WATER
IN THE ECO-PHYSIOLOGY OF
DESERT SHEEP

By

P. K. GHOSH & R. K. ABICHANDANI

ICAR

CENTRAL ARID ZONE RESEARCH INSTITUTE
JODHPUR

DECEMBER 1981

CAZRI Monograph No. 17

Published by the Director, Central Arid Zone Research Institute, Jodhpur.
Printed at the Harvard Press, Jodhpur.

Preface

In a recent publication from this Institute (SHEEP IN RAJASTHAN by Sen *et al.*, CAZRI Monograph series, No. 14, 1981), the pre-eminence of the sheep sector in Rajasthan's economy has been stressed with the help of the available census and production data. An interesting feature of this earlier study has been the finding that sheep population, as a percentage of the total livestock population, is higher in the arid western districts than in other parts of the state. In fact, the five most arid districts, viz. Jaisalmer, Barmer, Bikaner, Churu and Jodhpur together produce as much as about 35 per cent of the total wool produced in the state. This is inspite of the low genetic and physiological production efficiency levels of the desert-adapted breeds. The nearly 45 million kg of wool, 110 million kg of meat and 20 million pieces of skin that are contributed annually by the 5.3 million strong sheep population of the arid belt of Rajasthan reflect the desert sheep's ability to survive, and produce, under the harsh ecological conditions of its habitat. The two principal hazards that these, and other, free-ranging desert animals encounter are intense solar radiation and lack of sufficient drinking water, the latter often escalating the impact of the former and, together these hazards strain the physiological limits of the animals' stamina to the maximum.

This, then, is the situation in which the sheep sector in the Rajasthan desert operates. A study of water in the ecophysiology of desert sheep should, therefore, be obviously relevant to an overall assessment of the net productivity of the desert biome. The paradox lies in the fact, however, that while water is admittedly the most crucial limiting factor for both plant growth and animal production, the efficiency of water use by sheep for wool production is rather poor (less than 1%). Obviously, one way of increasing the productivity of the sheep sector would be to search for, and propagate, animals and breeds of superior water use efficiency ratings. The story of this search, made at CAZRI for the last several years, has been recounted in the following pages. The account does not, however, include CAZRI's considerable store of new information on the role of available water in the physiological processes of reproduction, nutrition, salinity tolerance and energy metabolism of different sheep breeds examined. We hope to publish these informations in future monographs.

In our attempt to project CAZRI's sustained efforts for establishing a physiological hierarchy for desert-worthiness

among the sheep breeds of Rajasthan, and for quantifying the actual water needs of these animals, we have been deeply inspired by the constant encouragement and generous material help given by our Director, Dr. H. S. Mann. We would wish to take this opportunity to pay our respectful tribute to Dr. Mann for his massive support to animal research at CAZRI.

Next to Dr. Mann, Prof. W. V. Macfarlane, former Head, Dept. of Animal Physiology, The Waite Agricultural Research Institute, Adelaide, Australia, has been our most ardent supporter and mentor. Our sincere thanks go to him.

All our colleagues in the Division of Animal Studies have helped us in one way or another. Shri A. K. Sen, Cartographer, and Shri B. L. Tak, Photographer in this Institute have rendered much valuable advice and assistance in the preparation of this monograph. We thank them all.

Division of Animal Studies,
Central Arid Zone Research Institute,
Jodhpur, December 1981.

P. K. Ghosh
R. K. Abichandani

Contents

Introduction

Sheep may be one of the first ruminants domesticated by man. It undoubtedly served early man with its wool, meat, milk and pelt. Rarely in the history of any religion or race we do not find a mention of sheep.

The desertic western part of Rajasthan which covers an area of approximately 1,80,060 square kilometres in north-west India, lying between 24° N and 30.5° N latitude and 70° E and 76.2° E longitude, is characterised by very high day temperature, particularly during the summer, and cool nights with the temperature frequently going below the freezing point in winter. The wind velocity is often as high as 110 km/hr. The rainfall is low and erratic. The average annual rainfall is about 350 mm and there are frequent spells of droughts. Most of the annual precipitation occurs during the July-September monsoon season. Drought recurs almost regularly every third year. When the monsoon fails, the water table usually goes down to a great depth. The underground water is of a limited quantity and is often saline.

Chronic, and at times acute scarcity of drinking water is the most crucial limiting factor for the survival of livestock in the arid and semi-arid tracts of western Rajasthan. Although a good number of stock - owners try to save their flocks by adopting transhumance during critical periods, the majority of the animals in the area are left to depend on their physiological adaptability to withstand body water deficit. The continuity of the breeds till today is obviously a resultant of the forces of natural selection. However, it is very likely that the different breeds have evolved physiological adaptive mechanisms of different efficiency levels, for example, in the lowering of the threshold of their satiety levels or in their ability to withstand haemoconcentration during spells of prolonged drought. Any attempt at a physiological ranking of the breeds with respect to their desert-worthiness would call for information regarding the relative merits of the different breeds in respect of their tolerance for sub-lethal degrees of water deprivation consistent with normal physiological functioning.

Sheep in the Rajasthan desert

Sheep population

The sheep population of the 11 arid and semi-arid districts of western Rajasthan is 6.7 million (1977 census) which yields about 40% of the total wool produced in India. There are 8 distinct breeds of sheep in Rajasthan, namely Marwari, Chokla, Pugal, Magra, Jaisalmeri, Nali, Malpura and Sonadi. The quality of wool from these breeds varies from coarse to medium and is generally considered as superior carpet wool (Map).

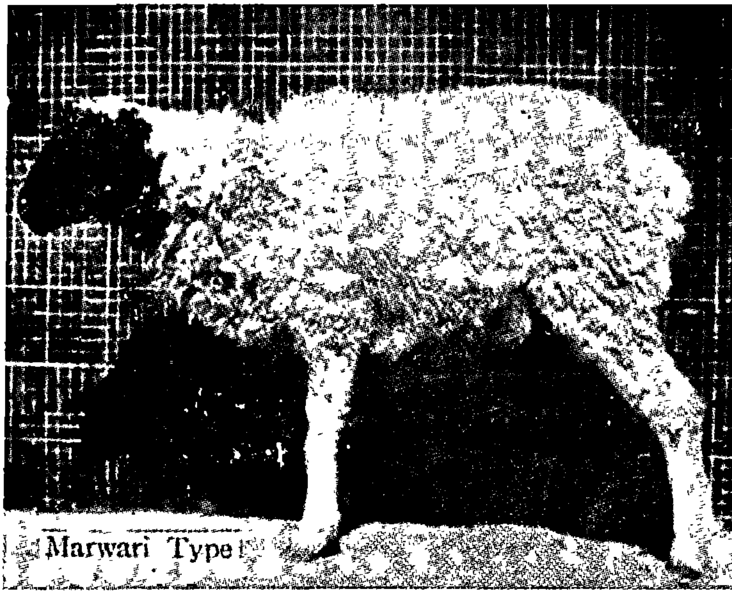
Ecological aspects

The land-animal-plant relationship has existed for centuries in this tract at the subsistence level and this is gradually intended to be raised for improvement of the standard of living of the farming community in this area.

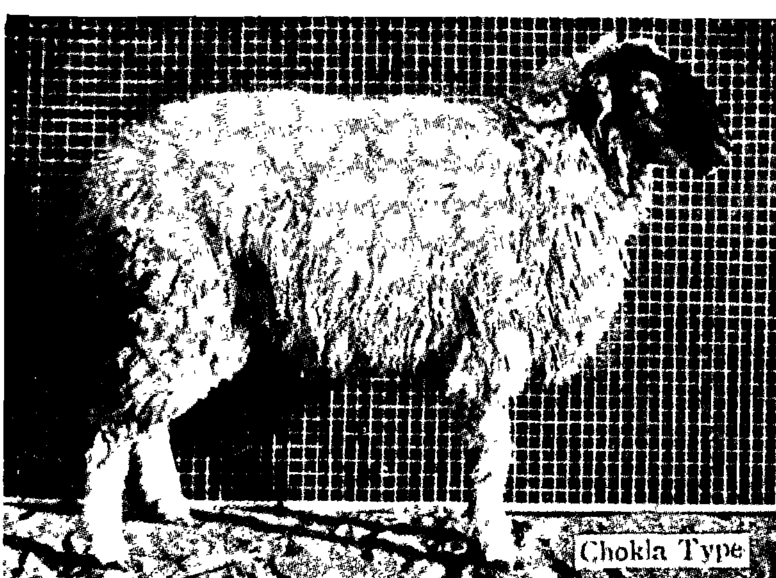
While there can be no doubt that water is the most important factor for life in the desert, it is quite surprising that here an ecological balance between the animal and the local flora has been struck in such a remarkable manner that the livestock have not only managed to survive but have also flourished. A study (Taneja, 1966) made at this Institute has shown that during summer when water is in very short supply, sheep instinctively go out in search of succulent feeds and, in particular, the pods of *Prosopis cineraria* (*Khejri*) tree which has a water content of as much as 68 per cent. This study indicated that the animals will be able to live without free water for the entire summer wherever *Prosopis cineraria* trees are in abundance.

Grazing

The sheep flocks in the Rajasthan desert normally graze natural pastures. During the monsoon in normal years there is lush growth of both annual as well as perennial grass and legume species providing abundant green feed to the animals. After the monsoon, the sheep are grazed on the stubbles of the harvested crops. The most common grasses of this desert are *Sewan* (*Lasiurus sindicus*), *Kala dhaman* (*Cenchrus setigerus*), *Bhurat* (*Cenchrus catharticus*), *Anjan* (*Cenchrus ciliaris*), *Karad* (*Dicanthium annulatum*), *Murat* (*Panicum turgidum*), *Aristida funiculata*, and *Eleusine compressa*. However, the grass production is never enough and the climate is too harsh. As a consequence, the animals' physiological adaptive mechanisms



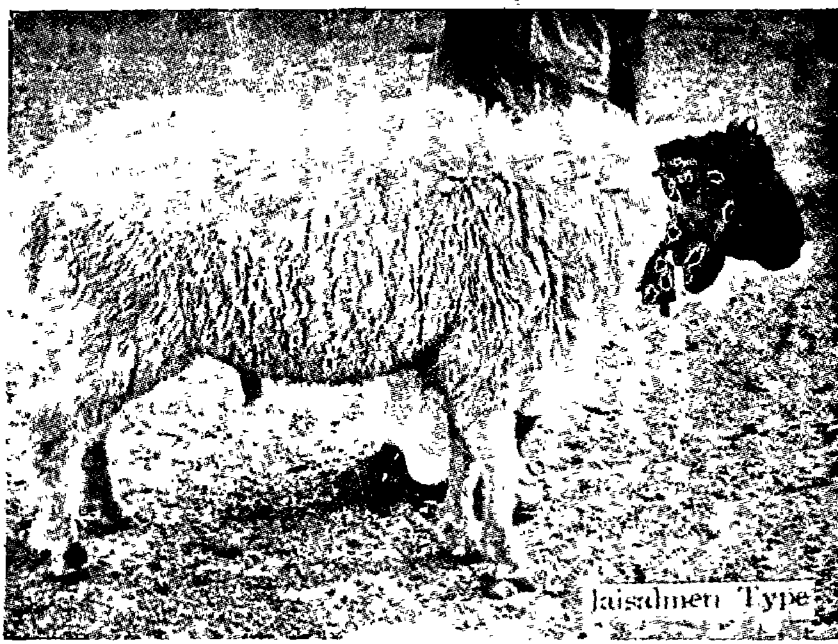
Marwari Type



Chokla Type

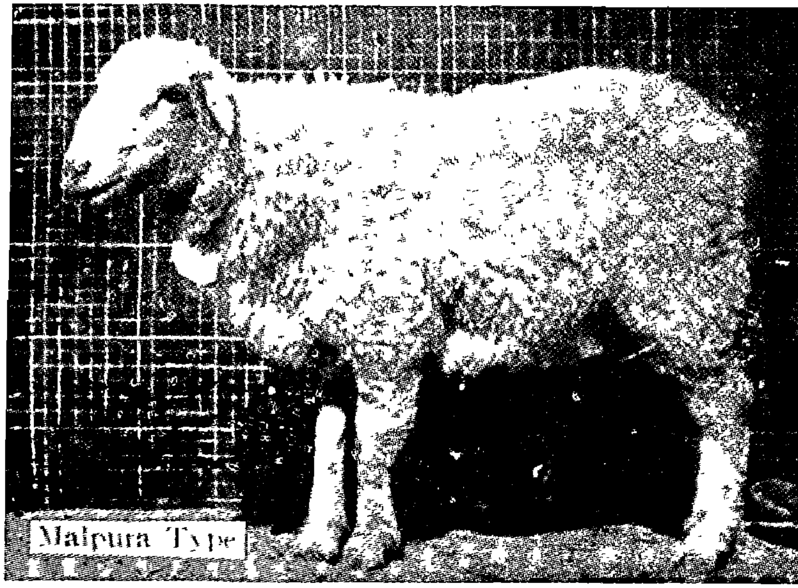
Pugal Type

Magra Type

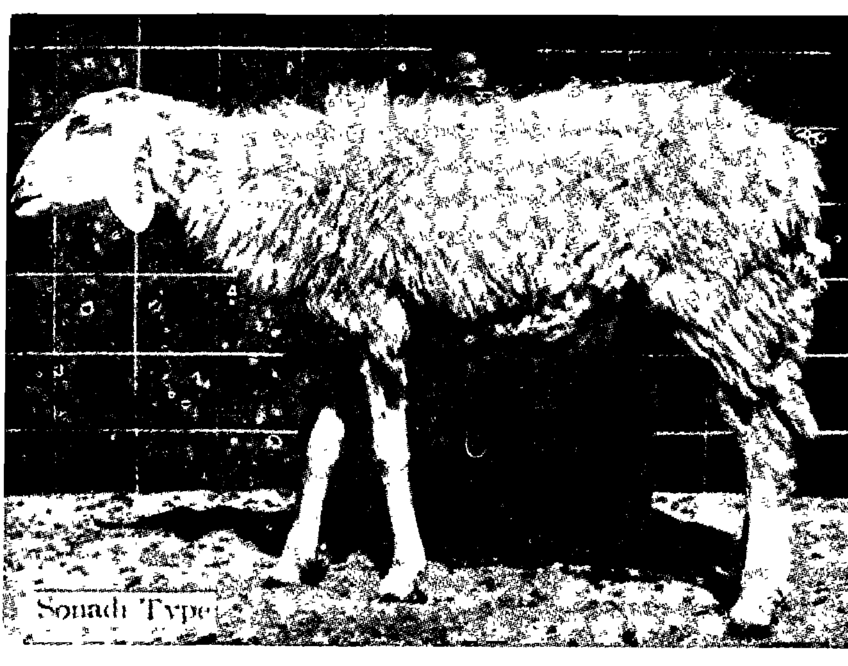


Jaisalmer Type

Nali Type



Malpura Type



Sonadi Type

are taxed to the extreme for mere survival.

Migration and water intake

During prolonged spells of drought, livestock migrate to adjoining areas from western Rajasthan in search of both food and water. In years of moderate water availability the animals are not migrated but the ration of water made available to them is limited, and when the animals have to walk over long distances to the watering holes, they are usually watered at intervals of 3 days. This practice has been followed here since time immemorial.

Physiological effects of limited water intake

A series of studies have been conducted at CAZRI with a view to obtain quantitative information on the ecological and physiological aspects of water use economy in desert sheep. Some of the salient features of these studies have been discussed in this monograph.

In Marwari sheep, a partial correlation between water intake and air temperature was found to be highly significant indicating that when absolute humidity was held constant, the increase in air temperature increased water intake (Taneja and Abichandani, 1967a).

Studies conducted on grazing adult (about 2-year old) Marwari and Magra sheep (Rams and ewes) at Pali (25° 50'N; 73°15'E) — situated about 75 km to the SE of Jodhpur — from September 1974 to May 1975 (first experimental period) and again from January 1976 to June 1976 (second experimental period) indicate that watering twice weekly (intermittent) on two fixed days, 2 and 3 days apart, does not impair the health and productivity of these breeds (Abichandani, 1981). The climatic data pertaining to the two study periods have been presented in Figs. 1 and 2 respectively. The intermittently watered animals of both the breeds consumed less than half the quantity of water consumed by the daily watered animals during these periods and by resorting to such a (i.e. twice/week) watering schedule, about 200 animals can be maintained on the water ration required by 100 sheep when watered daily. Saving of drinking water to the tune of 50 to 85 litres per sheep per month has been found achievable by watering the animals twice every week instead of daily (Tables 1 and 2; Figs. 3, 4, 5 and 6). Intermittently watered Magra and Marwari lambs (4-5 months old, born to twice-weekly watered parents) also consumed less water and a net saving of 25-30 litres per month per lamb could be achieved by resorting to twice-weekly watering schedule instead of daily watering. Around 9-12 months old Magra ewes, when watered twice a week consumed about 62 per cent of the amount of water consumed by daily watered animals (Table 3) (Abichandani, 1981). The water intake on unit body weight basis by the water restricted group, as per cent of the quantity consumed by the daily watered group, during the first $1^1/_2$ months (first 3 fortnights) was comparatively more (80-94 per cent) in comparison to the subsequent fortnightly water intakes (51-70

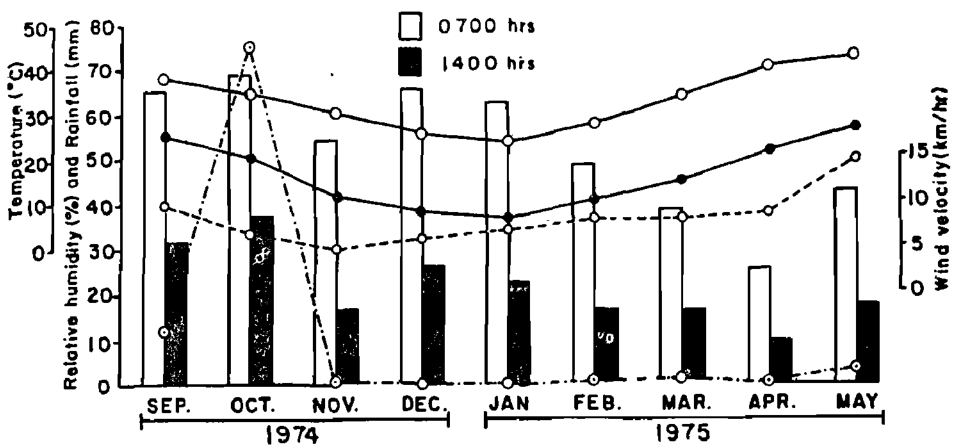


Fig. 1 Mean maximum (o——o) and minimum (•——•) temperature, wind velocity (o- - -o), relative humidity (□■) and rainfall (o—·—o) at Pali during the experimental period

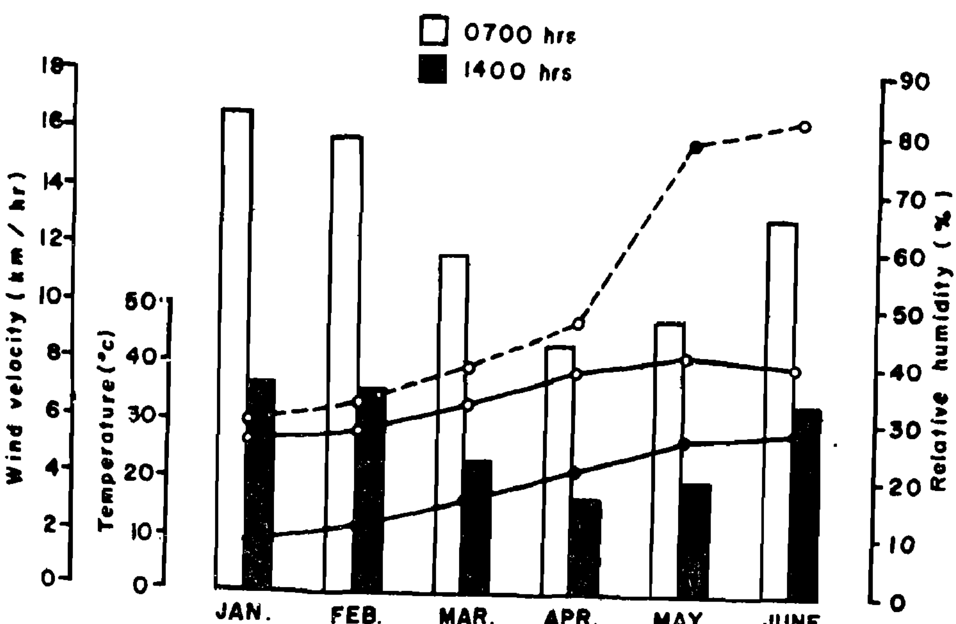


Fig. 2. Mean maximum (o——o) and minimum (•——•) temperature, wind velocity (o- -o) and relative humidity (□■) at Pali during 1976

Table 1. Effect of daily and intermittent (twice a week) watering on water economy and productivity in two desert sheep breeds (September 1974 to May 1975)

Breed	Sex	Watering treatment	No. of animals	Monthly mean (± S. E.) water intake (l) and body weight (kg, in parenthesis) per animal: Initial (Sept. 1974)	Final (May 1975)	Percentage change in body weight over the initial body weight	Mean water intake, l/100 kg body weight/day, for the experimental period	Water intake by restricted animals as percentage of intake of daily watered animals	Water saving (l) per sheep per month if watered twice a week instead of daily
Magra	Ram	Intermittent	2	69.5* (30.0 ± 0.99)	85.0 ± 2 00 (38.5 ± 1.49)	+ 28.3	5.5	42	85
		Daily	2	154.5 (35.0 ± 1 99)	196.5 ± 4.50 (39.0 ± 0.99)	+ 11.4	11.8		
Marwari	Ram	Intermittent	2	78.5 (34.5 ± 0.49)	81.0 ± 0.00 (40.0 ± 3.00)	+ 15 9	5.1	43	79
		Daily	2	151.5 (36.5 ± 2 49)	181.5 ± 1.50 (41.5 ± 2.50)	+ 13.6	11.2		
Magra	Ewe	Intermittent	8	55.0 (22.7 ± 0.72)	58 2 ± 0 79 (31.2 ± 0.99)	+ 37.4	5.0	45	53
		Daily	7	99.3 (26.7 ± 0.74)	157.1 ± 1.56 (33.5 ± 1.94)	+ 25.4	10.2		
Marwari	Ewe	Intermittent	5	61.4 (24.7 ± 1.17)	61.6 ± 1.02 (33.0 ± 0.89)	+ 33.6	5.2	43	62
		Daily	5	122.4 (27.7 ± 1.01)	150.0 ± 0.95 (30.7 ± 2.84)	+ 10.8	11.6		

*Water intake during first month was determined group wise, hence S. E. could not be calculated.

Table 2. Effect of daily and intermittent (twice a week) watering on water economy and productivity in two desert sheep breeds (January 1976 to June 1976)

Breed	Sex	Watering treatment	No. of animals	Monthly mean (± S. E.) water intake (l) and body weight (kg, in parenthesis) per animal: Initial (Jan. 1976)	Final (June 1976)	Percentage change in body weight over the initial body weight	Mean water intake, l/100 kg body weight/day, for the experimental period	Water intake by restricted animals as percentage of intake of daily watered animals	Water saving (l) per sheep per month if watered twice a week instead of daily
Magra	Ram	Intermittent	2	49.0 ± 2.00 (45.0 ± 1.00)	70.2 ± 0.25 (36.0 ± 2.00)	− 20 0	5.2	47.7	60
		Daily	2	99.0 ± 0.00 (44.7 ± 3.25)	150.0 ± 0.00 (35.2 ± 3.75)	− 21.2	10.9		
Marwari	Ram	Intermittent	2	43.0 ± 1.00 (43.2 ± 3.25)	74.0 ± 1.00 (37.0 ± 2.50)	− 14.3	4.9	47.0	66
		Daily	2	84.0 ± 6.00 (44.2 ± 2.25)	170.2 ± 2.25 (39.7 ± 2.75)	− 10.1	10.4		
Magra	Ewe	Intermittent	8	28.3 ± 0.94 (29.3 ± 0.77)	53.5 ± 1.35 (26.0 ± 0.98)	− 11.2	5.3	53.7	50
		Daily	7	45.8 ± 2.62 (32.0 ± 1.73)	127.5 ± 2.59 (29.4 ± 1.19)	− 8.1	10.0		
Marwari	Ewe	Intermittent	5	31.4 ± 0.93 (29.5 ± 0.52)	58.2 ± 1.49 (29.3 ± 0.75)	− 0 6	5 3	45 4	53
		Daily	5	57.6 ± 1.12 (30.0 ± 1.37)	135.7 ± 1.15 (29.0 ± 1.43)	− 3.3	12.0		

Table 3. Water intake, wool yield and changes in body weights in intermittently watered (twice a week) and daily watered Magra ewes (9-12 month old)

Watering treatment	Mean total water intake, l/animal, during the experimental period	water saving (l) per 100 sheep per month if watered twice a week instead of daily	Mean body weights (kg)				Wool weight, kg/100 kg body weight (Mean ± S. E.)	
			Pre-monsoon		Post-monsoon			
			Initial	Final	Initial	Final	Summer	Autumn
Intermittent	245 (62%)*	2480	18.68	17.68 (5.3)**	20.06	24.15 (20.3)***	2.21 ± 0.13	2.40 ± 0.12
Daily	394	—	18.68	18.53 (0.8)**	21.15	24.78 (17.1)***	2.12 ± 0.12	2.72 ± 0.17

* Intake of restricted group as a per cent of intake of daily watered group.

** Per cent loss in body weight.

*** Per cent gain in body weight.

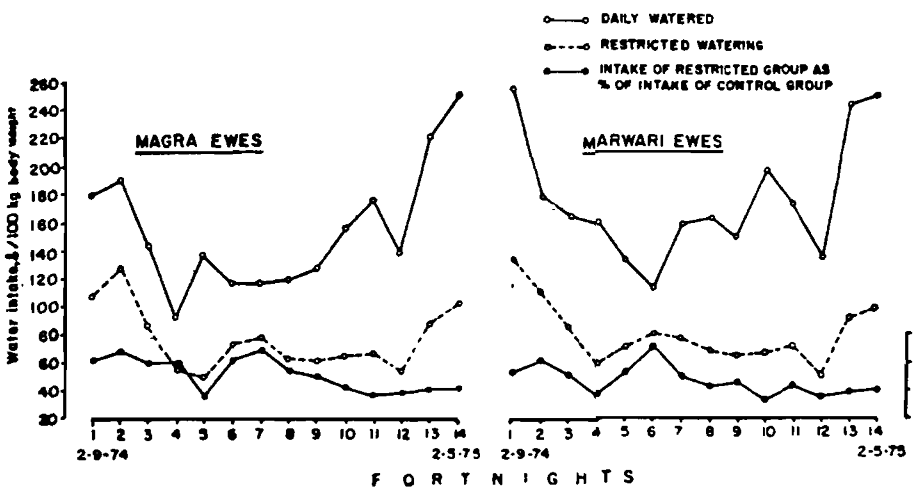


Fig. 3. Fortnightly water intake, 1/100 kg body weight, in daily watered and water restricted (watering twice a week) Magra and Marwari sheep (ewes).

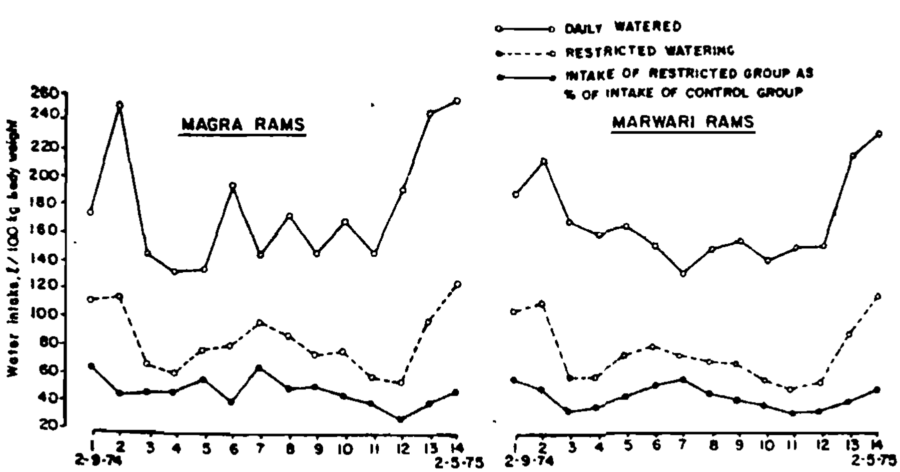


Fig. 4. Fortnightly water intake, 1/100 kg body weight, in daily watered and water restricted (watering twice a week) Magra and Marwari sheep (rams).

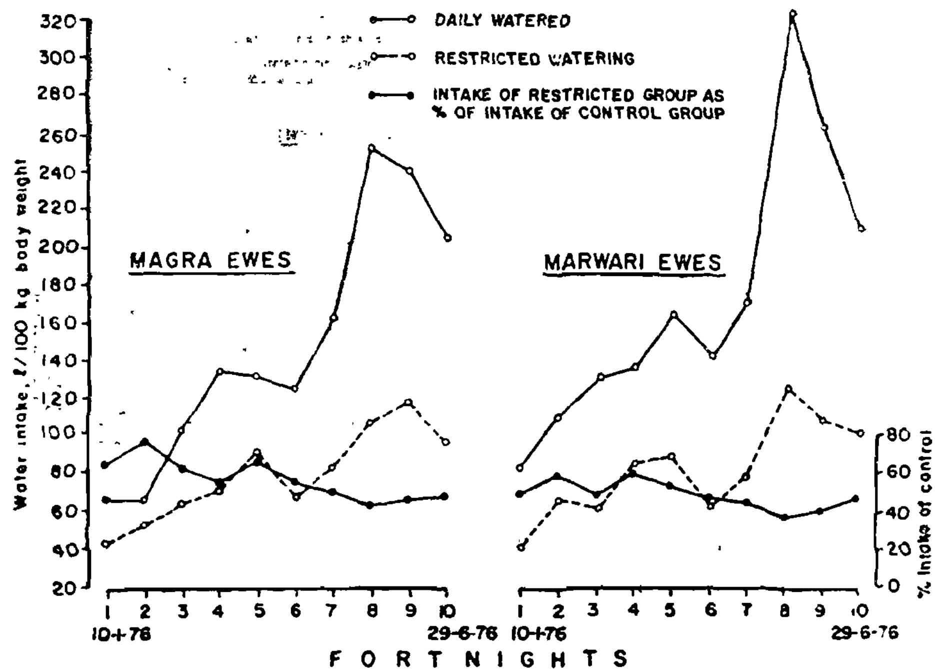


Fig. 5. Fortnightly water intake, 1/100 kg body weight, in daily watered and water restricted (watering twice a week) Magra and Marwari sheep (ewes).

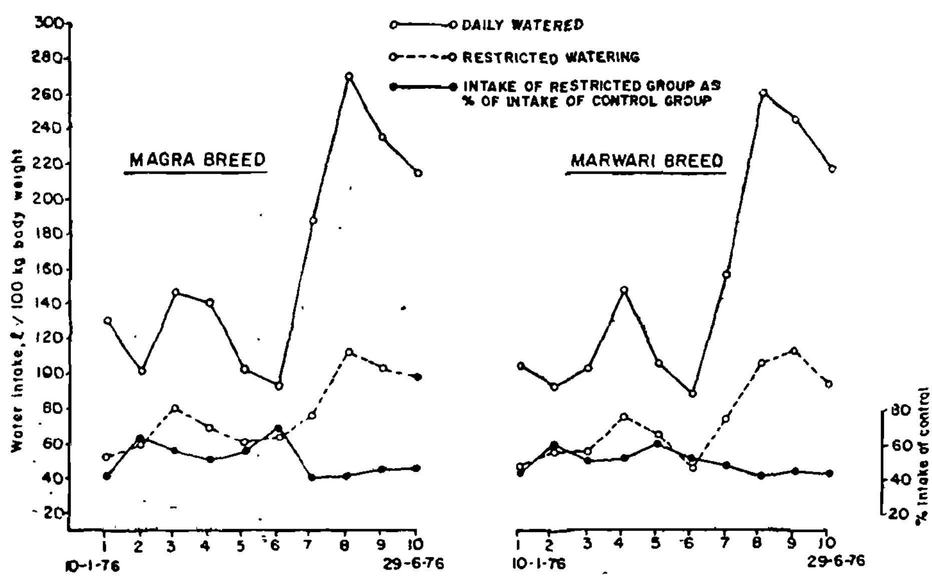


Fig. 6. Fortnightly water intake, 1/100 kg body weight, in daily watered and water restricted (watering twice a week) Magra and Marwari sheep (rams).

per cent). It would seem that the water restricted animals are not able to adapt to a twice weekly watering schedule immediately, and hence, a comparatively higher water intake in the initial stages of the experiment. No significant treatment effect on body weight was recorded. Water restriction also had no effect on wool production and lambing performance of the animals. The daily watering of sheep would, therefore, appear to be a dispensable practice, at least in the management of desert adapted breeds. Taneja (1965) working on Marwari wethers also concluded that 169 animals can be maintained on the water ration required for 100 animals if the watering is done on every third day and that, this practice allows the animals to maintain near-normal respiration rate and body temperature. He further added that it would not be safe to water the animals less frequently than on every third day.

Maloiy and Taylor (1971) observed that in haired sheep from the arid Northern Frontier Region of Kenya, the daily water consumption was of the order of 8 per cent of the body weight when water was available freely while this was reduced to about half (or 4 per cent of the body weight per day) when the water intake was restricted. Earlier, Clark and Quin (1949), working during the late spring in South Africa with moderate air temperatures ranging upto 36°C, had observed that withholding of water from sheep would seem to have a sparing effect on expenditure (Table 4). They suggested that a dehydrated sheep may be able to reduce its water expenditure, although they gave no hint of the mechanism involved. According to Maloiy and Taylor (1971), evaporation is the major source of water loss in sheep. In their study, it was reduced from 6 per cent of body weight per day to about 3 per cent when water was restricted under hot, dry conditions.

Quantitative information on the effect of water restriction on faecal water output in ruminant animals is very limited, although it has generally been observed that during dehydration the faecal moisture content is greatly reduced. Purohit *et al.* (1974) working on Marwari and cross-bred (Russian Merino X Marwari, F_1 generation) observed that on 50% water restriction, significant decreases ($P<0.01$) in urine volume, faecal water content, and in the Transfer Function of Kidney (TFK) occurred, while urinary electrolyte concentration increased significantly ($P<0.01$). When water restricted animals were offered water *ad lib.*, the urine volume was recovered on

Table 4. Water intake in South African sheep

	Average water intake per day	Control sheep, daily watering
Water every 2 days	1.8	1.8
3 days	1.5	2.4
4 days	1.5	2.4

(From Clark and Quin, 1949).

the next day. The reduction in urine volume and faecal water content during water restriction in these sheep breeds was apparently an adaptive mechanism to conserve body water for the maintenance of water balance (Purohit *et al.*, 1974). Several others have reported reduction in urine volume and faecal water during water restriction in sheep (Macfarlane *et al.*, 1956; Yesberg *et al.*, 1970; Warner, 1971; Wilson, 1970). Yesberg *et al.* (1970) observed that in Australian Merino sheep, the urine volume remained unchanged on rehydration after prolonged deprivation of water because of an increase in anti-diuretic hormonal activity in the blood. Purohit *et al.* (1974) were of the view that during short term water deprivation, the anti-diuretic hormonal activity of the blood of the water restricted animals may not increase upto an extent which can affect urine volume.

Purohit *et al.* (1972) working on Marwari rams observed that the water deprived sheep lost 17.8% of body weight in 3 days, an average loss of 6% per day. In Macfarlane's studies, Shorthorn cattle lost weight at about 8% per day in summer, Merinos at 4-5% per day, and camels at less than 2% per day. This would put the Marwari sheep in a category between the Merino and the Shorthorn cattle - a position occupied by horses and donkeys. However, no comparison of resistance to dehydration is possible because pastoral and climatic conditions were not the same in all cases.

In field experiments carried out by Macfarlane's group in the hot arid regions of central Queensland, sheep were deprived of drinking water for 5 days. As they stood in the summer sun they were given full rations of feed, so the additional strain of walking around to seek the food was absent. In these sheep the average body weight decreased from 50.3 kg to 38.4 kg, a loss of 23 per cent (Macfarlane *et al.*, 1956).

Purohit *et al.* (1972) have also reported on the Marwari animal's ability to withstand a dehydration loss of 18% in body weight and to conserve its extracellular fluid volume relatively efficiently during water stress. As stated earlier, Abichandani (1981) observed that both the Marwari and Magra sheep are able to face prolonged sub-lethal water restriction with equal felicity.

Effect of water restriction on body weight

Purohit (1972) reported that on complete water deprivation for 3 days during summer there was an average loss of 20.91%, 25.40%, 28.84% and 25.48% in body weight in the Marwari, Russian Merino X Marwari, Pugal and Chokla breed, respectively. In winter, the body weight losses were of the order of 16.13%, 21.99%, 16.00% and 16.80% in these breeds, respectively. The Marwari was more tolerant of water restriction than any other breed. The Pugal was the least tolerant of all the breeds in this respect.

In general, Purohit's (1972) findings are in close agreement with the results obtained by earlier workers (Macfarlane *et al.*, 1956, 1961; Taneja, 1965, 1966). These authors have found that the loss in body weight in sheep is related to the degree of dehydration.

Taneja (1965) investigated the effect of watering at different intervals, viz. watered daily (normal) and on second, third and fourth day, on rectal temperature, respiration rate and body weight loss of 2-year old wethers of the Marwari breed. Rectal temperature was higher in the dehydrated animals than in the hydrated ones and its effect was more pronounced with increasing dehydration. The weight loss in the animals watered on every second, third and fourth day was 5.5, 9.3 and 12.3 per cent, respectively. The environmental temperature during the experimental period (12 days) varied from 74° to 88° F.

Taneja (1966) also examined the effect of restricted watering, i.e. watered once daily and in amounts representing $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$ and $^{1}/_{16}$ of that given *ad libitum* once for 4 days, on the body temperature, respiratory rate, pulse rate, body weight, packed cell volume and specific gravity of blood, in 7-8 year old wethers of Marwari sheep; the effect of complete deprivation of water for 4 days was also studied. The loss in body weight was proportional to the degree of water restriction and significant losses occurred only in the animals receiving half or less than half of the quantity of water consumed by the daily watered animals. Recovery (50 per cent) in weight was obtained if water was provided at the end of the restriction period. The loss in body weight was significantly correlated with the rise in body temperature. A similar correlation, though not significant, was observed in respect of respiration rate. The differences in the mean packed cell volume, estimated before and after the watering treatments, gradually increased with increasing degree of water restriction, but these differences were significant only when the animals received $\frac{1}{8}$ or less of the amount of water given *ad libitum*. The values for specific gravity of plasma showed almost similar trends as packed cell volume.

Purohit *et al.* (1972) working on Marwari sheep observed that the most conspicuous change in fluid distribution in the animals when deprived of water for 3 days was the decrease in plasma volume which was reduced to almost half (43%) and the extracellular fluid volume by 33% of its initial value. This is similar to the 45% decrease in plasma volume of the Australian Merino during dehydration loss of 25% in body weight (Macfarlane *et al.*, 1956). A similar response has been observed in the guanaco (*Lama guanicoe* Muller) - a near relative of the camel (Rosenmann and Morrison, 1963), although the camel itself (Schmidt-Nielsen *et al.*, 1956) and the burrow (*Equus asinus*) (Yousef *et al.*, 1970) are known to resist any precipitous fall in plasma volume during dehydration. Macfarlane (1964a) had concluded that the sheep draws approximately half of the water used for urine formation and evaporative cooling from the extracellular space and the rest comes from gut and cell wall. Purohit's (1972) findings on the Marwari sheep tend to support this view. He observed that in Marwari sheep, as in the Merino, there is, apparently, no mechanism for sparing of the circulatory fluid during dehydration. Unlike Macfarlane's Merinos which had identical percentage reduction in plasma and ECF volumes at the end of the 5-day experimental period during summer (Macfarlane *et al.*, 1956), the Marwari, examined by Purohit during winter, tended to conserve its ECF volume somewhat more efficiently, their being a reduction in SCN space by only 33%. This fact may have some significance from the point of view of desert living, as, a slower loss of ECF would mean a slower change in the water status of the gut (Purohit *et al.*, 1972). It would appear that derangement of the water distribution pattern in the body of the Marwari animal occurs only at a level between $\frac{1}{4}$ and $\frac{1}{2}$ water restriction. It can, therefore, be taken that the Marwari animal will not suffer any undue stress, at least in winter, if it is deprived of upto $\frac{1}{4}$ its voluntary water intake for a short period, but, these animals would be unlikely to thrive at a watering level below 75% (Purohit *et al.*, 1972). These findings clearly point to an unusual ability of these animals to maintain circulation even when faced with considerable haemoconcentration.

Purohit *et al.* (1972) concluded that Marwari animals are able to withstand a dehydration loss of 18% in body weight and they are reasonably well adapted to dehydration. They do not, however, seem to possess the ability to maintain an expanded plasma volume against general dehydration - a significant deficiency from the point of view of desert adaotation.

In Abichandani's (1981) experiment, both the experimental and control groups of Magra and Marwari breeds registered increases in their body weights during the first experimental period; however, the increase was somewhat more in the water restricted groups (Fig. 7). Since body weight gain is considered as an index of overall well being of an animal, the intermittently watered sheep may be said

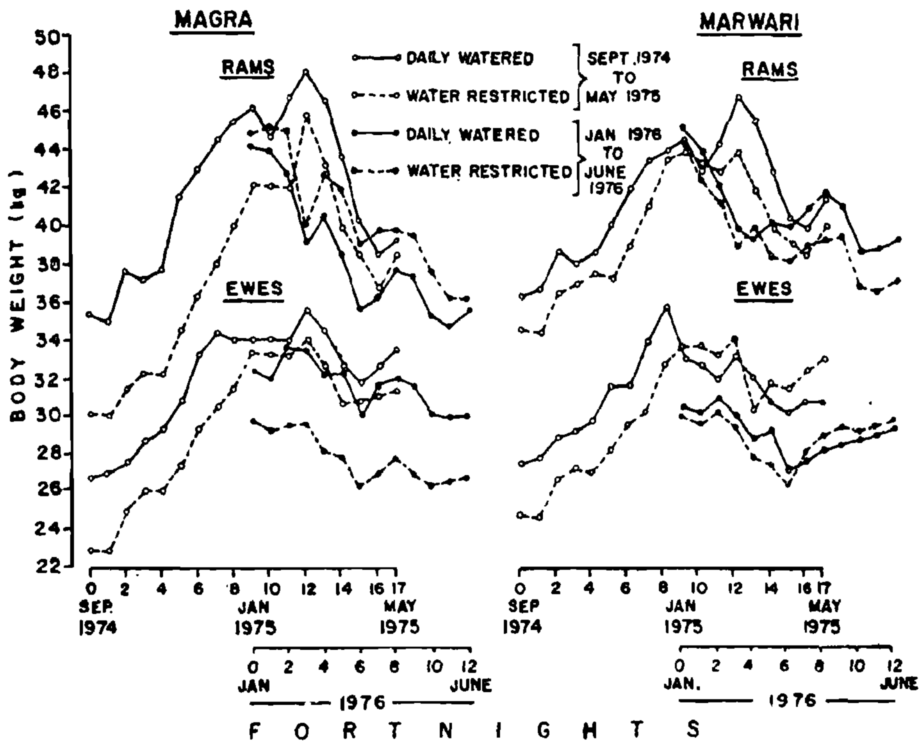


Fig. 7. Fortnightly body weights of water restricted (watering twice a week) and daily watered sheep of Magra and Marwari breeds.

to have been doing reasonably well. The observed increase in the body weights of the intermittently watered animals may be due to:

(a) a slower rate of passage of the feed through the gut (Purohit, 1972), and (b) an increase in the digestibility of crude fibres (Purohit *et al.*, 1976). The additional energy derived from a better utilisation of the crude fibre component of the feed is likely to be responsible for the relatively higher body growth increment shown by the water restricted animals. In a non-ruminant species, the Somali donkey, Maloiy (1970) also noticed a similar increase in the apparent digestibility of dry matter when the animals were subjected to heat stress and dehydration.

Water restriction of dams and sires had no effect on either the birth weight or the growth rate of the lambs born to them in both Marwari and Magra breeds (Fig. 8) (Abichandani, 1981). The increase in the body weight of animals during the first experimental period (September 1974 to May 1975) and a decrease during the second experimental period (January 1976 to June 1976) (Fig. 7) would seem somewhat intriguing, particularly in view of the possible physiological explanation for the former observation indicated earlier. It needs mentioning here that ecological conditions were markedly different in the two experimental periods, with attendant

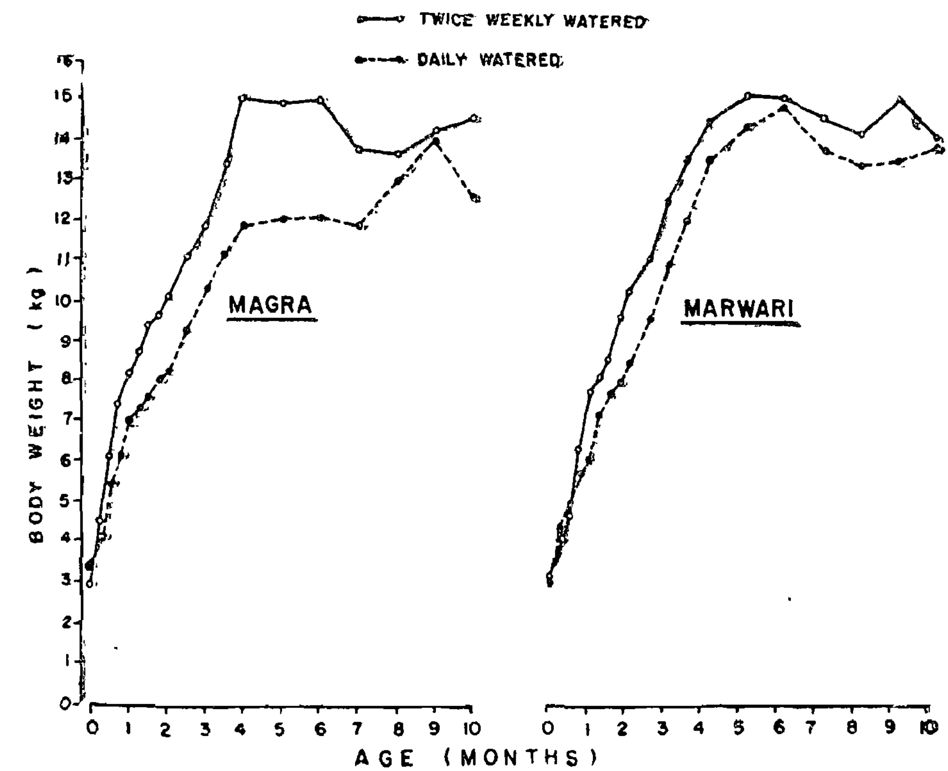


Fig. 8. Growth rate of Marwari and Magra lambs born to twice weekly watered and daily watered parents.

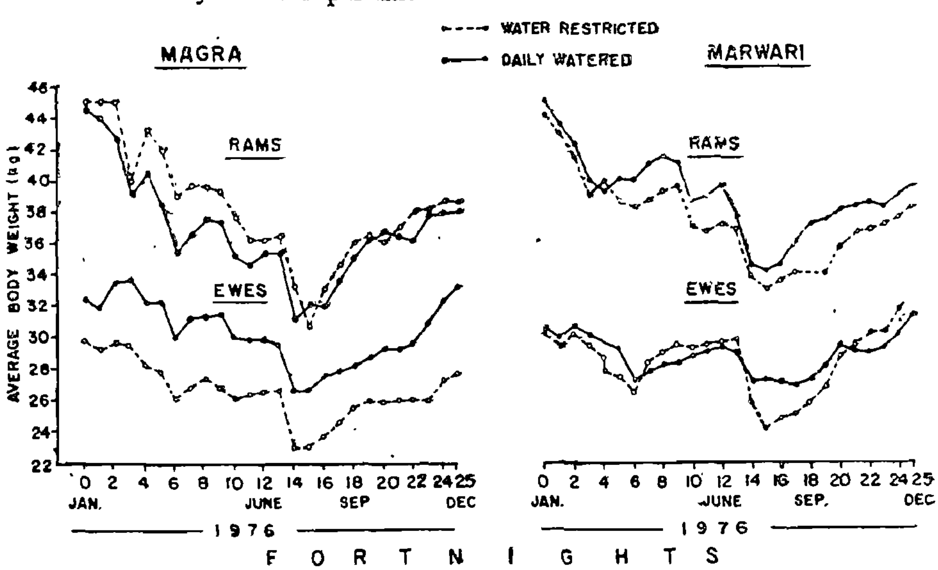


Fig. 9. Effect of intermittent watering (watering twice a week) on body weight in Magra and Marwari sheep over a period of one year.

variations in the availability and digestibility of the forages. The general decrease in the body weight of the animals from the peak in December-January to the first week of May is a reflection of a slow decline in the nutritive status of the forage. The gradual increase in body weight from September to December is clearly an effect of grazing on an abundant and lush monsoonal pasture. The apparent paradox of a relatively heavier body weight at the peak of summer, i.e. in May, than in the peak of monsoon, i.e. in September (Fig. 9), can be explained by observing that the grasses at the earlier intensive stages of the monsoon usually contains a considerable amount of water and, consequently, dry matter intake by grazing animals is relatively less during that period. This results in reduced energy intake and, as a result, the body weight decreases. Thus, while the body weights of the animals in the beginning of May are understandably lower than in January, they are still comparatively higher than those in September. Presumably, the animals gain in body weight from October till the end of January and then the body weight starts declining till it reaches the trough of the curve by the end of September.

Lynch *et al.* (1972) had observed a significant reduction in the birth weight of the lambs of Merino ewes maintained without drinking water for 12 months. In the CAZRI studies, restriction of

Table 5. Wool yield (kg/100 kg body weight), mean ± S. E. of daily and intermittently (twice a week) watered desert sheep

Breed	Sex	Wool clip		Watering treatments: Intermittent N	Intermittent Wool yield	Daily N	Daily Wool yield	Difference between treatments
Magra	Ram	March	1975	2	3.07 ± 0.14	2	4.10 ± 0.05	**
		Oct.	1975	2	3.78 ± 0.12	2	4.29 ± 0.27	*
		March	1976	2	1.99 ± 0.03	2	2.44 ± 0.16	*
		Oct.	1976	1	1.66	1	2.17	
Marwari	Ram	March	1975	2	2.43 ± 0.29	2	2.46 ± 0 39	N.S.
		Oct.	1975	2	2.75 ± 0.05	2	3.05 ± 0.65	N.S.
		March	1976	2	1.88 ± 0.19	2	1.91 ± 0.29	N.S.
		Oct.	1976	2	1.59 ± 0.03	2	1.66 ± 0.19	N.S.
Magra	Ewe	March	1975	8	2.32 ± 0.19	7	1.98 ± 0.12	N.S.
		Oct.	1975	8	3.85 ± 0.42	7	3.63 ± 0.21	N.S.
		March	1976	8	1.97 ± 0.18	6	2.14 ± 0.09	N.S.
		Oct.	1976	4	1.45 ± 0.27	5	2.02 ± 0.09	N.S.
Marwari	Ewe	March	1975	5	1.88 ± 0.12	5	1.77 ± 0.25	N.S.
		Oct.	1975	5	2.06 ± 0.14	5	1.63 ± 0.18	***
		March	1976	5	1.28 ± 0.19	5	1.28 ± 0.13	N.S.
		Oct.	1976	3	1.18 ± 0.42	3	1.51 ± 0.46	N.S.

N : Number of animals
*** : Significant at 0.1% level of probability
** : Significant at 1% level of probability
* : Significant at 5% level of probability
N.S : Not significant

water intake over a prolonged period has failed to produce any such effect.

In a 2-year study conducted at Armidale, Lynch (1969) had observed that water deprived Merinos performed atleast as well as control sheep in both wool growth per head and mean body weight. In a later experiment Lynch *et al.* (1972) found that depriving breeding Merino ewes of drinking water had little effect on their wool production. In the CAZRI study (Abichandani, 1981) also, prolonged water restriction does not seem to have affected the wool growing potentiality of the animals of the two breeds examined. Water restriction had no adverse effect on the wool yield on unit body weight basis in both the summer as well as in the autumn clip (Table 5). The mean wool yields (kg/100 kg body weight ± S. E.) of the water restricted and daily watered groups of 9-12 month old Magra ewes for the summer clip were 2.21 ± 0.13 and 2.12 ± 0.12, and the values for the autumn clip were 2.40 ± 0.12 and 2.72 ± 0.17, respectively (Table 3). The difference in wool yield between the 2 groups was not statistically significant in either clip.

Thus, the CAZRI's findings (Abichandani, 1981) indicate that not only considerable water saving may be achieved by resorting to a twice weekly watering schedule instead of watering the sheep daily over a prolonged period, this watering practice will also maintain animal production in terms of body weight and wool growth.

Seasonal variation in normal water intake

A study on seasonal variation in normal water intake by different indigenous and cross-bred sheep [Marwari, Chokla, Pugal and Russian Merino X Marwari (F_1 generation)] was conducted in two seasons, viz. summer and winter (Purohit *et al.*, 1975). It was observed that water intake in all the breeds was higher in summer (double) than in winter, and the differences between seasons were highly significant ($P<0.001$).

A study on the effect of 24 h water deprivation on body weight loss and rectal temperature in 5 indigenous (Marwari, Magra, Jaisalmeri, Pugal and Chokla) sheep breeds has revealed that Marwari has a relatively superior physiological mechanism for the maintenance of body equilibrium while animals of the Pugal breed are apparently the least efficient in this respect (Abichandani and Ghosh, unpublished observations). The Marwari animals also seem to be at an advantageous position with regard to body weight maintenance under water stress conditions, as well as in respect of water requirement, although the Magra animals in this experiment had the highest body weight recovery upon rehydration after 24 h water restriction (Table 6).

The maximum average body weight loss due to dehydration in all the breeds examined was between 18% and 26% (Table 6) during the months of April and May when the maximum air temperature varied between 38.7° C and 40.9° C. The minimum weight loss ranging from 8% to 13% occurred during December-January when the air temperature varied between 23.1° C and 29.2° C. With increases in the ambient temperature, there were corresponding increases in the percentage of body weight loss of the animals after 48 h of water deprivation. These findings are in agreement with those of Macfarlane *et al.* (1956) who, working in the hot arid region of Australia, reported a loss of 23% (around 12.0 kg) in the body weight of sheep deprived of drinking water for 5 days. When Macfarlane's sheep were offered water after 5 days, they were able to restore their water content and do so rapidly by drinking 7 to 9 litres 'at once'. This is around 18% to 23% of the dehydrated body weight, and is similar to the drinking capacity of the camel and the donkey. Since the average weight loss was 12 kg, and some fraction of this was due to loss of tissues, it seems that sheep drink to restore their body

Table 6. Percentage loss in body weight after 24 h and 48 h water restriction and percentage recovery on watering *ad-lib.*

Breed	2.12.1974 to 4.12.1974			30.12.1974 to 1.1.1975			27.1 1975 to 29.1.1975			23.2.1975 to 25.2.1975			23.3 1975 to 25.3.1975			20.4 1975 to 22.4.1975			18.5.1975 to 20.5.1975		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Marwari	5	10	97	5	9	60	5	8	117	6	11	111	8	13	98	13	21	126	13	22	118
Magra	5	10	131	7	11	80	6	11	115	6	11	139	8	13	127	13	21	123	14	23	122
Jaisalmeri	5	10	112	5	9	73	5	9	122	6	11	113	8	13	95	13	21	133	15	25	113
Pugal	6	12	100	5	9	81	7	13	100	4	11	122	8	14	73	12	23	121	18	26	100
Chokla	4	9	115	5	10	86	4	9	100	6	12	106	8	15	84	14	24	134	15	26	113
Cross-bred (Russian Merino X Marwari)	4	8	131	5	8	78	5	10	123	6	11	128	5	10	97	10	18	135	13	22	100

A = Body weight loss (%) on 24 h water restriction.
B = Body weight loss (%) on 48 h water restriction.
C = Recovery (%) in body weight loss on watering *ad-lib.* after 48 h water restriction.
Note : All the figures are rounded to the nearest whole numbers.

water content, and do so rapidly (Macfarlane *et al.,* 1956). In our experiments, sheep, after 48 h water restriction in summer, consumed between 6.0 and 10.1 litres at a single bout. However, at lower temperatures, the intake was between 1.8 and 4.3 litres (Table 7). The lost body weight of 48 h water deprived sheep was almost fully recovered after a single drench, and in some cases, the recovery was even more than 100% (Table 6). Macfarlane *et al.* (1961) and Macfarlane (1964b) reported that sheep make up about 65% of the body weight lost during dehydration with the first draught and complete rehydration is achieved within a day or two. It would appear that at higher ambient temperatures, the recovery of lost body weight due to dehydration is faster than at milder ambient conditions.

Animals of all the indigenous breeds examined by us were able to maintain their rectal temperature within a narrow range during experimental water deprivation for 48 h in different seasons when maximum ambient temperature varied from 24.4° C to 42.4° C and the maximum mean monthly temperature varied from 23.1° C to 40.9° C. Sheep exposed to the hot arid conditions of Queensland, Australia, in the summer, showed only moderate diurnal variations (about 1.5°C to 2.0° C) in their body temperature. This is a more moderate fluctuation in body temperature than is found in the camel. This relative stability of body temperature in desert sheep is achieved mainly by evaporation of water through panting. The observed initial rise in the rectal temperature of the dehydrated animals may be due to dryness in the gut of those animals, and with increasing dehydration it tended to stabilize (Taneja. 1965). However, Maloiy and Taylor (1971) did not observe any effect of water restriction on the body temperature in African haired sheep and goats. The respiratory rate per minute in Marwari sheep decreased by half during complete deprivation of water for three days (Purohit, 1972). It seems that these desert sheep breeds tend to conserve water by reducing moisture loss through ventilation. Similar observations have been made by other workers also (Macfarlane, 1964a; Taneja, 1965).

Taneja (1966) also observed that the major loss in weight of sheep occurred during the first 24 h of water deprivation. The total body weight loss during the first 48 h was as high as 20 per cent if the animals were completely deprived of water and loss in body weight during the following 48 h was not more than 5 per cent. The maximum strain of dehydration was, therefore, manifested during the first 2 days of water deprivation.

Taneja (1966), working on Marwari wethers, reported that dehydrated animals tend to have a higher rectal temperature which in some of the animals reached as high as 105° F. Macfarlane *et al.* (1956) have also recorded rectal temperature of 105.8° F in Merino sheep deprived of water for 5 days.

Taneja (1965) observed that in Marwari wethers the body temperature of animals watered every second day was higher than that of animals watered daily although the rise was still within the range of thermoneutrality. He also noted that in animals watered every third and fourth day, the rectal temperature at first rises on the day following the first day of dehydration and then drops on the following waterless day, although the

Table 7. Water intake (l)/animal in a single drink after 48 h water deprivation

Breed	2.12.1974 to 4.12.1974	30.12.1974 to 1.1.1975	27.1.1975 to 29.1.1975	23.2.1975 to 25.2.1975	23 3.1975 to 25 3.1975	20.4.1975 to 22.4.1975	18.5.1975 to 20.5.1975
Marwari	3.1 (11.3)*	1.8 (6.5)	3.4 (12.6)	3.4 (13.5)	3.6 (13.9)	6 8 (33.0)	6.8 (33.7)
Magra	4.3 (16.2)	2.8 (10.3)	3.8 (15.0)	4.3 (17.2)	4.6 (19.5)	7 6 (35.7)	10.1 (48.4)
Jaisalmeri	3.5 (13.1)	2.4 (9.1)	3.6 (14.3)	3.5 (14.2)	3.2 (13.4)	6.0 (34.9)	8.0 (39.6)
Pugal	3.7 (15.0)	2.7 (10.6)	4.3 (19.2)	4.0 (17.2)	2.6 (11.5)	7.5 (36.5)	7.0 (37.3)
Chokla	3.0 (13.7)	2.3 (10.6)	2.3 (10.8)	3.0 (14.7)	2.6 (14.2)	6.3 (41.7)	8.0 (49.2)
Cross-bred (Russian Merino X Marwari)	4.3 (12.7)	2.7 (8.2)	4.6 (15.1)	5.2 (15.8)	4 0 (12.1)	8.0 (31.1)	8.0 (29.6)

* The values in parenthesis represent the amount of water intake as percentage of the dehydrated body weight after 48 h water deprivation.

final temperature, on the average, tends to be higher than the initial temperature.

Contrary to the findings of the above workers (Macfarlane *et al.,* 1956; Taneja, 1965, 1966), a recent study (Abichandani and Ghosh - unpublished data) has revealed that the variation in the rectal temperature of Rajasthan desert sheep, when watered daily and when kept without water for 48 h, are comparable and are within the zone of thermoneutrality. However, as compared to the body temperatures of daily watered animals, there are more animals with higher rectal temperature when the same animals are subjected to 48 h water deprivation.

Dehydration and tolerance to water depletion

Almost 100 per cent of the body weight lost by Marwari and Magra sheep after 48 h of water restriction is usually recouped with a single draught. The mean water intake/animal on watering *ad lib.* after 48 h water deprivation varied between 2.3 and 5.2 litres and the animals drank between 10.8 and 19.2 per cent of the dehydrated body weight. Taneja (1966) reported that sheep receiving little or no water were relatively slow in drinking because the resorption of water from the tissues was not quickly restored. In his study, sheep receiving full, $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $^{1}/_{16}$ and 0 quantities of water lost, respectively, 1.12, 2.12, 3.87, 6.49, 6.87, 7.13, 6.25 kg of body weight at the end of the water restriction period of 4 days and drank 2.5, 2.9, 3.6, 3.5, 4.6, 4.4 and 4.0 1/animal respectively. In Taneja's (1966) study, sheep receiving as low as $\frac{1}{2}$ of the *ad libitum* intake of water were able to restore their lost body weights fully when they were offered water *ad lib.* However, the animals which were offered less than $\frac{1}{2}$ the daily normal intake of water after a 4-day water deprivation period could make up only upto half the loss in body weight.

Purohit (1972) also reported that after 3 days of water deprivation in summer, the average body weight losses in adult animals of the Marwari, Russian Merino X Marwari, Pugal and Chokla sheep breeds were of the order of 8.90, 6.00, 9.00 and 7.65 kg, respectively. The average amounts of water drank by animals of these breeds when water was offered on the 4th day of the experiment were 7.8, 5.4, 7.2 and 5.9 litres, respectively. In Purohit's (1972) study, the recovery of lost body weight was 86% in Marwari, 90% in Russian Merino X Marwari, 63% in Pugal and 77% in Chokla breed, respectively, on the first day of rehydration. By the 3rd day of rehydration the entire loss in body weight was recouped. The interesting observation recorded was that while the loss in body weight of the animals, during dehydration was gradual, the recovery of the lost body weight was almost fully achieved on the first day of rehydration. In our studies on the effect of 48 h water deprivation on 5 indigenous and a cross-bred sheep, during November 1974 to May 1975, the maximum loss in body weight was in May, the values being 5.8, 6.2, 6.8, 6.8, 5.5 and 7.7 kg in Marwari, Magra, Jaisalmeri, Pugal, Chokla and cross-bred (Russian Merino X Marwari) animals, respectively for which the recoveries of lost body weight after rehydration were 118, 122, 113, 100, 113 and 100% (Table 6), respectively. The average amounts of water intake in May by animals of these breeds on rehydration after water deprivation was 6.8, 10.1, 8.0, 7.0, 8.0, 8.0 litres in Marwari, Magra, Jaisalmeri, Pugal, Chokla and cross-bred animals (Table 7), respectively. The average water intakes of desert sheep in summer, as recorded in Purohit's (1972) and our study, were in the same range but the recovery in lost body weight of the animals after rehydration in Purohit's study was not as high as in our studies. Macfarlane *et al.* (1956) working on Merino sheep also observed that, on an average, each sheep took 9.0 litres of water on rehydration and were able to restore their body water content rapidly after remaining water deprived for 5 days and suffering a loss of 11.8 kg in body weight. Schmidt-Nielsen (1964) and Schmidt-Nielsen *et al.* (1956) had observed that while the camel can recover its lost body weight within 10 minutes, the desert donkey, with its capacity to drink 8 litres per minute, has the fantastic ability to regain a similar proportion of the lost body weight within just 2 minutes. The desert sheep breeds examined may be considered as belonging to the category of the camel and the desert donkey in so far as the ability to recover lost body weight on rehydration after dehydration is concerned.

It can, therefore be concluded that sheep are able to almost fully recover their lost body weight usually quite quickly on rehydration after water deprivation. At low ambient temperatures, the recovery may be about 75% immediately on watering *ad lib.*, and 100% in a day or two. Schmidt-Nielsen (1964) has also opined that an animal which drinks occasionally at a water hole where it may fall prey to a carnivore must drink fast and get away fast. It seems possible that modern domestic sheep might be following a pattern of behaviour acquired from their wild ancestors.

Effect of water restriction on feed intake and utilization

The relationship between feed and water intake has been studied in several species of mammals. It has been observed that water and feed intake are interdependent - there being a voluntary reduction in one whenever the other is restricted.

In the dry season there is often no leafy material left for grazing and browsing and the animals are forced to eat materials of practically no nutritive value. But, there are certain shrubs and trees, the leaves and pods of which contain fairly high amounts of protein and sufficient moisture are available in abundance during the dry seasons. These provide a ready source of essential nutrients to the otherwise starving animals. It has been found that the grazing Marwari sheep do not lose body weight even after twelve days of water restriction during summer provided they have free access to the fallen pods of *Khejri* (*Prosopis cineraria*) which contain about 68% water and are highly nutritious (Taneja, 1966).

Dry matter intake

Purohit (1972) recorded statistically non-significant reductions in dry matter intake of the order of 8.50% and 11.70% in Marwari and Russian Merino X Marwari sheep respectively when these animals were on a 50% water deprivation regime for 21 days. Earlier workers (Lloyd *et al.,* 1962; Bianca *et al.,* 1965; Forbes, 1968; Clark and Quin, 1949) had observed that dry matter intake in livestock is generally reduced when the frequency of watering is reduced. In the Australian Merino, dry matter intake is greatly reduced after two days of water deprivation (Macfarlane *et al.,* 1961). In the studies of Purohit (1972), feed intake by sheep was more or less maintained upto 21 days of 50% restriction of water. This is comparable to the finding in the camel the feed intake of which remains unaffected during water deprivation upto 20% to 30% loss in body weight (Schmidt-Nielsen, 1964).

Rate of passage of feed through the gut in relation to water availability

Of the ruminant animals studied, the rate of passage of feeds, particularly of lucerne hay, through the digestive tract of the sheep appears to be the highest and this may be ascribed to the high level of fermentation in the rumen of this species. The lucerne hay when fed to sheep, showed a faster rate of passage when compared to the other feeds (Chowdhary, 1966). A negative correlation between intestinal retention time and the percentage of water in the faeces has been reported to exist in ruminants (Castle, 1956; Coombe and Kay, 1965). This relationship would suggest that the efficiency of water absorption is dependent on the length of time for which food particles are retained in the intestine. Purohit (1972) reported that in the Marwari and Russian Merino X Marwari sheep, faecal water is decreased by 40 to 50% when water intake is restricted to 50% of normal requirement. It may be noted, however, that this relationship does not hold good in the case of goat (Weston, 1968), where a higher faecal water content has been found to accompany a higher retention time and a factor other than retention time has been suggested to play a significant role in the determination of the water content of faeces.

Purohit (1972) opined that when sheep are allowed restricted water intake, not only feed intake is considerably reduced, but the passage of feed through the digestive tract is also considerably delayed. He reported that it took 58.5 hours for 50% of ingested stained feed to pass through the digestive tract of the animals receiving half the quantity, of normal water intake whereas the time taken for similar excretion in the fully watered sheep was 48.0 hours. Purohit (1972) concluded that the rate of passage of feed through the digestive tract of at least the Marwari breed of sheep is influenced by the volume of water drunk.

Dry matter digestibility

Purohit *et al.* (1976) reported that 50% water restriction over a period of 21 days had no effect on dry matter (DM) intake per unit body weight and in the coefficient of digestibility of dry matter, crude protein (CP), ether extract (EE) and nitrogen free extract (NFE) in comparison to *ad libitum* watering treatment in desert-adapted sheep. The coefficient of digestibility of crude fibres (CF) was, however, found to be significantly ($P<0.01$) increased in the water restricted animals. It has, however, been speculated that the improvement in crude fibre digestibility during water restricted regimes may not be a direct effect of water restriction but may result indirectly from the production of additional saliva during such conditions (Blaxter *et al.,* 1956). There was no treatment effect on the nitrogen balance of the animals. Since there was a marginal increase in digestible energy intake of the water-restricted animals, it seems probable that desert-adapted sheep may have a somewhat better energy balance under water scarcity conditions.

Bohra and Ghosh (1977) working on 3-year old Marwari rams have reported that on 50% water restriction in summer, dry matter intake (DMI) and digestible energy intake were reduced but no significant treatment effect was observed by these workers on the digestibility coefficients for dry matter, organic matter and cell-wall constituents of the feed. The values for the latter, were, however, consistently higher in the case of the water restricted animals. The digestibility coefficient of crude protein for normally watered and water restricted animals was -3.63% and -16.63%

respectively. Throughout the experimental period, animals of both the groups remained in negative nitrogen balance, this being somewhat more pronounced in the water restricted group. Similar observations have been reported by Thornton and Yates (1969) in cattle and by Osman and Fadlalla (1974) in Sudanese sheep. They concluded that as the feed intake is reduced due to the water restriction, nitrogen intake necessarily declines and, consequently, the relative proportion of endogenous nitrogen in the total amount of nitrogen excreted becomes greater. These authors believe that this phenomenon is of paramount importance in differentiating between the nitrogen retention values *per se* as a property of the feeds, and the nitrogen retention values obtained with the particular feed under conditions of sub-optimal feed intake. This effect is likely to be magnified by the desquamation of the epithelial tissues of the digestive tract, caused by the fibrous components of the feed. Purohit *et al.* (1976) in their studies made in winter, did not observe any adverse effect of 50% water restriction on either DMI or nitrogen balance in Marwari sheep. This would suggest that there is a marked seasonal variation in this breed's response to restricted water intake in respect of DMI and N metabolism. Interestingly, Livingstone *et al.* (1964) and Utley *et al.* (1970) observed increases in nitrogen retention in cattle when water restriction was imposed.

Bohra and Ghosh (1977) also observed that there was a decreased water loss through both urine and faeces in water restricted sheep. The reduced faecal water loss was apparently duc to (a) a reduction in total faecal output, and (b) a reduction in the amount of moisture/g of fresh faecal matter (which was reduced by 22.1%). It would seem, therefore, that reduction in faecal water loss is one of the important measures by which these animals conserve body water during periods of water scarcity. Thornton and Yates (1969), working on cattle, had arrived at a similar conclusion. In their view, the hind gut is likely to have a regulatory role in the observed response to water restriction.

It is likely that water restriction reduces the passage of boluses (Balch *et al.*, 1953), allowing for increased reabsorption of moisture from the gut. Similar observations have been made on water restricted Marwari sheep (Purohit, 1972).

Bohra and Ghosh (1977) further observed that after a 23-day experimental period, both normally-watered and water-restricted sheep lost in body weight, the average loss being of the order of 5.3% of the initial weight in the former and 21.2% in the latter. At the end of the 23-day experimental period, when the water restricted animals were offered water *ad libitum,* they drank about 6-7 litres within 7 minutes and recovered 71.5% of their lost body weight within 3 days.

Body water distribution

In desert sheep and goat

The pattern of distribution of water during water deficiency conditions in various body compartments, and the efficiency of the kidneys in reabsorbing the filtered water back into the system determine the survivality of an animal in the desert. During water restriction, water lost from an animal is drawn from various body water compartments and the degree by which these compartments are depleted during dehydration differ from species to species. For example, in the Marwari (Barmer) goat, 4 days of water deprivation during summer brought down plasma volume (PV) by about 13% of normal (Khan *et al.,* 1979). However, in the Marwari sheep, PV was reduced by as much as 43% only after 3 days of water deprivation under similar conditions. Examination of the levels of cell and gut water as per cent of total loss in body water at the end of dehydration regimes in the sheep and goat has revealed that while in the goat the reduction is of the order of 90%, in the sheep it is only to the extent of 62% (Khan *et al.,* 1979). Cell and gut water is of special significance during periods of water stress in desert animals because it is this water which is mainly relied upon by the circulatory medium for the maintenance of its normal volume (Ghosh and Khan, 1980). The cell and gut water may, thus, be considered as the "emergency water reservoir". The inability of the sheep to use this water fully at times of water crisis, and its primary dependence on circulatory water for evaporative cooling and other essential purposes makes the sheep decidedly less desert worthy than the goat (Ghosh and Khan, 1980).

With regard to responses of kidneys to dehydration in these two species, it was observed that in the event of water stress, the urine output of the goat was reduced considerably on the 4th day of water deprivation, the reduction being as much as 77%. Although the desert sheep also reduces its urine output, it is not capable of reducing it to the extent as the goat does. Glomerular filtration rate (GFR) in Marwari (Barmer) goats receiving a quarter of their normal daily water intake during summer was reduced to $^1/_3$ of the normal (Ghosh and Khan, 1980). It is conceivable that in desert adapted animals, a reduced GFR is one of the principal adaptational strategies to meet the threat of water insufficiency. Unlike Marwari sheep, the Marwari (Barmer) goat, apparently employ a combination of several strategies, prominent among which are a reduction in GFR and maintenance of the fluidity of the blood at the cost of the water status of the gut and cells.

Body water turnover in desert sheep and goat

In arid zone the efficiency of water use is a major aspect of animal production. It is normally assumed that there is a trade-off between water use and productivity. Body water turnover rate in a given environment is an accurate index of overall water use functions of an animal. The average water turnover in Marwari (Barmer) goat is considerably lower (74 ml/kg. b. wt/24 h) than in Marwari sheep (112 ml/kg. b. wt/24 h) during summer (Khan, 1982). The water turnover values of the Marwari sheep are comparable with those reported for Australian Merino and Awassi sheep of Israel (Macfarlane and Howard, 1972). The Marwari (Barmer) goat, however, would seem to be a more efficient user of water than other reported desert adapted goat breeds (Macfarlane and Howard, 1972; Shkolnik *et al.*, 1979). The comparatively low water turnover in Marwari (Barmer) goats is likely to be of considerable eco-physiological significance as this would enable these animals to graze over long stretches of the desert range for 3 - 4 days at a time before reaching a water hole. By contrast the Marwari sheep will at best be able to stand only 2 days grazing away from any source of water. The superior water use efficiency of the desert goat must have been responsible for the enormous increase in goat numbers (about 70% increase during the decade 1961-71) in western Rajasthan while the growth rate of the sheep population of this tract has preceded at a much slower rate.

Effect of water restriction on blood constituents

Physiological changes in the blood constituents of the Australian Merino and the Marwari sheep, receiving restricted quantities of water have been reported (Macfarlane *et al.*, 1961; Taneja, 1965, 1966). Very little changes in haemoglobin concentration have been recorded in the Australian Merino deprived of water for three days, but by the end of the fifth day the haemoglobin concentration was increased by 32%. In Purohit's (1972) study, on an average there was an increase of 21% in haemoglobin concentration in all the sheep breeds examined after water deprivation for 5 days. An apparent increase of 42% in haemoglobin concentration was noted in the Guanaco when water was restricted upto 23.4% loss in body weight (Rosenmann and Morrison, 1963). It appears that the Australian Merino and the Guanaco respond to water restriction similarly in respect of haemoglobin concentration. The haematocrit value (cell volume) after six days of deprivation of water, increased by 25% in the Merino (Macfarlane *et al.*, 1956, 1961).

Purohit (1972) also observed that in his animals after 5 days of water deprivation, the haematocrit (packed cell volume) increased by 13.14%, 15.88%, 17.74% and 10.19% in the Marwari, Russian Merino X Marwari, Chokla and Jaisalmeri breed respectively. This was a clear indication of the haemoconcentration caused by the imposed treatment. Taneja (1965) also found a 22% increase in packed cell volume in Marwari sheep when these animals were subjected to water restriction for foui days. He had further observed that the increase in packed cell volume was associated with increase in the degree of water restriction. A 39% increase in packed cell volume in the Australian Merino, after 5 days of water restriction, has been reported (Macfarlane *et al.*, 1961). The increase in the packed cell volume reported by Purohit (1972), was relatively less when compared to the findings of Taneja (1965) and Macfarlane *et al.* (1961). Such differences may be due to the differences in the experimental conditions.

The plasma sodium and potassium concentration in the Australian Merino apparently remain within reasonable limits after 3 days of water deprivation. For example, Macfarlane *et al.* (1956) had earlier recorded a 9% increase in plasma sodium concentration in the Australian Merino after the animals were maintained without water for 5 days.

Purohit (1972) observed that the plasma sodium concentration remained unaffected after five days of water deprivation in Marwari, Russian Merino X Marwari, Chokla and Jaisalmeri breeds. The plasma potassium concentration did not increase appreciably even after 6 days of water deprivation; while the normal range of plasma potassium concentration was from 3.82 to 4.36 meq/1, a range of 4.14 to 4.72 meq/1 was recorded in the dehydrated animals (Macfarlane *et al.,* 1961). Purohit (1972) also observed that as in the case of plasma sodium, plasma potassium concentration also remained unaffected in all the Indian breeds of sheep examined by him, after the animals were water deprived for 5 days; however, significant breed differences were observed in this respect. Purohit's (1972) findings are in agreement with the observations of Macfarlane *et al.* (1961) on the Australian Merino subjected to six days of water deprivation.

The constituents of the blood of the goat have also been reported to change during prolonged water restriction (Ohya, 1964).

Purohit (1972) recorded increases of 0.38%, 0.49%, 0.58% and 0.58% in the specific gravity of the plasma of 5-day water-deprived Marwari, Russian Merino X Marwari, Chokla and Jaisalmeri sheep respectively. Whole blood specific gravity rose by 1.05%, 0.66%, 0.66% and 0.86% respectively in these breeds after 5 days of complete water deprivation. The differences due to water restriction were significant. Water restriction, however, had no effect on red cell fragility. In Bianca's (1970) studies on cattle, however, the red cell fragility increased and remained unchanged for several hours after rehydration. It seems that sheep and cattle differ in this respect. Purohit (1972) also reported a significant increase in the number of circulating red blood cells after 5 days of complete water deprivation. The increase was of the order of 16.18%, 22.82%, 13.04%, and 13.29% in the Marwari, Russian Merino X Marwari, Chokla and Jaisalmeri breed respectively. These findings are in agreement with the findings of Bianca (1970) on cattle. It has also been reported that when the guanaco are dehydrated to a body weight loss of 23.4%, the total number of red blood cells increase by 38.18% (Rosenmann and Morrison, 1963). It appears that the increase in the total number of red blood cells, due to water restriction, is of somewhat less magnitude in sheep than in the guanaco.

Blood potassium types and water use efficiency

On the basis of concentration of potassium (K) in the blood, sheep can be classified into high (HK) and low (LK) potassium types. The sheep with potassium concentration between 9-12 meq/l are designated as low (LK) potassium type and those with K concentration between 22-25 meq/1 are designated as high (HK) potassium type. These two potassium types have been reported in numerous breeds of sheep.

A survey of six sheep breeds of Rajasthan, viz. Marwari, Malpura, Chokla, Magra, Sardarsamand and Pugal, has shown the existence of two K types (Table 8). There are no intermediate potassium types between HK and LK.

Evans (1957) recorded differences in the water metabolism between LK and HK sheep and suggested that LK animals may have more chance of survival in relatively arid regions than HK animals. This hypothesis does not hold true when examined for the Indian breeds. The predominance of HK in the Indian breeds of sheep has been thought to be due to the migration of HK animals from Afghanistan to this region (Taneja and Ghosh, 1965).

LK type sheep reportedly drank a relatively lesser quantity of water than HK (Taneja, 1967). On a larger sample, when potassium types were adjusted for variations in body weight, the differences between potassium types for water intake were, however, not statistically significant, but the interaction between season and the type was significant (Purohit,

Table 8. Blood potassium type in Rajasthan sheep

Breed	Number of sheep	HK sheep (%)
Chokla	259	57
Malpura	99	65
Magra	115	65
Marwari	113	72
Sardarsamand	12	66
Pugal	24	79

(From Taneja, 1970).

1972). The differences in water intake by the two K types of animals varied from season to season. The differences between the two K types in respect of water loss through faeces, urine, sweating and respiratory tract were also not significant. It was observed that the differences between the two types in respect of water intake were largely in mode than in mean. That is, there were more animals in the LK than in the HK group which drank lesser quantities of water. During water deprivation, the differences in loss in body weight between the two K types were practically nil. It may, thus, be concluded that the occurrence of a high proportion of HK type animals in the Rajasthan desert cannot be attributed to their tolerance to water deficiency conditions in this region (Taneja, 1970).

Exercise and water consumption

In the desert, animals have to walk long distances in search of feed and water. The ability of the animals to walk fast and recuperate the losses are of prime importance. Dowling (1956) considered that the time required for body temperature to return to normal after exercise is an excellent measure of an animals' adaptation to tropical fatigue. Taneja *et al.* (1967) working on Marwari sheep observed that body temperature in LK animals rose significantly more than in HK when subjected to exercise.

The rise in body temperature of LK animals was related to their ability to conserve body water as, after the exercise, these animals did not drink as much as HK type animals. In this respect, the LK animals are comparable to the camel.

Physiologically a rise in body temperature above normal limits is detrimental to an animal and while selecting animals preference is given to those in which the rise in body temperature during stress is less. Although regulation of body temperature is generally considered to have priority over water balance, yet it may be logical to conjecture that in chronically water deficient areas the evolution of physiological adaptive mechanisms might have been directed primarily towards saving of body water. This would mean a necessary shift in the prerogatives for the stability of different physiological parameters. The thermoregulatory behaviour of LK sheep is probably a manifestation of such generalised physiological principles aimed at fitting it properly into its desert niche (Taneja *et al.*, 1967).

General discussion

In the Rajasthan desert, scarcity of water is the main problem and, therefore, it is essential to gain information about the adaptation of sheep to this region. The underground water in this desert is fairly limited and the water table is also very low. The water here is often saline. Sheep are driven several miles daily to watering ponds.

Inspite of heavy stress imposed on the animals due to scarcity of water, the sheep population in Rajasthan has been gradually rising. It seems to indicate a relatively high degree of tolerance to desertic stress in sheep which have managed to escape the conditions of frequent droughts and scarcity of water.

Different breeds of sheep, when subjected to various degrees of water stress, lost around 27% of their body weight without any physiological disfunction, and on rehydration, they regained the lost body weight quickly. It is unlikely that reasonably restricted watering of desert-adapted sheep during a period of water scarcity would affect the economic traits. Unlike that in cattle, the end products in sheep for human consumption -wool and mutton - would require relatively lesser quantity of water.

When sheep are deprived of water, the food intake decreases. The food consumed is also retained longer in the gastrointestinal tract when the sheep are given restricted amounts of water. This could be advantageous to the animals if a relatively longer retention of the feed in the intestinal tract results in a better absorption of the nutrients in the animals' bodies. The ability of an animal to withstand loss in body weight during water deprivation might possibly be compensated for by this mechanism.

There is an enormous amount of haemoconcentration during water restriction in sheep. This suggests that sheep are incapable of maintaining proper blood circulation in the face of dehydration. The animal overcomes the water loss from the body during water deprivation mainly by passing lesser quantities of urine. In this respect, sheep resemble the camel. The sodium concentration in the urine increases significantly during dehydration in the Australian Merino (Macfarlane *et al.*, 1961). In desert breeds also, during water restriction, the concentration of total electrolytes in the urine increases.

In sheep, on water restriction, the extracellular and intracellular water compartments of the body are severely affected. There is an overall reduction in body fluids and the reduction is proportional to the degree of water restriction. However, the body fluid compartments remain unaffected when sheep are watered 25% less than their normal daily requirement, but as soon as reduction in water intake goes below this level, the body fluid compartments begin to shrink. The maximum reduction observed in the total body water of water-deprived sheep was 46%. Apparently, these sheep survive such a heavy reduction in body fluids and it indicates the efficiency of these animals to live under conditions of water stress in the desert.

Some of the physiological norms are affected during water restriction. The rectal temperature rises during water deprivation presumably due to the overall dryness of the body. The respiratory frequency decreases to conserve moisture from being lost from the respiratory tract. The rise in body temperature and decrease in respiratory frequency are directly proportional to the degree of water restriction.

When desert sheep are watered twice a week, or are allowed 50 per cent of the normal daily water intake, there is a saving of 50% in the water expenditure, while there are no ill effects on the physiological functioning of the animals. Saving of drinking water to the tune of 50 to 85 litres per sheep per month has been found achievable by resorting to watering of the animals twice every week instead of daily, the corresponding saving in the case of lambs being about 25 to 30 litres per lamb per month. It would, therefore, seem that it will be possible to maintain around 200 sheep on the normal water ration of 100 sheep if the animals are allowed to drink twice every week instead of daily.

Bibliography

Abichandani, R. K. (1981). Water use economy in Rajasthan desert sheep. *Ann. Arid Zone 20*(3): 215-228.

Balch, C. C., Balch, D. A., Johnson, V. W. and Turner, J. (1953). Factors affecting the utilization of food by dairy cows. 7. The effect of limited water intake on the digestibility and rate of passage of hay. *Brit. J. Nut. 7*: 212-224.

Bianca, W. (1970). Effects of dehydration, rehydration and overhydration on the blood and urine of oxen. *Brit. Vet. J. 126*: 121-131.

Bianca, W., Findlay, J. D. and McLean, J. A. (1965). Responses of steers to water restriction. *Res. Vet. Sci. 6*: 38-55.

Blaxter, K. L., Graham, N. M. and Wainman, F. W. (1956). Some observations on the digestibility of food by sheep and on related problems. *Brit. J. Nut. 10*: 69-91.

Bohra, H. C. and Ghosh, P. K. (1977). Effect of restricted water intake during summer on the digestibility of cell-wall constituents, nitrogen retention and water excretion in Marwari sheep. *J. agric. Sci. (Camb.) 89*: 605-608.

Castle, E. J. (1956). The rate of passage of foodstuffs through the alimentary tract of goat. 2. Studies on growing kids. *Brit. J. Nut. 10*: 115-125.

Chowdhary, B. R. (1966). Straw feed trial with sheep. *M. Sc. (Agric. Sci.) thesis, University of Centribury,* New Zealand.

Clark, R. and Quin, J. I. (1949). Studies on the water requirements of farm animals in South Africa. I. The effects of intermittent watering of Merino sheep. *Onderstepoort J. Vet. Sci. 22*: 335-343.

Coombe, J. B. and Kay, R. N. B. (1965). Passage of digesta through the intestines of the sheep. Retention times in the small and large intestines. *Brit. J. Nut. 19*: 325-338.

Dowling, D. F. (1956). An experimental study of heat tolerance of cattle. *Aust. J. Agric. Res. 7* (5): 469-481.

Evans, J. V. (1957). The stability of the potassium concentration in the erythrocytes of individual sheep compared with the variability between different sheep. *J. Physiol. 136*: 41-59.

Evans, J. V. and Mounib, M. S. (1957). A survey of the potassium concentration in the red blood cells of British breeds of sheep. *J. agric. Sci. (Camb.) 48*: 433-437.

Forbes, J. M. (1968). The water intake of ewes. *Brit. J. Nut. 22*: 33-43.

Ghosh, P. K. and Khan, M. S. (1978). The desert goat. *Ind. Fmg. XXVII* (10): 32-33.

Ghosh, P. K. and Khan, M. S. (1980). The goat in the desert environment. *CAZRI Monograph* No. 12, 26 pages.

Ghosh, P. K., Khan, M. S. and Abichandani, R. K. (1976). Effect of short-term water deprivation in summer on Marwari sheep. *J. agric. Sci.* (*Camb.*) *87*: 221-223.

Khan, M. S. (1982). Body water turnover in Indian desert sheep and goat. *Current Science* (communicated).

Khan, M. S., Sasidharan, T. O. and Ghosh, P. K. (1979). Water regulation in Barmer goat of the Rajasthan desert. *Experientia 35* (9): 1185-1186.

Livingston, H. G., Payne, W. J. A. and Friend, M. T. (1964). Nitrogen metabolism of cattle in East Africa. I. The problem and the experimental procedure. *J. agric. Sci.* (*Camb.*) *62*: 313-319.

Lloyd, L. E., Donefer, E., Bowman, A. L. and Crampton, E. W. (1962). Effect of certain forage characteristics on water intake by sheep. Abstract of paper presented at the 54th Annual National Meeting of the American Society of Animal Science. *J. Anim. Sci. 21*: 1036.

Lynch, J. J. (1969). The performance of Merino ewes deprived of drinking water. *Aust. J. Sci. 31*: 369.

Lynch, J. J., Brown, G. D., May, P. F. and Donnelly, J. B. (1972). The effect of withholding drinking water on wool growth and lamb production of grazing Merino sheep in temperate climate. *Aust. J. agric. Res. 23*: 659-668.

Macfarlane, W. V. (1964a). Merino sheep as desert animals. *Proc. Lucknow Symp. on Environmental Physiol. and Psychol. in Arid Conditions.* UNESCO., Paris. pp. 259-265.

Macfarlane, W. V. (1964b). Terrestrial animals in dry heat: ungulates. In *Handbook of Physiology-environment, 4*: 509-531. Dill, D. B. (ed.), Washington, D. C.: American Physiological Society.

Macfarlane, W. V. and Howard, B. (1972). Comparative water and energy economy of wild and domestic mammals. *Proc. Symp. Zool. Soc., London,* No. 31, pp. 261-296.

Macfarlane, W. V., Morris, R. J. H. and Howard, B. (1956). The water economy of tropical Merino sheep. *Nature 178*: 304-305.

Macfarlane, W. V., Morris, R. J. H. and Howard, B. (1958). Heat and water in tropical Merino sheep. *Aust. J. agric. Res. 9*: 217-228.

Macfarlane, W. V., Morris, R. J. H., Howard, B., McDonald, J. and Budtz-Olsen, O. E. (1961). Water and electrolyte changes in tropical Merino sheep exposed to dehydration during summer. *Aust. J. agric. Res. 12*: 889-912.

Maloiy, G. M. O. (1970). Water economy of the somali donkey. *Am. J. Physiol. 219*: 1522-1527.

Maloiy, G. M. O. and Taylor, C. R. (1971). Water requirements of African goats and haired sheep. *J. agric. Sci.* (*Camb.*) *77*: 203-208.

Ohya, M. (1964). Experimental studies on dehydration in ruminants, especially on clinical observations, change in blood characters and fluctuations of various phases of body fluids in prolonged water restriction in goat. *Jap. J. Vet. Sci.* *12*: 23.

Osman, H. Elsayed and Fadlalla, B. (1974). The effect of level of water intake on some aspects of digestion and nitrogen metabolism of the 'desert sheep' of the Sudan. *J. agric. Sci. (Camb.)* *82*: 61-69.

Purohit, G. R. (1972). Water metabolism in desert sheep. *Ph. D. thesis, University of Jodhpur,* Jodhpur.

Purohit, G. R., Ghosh, P. K. and Taneja, G. C. (1972). Water metabolism in desert sheep: Effects of various degrees of water restriction on the distribution of body water in Marwari sheep. *Aust. J. agric. Res.* *23*: 685-691.

Purohit, G. R., Ghosh, P. K. and Taneja, G. C. (1973). Effects of varying degrees of water restriction on the distribution of body water in high- and low - potassium - type Marwari sheep. *J. agric. Sci. (Camb.)* *80*: 177-180.

Purohit, G. R., Ghosh, P. K. and Taneja, G. C. (1974). Effects of water restriction on excretory losses in pure and cross-bred Marwari sheep. *Indian J. Anim. Sci.* *44* (9): 679-682.

Purohit, G. R., Ghosh, P. K. and Taneja, G. C. (1975). A note on seasonal variation in normal water intake by indigenous and cross-bred sheep. *Ann. Arid Zone* *14* (3): 274-276.

Purohit, G. R., Ghosh, P. K. and Taneja, G. C. (1976). Effect of water restriction on dry matter intake and digestibility of nutrients in pure and cross-bred Marwari sheep. *Ann. Arid Zone* *15* (1 & 2): 95-101.

Rosenmann, M. and Morrison, P. (1963). Physiological response to heat and dehydration in the Guanaco. *Physiol. Zool.* *36*: 45-51.

Schmidt-Nielsen, B., Schmidt-Nielsen, K., Houpt, T. R. and Jarnum, S. A. (1956). Water balance of the camel. *Amer. J. Physiol.* *185*: 185-194.

Schmidt-Nielsen, K. (1964). *Desert animals: Physiological problems of heat and water.* Clarendon Press, Oxford.

Shkolnik, A., Maltz, E. and Choshniak, I. (1979). *Proc. 5th Inter. Symp. on Ruminant Physiology.* Clermont, Ferrand. September 3-7. pp. 731-742.

Taneja, G. C. (1965). Effect of varying the frequency of watering during summer on the temperature, respiration, body weight and packed cell volume of blood of sheep. *Ind. J. exp. Biol.* *3*(4): 259-262.

Taneja, G. C. (1966). Some physiological correlates of water restriction in Sheep. *Indian J. exp. Biol.* *4* (3): 167-170.

Taneja, G. C. (1967). Water intake in relation to blood potassium types in desert sheep. *Experientia* *23*: 645.

Taneja, G. C. (1969). Variations in body temperature, respiratory rate, pulse rate, water intake and body weight of Marwari sheep during the year. *Ind. Vet. J.* *46* (1): 49-56.

Taneja, G. C. (1970). Blood potassium types in sheep in relation to animal production in arid environment. *Proc. Ind. Nat. Sci. Acad.* *36 B* (5): 311-320.

Taneja, G. C. and Abichandani, R. K. (1967a). A note on interdependence amongst water intake, air temperature and humidity in sheep. *Ind. Vet. J. 44* (1): 41-42.

Taneja, G. C. and Abichandani, R. K. (1967b). Evidence of genetic control of blood potassium type in the Marwari breed of sheep in India. *Experientia 23*: 273.

Taneja, G. C., Fuladi, B. M. and Abichandani, R. K. (1966). Differences in blood and serum characteristics of high and low potassium types of Marwari sheep. *Indian J. exp. Biol. 4*(2): 125, 126.

Taneja, G. C., Fuladi, B. M. and Abichandani, R. K. (1967). Blood potassium types and body temperature during exercise in Marwari sheep. *Indian J. exp. Biol. 5*(3): 188-189.

Taneja, G. C. and Ghosh, P. K. (1965). Variation in potassium concentration of blood in Marwari sheep. *Ind. J. exp. Biol. 3* (3): 166-167.

Thornton, R. F. and Yates, N. G. (1969). Effect of water restriction on nitrogen metabolism of cattle. *Aust. J. agric. Res. 20*: 185-189.

Utley, P. R., Bradley, N. W. and Boling, J. A. (1970). Effect of water restriction on nitrogen metabolism in bovine fed two levels of nitrogen. *J. Nut. 100*: 551-556.

Warner, A. C. I. (1971). Recovery following prolonged dehydration in sheep. *Search 2*: 202-203.

Warner, A. C. I., Stacy, B. D., Brown, G. D. and Downes, A. M. (1970). Prolonged water deprivation in sheep. *Arid Zone Newsletter*. Division of Animal Physiology, Ian Clunies Ross Animal Research Lab., Prospect, New South Wales, Australia, C.S.I.R.O., Canberra.

Weston, R. H. (1968). Factors limiting the intake of food by sheep. III. The mean retention time of feed particles in sections of the alimentary tract. *Aust. J. agric. Res. 19*: 261-266.

Wilson, A. D. (1970). Water economy and food intake of sheep when watered intermittently. *Aust. J. agric. Res. 21*: 273-281.

Yesberg, N. E., Henderson, M. and Budtz-Olsen, O. E. (1970). The secretion of Vasopressin by normal and dehydrated sheep. *Aust. J. exp. Biol. med. Sci. 48*: 115.

Yousef, M. K., Dill, D. B. and Mayes, M. G. (1970). Shifts in body fluids during dehydration in the burro, *Equus asinus*. *J. appl. Physiol. 29*: 345-349.

CAZRI monograph series

No. 1	Desert Ecosystem and its Improvement, pp. 1-387 (1974).	Edited by H. S. Mann
No. 2	Proceedings of Summer Institute on Rodentology (Mimeo.), pp. 1-365 (1975).	Edited by Ishwar Prakash
No. 3	Solar Energy Utilization Research (Mimeo.), pp. 1-48 (1975).	by H. P. Garg
No. 4	Rodent Pest Management — Principles and Practices, pp. 1-28 (1976).	by Ishwar Prakash
No. 5	White Grubs and their Management, pp. 1-30 (1977).	by S. K. Pal
No. 6	The Amazing Life in the Indian Desert, pp. 1-18 (1977).	by Ishwar Prakash
No. 7	Geomorphological Investigations of the Rajasthan desert, pp. 1-44 (1977).	by Surendra Singh
No. 8	Proceedings of Summer Institute on "Resource Inventory and landuse planning", pp. 1-373 (1977).	Edited by K. A. Shankarnarayan
No. 9	Land Use Classification System in Indian Arid Zone, pp. 1-43 (1978).	by Amal Kumar Sen
No. 10	Ecology of the Indian desert gerbil, *Meriones hurrianae*, pp. 1-88 (1981).	by Ishwar Prakash
No. 11	*Khejri* (*Prosopis cineraria*) in the Indian desert — its role in Agroforestry, pp. 1-78 (1980).	Edited by H. S. Mann and S. K. Saxena

No. 12 The goat in the desert environment, pp. 1-26 (1980). by P. K. Ghosh and M. S. Khan

No. 13 *Bordi* (*Zizyphus nummularia*)- A shrub in the Indian Arid Zone. Edited by H. S. Mann and S. K. Saxena

No. 14 Sheep in Rajasthan, pp. 1-38, (1981). by A. K. Sen, P. K. Ghosh, K. N. Gupta and H. C. Bohra

No. 15 Water proofing of field irrigation channels in desert soils. by K. N. K. Murthy, V. C. Issac and D. N. Bohra

No. 16 Termite pests of vegetation in Rajasthan and their management, pp. 1-31, (1981). by D. R. Parihar