops during dry spells.

Moisture conservation measures largely center around the nature of climate (rainfall and evapotranspiration) and soils of the region. The various climatic and soil constraints are discussed below.

Climatic Constraints

Low rainfall: The annual rainfall in the dryland areas varies from less than 200 mm to 750 mm as against the potential evapotranspiration varying

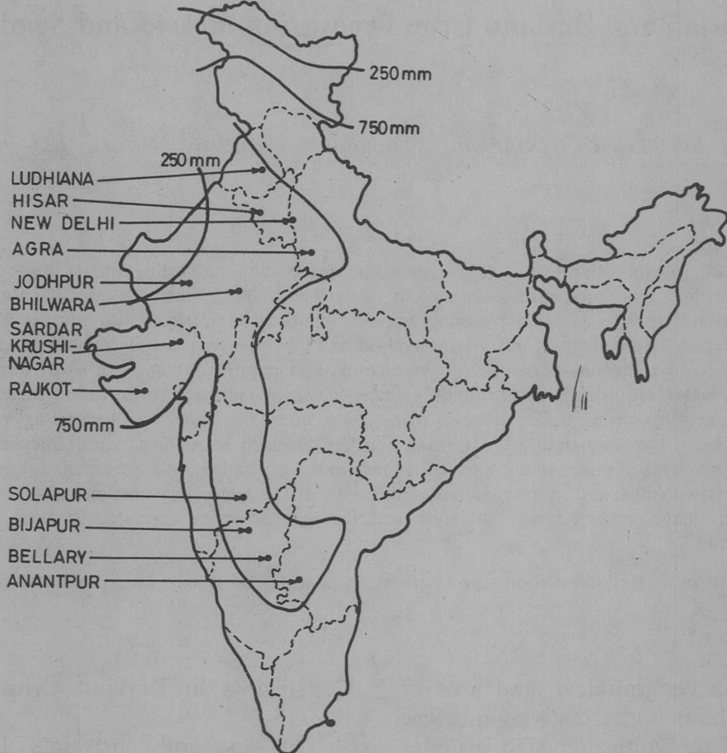

Fig 1 Dryland areas of hot arid and semi-arid regions of India

from 1400 to 2000 mm. In the north-western and central states about 80 to 85 per cent rainfall is received in summer season (July to September) and only 5 to 10 per cent is expected in winter season (November to March). In the southern states about 55 to 60 per cent rainfall is received during June to September and 30 to 35 per cent during November to January. In other words, the rainfall is bimodal. The average rainfall of summer and winter seasons at some of the research centres is reported in Table 1.

Erratic rainfall : The rainfall is highly erratic and variable, both in magnitude and direction. The coefficient of variance of annual rainfall is as high as 66 per cent at Jaisalmer (Rajasthan), 40 per cent at Hisar (Haryana), 34 per cent at Karnal (Haryana), 32 per cent at Sardarkrishi Nagar (Gujarat), 30 per cent at Solapur (Karnataka) and 25 per cent at Anantpur (Andhra Pradesh). On monthly and weekly basis these variations may exceed 200 and 300 per cent. The rainfall has aberrations such as delayed, early on-set, early withdrawal, continuous rains at on-set and long dry spells (2-3 weeks or more) during growing season. The rainfall is often intense and it produces run-off, particularly from sloping lands.

Table 1 *Average summer/winter rainfall (mm) at some dryland research centres*

Station	Rainfall		Station	Rainfall	
	Summer	Winter		Summer	Winter
Agra	590	62	Jodhpur	310	37
Anantpur	320	202	Ludhiana	530	75
Bellary	291	185	New Delhi	465	60
Bhilwara	600	50	Rajkot	590	30
Bijapur	405	217	Sardarkrishi Nagar	530	60
Hisar	320	45	Solapur	535	150

Soils Constraints

The soils of dryland areas of India can be grouped under (i) desert soils, (ii) alluvial soils, (iii) black soils, and (iv) red soils. The distribution of these soils in various states and their major constraints for water conservation and crop production are presented in Table 2.

Table 2 *Soils of arid and semi-arid regions and their major constraints*

Soil	Area represented	Major constraints
Desert	Western Rajasthan, Parts of Haryana	Low water holding capacity (WHC 10-15 cm/m), high infiltration rates and erodibility, presence of calcium-carbonate concretions in root-zone.
Alluvial	Parts of Rajasthan, Punjab, Haryana, U.P., Delhi and Gujarat	Soil crusting, hard pan at plough-depth, WHC 15-25 cm/m.
Black	Maharashtra, Western Madhya Pradesh, Parts of Karnataka, Andhra Pradesh and Gujarat	Soil cracking, heavy texture, poor drainage, WHC 25-35 cm/m.
Red	Parts of Andhra Pradesh, Karnataka, and Madhya Pradesh	Soil crusting, shallow depth, sub-soil compaction, WHC 15-20 cm/m.

Soil surface crusts, formed due to impact of rainfall, hinder the rapid intake of rainfall in the soil, enhance run-off and reduces rain water conservation, besides hampering emergence of seedlings and establishment of crops. Presence of hard pan/calcium carbonate concretion, hinders movement of water and ramification of plant roots and reduces water storage capacity of soils. Shallow soil depths do not allow normal root ramification, reduce feeding zone of roots and restrict plant growth and water storage capacity of the soil profile. Soil cracks allow free entry of atmospheric air into soil, resulting in rapid evaporation of water from the soil. Heavy texture poses problems for tillage and the soil does not come to workable condition easily. Such soils remain water-logged for a long time after heavy rains, resulting in poor aeration of the soil and poor plant growth.

In general, soils of hot dryland areas are deficient in available nitrogen, low to medium in phosphorus and zinc, and medium to high in potassium. Sub-soil salinity is not uncommon in these soils (Oswal & Khanna 1983).

Moisture conservation

Water balance - A managerial skill : For effective conservation of rainfall, studies on rain water balance are helpful to decide the appropriate measures. The water balance of a field can be expressed mathematically as:

$$R = S \pm M \pm U + ET \quad \text{... (i)}$$

where, R is rainfall in a given period, S is surface runoff, M is change in soil moisture content in the root zone, U is capillary contribution at the bottom of root zone, and ET is evapotranspiration during the period.

Rainfall is not amenable to control, except through an uncertain process of cloud seeding. Therefore, efforts to conserve moisture in the soil profile aim at reducing surface runoff, deep percolation and evapotranspiration. Water balance studies (Oswal & Dakshinamurti 1975, Oswal *et al*. 1988), conducted on alluvial soil of I.A.R.I., New Delhi, and desertic soil of HAU, Hisar, for dryland summer crops revealed that under good management about 75 to 80 per cent of the rainfall could be utilized for ET, 5 to 10 per cent is lost as deep percolation, and another 10 to 15 per cent is left out in the soil profile after crop harvest when the field is bunded well with no runoff. This balance, of course, is very delicate and is tilled easily in favour of non-productive components like run-off, deep percolation and evaporation. Mainte-nance of a favourable balance is an important strategy for effective moisture conservation and improved dryland crop production. The various measures needed to maintain a favourable field water balance are discussed below.

Improving infiltration : All efforts should be made to retain as much rainfall as possible within the rhizosphere of growing crops. For this, measures conducive for quick intake of rainfall by the soil and its subsequent transmission in the sub-soil are needed. Singh & Oswal (1983) reported reduction in the eavporation loss of water with increasing depth of penetration of water in the soil profile. The water penetrating below 45 cm depth in summer and 30 cm depth in winter was not easily susceptible to evaporation loss. The various steps for improving infiltration are described here.

Bunding : All dryland fields should be well bunded with boundary bunds (0.3 m height) along contour, besides bunding of each plot (0.1 m height) and sub-plots in such a way that there is no runoff from the field. Bunding increases moisture conservation and land productivity vis-a-vis non-bunded fields (Kanitkar *et al.* 1960).

Deep ploughing : In soils with hard pan/calcium carbonate concretions at shallow depth and textural profile of heavy texture, deep ploughing by chisel plough/sub-soiler improved the infiltration rates, water storage yield (Table 3) and water-use-efficiency of cultivated crops (Oswal & Dakshinamurti 1975, Gupta *et al*. 1984). The effect of deep ploughing is more pronounced in dry years and in the events of intense rainfall.

Table 3 *Effect of deep ploughing on yield (t ha^{-1}) of some dryland crops*

Tillage & its depth	Pearl millet (New Delhi)	Maize (Ludhiana)	Wheat (Ludhiana)	Tobacco (Anand)	Sorghum (Solapur)
Country ploughing (8-10 cm)	2.24	2.22	2.38	0.89	0.82
Deep ploughing (35-45 cm)	2.56	2.65	2.81	1.04	0.93

Preparatory tillage : Due to compacting nature of plough layer and crusting nature of surface soil layer and weed infestation, initial tillage of the land at the onset of monsoon is essential to prepare a good seed bed. For most desertic soils sweep cultivation or a combination of country plough and blade harrow is necessary, while for alluvial soils two harrowings are required. For black and red soils two to four harrowings at optimum moisture are enough to prepare a good seed bed. In a summer fallow land for fallow-crop sequence, 2 to 3 harrowings during monsoon season are required to control weeds and to keep soil open for rapid infiltration of rainfall. About 30 per cent rainfall can be conserved in soil profile by this techique (Oswal & Singh 1989). The last ploughing on withdrawal of monsoon should be coupled with planking. Post-harvest ploughing of land is essential to remove weeds and to keep the land ready to absorb subsequent rains. Effect of preparatory tillage on yield of pearl millet is reported in Table 4.

Deep percolation losses : As the studies on field water balance are limited, not much information has been generated on the extent of deep percolation losses under various agroclimatic situations. Oswal (1972) reported that under deep ploughing in a high rainfall year, about 21 per cent of the total rainfall is lost as deep percolation, as against only 7 per cent under ploughing with a local plough in an alluvial soil of Delhi with pearl millet as a test crop. This loss in light desertic soils could be 25 to 40 per cent and can be reduced by sub-surface compaction by giving 12 passes of 0.5 ton roller or 6 passess of 1.5 ton roller (Gupta *et al.* 1984). Sub-surface barrier of asphalt can also reduce this loss (Gupta *et al.* 1989). Deep percolation

Table 4 *Effect of preparatory tillage on grain yield of crops*

Location	Crop	Tillage	Yield (t ha^{-1})
Hisar	Pearl millet	Control (No tillage)	1.00
		Disc-harrowing	1.65
New Delhi	Pearl millet	Control	1.49
		Disc-harrowing	2.24
Solapur	Sorghum	Control	0.18
		Disc-harrowing	0.92

losses of water can be reduced substantially by regulated entry of water into the soil such that only water required to bring the crop rhizosphere to field capacity is allowed to enter the soil and the remaining water is collected in a farm pond. This will reduce deep percolation losses in the event of high rainfall even if the land is deep ploughed. This is possible by continuous monitoring of soil moisture and planting crops under ridge-furrow system.

Evapotranspiration : In dryland the evapotranspiration should be minimized. This may be achieved through control of weeds and transpiration.

Control of weeds : In most of the dryland areas, proper weeding is seldom done and weeds are usually allowed to grow intentionally along with crops to serve as green fodder for cattle. Researches have found it to be an unproductive practice (Oswal & Khanna 1983) and recommend early (within 20 to 35 days after sowing) weeding in crops. The period upto which the crops need to be weed free are as under :

Crops	Period (week)
Mung bean, pearl millet, and sunflower	4
Finger millet, sesame, sorghum	5
Maize	6
Groundnut	7
Castor	8

To facilitate weeding, the crops should be planted wider. Further, sweep instead of blade harrow is more effective for interculture as it cuts the soil deep, uproot weeds and leads to earthening up of plants. Improved wheel hand hoe (blade/tine) and blade hoe are more effective than traditional hand hoe and country plough, respectively (Malik & Oswal 1981). For heavy soils, the hoe should be tine-shaped. Use of these implements in light and medium textured soils not only control the weeds but also help in conserving more water in the soil due to creation of dust mulch which checks evaporation from the soil. The dust mulch further helps in quick entry of rains in the soil profile. Such implements should be used after every effective rainfall till the crop suppresses the weeds on its own. Weed free plots of pearl millet, maize and sorghum gave yields of 1.78, 4.66 and 1.46 t ha^{-1} as against only 0.93, 1.76 and 0.92 t ha^{-1} obtained from unweeded plots at Ludhiana. In a low rainfall year (250 mm) at Hisar, the unweeded plots of pearl millet and mung bean produced no grain against 1.14 and 0.37 t ha^{-1}, respectively, obtained from plots weeded with wheel-hand hoe.

Chemical weed control is not common in dryland areas due to (i) high costs of weedicides, (ii) the practice of inter-cropping, and (iii) easy availability of family labour. However, the following herbicides are recommended for controlling weeds in the event of non-availability of labour :

Crops	Herbicide
Sorghum, maize, pearl millet	Atrazine @ 0.5 kg ha^{-1}
Soybean, pigeonpea, groundnut	Pendi Methalin @1kg ha^{-1} 2, 4-D @ 0.25 kg ha^{-1}
Wheat	Iso-proturon @ 1 kg ha^{-1}
Cotton	Pendi Methalin @ 1.5 kg ha^{-1}

Chemical weed control has not been found promising in sunflower, castor, clusterbean and mung bean crops.

Control of evaporation : Evaporation loss of water from soil is unproductive, but is very high (Kanitkar *et al.* 1960 and Oswal & Dakshinamurti 1975). Even with a leaf area index of 2 evaporation is about 50 per cent of ET. The evaporation is much higher during early stage of plant growth. Even a small reduction in this loss may go a long way to improve dryland production.

The stages of soil water evaporation are (i) rapid (governed largely by atmospheric demand) rate, (ii) falling (governed by water transmision characteristics of the soil) rate and (iii) slow (depends on temperature gradient in the soil profile) rate . Vegetative mulches help in reducing incident solar and wind energy on the soil surface and improving water conservation by reducing evaporation during first stage. However, mulches are effective for short-term moisture conservation and are therefore, useful for attaining good germination (Bansal *et al.* 1971, Jalota & Prihar 1979). The rate of application (4 to 8 t ha^{-1}) of mulches increases with increasing evaporativity (Prihar & Arora 1980) and their post-monsoon application is useful in improving moisture in the seeding zone and better establishment of winter crops (Table 5) under receding soil moisture conditions. However, effects of mulch application to established summer crops during monsoon season were consistent (Prihar *et al.* 1979 and Oswal 1990). While their use for winter crops is beneficial (Roy *et al.* 1974 and Giri *et al.* 1983). The difficulty in using vegetative mulch is the non-availability of mulching materials.

Table 5 *Effect of application of vegetative mulch on crop yields*

Location	Crop	Yield, t ha^{-1}	
		Control	Straw mulch
Agra	Barley	2.25	2.99
Anand	Tobacco	1.15	1.27
	Groundnut	1.17	1.27
Hisar	Chickpea	0.24	0.70
	Mustard	0.87	1.77
	Pearl millet	3.36	3.43
	Green gram	1.20	1.22
Hoshiarpur	Wheat	2.86	3.51

The water loss during second stage of evaporation is substantial and its reduction is possible through chemicals (PVA, VAMA, Krilium). These chemicals help in building surface soil aggregates of 0.02 to 0.2 mm size. Very fine aggregates help in air circulation through cracks and very large aggregates help in direct entry of air into the pores causing evaporation. Tillage at appropriate moisture content and application of FYM can be useful to achieve good soil aggregation of desired size and in reducing evaporation loss of water.

In alluvial soils which develop crusts, interculturing with wheel- hand-hoe helps in breaking the soil crust into pulverised soil which on drying acts as a soil dust mulch besides eradicating weeds (Oswal & Khanna 1983). In black soils, soil mulching results in filling the soil cracks with the loose soil which helps in minimising evaporation (Anonymous 1982). The effectiveness of soil mulch, however, depends on the fineness and thickness. Under high evaporative demand (10 mm d^{-1}) coarse to medium tilth (MWD 10-20 mm and 5-10 mm) and under medium to low evaporativity medium tilth is promising (Gill *et al.* 1977). In sandy loam soils 2.5 cm thickness of soil mulch or dunal sand and mulch was found to be the most effective in evaporation control (Singh & Oswal 1983).

Control of transpiration : Use of antitranspirants has not been found promising to control transpiration. Antitranspirant like kaoline, which reflects solar radiation more in the wave length range 0.7 to 1.3 μ has been reported to be promising in mustard (Oswal 1990), barley (Agarwal & De 1977) and wheat (Giri *et al.* 1983).

Water harvesting : In dryland areas interplot water harvesting in considered useful for horticultural/forestry plantation and crops. However, possibilities of harnessing runoff is more for sloppy and rocky areas. Khadins of Jaisalmer (western Rajasthan) are the oldest interplot water harvesting systems for harnessing the rainfall for productive purposes. Attempts have also been made (Oswal & Singh 1975) to raise spreading type vegetables (cucurbits) around an embedded earthen pitcher (4 L capacity) with its mouth slightly above the ground level to serve as a run-off collection pond as well as a sub-soil irrigator. Inter-plot water harvesting technique has been found promising for *in situ* water conservation and harvesting the excess rainfall in a farm dug out (pond) for irrigating dryland crops in the event of drought. The Ridger-Seeder developed by Haryana Agricultural University, is useful implement for adopting this technique and for getting a good crop stand by seeding summer crops on ridges and winter crops in furrows. The yield of crops as affected by the method of sowing is presented in Table 6. Crops grown on shallow soils are benefited by this system of cultivation due to increase in soil depth when sown on ridges.

Runoff collection : Surface runoff is inevitable in the tropical climate particularly on sloppy lands, on the soils which are prone to surface crusting and on black soils having low infiltration rates. The amount of runoff, however, depends on the soil type, land slope and the amount and intensity of rainfall, besides physiography of the land, and may vary from 10 to 40 per cent (Anonymous

Table 6 *Grain yield (t ha^{-1}) and water-use-efficiency (kg seed ha^{-1} mm^{-1}) of some dryland crops at Hisar*

Rainfall	Method of sowing	Pearl millet		Mustard	
		Yield	WUE	Yield	WUE
Low	Flat	1.28	5.1	0.67	6.7
	Ridge-Furrow	1.78	7.2	1.20	12.0
High	Flat	3.03	10.7	1.40	14.0
	Ridge-furrow	3.50	11.6	1.94	19.4

1982 and Oswal & Khanna 1983). The runoff should be collected in a suitably designed and lined farm pond. The optimum size of farm pond depends on the amount of expected runoff, hydrology of the area, crops to be grown, cost of the pond and expected benefits which could accrue from the harvested water. A rough estimate for size of farm ponds for different regions is given below :

Jodhpur region–Light-textured desertic soils–200 m^3

Hisar region–Medium texture alluvial soils–1000 m^3

Solapur region–Heavy-textured black soils–1000 m^3

The main problem with farm ponds is the very high rate of seepage losses. Control of seepage from such ponds is essential. A cemented pond is the best for reducing seepage but is very costly proposition. Use of some locally available sealants or polythene sheet (Table 7) for lining can reduce the cost substantially (Miranda *et al.* 1983). Careful lining of farm pond with polythene would also effectively control the seepage (Vijaylakshmi 1983). Natural silting over years reduces seepage but the storage capacity is reduced.

In order to minimise evaporation losses of water from a farm pond, polythene granules of 2 to 3 mm size should be applied at the rate of 11 kg ha^{-1}. Broadcasting of these granules on water surface, makes a mono-layer (White) which reflects solar radiation and cut the evaporation losses by about 30 per cent (Oswal & Khanna 1983). For reducing wind effects, trees should be planted along the boundary of the farm pond.

Simple device to lift water from small pond, is still to be developed. Since the quantity of water available through runoff collection is limited and is hardly enough for 1 to 2 irrigations to a small area, some custom hire service is required. This small quantity of water should be applied in alternate furrows for all crops raised under ridge-furrow system to increase efficiency of the precious water.

Productive Use of Water in Dryland Crop Production

In dryland agriculture, water is the most limiting factor in crop production. Every drop of water must be carefully conserved and used. The conserved/harvested water could be of real use only when it improves the crop production. For productive use of the precious water, selection of short duration, low water requiring crops and

Table 7 *Some effective sealents for lining of farm ponds*

Location	Sealent	Seepage as % of control
Dantiwada, Hyderabad	Plastic lining overlaid by cement plastering	0
Hyderabad	Red soil + black soil (1:2) compacted	10
Ludhiana	Bottom polythene lining	5
Varanasi	Soil + cow-dung + straw (7:2:1)	11
Rajkot	Black soil + Na_2CO_3	67
Hyderabad	Balck Soil + Na_2CO_3	4

their varieties, cropping systems and critical crop stage and quantum and right method of application of harvested water and improved agronomic measures for cultivation of crops including the balanced doses of plant nutrients, are to be determined. The water requirement for optimum production of various commonly grown dryland crops is given in Table 8.

The crop should be selected on the basis of water requirement of the crop and expected rainfall during the growing season, i.e., water availability period. The available information on water availability period at different agro-climatic zones is very limited. Based on the weekly and potential evapotranspiration (modified Penman), Oswal & Saxena (1980) worked out the water availability periods of Bhiwani, Hisar, Mahendergarh and Sirsa (Haryana) rainfall (probability≥ 50%) as 7, 8, 12 and 14 weeks, respectively. Therefore, crops which can mature physiologically in the aforesaid water availability periods should be selected for each of these locations. Information on response of crops to water will be more useful, but is lacking. Some efforts in this direction were made by Oswal (1976). The water production functions of some important dryland summer crops of N-W India are :

$$Y/41.8 = 1.09 - 1.89\ (1-X/300) \quad \ldots (2)$$
for pearl millet;

$$Y/16.4 = 1.03 - 1.55\ (1-X/240) \quad \ldots (3)$$
for mung bean; and

$$Y/20.6 = 1.14 - 1.65\ (1-X/315) \quad \ldots (4)$$
for clusterbean.

The water production function of winter crops, whose success largely depends upon the amount of stored water in the soil profile at the sowing time, are :

$$Y = -7.62 + 0.11X \quad (r = 0.94) \quad \ldots (5)$$
for wheat;

$$Y = -2.46 + 0.10X \quad (r = 0.95) \quad \ldots (6)$$
for barley;

$$Y = -0.95 + 0.08X \quad (r = 0.95) \quad \ldots (7)$$
for gram; and

$$Y = 4.96 + 0.05X \quad (r = 0.96) \quad \ldots (8)$$
for mustard;

where : X = evapotranspiration (mm) and Y = grain yield of the crop (q ha^{-1}). These functions are valid for $X > 100$ mm.

Critical irrigation

Critical irrigation with a small quantity of water, harvested in a pond, is of immense value to improve and stabilise the dryland crop production and to build up confidence of farmers in dry farming (Venkateswarlu 1982). Such irrigation, when applied as life saving irrigation or as pre-sowing irrigation, can increase crop yield many fold (Table 9). Even a small quantity of water (2.5 to 3.0 cm) available for irrigation is quite useful to harness the carried over sub-soil moisture for crop production, after the harvest of a short duration summer crop, or after the summer fallowing. When such an irrigation is applied it charges the otherwise dry top soil with water, which on joining the sub-soil moisture makes an ideal moisture profile for crop growth. Uppal *et al.* (1986) reported increasing yield of wheat with increasing stored moisture of sowing. Usually flowering stage is most critical and highly responsive to irrigation. In case of wheat at Ludhiana, post-sowing irrigation applied 30 days after

Table 8 *Water requirement of some dryland crops*

Summer crops	Water requirement	Winter crops	Water requirement
Black gram, cowpea, mung bean	250 mm	Rocket plant	150 mm
Clusterbean, pearl millet, finger millet	300 mm	Mustard	200 mm
Sesame	350 mm	Barley, pea, safflower	300 mm
Castor, red-gram, sorghum	400 mm		
Groundnut, maize, soybean	350 mm	Sunflower, wheat	350 mm
Sunflower, tobacco	500 mm		

Table 9 *Effect of critical irrigation on performance of dryland crops*

Location	Crop	Yield, t ha^{-1}	
		Without irrigation	With critical irrigation
Agra	Wheat	2.19	2.74 (5 cm)
Anand	Tobacco	1.21	1.81
Bellary	Safflower	0.13	0.29
Hisar	Pearl millet	1.32	2.24 (7 cm)
	Mung bean	0.83	1.30
	Chickpea	0.58	1.90
	Mustard	0.75	1.44 (5 cm)
Hyderabad	Chickpea	0.82	3.57
Ludhiana	Sorghum	2.57	3.57
	Wheat	1.92	4.11 (7 cm)
Solapur	Chickpea	0.80	1.04 (5 cm)
	Safflower	0.77	1.03

sowing had more favourable effect on yield than that applied as pre-sowing (Gajri 1980). Further split application as pre and post irrigations was more advantageous than a single application. However, the harvested water should be used as early as possible to minimise the losses of stored water.

Dryland crops invariably fail to produce good yield, largely due to high water stress at the reproductive phase. This moisture stress could be released to some extent at the cost of reduced water expense during the vegetative phase by planting crops with less than normally recommended plant density. This technique is useful to stabilize crop production in low rainfall years (Singh *et al.* 1990). More research efforts are, however, required to determine the optimum population. As far as possible, the entire exercise of dry farming should be taken on watershed basis. For stabilizing farm income, mixed farming of crops, horticulture, forestry, silvipasture and goat rearing is essential.

Conclusion

It is concluded from the review that with proper conservation, harvesting and appropriate use of limited rainfall, it is possible to greatly improve and stabilize the yield of short duration and low-water-requiring improved dryland crops. Proper bunding and tillage of land and interculture of crops are required for efficient conservation of moisture in the soil. In summer fallow land, deep harrowing, followed by blade harrowing at an interval of 3 to 4 weeks from the onset to withdrawal of monsoon is essential for effective *in-situ* conservation of rainfall. For post-monsoon evaporation control, suitable and easily available vegetable mulching material needs to be explored for each region.

Water budgeting under cropped and bare soil conditions and establishment of yield-water functions for different crops under different agro-climatic situations should continue to be a thrust area of dryland research. For stabilizing the yield of dryland crops, particularly in low rainfall years, sustainable plant density needs to be worked out for each agro-climatic situation.

All dryland crops should be raised under ridge-furrow system to ensure good crop stand, efficient rain water harvesting *in- situ* in a farm pond and easy recycling of harvested water for critical irrigation. Ponds should form an integral part of dryland agriculture to stabilize crop yield and to build up confidence of farmers in dryland agriculture. The technology for pond water harvesting needs further refinement for appropriate pond size and sealant for lining which suits individual farm situation as also community watersheds. The progress in the adoption of water harvesting methods has been slow. Custom hire services to dryland farmers for seeding plantation on ridge-furrow system, for providing critical irrigation from the farm pond and for deep tillage of land, should be made available by the development agencies for easy adoption of dry farming technology. For sustainable farm income a mixed farming of crops, horticulture, forestry, silvipasture and rearing of goats is required. As far as possible dryland agriculture should be developed on watershed basis.

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