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Plant Ecology

OPTIMUM USE OF WATER FOR AGRICULTURAL CROPS, HORTICULTURAL, AND FUEL TREES IN THE DESERT AREAS

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INTRODUCTION

Optimization of the water use of plants assumes a great practical significance in the desertic regions in view of the general paucity of water and the intimate relationship between the plant production and water use. The actual water use by plants may, however, vary substantially not only due to species variations but also due to variations in the amount and distribution of rainfall, soil and soil-water conditions and changes in other environmental factors. While it is necessary to quantify these variabilities of water use of the vegetation components of the desert, it is useful to bear in mind that the emergence of new strategies for the optimization of water use largely rests on the knowledge and understanding of the plant and the soil systems which are the only two factors of the overall soil-water-plant-environment complex which are liable, to an extent, to human manipulations.

In view of these, an attempt has been made here to relate the general trend and characteristics of the water use behaviour of different desertic vegetation and to identify the arenas of technology which help in the optimum use of the limited water resources.

Since the factors of the physical environment such as radiation, temperature, humidity and soil-water largely influence the plant growth and yield indirectly through their effects on plant processes, the assessment of water use by emperical formulae, which are otherwise useful, have a serious limitation. In view of this, data on water use, based on field measurements, have only been considered here.

VARIABILITIES OF SOIL-WATER CONDITIONS

It is necessary in the present context to evaluate the variabilities of soil moisture commonly encountered in the arid regions because of its intimate link with plant water use and productivity. Rain dependent soil-water variabilities, a predominant factor for yield variations in these areas, have been found (Lahiri, 1975b) to assume different characteristics in different years. In one case rainfall may be erratic and thus yields may be low due to sporadic droughts. In another case early rains followed by progressive reduction of soil moisture due to a prolonged dry spell may also cause detrimental effects to crops. There may be again another situation where low soil water conditions prevail owing to the low precipitation throughout the growing period of the crop. Soil moisture conditions, as such, may be often widely different from one area to the other even when located at close proximity, due to the variabilities in the intensities and distribution of rainfall.

Apart from these, it has been pointed out (Lahiri, 1977a) that soil moisture status in the arid and semi-arid areas may be markedly influenced by diverse other factors like topography, land form, soil conditions and rain interception by the existing vegetation component.

It seems, therefore, that the variability of soil moisture conditions, among other environmental constraints, is one of the most important factors which modulate the water use and contribute towards the instability of production from desert ecosystem.

Influence of Soil Moisture on Transpiration

It is necessary in this regard to picture the influence of soil moisture on the process of transpiration of desertic plants. Investigations on the seedlings of *Tecomella undulata*, a timber tree of the Indian desert, indicated (Lahiri & Kharabanda, 1966) that fluctuations of soil moisture brought about by different levels and intervals of watering, did not significantly affect the rate of transpiration per unit of leaf area. However, the economy of water use under low soil moisture conditions was brought about by the reduction of area of individual leaves, as well as, by the reduction of the total transpiring surface caused by leaf fall. The available reports (Oppenheimer, 1960) indicate that this mechanism may be operating in a large number of desert plants.

The reduction in the rate of transpiration, however, does occur in a drought cycle when the soil moisture is depleted within a short period of time. Simultaneous measurements of transpiration, relative turgidity of leaves and soil moisture helped (Lahiri & Kharabanda *loc cit*) in establishing their following interrelations: (a) *Constant rate phase:* In the initial stages of water restriction, soil moisture started declining at fast rate, but the transpiration rate and relative turgidity virtually remained unaltered. Little stomatal control was discernible; (b) *Falling rate phase* : In the subsequent stage soil moisture approached the wilting point and this was coupled with a decline in both rate of transpiration and relative turgidity. Stomatal closure increased the resistance at this stage in the pathway of water movement; (c) *Cuticular phase :* In the next stage, a sharp drop in relative turgidity was accompanied with a minimum of transpiration. The water loss presumably was largely through the cuticle, stomatal resistance being at the maximum; and (d) *Rehydration phase :* On rewatering tissue hydrature and the rate of transpiration was restored with a minimum of time lag.

It has generally been observed that a fast recovery or normalization of processes at the rehydration phase is an inherent trait in most desert plants. It has further been observed that at the termination of a drought, plants maintained earlier under low moisture regime develop greater transpiration potential as compared to plants maintained under more favourable soil moisture condition.

TRENDS OF WATER USE IN TREES

In an established tree, however, the "Falling rate phase" and the "Cuticular phase" are hardly ever encountered although the soil moisture up to about 2 metre depth may often remain close to the permanent wilting percentage during the rainless period which extend in these areas from October to June. The available data (Abichandani *et al.*, 1967, Lahiri, 1965) on the dynamics of soil moisture under natural vegetation, during and after the rainy period, indicate that there is hardly any possibility of growth of shallow rooted plants under the adverse soil water tensions that prevail in the upper soil layers during the rainless period of the year. The root systems of the perennial desert grasses like *Cenchrus ciliaris*, *C. setigerus*, *Panicum antidotale* and *Dichanthium annulatum* are known to extend up to 117-196 cm and that of *Lasiurus sindicus* may even go up to 403 cm (Dabadghao *et al.*, 1962). Despite their generally extensive root system, they mostly dry up beyond the month of October and resprout only again with the showers of the next monsoon. However, grasses like *L. sindicus*, may often display winter or spring growth, more so, when soil moisture conditions are favourable due to high rainfall of the previous summer.

Studies (Lahiri & Kumar, 1964, Lahiri, 1964, 1965, 1968, 1975a) have indicated that the established desertic trees of this area generally transpire at a high rate all round the year although certain species like *Salvadora oleoides* generally maintain a relatively lower rate of transpiration. During the winter, the effective period of water loss may be shortened, or in some cases the rate may be reduced, due to the low temperature at dawn and dusk and due to the shorter day length. However, the rates at peak periods in all seasons were comparable. The data available here on the transpiration rates of desertic vegetation, with reference to the microclimate, indicate that the existing deep rooted perennials of the desert hardly ever economise in their water turnover.

Attempts were made to derive an approximate estimate of total water loss from the community of *Prosopis cineraria*, an important fodder tree, which abounds in the sandy desertic plains (Lahiri & Kumar, 1967). The results indicated that approximately 222 mm of water was lost to the atmosphere annually from one hectare of land having about 50 trees and this information becomes very meaningful if we take into account that the annual average rainfall of the experimental area was only about 366 mm.

Such desertic trees in most cases have deep root systems which enable them to tap water from deep moist layers. Root excavation of *P. cineraria* tree undertaken by late Prof. B.E. Nikolaevitch, UNESCO expert at this Institute, showed that roots could go down beyond a depth of 8-10 metres. At that point roots with thick secondary growth were found to go further down penetrating the Kankar layer in the course of their growth.

It is, thus, possible that many desertic trees of this area behave like a 'Phreotophyte' or 'well plant' of Meinzer (1927) which habitually obtain their water supply from the zone of saturation either directly or through capillary fringe and thus the perennial and secure supply of ground water makes them independent of the moisture regime of the upper strata of soil. Robinson (1958) has provided considerable information on this subject and it has been felt that useful and productive trees should be grown in the desert so that the large quantities of water consumed by them go towards human benefit.

Thus, an apparent lack of competition between the established trees and shallow rooted crops or grasses for soil moisture, ask for an evaluation of moisture status below the trees. This has an obvious significance in agri-silva and silvi-pastoral programme. The soil moisture status beneath the different trees may, however, be different due to the differences of foliage characteristics, their wetting properties, absorption by dead plant parts, stem flow, etc. Informations in this regard are rather scarce for arid areas of western Rajasthan. Studies undertaken by Gupta *et al.* (1975) under Jodhpur conditions indicated that the soil moisture in the 90 cm profile of the *Eucalyptus* forest increased from about 4 cm to 7.5 cm after a 35.1 cm of shower during September 1969 but the order of increase was much less in the fallow land, grass land and in *Acacia* forest. Comparative study on the soil moisture status in 120 cm soil profile of different tree communities undertaken here by Dr. J.P. Gupta (personal communication) indicated that the moisture regime remained generally high below *Prosopis cineraria* and *Tecomella undulata* as compared to certain other species like *P. juliflora*, *Albezzia lebbek* and *Acacia senegal*. This could be one of the reasons of increased growth of the ground cover often observed beneath the *P. cineraria* trees. Shankar *et al.*, (1976) noted 2.3 t/ha of dry herbage yield under *P. cineraria* as against 1.6, 1.3, 0.8, and 0.8 t/ha under *T. undulata*, *A. lebbek*, *P. juliflora*, and *A. senegal* respectively. Since certain trees (e.g. *P. cineraria*) have a capacity to absorb moisture from sporadic rains through foliage (Bhatt & Lahiri, 1964), soil moisture enrichment may be possible only under conditions of heavy showers. Again, there are reports (Lahiri & Gaur, 1969) that the growth of ground cover under certain trees like *P. juliflora* is restricted due to inhibitors of the leaf litter. It has also been noted (Aggarwal & Lahiri, 1977) that the organic matter build-up of the soil below the desertic trees vary considerably depending on the species. However, the links between the differences in soil moisture regime below the tree species and the organic matter build-up process have yet to be established.

It may be mentioned in this context that the data on the water use of horticultural trees of these areas are rated meagre.

Trends of Water Use in Crops

Water balance studies of rainfed crop fields have indicated (Lahiri, 1975a) that the consumptive use is largely dependent on the rainfall and soil water conditions of the upper soil layers because of the relatively shallow root system of the plants. It may be found from the Table 1 that the component of consumptive use and deep drainage of the water balance equation may undergo wide variations from one year to another largely due to rainfall conditions. It has also been found that good distribution rain, rather than the total quantity, increases the

TABLE I

The variabilities in consumptive use of moisture and deep drainage in field plots of pearl millet varieties in different years. N and P_2O_5 each @ 20 kg/ha were applied in all cases. (After Lahiri 1975a).

Year	Variety	Total precipitation (mm)	Consumptive use of moisture (mm)	Deep drainage (mm)
	RSK		180·0	54·5
1966	RSJ	263·3	176·8	30·5
	Ghana		183·5	20·9
	RSK		131·8	Nil
	RSJ		120·0	-do-
1968	Ghana	178·6	130·3	-do-
	HB 1		158·8	-do-
	HB 2		133·4	-do-
	RSK		68·3	Nil
	RSJ		79·7	-do-
1969	Ghana	92·7	73·1	-do-
	Chaddi		63·2	-do-
	HB 1		86·3	-do-
	RSK		155·8	297·7
	RSJ		130·8	306·6
1970	Ghana	594·8	152·5	326·4
	Chaddi		154·1	353·9
	HB 1		171·1	290·3
	RSK		214·4	38·2
	RSJ		183·7	77·7
1971	Ghana	307·6	108·7	37·7
	Chaddi		204·0	49·6
	HB 1		187·7	55·5

consumptive use. For instance, precipitation as such was more during 1970, as compared to 1971, but the water use by plants was more during 1971 due to the even distribution of rainfall. Higher rainfall of 1970, in major spells, contributed largely towards the increase of deep drainage. The data presented in the Table II indicate that the significant effects due to varietal differences and fertilizer effects are discernible only under favourable rainfall conditions when the consumptive use is high. In a year having low rainfall, low consumptive use of moisture is ofter associated with absence of significant effects due to variety and fertilizer (Table II). Under low rainfall conditions, application of fertilizers may sometimes increase the water use during the vegetative period leading to soil water shortage at the reproductive phase. This is often associated with decrease in the yield of fertilized plots. This situation cannot, however, be compared with sporadic drought conditions, as encountered in rainfed, high rainfall or semi-arid areas, where fertilizer application often helps to stabilize the yield (Lahiri, 1978).

TABLE II

Extent of variation in water use and yield due to rainfall variations (After Lahiri, 1973)

Bajra varieties	Year 1969, Rainfall 92·7 mm									Year 1970, Rainfall 594·8 mm								
	Consumptive use of water in mm at indicated doses of N and P_2O_5				Yield in gm per 1/200 ha at indicated doses of N and P_2O_5					Consumptive use of water in mm at indicated doses of N and P_2O_5				Yield in q/ha at indicated doses of N and P_2O_5				
	0	20	40	60	0	20	40	60	Mean	0	20	40	60	0	20	40	60	Mean
RSK	63·6	68·3	75·0	75·1	4·9	1·9	1·7	3·7	2·9	134·7	155·8	150·5	189·9	15·9	17·0	24·0	20·7	19·4
RSJ	65·6	79·7	80·6	80·3	2·7	2·6	4·1	3·3	3·1	137·9	130·8	142·0	157·0	17·4	19·3	19·4	21·1	19·3
Ghana	60·6	73·1	78·0	71·5	2·1	2·9	2·7	1·3	2·3	123·6	152·5	151·8	180·0	8·5	10·6	19·4	22·2	17·7
Chaddi	63·0	63·2	68·1	72·2	2·6	1·4	4·0	1·9	2·5	150·6	154·1	169·3	160·9	14·1	19·0	20·4	18·5	17·9
HB 1	67·4	68·3	69·4	69·4	1·3	2·5	2·8	2·5	2·6	162·9	171·1	173·9	199·3	19·7	24·9	28·7	30·8	26·0
	Mean				2·7	2·3	3·1	2·4		Mean				17·1	18·2	22·3	22·6	

Year 1969:

Variety and fertilizer effects are not significant

S. Em. for Var. ± 0·5
S. Em. for Fert. ± 0·45

Year 1970:

	S. Em.	LSD 5%	LSD 1%
Var.	± 1·899	5·462	7·367
Fert.	± 1·698	4·884	6·584
Inter.	± 3·799	NS	NS

There may be again some difference in the water use behaviour between the different species. It has been found (Lahiri, 1975b) that legumes like guar, moong and moth consume generally less water as compared to bajra but water use efficiency of bajra is generally higher than these legumes.

Trend of Water Use in Grasses

Study of soil water regime (up to 2 m depth) and consumptive use of moisture of natural cover of vegetation of *Dactyloctenium sindicum, Cenchrus ciliaris, Eleusine compressa,* etc. (Lahiri, 1965) indicated that during 1963 when the rainfall during the growing period was 163.8 mm, the consumptive use of moisture was 162.9 mm. This observation indicated that the moisture received through precipitation was totally consumed by the plants. Restrictions imposed by the limitation of soil moisture appeared to be the main reason for the cessation of growth beyond September as the ground cover displayed progressive increase in growth under irrigated condition during January to May.

Studies undertaken by Drs S. Kathju, A.N. Lahiri and K.A. Shankarnarayan in this Institute have indicated that management conditions of fodder grasses like *Lasiurus sindicus, Cenchrus ciliaris* and *C. setigerus* have a close relationship with their consumptive use of moisture and water use efficiency. The modulations of water use and water use efficiency of these grasses, due to nitrogen doses, interval and height of cutting, seem very obvious from the data presented in the Table III.

Table III

Effects of nitrogen, cutting interval and height on the water use (mm) and water use efficiency (kg dry matter/ha/mm water used) in C. setigerus, C. ciliaris *and* L. sindicus *during 1976 (Precipitation during experiment=537·7 mm; Total precipitation=639·7 mm).*

Treatments	*C. setigerus*		*C. ciliaris*		*L. sindicus*	
	Consumptive use (mm)	Water use effiiciency (kg/ha/mm)	Consumptive use (mm)	Water use efficiency (kg/ha/mm)	Consumptive use (mm)	Water use efficiency (kg/ha/mm)
(a) Nitrogen doses						
0 kg/ha	151·8	10·40	173·0	13·73	180·0	11·36
20 kg/ha	176·3	12·96	182·5	13·98	190·6	12·33
40 kg/ha	191·3	11·85	176·6	18·34	194·4	15·71
(b) Interval of cutting						
10 days	175·7	11·80	167·9	11·74	173·6	5·89
20 days	174·0	9·86	191·8	14·15	173·6	10·35
30 days	177·3	13·97	171·7	17·42	200·1	12·53
60 days	182·5	12·00	182·2	18·11	206·2	18·28
(c) Cutting height						
5 cm	158·5	12·81	171·8	17·03	183·6	12·13
10 cm	185·5	11·07	178·2	14·89	189·1	11·58
15 cm	175·5	11·85	186·7	14·14	192·3	11·58

Prospects of Improvement of Water Use and Productivity

Various attempts have been made in the Indian arid zone, as elsewhere, to improve the plant water use and productivity by the adoption of different technologies. Some of the promising approaches have been briefly discussed here.

Runoff Farming : Investigations have been undertaken under Jodhpur conditions (loamy sand soil) to harvest the runoff water from artificial micro-catchments (sealed with tank silt) for the stabilization of yield of crops in the adjoining flat land (Singh *et al.*, 1973 and Singh, 1976). Among the various ratios of catchment to cultivated areas (viz. 0.5, 1.0 and 1.33), 0.5 ratio has appeared to be promising. It has been observed from trials with various crops like bajra, moong, guar, cowpea, til and sunflower that such method improves the soil water condition, minimizes the risk of crop failures in a drought year, generally increases and stabilizes the yield and improves the water use efficiency. The apparent disadvantage of transfer of some area for making catchments is sufficiently compensated by accumulated benefit over years.

Preliminary experiments in the fruit tree, *Zizyphus mauritiana*, have indicated (personal communication of Dr O.P. Pareek) that under arid conditions water harvesting with a catchment slope of 5% has generally resulted in highest soil moisture storage and highest plant survival and growth as compared to those in flat land or with 0.5 or 10% of catchment slopes.

Water harvesting from natural catchments : In the sub-stations of the CAZRI located in the desert areas (200 mm or less rainfall) rainwater is being harvested since early sixties from natural slopes (3 to 6%) and collected in cement tanks, each having a capacity of about 2 lakh litres (Prajapati *et al.*, 1973). Although this water is presently being utilized for human and experimental animals, in the absence of other sources of water in these areas, there is ample prospect of recycling this water for cultivation.

Contour furrowing and bunding : Although specific data on plant water use is not available for such treatments, but studies undertaken in the range lands of this Institute (Ullah *et al.*, 1972) located in Jaisalmer (178.5 mm avg. rainfall), Bhopalgarh (316.8 mm), Palsana (468.6 mm) and Jadan (411.0 mm) indicated that contour bunding of 75 cm height and 80 cm vertical spacing combined with contour furrowing 10-15 cm height or depth, and 100-125 mm vertical spacing, generally improves the forage yield associated with increase in soil moisture status as compared to the control or only bunding or furrowing (Table IV). There were, however, variations due to soil, rainfall and range conditions.

Promising crop yields have also been achieved by providing contour bunds across the slope which provided effective soil and water conservation. Studies undertaken by Misra (1966) at the Pali sub-station of this Institute (located in the semi-arid tract and having shallow sandy loam soil with 1.5% natural slope) indicated that bunded plots conserved more moisture as compared to the unbunded plots and the yield of gram crop was also higher in the former treatment as compared to the latter.

TABLE IV

The percentage increase in soil moisture over the control (based on peak observed values) in different moisture conservation treatments and the average forage yield from the grassland in Jaisalmer during 1966. (After Uallah et al., 1972*)*

Treatments	% increases in soil moisture over the control at indicated depths in cm			Forage yield (q/ha)
	0·5	5·15	15·25	
1. Contour furrow	100·4	75·6	40·0	3·04
2. Contour bund	45·6	18·9	23·6	2·75
3. Contour furrow and contour bund	129·5	90·9	47·2	4·06
4. Control	—	—	—	1·44

Moisture conservation in sandy soils by subsurface barrier and use of amendments : Placement of a barrier at a depth in the soil is a rational measure for arresting the high percolation losses in sandy soils. Experiments undertaken here by Gupta and Aggarwal (1978) indicated that improvements of soil moisture brought about by the placement of subsurface barrier of asphalt (*ca.* 2 mm thick at 60 cm depth) brings about a higher mineralization of nitrogen and an increase in the uptake of nitrogen by bajra plants. These were associated with higher water use, water use efficiency and yield from the crop (Table V). Mann and Singh (1977) have also reported that the yields of *tinda* remained consistently higher over four successive years where a moisture barrier of bentonite clay (at 75 cm depth) was placed, as compared to those, obtained without the barrier.

Unpublished data of Dr J.P. Gupta have further suggested that improvements of moisture retention, through application of pond silt or exfoliated vermiculite in sandy soil also helps in improving the yield and water use efficiency of bajra crop.

The placement of subsurface barriers at present poses a problem due to the absence of suitable machinery, as evolved in certain other countries. However, application of pond silt in sandy soil is a relatively easy operation where the only constraint is the availability of the required quantities of silt.

TABLE V

Effects of Asphalt barrier on water use, yield, mineral-N of soil and N-composition of Bajra during 1976 at the Central Research Farm of the CAZRI (After Gupta & Aggarwal, 1978*)*

Treatments	Mineral-N (ppm) (0–45 cm)	% N in grains	% N in straw	N-uptake (kg/ha)	Grain yield (kg/ha)	Water use (mm)	Water use efficiency (kg/mm/ha)
Without barrier	33·6	1·51	0·43	29·08	11	188	5·85
With barrier	56·0	2·00	0·59	53·47	17	284	6·00

Experiments undertaken by Dr H.P. Singh in this Institute during 1973, have revealed that subsurface incorporation of *Calotropis procera*, a latex containing plant (@ 15 tonnes/ha of green matter), increased the soil moisture storage by 26 to 34% as compared to untreated loamy sand soil. The chopped plants were incorporated in the soil at 25 to 30 cm depth. Under these conditions, bajra (var. HB3) and moong (var. 512) displayed increase in the yield by 53 and 18% respectively as compared to the control.

Use of surface mulches : Conservation of soil moisture by mulching has a direct relevance to the optimisation of water use. In the desertic areas, where the sand is frequently found in abundance on the surface soils, moisture losses from soil is generally minimized. None the less, evaporation losses from the soil, more so in heavier soils, may be substantial. These losses, however, may be conveniently restricted by the use of mulches.

Experiments undertaken by the Dry Farming Centre at this Institute, indicated (CAZRI Technical Bulletin No. 1, 1976) that bajra husk mulch, wheat straw and grass mulch helped to maintain a high moisture regime in the soil profile in both favourable and unfavourable rainfall conditions, and the use of mulches generally contributed towards the yield improvements of moong and bajra. Gupta (1978) also noted that polyethylene and bajra husk mulches significantly improve the grain and straw yield of bajra as compared to the control with an associated increase in water use efficiency. Table VI indicates that polyethylene mulch was found to be better than bajra husk. It has further been observed that higher soil temperature regime under the polyethylene mulch as compared to bajra husk, was not detrimental to the growth and yield of bajra.

TABLE VI

Effects of mulches on water use efficiency, dry matter production and grain yield of bajra (var. BJ 104) (After Gupta, 1978)

Treatments	Grain yield (q/ha)	Straw yield (q/ha)	Water use (mm)	Water use efficiency (kg/mm/ha)
Polyethylene	29·0	35·0	279	10·4
Bajra husk	23·0	30·3	269	8·5
Control	17·4	26·0	291	6·0
LSD at 5%	1·0	2·0		

Choice of crops: The water use of plant, as such, may be highly variable from one year to another depending on the rainfall and other conditions. However, there may be certain variabilities between different crop varieties and species, as regards their water use and water use efficiency. For instance, bajra (var. HB1) has been found to have water use efficiency (kg/mm of water used) of about 23, while under the same conditions other varieties like RSK, RSJ, Ghana and Chaddi showed efficiency indices varying from *ca.* 12 to 15. Investigations have also shown (Lahiri & Singh, 1970) that performance of different varieties may also vary significantly depending on the ranges of soil water tensions. Hewever, under extreme conditions of soil water shortage, varietal merits often appear to be rather obscure.

STABILIZATION OF CROP PRODUCTION UNDER LOW SOIL MOISTURE CONDITIONS

Irregular distribution of precipitation often create a condition of drought where the plants may be subjected to moisture stress at any stage of growth. Such sporadic droughts may be encountered both under high and low rainfall areas. It has been experimentally demonstrated (Lahiri *et al.*,1973) that the adverse effects of droughts, no matter at which stage of growth the water shortage is experienced, could be substantially evaded where optimum plant vigour was induced by adequate soil fertility. It was found that pearl millet plants (var. RSK and HB1) grown under high level of nitrogen, displayed significantly better performance, despite sporadic droughts, as compared to plants grown under low level of nitrogen. Under such conditions root growth was increased and ear emergence was hastened. Drought decreased the absolute nitrogen content per plant at post drought stages as compared to undroughted plants. But high dose of nitrogen helped to maintain a high endogenous level of nitrogen per plant under drought conditions and the level was comparable or higher than undroughted plants under lower nitrogen doses. The physiological and biochemical basis of this drought proofing measure, which is only applicable in the rainfed semi-arid or high rainfall areas, have been explained in detail in certain recent publications (Lahiri, 1977a, 1978). The concept of nutrition induced vigour as a means for drought avoidance has further gained support from studies (Lahiri and Kathju 1973, Kathju & Lahiri, 1976) which indicated that plants raised under high soil fertility display higher activity of enzymes both under conditions of hyperthermia and desiccation. It emerged (Kathju & Lahiri, 1976) that the tissue turgor is unlikely to be the key to general growth reduction under water shortage. It has been speculated that growth and metabolic efficiency is more dependent on nutrition rather than tissue hydrature at least up to a certain level of water shortage.

OPTIMUM USE OF WATER IN IRRIGATED CROPS

The highest possible evapotranspiration of a crop completely covering the soil (the potential evapotranspiration) is determined by the evaporating capacity of the atmosphere, as long as soil is moist. With decreasing soil moisture contents, evapotranspiration becomes dependent on the available moisture. The plant plays only a passive role in the process of transpiration, serving as a means of transport for water from soil to air and adopting itself to the circumstances by closing or opening the stomata.

Although to a certain degree plant production is related to the total amount of water used, the increase in production may no longer be dependent on an increase of available water after a certain level of production. More water at that point may not contribute to the yeild because of certain constraints of inputs, such as, soil fertility, selection of variety, etc. Often, however, amount of irrigation water required is determined only on the basis of evaporating capacity of the atmosphere. Since, there is a prospect of achieving different levels of production at the same level of water use by optimisation of the inputs, the study of input manipulations assumes a singular importance in arid areas where water for irrigation is limited. It has been found (Lahiri, 1975b, Ram & Lahiri, 1974) that substantial and economic yields can be achieved in this area by optimizing the inputs like nitrogen and phosphorus at a low level of water availability.

The foregoing adjustment of irrigation to production would in several cases lead to the possibility of extension of the irrigated area. Although under such circumstances crop yield per unit area may decrease, but the total production from a project area may increase. The data (Table VII) provided by Singh (1976) indicate that a marked increase in total productivity of different crops may be possible by using a given amount of water over a larger area.

The quest for efficient use of limited water resource has also led to the assessment of relative merits of different irrigation methods. It has been found (Singh,1974) that on equal quantity of water application, the yield of sprinkler irrigated wheat (var. Kalyansona) was 43.01 q/ha which was 36.5 and 33% higher than the yields under border strip and check basin respectively.

Vijay Kumar & Raheja (1969), however, did not find any significant effect of flat, furrow and sprinkler irrigation on cotton (var. 216 F, 414 and Andrews) but reported that soil water tension has a greater relevance.

In this regard trickle system of irrigation, particularly in case of fruit and vegetable crops, presents considerable promise for optimizing the production with limited water resources. Evidences from contemporary literature (Kirkpatrick, 1970; Chapin & Chapin, 1971; Buclon, 1974) indicate a number of advantages of trickle irrigation such as, (a) 30-50% water economy may be achieved as compared to furrow irrigation permitting a diversion of the limited water over a larger area, (b) produce is improved, (c) yield is increased as compared to both, furrow and sprinkler irrigation, (d) water with excess of salts, as often encountered in arid areas, may be used for irrigation, (e) nutrients may be directly applied through drip system, and (f) weed growth is restricted due to dry soil between the plants.

TABLE VII

Production for a given quantity of water used over different areas (After Singh, 1976)

Crop	Water use (cm)	On area (ha)	Production (q)
(a) Wheat	84	1	55
		3	91
(b) Bajra (HB3)	25	1	42
		4	103
(c) Jowar (CSH 1)	28	1	44
		2·5	64
(d) Sunflower (EC 68414)	50	1	16
		2	27
(e) Mustard (Haryana No. 1)	25	1	11
		1·5	20

Investigations undertaken here (Singh, 1974) indicated (Table VIII) that the yield and efficiency of water use of a number of crops like bottlegourd, ridge-gourd, round-gourd and watermelon may be increased to different degrees by the adoption of trickle irrigation method as compared to those obtained under furrow and sprinkler irrigation.

While it is generally acknowledged the trickle system is well suited for high value vegetable and plantation crops, there is a dearth of data on the economic of returns from specific crops in the context of regional soil-environment conditions. In the current Operation Research Programme of this Institute in Dahijar village near Jodhpur, about 0.6 ha of area has been brought under potato (1 metre spacing where each lateral feeding double rows of plants spaced 15 to 20 cm apart over a length of 30-50 metres. Individual drippers on the laterals were 50 cm apart), where the initial investment has been estimated by Dr Panjab Singh of this Institute to be roughly Rs. 18000/- per hectare (excluding pump installation). The cost has been kept low by the fabrication (*ca.* Rs. 0.45 per dripper) of the drippers in this Institute from high density polyethylene. The initial cost, however, has been relatively less (about Rs. 6000/- per ha) in case of orchards of pomegranate and citrus in ORP area where plants were located at distances of 6 m or more. The whole economies, however, have to be viewed from the profits gained over time. Efforts are also being made here to reduce the overall cost by reducing the number of laterals through adjustment of planting pattern and system design.

TABLE VIII

Yield and water use efficiency of vegetable crops under various methods of irrigation. (After Singh, 1974).

Crop	Irrigation method	Water use (cm)	Yield (tonnes/ha)	Yield of water use (q/cm)
Bottle-gourd	Furrow	84	38·01	4.5
	Sprinkler	84	38·60	4·6
	Trickle	74	55·79	7·5
Ridge-gourd	Furrow	84	10·74	1·3
	Sprinkler	84	9·96	1·2
	Trickle	74	12·03	1·6
Round-gourd	Furrow	80	29·47	3·7
	Sprinkler daily	80	30·84	3·8
	Sprinkler per 5-day cycle	80	40·62	4·2
	Trickle	80	40·62	5·1
Water-melon	Furrow	80	67·24	8·4
	Sprinkler daily	80	68·76	8·6
	Sprinkler per 5-day cycle	80	74·64	9·3
	Trickle	80	82·33	10·3

The possibilities of the use of saline water through trickle irrigation make this method more suited to arid areas where ground water is often saline. In certain experiments undertaken here in the Agronomy section, the yield of potato was about 26 tons/ha with water having 3 milimhos conductivity and about 14 tons/ha with water having 10 milimhos conductivity. Under furrow irrigation with sweet water the yield was 19 tons/ha and that under the trickle system was 31 tons/ha. It, therefore, seems that the trickle system avoids detrimental accumulation of salts in the vicinity of the roots and thus water having a high salt content can also be used under this system.

Irrigation Need of Fruit Trees

Very little data are available on the water use and irrigation needs of fruit trees of this area. However, preliminary studies undertaken by Dr O.P. Pareek of this Institute have indicated that the performance of ber *Zizyphus mauritiana* (var. Seb, Gola and Mundia) plants under rainfed, limited irrigation (two irrigations during February-April) and frequently irrigated conditions (10-20 days, interval) showed a progressive increase in growth from rainfed to irrigated conditions. Among the varieties, Gola displayed the highest growth under frequently irrigated conditions while Mundia recorded the highest linear growth under limited irrigation.

Future Needs of Research

The foregoing account indicates that diverse facets have been explored for the optimum use of the limited water resources of the area and considerable success has been achieved in different fields. The development of technologies related to increasing plant production from the desertic regions, however, largely depend on the understanding of the principals of soil-water-plant relationships keeping in view that soil, topographical and other conditions which may vary considerably from one area to the other.

A general thrust towards the manipulation of the soil system and the plant system seems to be the only rational approach to the problem. However, the overall issue being highly involved, systematic evaluation of the different dimensions of the problem is necessary. For instance, lack of competition for moisture between the established trees and shallow rooted plants like crops and grasses does not necessarily mean that all the desertic trees are suited for silvi-pastoral or agri-silva operations. Differences in stem-flow or other causes, like presence of present considerable promise in this area for the stabilisation of growth and yield of rainfed crops. Standardisation of these methods, in the context of regional conditions, is necessary while water use of newly evolved crop varieties need systematic screening to assess their suitability in the arid areas. There are again limited data on the water use aspects of conservation farming and mixed cropping under rainfed conditions. Such information may be very useful for production stabilization.

General dependence of fuel and fodder trees on the moisture status of the upper soil layers during the early stages ask for an intensification of studies on their water relations in the context of growth and establishment. The most significant gap in our knowledge is regarding the water use and yields of fruit trees of this area. The number of fruit trees, adopted to this condition is, however, limited [date palm, pomegranate, mulberry, grapes, guava, ber, gonda (*Cordia mixa*), sour lime are the main fruit trees] and adequate emphasis is needed to standardise the conditions of their optimum growth.

It is a known fact that the dry regions may often pass through wet years, when the rainfall is high. It has been observed that in such years crop yields are often poor due to infestations of insect pest and fungal diseases. It is very necessary, therefore, to divert our research efforts for effective control measures to eliminate these hazards. It may be necessary to undertake in-depth studies to counter the problems of specific crops, such as, ergot disease of bajra.

It is further necessary at this juncture to evolve suitable land use patterns for this area consistent with the climatic characteristics and long term productivity of the land. Identification of priority arenas in this regard will help in furthering research activities on the optimum water use of the adopted plant components of the desert ecosystem.

REFERENCES

Abichandani, C. T., Krishnan, A., Bhatt, P. N., & Rakhecha, P. (1967). Some observations on soil moisture changes in arid zone soils. *J. Ind. Soc. Soil Sci.*, **15**, 7-15.

Aggarwal, R. K. & Lahiri, A. N. (1977). Influence of vegetation on the fertility build up of the desert soils. *Sci. Cult.*, **43**, 533-535.

Bhatt, P. N. & Lahiri, A. N. (1964). Some evidence of foliar absorption of water in a xeric tree *Prosopis spicigera*. *Naturewiss*, **14**, 341-342.

Buclon, F. (1974). Trickle irrigation in the USA. *Plasticulture No. 21*, March issue, p. 43.

CAZRI Technical Bulletin No. 1. (1976). *Improved Dryland Agriculture for Western Rajasthan.* (Ed. R. P. Singh).

Chapin, R. D. & Chapin, R. E. (1971). Double Wall Tubing for Drip Irrigation of Row Crops. 10th National Agricultural Plastics Conference, Chicago, USA, p. 8.

Dabadghao, P. M., Marwaha, S. P., Gupta, B. S., Das, R. B. & Deb Roy, R. (1962). Root ecology of some promising desert grasses of Rajasthan. *Ann. Arid Zone*, **1**, 1631–73.

Gupta, J. P. & Aggarwal, R. K. (1978). Effect of Asphalt Sub-surface Moisture Barrier on Water Characteristics and Productivity of Sand Soil. *Symp. on 'Arid Zone Research and Development'* held at Central Arid Zone Research Institute, Jodhpur, February 14-18.

———(1978). Effects of mulches on moisture and thermal regimes of soil and yield of pearl millet. *Ann. Arid Zone*. (In Press).

Gupta, J. P., Ullah Wasi, & Issac, V. C. (1975). Note on some soil moisture changes under permanent vegetative cover. *Indian Forester* **101**, 523-526.

Kathju, S. & Lahiri, A. N. (1976). Effect of soil fertility on the activities of certain enzymes of desiccated wheat leaves. *Pl. Soil*, **44**, 709-713.

Krikpatrick, W. B. (1970). Development of Trickle Irrigation in Australia. *Proc. 4th Int. Colloquium on 'Plastics in Agriculture*, Paris, June issue, p. 304.

Lahiri, A. N. (1964). Moisture Relations of Some Desert Plants. *Proc. Symp. on 'Problems of Indian Arid Zone'*. Ministry of Education, Govt. of India, pp. 154-160, Lahiri, A.N. (1965). Some aspects of soil water relationship in the growth of plants in arid environment. In: *Growth and Development of Plants.* (Eds. R. D. Asana and K. K. Nanda). Today and Tomorrow Book Co., New Delhi, pp. 152-168.

———(1973). Plant water relations as basis for maximizing plant production in the arid areas. Presented at the Winter School on the "Development of Rajasthan Desert" organized by the Indian National Science Academy at the CAZRI, Jodhpur.

———(1975 a). Water use by desertic vegetation and its hydrological implications. *Ann. Arid Zone*, **14**, 135-148.

———(1975 b). Plant responses to soil water status under arid conditions. Proc. of the ICAR Symp. on "Crop Plant Responses to Environment Stresses", held at Vivekananda Laboratory for Hill Agriculture, Almora, U. P.. pp. 13-24.

———(1977a). Plant in relation to soil moisture conditions of the arid areas. In : *"Desertification and its Control.* Indian Council of Agricultural Research, New Delhi, pp. 225-236.

———(1977b). Plant-water relationships under arid conditions of western Rajasthan. *Symp. on 'Natural Resources of Rajasthan'*, vol. I, pp. 275-287, University of Jodhpur and University Grants Commission.

———(1978). Relevance of soil fertility in drought evasion. In : *Environmental Physiology and Ecology of Plants.* (Ed. D. N. Sen). Bishan Singh Mahendra Pal Singh, Dehra Dun, pp. 277-288.

Lahiri A. N. & Gaur, Y. D. (1969). Germination studies on arid zone plants. V. The nature and role of germination inhibitors present in leaves of *Prosopis juliflora. Proc. natn. Inst. Sci. India*, **35**, 60-71.

Lahiri, A. N. & Kathju, S. (1973). Influence of soil fertility on the thermostability of different enzymes of pearl millet leaves. *Proc. Indian natn. Sci. Acad.*, **39**, 705-709.

Lahiri, A. N. & Kharabanda, B. C. (1966). Studies on plant water relationship II. Influence of soil moisture on the transpiration of *Tecomella undulata* seedlings. *Proc. natn. Inst. Sci. India*, **32**, 34-46.

Lahiri, A. N. & Kumar, V. (1964). Transpiration behaviour of dune plants in relation to soil moisture status. *Agric. Res.*, **4**, 196-197,

———(1967). The annual water turnover from a xeric tree *Prosopis cineraria. Sci. Cult.*, **33**, 77-78.

Lahiri, A. N. & Singh. S. (1970). Studies on plant water relationship. V. Influence of soil moisture on plant performances and nitrogen status of the shoot tissue. *Proc. natn. Inst. Sci., India*, **36**, 112-125.

Lahiri, A. N. & Singh. S., & Kackar, N. L. (1973). Studies on plant water relationship, VI. Influence of nitrogen level on the performance and nitrogen content of plant under drought. *Proc. Indian natn. Sci. Acad.*, **39**, 77-79.

Mann, H. S. & Singh R. P. (1977). Crop production in the Indian arid zone. In *'Desertification and its Control'.* Indian Council of Agricultural Research, New Delhi, pp. 215-224.

Meinzer, I. E. (1927). Plants as indicators of ground water. *U. S. Geol. Survey Water Supply.* Paper No. 557.

Misra, D. K. (1966). The moisture conservation by bunding in semi-arid region of Pali. *Proc. of Symp. 'Water Management'*, held at Univ. of Udaipur, Organised jointly by Indian Society of Agronomy and ICAR. pp. 62-65.

Oppenheimer, H. R. (1960). Adaptation to drought : Xerophytism in 'Plant water Relationships in arid and semi-arid conditions'. *Review of Research.* UNESCO, Paris, p. 105-138.

Prajapati, M. C., Vangani, B. S. ; and Ahuja, L. D. (1973). In the dry rangelands of western Rajasthan 'Tanka' can be the answer. *Indian Fmg.* **22**, 27-32.

Ram, K. & Lahiri, A. N. (1974). Economic analysis of wheat production with fertiliser under adequate and limiting irrigation water. *Indian J. Agric. Res.*, **8**, 25-36.

Robinson, J. W. (1958). Phreatophytes. *U. S. Geol. Survey Water Supply.* Paper No. 1423.

Shankar, Vinod, Dadhich, N. K. & Saxena, S. K. (1976). Effect of Khejri tree (*Prosopis cineraria* Macbride) on the productivity of range grasses growing in its vicinity. *Forage Research*, **2**, 91-96.

Singh, S. D., Daulay, H. S. & Muthana, K. D. (1973). Run-off farming making the best of available water. *Indian Fmg.* **23**, 7-8.

Singh, S. D. (1974). New dimensions of agronomy in arid areas. *Indian Fmg.* **24**, 5·9.

———(1976). New approaches to use of scarce water resources. *Trans. Indian Soc. Desert Techn.*, **1**, 83-87.

Uallah, Wasi, Chakravarti, A. K., Mathur, C. P., & Vangani, N. S. (1972). Effect of contour furrows and contour bunds on water conservation in grasslands of western Rajasthan. *Ann. Arid Zone*, **11**, 169-182.

Vijay Kumar & Raheja, P. C. (1969). Irrigation studies on cotton II. Boll weight and fibre properties. *Ann. Arid Zone*, **8**, 105-108.