

**Technical Bulletin No. 1**



**IMPROVED  
DRYLAND AGRICULTURE  
FOR  
WESTERN RAJASTHAN**

**CENTRAL ARID ZONE RESEARCH INSTITUTE**

**JODHPUR (RAJASTHAN)**

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## FOREWORD

It is often said that rainfed agriculture in the arid Rajasthan is beset with the twin problems of instability and low productivity. An appraisal of this situation indicates an imbalance of various components of productivity of arid eco-system. In order to achieve a harmonious interaction of various factors, of which moisture is the most crucial, research approach to this complex problem has to be inter disciplinary. It is only when different inputs like tillage, soil and moisture conservation, varieties and nutrition are made to interact that crop yields could be stabilized at a higher yield level.

Establishment of a Main Centre of the All India Coordinated Research Project for Dryland Agriculture at Central Arid Zone Research Institute in 1971 is a significant step in this direction. The scientists engaged in dryland agricultural research have worked out solutions to some of the important problems of dryland crop production in arid Rajasthan. Developing crop production technology for prevailing rainfall patterns and weather aberrations, evolving suitable systems of planting, inter-cropping and water harvesting, identification and breeding of promising varieties of pulse and oilseed crops and use of organic mulches for moisture conservation and locally available soil amendments like bentonite clay as barriers to prevent deep percolation moisture losses for vegetable production, are some of the significant achievements. On the basis of experience gained intensive research oriented towards imparting greater stability to production under conditions of deficient rainfall through alternative crop plans, contingency plans, mid-season correction, crop life saving research etc. are in progress. Temporary storage of run-off water and its recycling for crop-life saving during short drought periods are being studied. However, there is need for understanding of soil-water-plant relationships. Research effort is now being directed to the manipulation of the surface soil to prevent crusting, increase water intake and prevent run-off. In short, concerted efforts are being made to the development of sound and viable farming systems for drylands.

This bulletin "Improved Dryland Agriculture for Drylands of Western Rajasthan" is a compilation of research information for crop production on drylands on basis of research during the past five years at the Dry Farming Research Main Centre of the Central Arid Zone Research Institute, Jodhpur. It is hoped that scientists, extension workers, farmers and others engaged in the field of dryland agriculture may find it useful. Comments and suggestions are invited.

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## C O N T E N T S

1.	Agro-meteorological studies	1
1.1.	Analysis of rainfall data	1
1.2.	Rainfall distribution models	3
1.3.	Water balance studies	4
2.	Moisture conservation on drylands	5
2.1.	Decreasing the deep percolation losses and increasing soil moisture storage capacity	5
2.2.	Reducing the evaporation losses	8
3.	Crops and varieties for dryland agriculture	9
3.1.	Crops and varieties for conditions of normal monsoon	10
3.2.	Crops and varieties for conditions of delayed onset of monsoon	11
3.3.	Moong breeding	13
3.4.	Crops and varieties for limited moisture supply in rabi season	14
3.5.	Improved crop varieties for drylands of Jodhpur tract	15
3.6.	Crops for conserved soil moisture	16
4.	Improved agronomy for drylands	17
4.1.	Crop stand establishment	17
4.2.	Planting patterns	17
4.3.	Fertiliser use	18
4.4.	Inter-cropping systems for drylands	20
4.5.	Capitalising good rainfall years	22
4.6.	Water harvesting systems for drylands	23
5.	Agricultural Engineering	25
5.1.	Tillage practices for bajra HB3	25
5.2.	Evaluation of sowing methods and seeding machinery	26
5.3.	Bullock drawn seed-cum-fertiliser drill developed	26
	Summary	27

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# Agro-meteorological Studies

## 1.1 Analysis of rainfall data :

An analysis of the daily rainfall data of Jodhpur for 75 years (1901-1975), revealed that Jodhpur falls in a region of low annual rainfall (366 mm), most of which (80 per cent) is received during the kharif season (July to September) only. The normal dates of onset and withdrawal of monsoon are 1st July and 15th September, respectively, thus restricting the period of moisture availability during the cropping season to 77 days. The mean number of rainy days during the cropping season are 21 only.

The normal weekly distribution of rainfall and the probability of occurrence of any rainfall in these weeks are presented in Table 1. It can be seen from Table 1 that the mean weekly rainfall and the probability of rainfall occurrence increases sharply from the last week of June (64%). The probability increases during July with the normal monsoonal activity during this period, the highest probability being observed during the 29th standard week (78%) followed by the 30 and 31st weeks. However, the highest quantum of normal weekly rainfall (about 35 mm/week) were recorded during the last two weeks of August (34 and 35 standard weeks) though the probability of occurrence was slightly less (69% and 62%, respectively). There is a sharp decrease in the weekly rainfall amount after the second week of Sept., while the probability of rainfall occurrence falls below 50% (chance probability) after the first week of September. Thus considering the rainfall distribution it can be said that the kharif season starts from the last week of June and extends upto the second week of September. It is interesting to note that there is a slight increase in the weekly rainfall during the last week of September. In fact in few of the years there had been substantial rains (as much as 100 mm) during this fag end of monsoon withdrawal.

TABLE 1

Normal weekly rainfall data of Jodhpur 1901-1975

Months	W E E K S				
	1	2	3	4	5
January	0.4 (9)	1.2 (16)	1.2 (16)	0.8 (12)	1.4 (20)
February	0.5 (14)	1.0 (20)	1.3 (20)	1.4 (18)	
March	1.0 (16)	0.8 (9)	1.3 (16)	0.5 (18)	
April	0.2 (9)	0.4 (7)	0.7 (20)	1.1 (12)	1.4 (18)
May	1.5 (23)	2.7 (34)	2.6 (20)	4.8 (39)	
June	4.1 (36)	6.6 (39)	8.4 (44)	12.6 (64)	
July	18.9 (66)	22.3 (73)	30.6 (78)	24.8 (75)	26.5 (75)
August	29.4 (68)	21.7 (73)	34.9 (69)	35.0 (62)	
September	16.6 (52)	18.8 (44)	4.9 (39)	9.7 (32)	
October	2.7 (12)	1.1 (9)	0.4 (16)	3.3 (9)	0.2 (4)
November	0.4 (7)	0.5 (7)	0.8 (9)	0.5 (4)	
December	1.5 (5)	0.3 (7)	0.7 (11)	0.2 (9)	

Note : 1. Rainfall is indicated in mm/week.

2. Figures in parentheses indicate % probability of occurrence of any rainfall.

The analysis of rainfall distribution further indicates the various aberrant weather situations for which the crop planners have to be prepared with proper management practices to have a stabilized crop production. The various situations operating in this region include (i) normal and (ii) good rainfall years occurring in one out of two years (48% probability) which are to be capitalised through improved yield plateaus to tide over the lean years (52% probability). One interesting



point that emerges from the rainfall distribution during these years is that 20 of these normal and good rainfall years (24% probability) i.e. one out of four years are quite favourable for double cropping. Further the need for adequate preparations for situations of early onset of monsoon occurring in one out of three seasons is obvious. There is also a necessity to come up with suitable crops that can perform well in situations of late onset of adequate rains possible in one out of four years (27% probability). Also proper management practices for situations of prolonged drought conditions (3 to 4 weeks) occurring at seedling stage (during July) in one out of five years (20% probability) and at flowering, grain formation stages (August and first fortnight of September) possible in two out of five years (40% probability) form an essential part in combating the drought conditions and stabilizing the crop production on drylands of Western Rajasthan.

## **1.2 Rainfall distribution models :**

An analysis of the rainfall distribution patterns of Jodhpur, for the past 73 years (1901-1973) resulted in the formulation of six rainfall distribution models accounting for the vagaries of rainfall distribution during the cropping seasons in this region. These models represent annual rainfall categorised into (A) good (>400 mm), (B) normal (350-400 mm), (C) below normal (250-350 mm) and (D) poor (<250 mm) rainfall years. Two other models E and F represent the rainfall distribution with prolonged periods of drought during the second fortnight of July (seedling stage) and second fortnight of August (active growth and flowering stage) occurring in eleven and twenty of the years studied respectively.

About twenty three years fall in the category (A) with an average rainfall of 565 mm, while twelve years experienced rainfall in the range 350-400 mm (B), the mean annual rainfall being 366 mm. However, the actual available moisture for crop growth under these two situations comes to about 283.5 mm and 213.9 mm, respectively, after accounting for the moisture losses due to run-off and deep percolation. Thus, models A and B taken together account for about 50 per cent of years when one could obtain remunerative crop yields on drylands of this region. Of the rest, about seventeen and twenty-one years fall under the categories C and D with mean annual rainfall of 293 mm and 169 mm, and moisture availability of the order of 172.7 mm and 124.2 mm, respectively during the cropping season. Thus the rainfall distribution models A, B, C, D, E and F showed probabilities of 31.5, 16.4, 23.3, 28.8, 15.1 and 27.4 per cent occurrence, respectively.

### **1.3 Moisture balance studies :**

In normal and good rainfall years a considerable portion of rainfall is lost as run-off and deep drainage due to the low moisture storage capacity of these sandy loam soils. Occasionally high intensity showers were also observed to occur. Attempts have been made to estimate moisture losses through moisture balance studies during the cropping seasons (1961-1973). Based on daily soil moisture budgeting as per the methodology suggested by Raman and Venkatraman (IMD Sci. Rep. No. 131, 1970) and estimating moisture losses under actual evapotranspiration, it was found that in good rainfall years the moisture losses under run-off and deep drainage taken together reach as high as 40 per cent of seasonal rainfall, each accounting for almost half of the total losses.

Moisture balance studies carried out for the past nine kharif seasons (1965-1973) indicated that in normal and below normal years the actual evapo-transpiration (AE) was around 75-85% of the kharif seasonal rainfall, while in good rainfall years it was 60 per cent. However, the evaporative moisture loss rate (AE/PE per cent) was low (30%) in most of the seasons studied, indicating a severe moisture deficiency for normal crop growth on the drylands of Jodhpur tract.

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## Moisture Conservation on Drylands

### 2.1 Decreasing the deep percolation losses and increasing the soil moisture storage capacity :

Sandy soils are known to be most productive soils in the world provided they can retain adequate moisture to sustain plant growth. In Western Rajasthan the soils are predominantly sand to sandy loam with very low organic matter content and consequently are vulnerable to losses of moisture both in evaporation as well as deep percolation. However, surface evaporation is not as problematic as deep percolation, for once the surface soil dries up which mostly is sand to loamy sand, it acts as a natural mulch against the losses of moisture in evaporation. Nevertheless, fast drying of surface soil and excessive evaporation just after rainfall does pose problems in seedling emergence and proper stand establishment, if there occurs a drought spell after sowing or during the establishment stage when the root zone is restricted to the surface 15-30 cm of soil depth. Under such conditions the use of surface mulches may prove to be advantageous in delaying the surface drying.

These aspects are suitably dealt with in the section on the use of mulches.

In good rainfall years and in years when bulk of the seasons rainfall is received in a short period – thereby creating a situation when rainfall amount exceeds the soil moisture storage capacity, considerable losses of moisture in deep percolation to the **Murrum** zone or the underlying substrata appearing at 40 cm to 1 m depth in the soil profile, take place. The kinds of sub-strata which are most widespread in the areas where water storage is a limitation, are as follows :

1. Partially decomposed bed rock debris impregnated with  $\text{CaCO}_3$ , mixed with sand and silt.

2. Undecomposed or partially decomposed calcareous rock debris.
3. Loosely oriented bouldary material.

In the case of latter two sub-stratas the deep percolation losses are most severe. The first kind, on the other hand, which is typical of Chirai and Pal series of Jodhpur district is quite retentive of moisture in general. However, since the moisture in this so-called **Murrum** zone is held at higher tensions due to its calcareous nature than that of the soil zone overlying the **Murrum**, the upward moisture movement gradient from **Murrum** to the soil is only seldom operative. Further, the surface pull does not mostly reach to this depth into the **Murrum** zone due to sandy soil texture and hence the moisture present in the **Murrum** is practically not available to shallow rooted crop plants. As such, studies on reducing the deep percolation losses and increasing the moisture storage capacity of sandy soil by the use of sub-surface moisture barrier and incorporation of organic amendments were started at this centre in rabi 1972.

#### **Incorporation of sub-surface moisture barrier :**

Preliminary studies using bentonite clay-which is available in plenty in Western Rajasthan, as sub-surface moisture barrier were conducted in rabi 1971 and kharif 1972. These studies revealed that :

1. Bentonite clay can successfully be used as sub-surface moisture barrier in these soils.
2. Since barrier is a costly input it may not be feasible to use it for general field crops in large areas due to non-availability of machines capable of incorporating the barrier below the root zone, i.e. at 70-80 cm depth in the soil profile.

As such in 1973, a spot or partial moisture barrier incorporation technique was devised, in which pits 45-50 cm in diameter were dug by tractor auger and bentonite clay at the rate of 2.5 kg/pit was incorporated by mixing in 3-4 cm soil layer at 70 cm depth in the profile and pits were refilled. *Tinda* for vegetable was grown in these pits. Placement of bentonite barrier at 75 cm depth gave an yield of 163 q/ha of tinda as against 109.5 q/ha obtained from control (no barrier) plot, in 1973 which was a good rainfall year – a rainfall of 544 mm was recorded during kharif season.

In 1974 moisture barrier technique was combined with that of run-off concentration for it was thought that in poor rainfall years moisture may not reach to the barrier-zone leaving it in-effective so far as soil moisture storage is concerned.

As such, run-off concentration aspect was included by providing inverted 'V' shape catchments 1.5 meter wide in each side, between two rows of pits in 1974.

The data on the yield of green vegetable are set out in Table 2.

TABLE 2  
Yield of tinda (q/ha)

Treatments	With micro-catchment		Flat	
1. Barrier	43.1		19.7	
2. Barrier + Bajra husk mulch	45.1		23.8	
3. Mulch only	22.1		14.2	
4. Control	18.2		13.4	
	'F' test	SEm ±	CD 5%	CD 1%
1. Run-off	N.S.	2.52	—	—
2. Barrier and Mulch	Sig.	2.71	8.34	11.7
3. Run-off × Barrier	N.S.	3.83	—	—

Table 2 shows that barrier and run-off concentration were particularly effective only when combined together. This is because in 1974 the kharif rainfall was too low (136 mm) and as such barrier alone did not help much in increasing the moisture storage. Observations made on soil moisture storage revealed that barrier with run-off concentration increased the moisture storage by 20-25% at different rainy spells.

The highest yield of 45 q/ha of *tinda* obtained from the treatment – run-off concentration + barrier + mulch, was quite encouraging for in 1974 most of the kharif crops – cereals, legumes and oilseeds had failed due to poor rainfall.

In 1975 barrier incorporation below the seed row by digging trenches was also investigated, which resulted in 26% higher yield of *tinda* over the pit incorporation technique.

#### Use of organic amendments for increasing the soil moisture storage capacity :

Studies on the incorporation of organic amendments were started in early 1972. Different amendments viz. FYM, chopped pieces of

*Calotropis* and Tumba cake were tried. *Calotropis* contains latex which it was thought, might improve the aggregation of soil particles and thereby increase the moisture storage capacity. In a field experiment conducted in 1973 sub-surface incorporation of amendments was found to be superior over surface application for both bajra as well as moong crops.

Both *Calotropis* and FYM incorporated in the sub-surface zone resulted in similar yields of bajra and moong crops – 53 and 34 per cent higher over control, respectively.

## 2.2 Reducing the evaporation losses :

**2.2.1. Use of organic mulches :** Studies carried out on some organic mulches like bajra husk, grass and wheat straw, have indicated that use of mulches considerably influences the micro-climate of the area on which they are applied, by changing the distribution of radiant energy and maintaining proper soil thermal regime, as well as by preventing losses of moisture due to excessive evaporation.

Experiments on the use of *bajra* husk mulch during kharif seasons of 1973 and 1974 and wheat straw and grass mulch during kharif 1975 showed that these organic mulches maintained a high moisture regime in the soil profile (for more than 30 days after application). During kharif 1974 when the seasonal rainfall was low (136 mm) the moisture content in the mulched plots 20 and 30 days after sowing was higher by 13.0 and 9.1 mm as compared to unmulched plots possessing 69.2 and 60.5 mm of moisture, respectively. During kharif 1975 (a good rainfall season) the moisture content was 9 to 14 mm higher in mulched plots as compared to un-mulched plots with 93.9 mm of moisture, even up to 42 days of application of mulch. As a result, there was an increase in the yields of moong (S8) and bajra (HB3) by 9 to 23 per cent and 12 to 30 per cent, respectively.

Mulches were also found to maintain an uniform thermal regime conducive to plant growth in the soil surface zone. Studies conducted with bajra husk mulch during winter 1972 showed that mulches not only maintained an uniform and higher thermal regime (21.6 to 23.2°C) in the sub-soil (at 5 cm depth) as compared to uncovered soil (16.0 to 21.8°C), but also reduced the fluctuations of diurnal temperature to a minimum (0.3°C as against 4.1°C under bare soil conditions). However, during summer and monsoon seasons, when soil temperatures are high for crop establishment, mulches like wheat straw were found to lower down sub-soil thermal regime by 7.8°C as against the bare soil conditions (41.0°C).

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## Crops and Varieties for Dryland Agriculture

Millets, pulses and oilseed crops form bulk of the crops grown under rainfed conditions in our country. A critical examination of most of the currently cultivated varieties of these crops on drylands of Western Rajasthan reveals that they have been selected for their ability to survive atmospheric and soil drought rather than for productivity. They are poor yielders with a prolonged vegetative growth and hence do not fit into the rainfall pattern of the region. The attributes necessary for survival are not necessarily the same as those essential for productivity. Thus, due to lack of adequate efforts to dovetail the plant breeding programmes with the other improvements in dryland agriculture in the past, the individual practices developed by the scientists for moisture and soil conservation have not found wide adoption because of their marginal impact on productivity. The high yielding varieties of crops developed in the past decade have provided a silver lining to the otherwise dark picture of dryland agriculture. Despite their excellent yield potentials and favourable developmental and maturity patterns, these crop varieties need suitable modifications to fit into the conditions prevailing on drylands. Considering the low and erratic rainfall and a short season of crop growth in Western Rajasthan, it has been observed that crop varieties to be grown on these drylands, should possess a considerable degree of tolerance to drought conditions, earliness of maturity and high yield potential in order to obtain consistently a high level of production. In other words, apart from a good measure of drought tolerance and earliness of maturity, a crop variety should possess a balanced combination of sink capacity and grain weight in order to result in consistent level of production under moisture stress conditions.

In view of the above considerations, efforts were made to identify suitable varieties of *moong (Vigna radiata)*, cowpeas (*Vigna*

*unguiculata*), til (*Sesamum indicum*), guar (*Cyamopsis tetragonaloba*), castor (*Ricinus communis*) and sunflower (*Helianthus annuus*), so that they can successfully fit into the cropping season and yield consistent returns, at the same time providing for a balanced diversification of crop cultivation.

### 3.1 Crops and varieties for conditions of normal monsoon :

**Moong (*Vigna radiata*) :** Among a wide range of *moong* varieties studied, variety S8 has been found to be promising. This variety has consistently out yielded the variety RS4 recommended by the Department of Agriculture, Rajasthan. S8 possesses a semi-compact plant type which gave an average 11.4 q of grain yield per hectare over a period of three years (1973-1975), taking around 65 days to mature, whereas RS4 variety, a spreading plant type, gave around 9 q of grain yield per hectare taking around 84 days to mature. Even in kharif 1974, a season characterised by acute drought, S8 gave an yield of 0.97 q/ha, as against 0.5 q/ha obtained from RS4. Root studies revealed that S8 possesses a deeper root system (28.7 cm) than RS4 (24.8 cm). Variety S8 showed a higher moisture use efficiency (5.7 kg/ha/mm) than RS4 (3.6 kg/ha/mm).

**Cowpeas (*Vigna unguiculata*) :** Variety FS68 of cowpeas possessing a compact plant type with pods coming out of the plant canopy has shown promising performance, giving an average grain yield of 11.5 q/ha, maturing in 70 days, as against 6 q/ha obtainable from JC10, a standard variety of a longer duration. Another promising variety is K11, with a compact plant type and an yield potential of around 10 q/ha, maturing in 75 to 80 days.

**Til (*Sesamum indicum*) :** T13, a branched and early maturing variety has been recommended for cultivation in Western Rajasthan. This variety gave an average yield of 6.5 q/ha, maturing in 80 days. Another variety, Var4-2 a branched plant type maturing in 85 days has been found to yield 7.0 q/ha. Both the varieties are white seeded.

In the year 1975 it was observed that the variety N32 (2.40 kg/ha/mm) and variety 4-2 (2.27 kg/ha/mm) showed a higher moisture use efficiency than T13 (1.80 kg/ha/mm).

**Guar (*Cyamopsis tetragonaloba*) :** Most of the existing varieties of *guar* are of long duration, taking more than 110 days. "Durgapura Saffed", a branched variety with an average yield potential of 5-7 q/ha, is recommended by the Department of Agriculture, Rajasthan. A single stemmed variety FS 277, maturing around a week earlier than Durgapura Saffed was also observed to be equally promising. 2470(12) and



4210(26) two branched selections, taking around 120 days to mature, have been found to be superior to FS277 and Durgapura Saffed in their yield potential. They yielded around 17 to 18 q of grain per hectare in 1975 as against 13 and 12 q/ha from Durgapura Saffed and FS277 respectively. Another more promising variety KVS1, with a compact plant type, tending towards a vegetable type with early maturity has yielded 20.1 q/ha in 1975 against 18.7 q/ha from 2470(12), 18.5 q/ha from Durgapura Saffed and 17.7 q/ha from FS277.

The moisture use efficiency of 2470(12) was found to be higher (4.96 kg/ha/mm) than that of FS277 (3.03 kg/ha/mm) or Durgapura Saffed (3.29 kg/ha/mm) in the year 1975.

**Castor (*Ricinus communis*)** : Although perennial castor is being grown on the field bunds in Western Rajasthan, annual castor crop is a new introduction to this region. Short duration annual castor varieties have shown a remarkable adaptability to the drylands of Western Rajasthan. Among a wide range of plant types tested, Aruna and Gujarat castor hybrid-3 (GH3) have shown promise for the region yielding on average around 10-12 q/ha, maturing in 130-140 days.

The results obtained over a period of two years (1973 and 1975) indicated that R-63 variety had higher yield potential as compared to Aruna and GH3. The moisture use efficiency in the case of R63 (5.5 kg/ha/mm) was also observed to be higher than that of Aruna (4.9 kg/ha/mm) or GH3 (4.5 kg/ha/mm) in the year 1975.

**Sunflower (*Helianthus annuus*)** : Like castor, sunflower is also a new introduction to the drylands of Western Rajasthan. It carries a much higher oil production potential (803 kg/ha) as compared to groundnut (326 kg/ha) and *til* (220 kg/ha) under rainfed conditions. This crop has an added advantage of being photo-insensitive and as such can be sown early or late depending on the onset of monsoon. Although no significant differences in yield have been observed among different varieties tested, variety EC68414 gave consistently higher average yields of 7 q/ha, maturing in 80 days (Fig. 1). The disadvantage associated with this crop is the enormous intra varietal variation for head size, seed filling, maturity and vigour. The present level of performance of sunflower varieties could be very much enhanced, provided the population performance could be improved and defective seed filling rectified.

### **3.2 Crops and varieties for conditions of delayed onset of monsoon :**

Very often, adequate rains to saturate soil profile (125 mm) are received late in July or in August. Such situations were found to



Fig. 1. Sunflower—a promising crop for drylands

occur in 37 years out of 75 years. In addition to this the delayed onset of monsoon is of common occurrence (once in 4 years) in this region. Hence, it is necessary to identify crops and varieties which can give remunerative yields under such conditions.

The experiments have shown that while *bajra* and *til* fail totally under conditions of late onset of monsoon, crops like *moong*, cowpeas, castor and sunflower could give remunerative yield levels.

Varieties S8, S9, and RS4 of *moong*, K-11 of cowpeas, Aruna and R63 of castor and EC68414 of sunflower are capable of yielding around 4 to 5 q/ha, under such conditions.

### 3.3 Moong breeding :

Work on varietal improvement of *moong* has been rather limited as compared to other dryland crops such as *sorghum* and *bajra*. Availability of limited genetic variability for important yield components such as pod number per plant, may be one of the reasons in this regard. A programme of mutation breeding was therefore, taken up in 1971 with a view to isolating mutants with high pod number, at the same time possessing tolerance to drought conditions prevailing on the drylands of Western Rajasthan.

Out of the ten promising mutants isolated from the M2 generation of EMS treated seeds of RS4 variety, only M16, M8 and M10 mutants out yielded RS4 and S8 varieties in kharif 1973, when rainfall quantum and distribution were favourable. However, under acute drought conditions of kharif 1974 (rainfall : 136 mm), only the mutant strain M8 significantly out yielded RS4 and S8 varieties. Even in kharif 1975, the mutant M8 significantly out yielded both the check varieties. This mutant is a semi-spreading plant type, maturing in 66 days, giving an average yield of 13.4 q/ha. It can be seen from the Table 3 that the

TABLE 3

Performance of M8, S8 and RS4 under dryland conditions over a period of three years (1973-75)

Variety	Mean number of days to maturity	Mean number of pods per plant	Number of seeds per pod	1000 seed weight (gm)	Mean grain yield (kg/ha)
M8 (mutant)	66	16	10.2	33.0	1340
S8	65	12	9.6	32.4	1138
RS4 (parent)	84	9	8.5	36.9	888

mutant matured earlier than the parent by 18 days, at the same time yielding over 50% more than the parent. The number of pods in the case of the mutant was almost double that of the parent. The number of seeds per pod in the case of M8 is slightly more than that of RS4, although there is a reduction in the grain weight of the mutant.

The mutant was found to be comparable to S8 in maturity, but excelled as far as number of pods per plant, seed weight and grain yield were concerned.

### 3.4 Crops and varieties for conditions of limited moisture supply in rabi season :

Due to the absence of monsoon, unirrigated agriculture is hardly possible in *rabi* and spring seasons in Western Rajasthan. Crops like wheat and chillies, whose water requirements are very high, are cultivated in restricted patches, with assured irrigation. The lack of adequate irrigation resources, a tremendous cost involved in lifting water and salinity of irrigation water limit the cultivation of such crops. Thus, there exists a need to identify suitable crops and varieties which can give remunerative yield levels with one or two irrigations.

The studies have revealed that mustard or *raya* (*Brassica juncea*) and safflower (*Carthamus tinctorius*) crops are efficient utilizers of limited moisture supply, resulting in remunerative levels of yield. Of these two, mustard (10-15 q/ha) was found to be superior to safflower (6-8 q/ha) from grain yield point of view. Whereas a wide variability for yield and yield components was observed among different genotypes of mustard under conditions of limited water supply, the varieties of safflower studied exhibited an uniform degree of yield potential.

**Mustard :** An examination of a wide range of *raya* varieties indicated that for conditions of short duration winter (130 days) and limited moisture supply (2 irrigations of 35 mm each) of Western Rajasthan, varieties possessing a high degree of yield potential and earliness of flowering would be the answer, as they can give higher seed yield maturing before the onset of hot weather spell falling in the second week of March. Variety KYSR (Kanpur Yellow Seeded Raya) has been found to be one such, as it took 45 to 50 days to flower and around 100 days to mature, resulting in a mean yield of 14 to 15 q/ha, when given only two irrigations.

The promising varieties of the next order have been found to be KB-1, BR-40 and T59 which yielded around 10-11 q/ha on average, maturing in 110 to 115 days. All the above mentioned varieties were

found to be superior to RL18, recommended by the Department of Agriculture, Rajasthan.

### Genetic variability for Nitrogen fixation in moong :

Studies carried out in a wide range of *moong* plant types indicated that there exists variability for Nitrogen fixation in this crop. Further investigations in this direction are in progress.

### 3.5 Improved crop varieties for drylands of Jodhpur tract :

Crop	Variety	Duration (days)	Yield† (q/ha)	Salient features
Moong	S8	60-65	10-12	Semi compact, Profuse bearing
	M8	60-65	13-15	Semi spreading, Profuse bearing
Cowpeas	RS4	70-75	7-9	Spreading type
	FS68	65-70	10-12	Compact plant type, profuse bearing, pods protrude out of leaf canopy, shattering of pods at maturity
Guar	K-11	70-75	10-11	Compact plant type
	JC-10	80-90	6-8	Spreading type
	KVS1	85-95	18-20*	Branched
	2470(12)	110-120	8-12	Branched
	FS277	100-105	5-7	Single stemmed
Castor	Durgapura	105-110	5-7	Branched
	Saffed			
	Aruna	130-140	10-12	Dwarf compact type
Sunflower	Gujarat	130-140	10-12	Dwarf hybrid
	Hybrid-3			
Til	EC68414	75-80	6-7	—
Raya	T13	80-85	5-6	Branched, white seeded
	Var 4-2	80-85	6-7	Branched, white seeded
Raya	KYSR	95-100	14-15	Compact plant type, profuse bearing, Synchronous in maturity, suitable for limited moisture supply conditions in <i>rabi</i> season
	T59	110-115	10-11	Medium early, less vegetative
	RL18	120-125	9-10	Late, excessively vegetative

† Mean of 2 to 3 years yield data

\* Based on one year (1975) data only

### **3.6 Crops for conserved soil moisture :**

An analysis of the past 75 years rainfall data revealed that there were 20 years of good rainfall ( $>400$  mm) when conserved soil moisture (80-100 mm) could be used for growing *rabi* crops. Availability of high yielding, short duration, photo insensitive crop varieties, a better knowledge of soil and water conservation measures and improved implements enable us to capitalise conserved soil moisture for crop production. Investigations have shown that raya T59/KB2 sown with the help of lister, with light soil covering on the seeds, resulted in good crop stand leading to reasonably good yields of the order of 6-9 q/ha.

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## Improved Agronomy for Drylands

### 4.1 Crop stand establishment :

On drylands poor crop stand often results due to hard seed coat of certain crops and fast drying out of the upper soil layer after seeding. Suitable pre-sowing seed treatments and optimum seeding depth are the two important factors to be considered in order to obtain a good crop stand and higher yields. Results of the studies carried out on pre-sowing seed treatments revealed that soaking of seeds of sunflowers, safflowers and castor in water for 24 hours before sowing resulted in early seedling emergence and good crop stand. More than 60 per cent seedling emergence was obtained in two days of initiation of emergence in the case of soaked seeds sown at shallower depths (3 and 5 cm in sunflower and safflowers and 5 to 10 cm in castor).

Seeding depth of 5 cm was found to be optimum in the case of sunflowers and safflowers. In the case of castor, on the other hand, 15 cm seeding depth was found to be the optimum, considering the coefficient of velocity of seedling emergence, rooting pattern, yield and moisture use efficiency.

### 4.2 Planting patterns :

Under conditions of acute drought (1974), paired row system of planting annual grain legumes (*moong* and cowpeas) resulted in more than one and one half to two times the grain yields of uniform system of planting. *Cenchrus ciliaris* (358) grass also gave higher green forage yield under the paired row system of planting. Results of the experiments conducted on systems of planting during a good rainfall year (1975) have shown the advantage of paired row system of planting resulting in about 2 q/ha higher grain yield of *bajra* and *moong*.

### 4.3 Fertiliser use :

A few years back it was commonly believed that fertiliser application to dryland crops may prove injurious and as such fertiliser use was not much in vogue. Moreover, the varieties of crops grown on drylands were also not responsive to fertiliser use. With the availability of fertiliser responsive varieties of dryland crops, enormous possibilities of achieving higher yield plateaus with judicious fertiliser use on drylands have now opened.

#### A. Cereals

1. **Bajra** : Under normal rainfall conditions (1971) applications of 40 kg N and 40 kg  $P_2O_5$ /ha to bajra HB3 gave 37 per cent higher grain yield than the unfertilised crop (11.3 q/ha). In good rainfall years (1973), however, fertilised bajra HB3 gave 158 per cent higher grain yield than the unfertilised crop (16.4 q/ha). Based on the mean of two years (1971 and 1972) it was observed that bajra HB3 did not respond to the application of nitrogen beyond 40 kg/ha, the response being 10 kg grains per kg of N. The returns per rupee invested in fertiliser use were of the order of Rs. 2.22 at 40 kg N/ha level.

2. **Jowar** : Although jowar is not the common crop of this tract, it showed comparatively much higher response to the application of fertiliser nitrogen, both in normal and high rainfall years. Application of 60 kg N and 40 kg  $P_2O_5$ /ha to jowar CSH1 resulted in 190 and 150 per cent higher grain yields in normal and high rainfall years than the unfertilised crops (7.3 and 20.4 q/ha) respectively.

Setaria H2 and Cheena (local) also exhibited very high response to the application of fertiliser N (40 kg nitrogen+40 kg  $P_2O_5$ /ha) resulting in 260 and 167 per cent higher grain yields than the unfertilised crops (3.0 and 3.6 q/ha) respectively.

Application of fertiliser has been found to be a paying proposition in the case of cereal crops.

#### B. Grain legumes :

In the case of moong (S12), application of fertiliser @ 15 kg nitrogen and 40 kg  $P_2O_5$ /ha resulted in 100 and 22 per cent higher grain yield during normal rainfall and high rainfall years than the unfertilised crop which gave an yield of 1.2 and 9.7 q/ha, respectively. Based on the results obtained it was observed that application of phosphorus was not an economical proposition in view of low yield potential in normal or low rainfall years and marginal response in high rainfall years.



In years of normal rainfall, application of 15 kg nitrogen+40 kg  $P_2O_5$ /ha to *guar* FS277, although resulted in more than double the seed yield (187%) than the unfertilised crop, it was not found to be an economical proposition due to low yield levels, whereas in high rainfall years, application of fertiliser to *guar* resulted in marginal increase in the seed yield. It was also observed that *guar* did not respond to phosphorus application beyond 40 kg  $P_2O_5$ /ha and application of the same may not be economical due to low response.

#### **Oilseeds :**

During normal rainfall years both under normal and late sown conditions, *till* did not exhibit an economic response to fertiliser application. However, during high and well distributed rainfall years, application of 40 kg nitrogen+40 kg  $P_2O_5$ /ha resulted in 180 per cent higher seed yield of *till* than the unfertilised crop (3.1 q/ha).

Application of 40 kg nitrogen and 40 kg  $P_2O_5$ /ha gave consistently higher seed yield of sunflower (11-77%) over three years as compared to the unfertilised crop. Based on the mean yield data of two years, it was observed that the seed yield increased with the increasing level of nitrogen, but there was a marginal increase in the seed yield with the application of phosphorus. Response per kg of nitrogen was the highest (9.3 kg seed) at 30 kg nitrogen/ha and resulted in maximum returns of Rs. 3.48 per rupee invested in fertiliser use. While in the case of phosphorus levels, response was very low (1.9-2.5 kg/ha of phosphorus) which resulted in negative returns.

Experiment on fertiliser use on castor in the year 1973, showed that there was no significant increase in the seed yield either due to nitrogen or phosphorus levels.

**Fodder crops :** In the case of fodder crops, application of fertilisers either to pure crops of *bajra* or *jowar* or to the mixtures of fodder crops proved beneficial, resulting in 46 to 103 per cent higher fodder yields than unfertilised crops.

**Forage grasses :** Based on the mean yields over (1971-1974) it was observed that the application of nitrogen and phosphorus @ 30 kg per ha resulted in 126.6 per cent increased green forage yield of *Panicum antidotale*, 70 per cent in *Cenchrus setigerus*, 60-68 per cent in *Cenchrus ciliaris* 357 and 358 as compared to unfertilised grasses yielding 36.5, 38.3, 52.6 q/ha, respectively. Among all the grasses, fertiliser use was found to be more paying in the case of *P. antidotale*, irrespective of rainfall distribution patterns. However, fertiliser use in *Cenchrus* sp. seems to be a paying proposition only in normal and good rainfall years.

#### 4.4 Inter-cropping systems for drylands :

Mixed cropping and inter-cropping are in vogue under unfavourable agro-climatic conditions of Western Rajasthan. Crops and varieties grown in mixed stands were mainly selected for their survival value and as such the impact of the mixed cropping or inter-cropping was negligible under these conditions.

##### 4.4.1 Inter-cropping in forage grasses :

There are number of perennial grass species suitable for different soil types and rainfall of Western Rajasthan. However, cultivation of grasses has not become popular due to farmer's preference for grain crops. Preliminary studies carried out at this Institute during 1966-68 have revealed that annual grain legumes like *moth*, *moong* and *guar* are suitable for inter-cropping with the principal perennial desert grasses viz. *Cenchrus ciliaris*, *Cenchrus setigerus*, *Lasiurus indicus* and *Dichanthium annulatum*. With the availability of short duration and high yielding crop varieties and better knowledge of fertilizer use, soil and water conservation measures and planting patterns more remunerative inter-cropping systems can be developed.

Results of the recent investigation indicated that the green forage yield of *Cenchrus ciliaris* 358 was not significantly influenced by uniform or paired row system of planting either in pure or mixed stands. However, paired row system of planting gave slightly higher green forage production than the uniform row system both under pure and mixed stands. Grass yield was not adversely affected by inter-cropping of any of the grain legumes. Among the inter-crops, guar FS277 gave the highest grain yield (10.8 q/ha) followed by moth-local (6.1 q/ha), moong-S8 (3.8 q/ha) and cowpeas-FS68 (3.4 q/ha). However, in years of normal rainfall and early recession of monsoon, moong and cowpeas being short duration crops may perform better than *guar* and *moth*. Further, it is also interesting to note that there were no marked differences in the consumptive use of pure stand of grass (338 mm) and mixed stands of grass+guar (344 mm) but productivity per unit area of water use is much higher (Rs. 12.00/ha/mm) in the latter than the former (Rs. 3.00/ha/mm). It is also advantageous to use legumes as inter-crops with forage grasses, as the nitrogen requirement of the grass could be met with, leading to an appreciable economy in fertiliser use.

##### 4.4.2 Inter-cropping in sunflowers :

Sunflower crop is a new introduction in this region. In order to make the crop more acceptable to farmers an inter-cropping system of

growing annual grain legumes with sunflower has been developed. During good rainfall years (1973 and 1975) inter-cropping of moong (S8) and cowpeas (FS68) did not adversely affect the seed yield of sunflower and gave an additional seed yield of 11 and 13 q/ha, respectively. Although, there were no differences in the consumptive use of pure sunflower and mixed stands, the total productivity was much higher in mixed stands (19.3 q/ha in sunflower+moong and 21.7 q/ha in sunflower+cowpeas) as against only 9.6 q/ha in pure sunflower. Further, it would be interesting to note that although the inter-cropped legumes had half the populations of the pure stand, they gave an almost similar seed yield obtained in pure stand of legumes. In order to maintain productivity of both the crops at high level in the inter-cropping system, fertilizer application @ 60 kg nitrogen + 40 kg phosphorus/ha was found to be necessary.

Studies on inter-cropping of *rabi* crops with sunflowers revealed that inter-cropping, potato, peas, lentil and gram did not affect the sunflower yield adversely, while *raya*, wheat and safflowers reduced the yield of the base crop. Inter-cropping of potato and peas with sunflowers resulted in higher returns and moisture use efficiency.

#### 4.4.3 Inter-cropping in the inter-row water harvesting system :

Among the five inter-cropping treatment combinations viz., *bajra*+*moong*, *til*+*moong*, sunflowers+*moong*, castor+*moong*, grass (*Cenchrus ciliaris*)+*moong*, on flat and in the inter-row water harvesting systems, the principal crops of *bajra* and *til* grown in the ditches of inter-row water harvesting system gave 41% and 30% higher yield as compared to flat system of planting. Regarding the yield of the companion crop (moong) the yield obtained in the flat system was 12% and 64% higher in *bajra*+*moong*, and *til*+*moong* mixtures than that obtained from inter-row water harvesting systems. In the case of sunflowers+*moong*, castor+*moong* and grass+*moong* mixtures, there was almost no difference in the yield of moong between flat and inter-row water harvesting systems.

#### 4.4.4 Inter-cropping of moong and bajra in different systems of planting :

(i) Planting of *bajra* (New HB3) in single, double and triple rows with and without *moong* (S8) indicated that *moong* crop gets suppressed by *bajra*. However, the paired row system of planting *bajra* resulted in the highest grain yield in 1975. The surface soil temperature decreased with the compression of rows, the minimum being under triple row system of planting.

(ii) Sowing of *moong* (S8) in single, double and triple rows with and without *bajra* (New HB3) indicated that, inter-cropping of *bajra* (one row) in double or triple row system of planting *moong* resulted in more than two times the total productivity, gross returns and moisture use efficiency over the conventional single row system of planting.

(iii) Under late sown conditions, triple row system of planting *moong* gave significantly higher grain yield as compared to the uniform, uniform + *bajra*, and triple + *bajra* systems of planting.

#### 4.4.5 Suitable plant types of moong for inter-cropping with forage grasses :

Perennial forage grasses like *Cenchrus* species have an important role in the agricultural economy of arid areas in Western Rajasthan. However, the cultivation of these grasses has not been taken up extensively, as farmers prefer to cultivate grain crops like *bajra* and *moong*. Thus, a system of inter-cropping with grasses such as *Cenchrus setigerus*, which would yield additional quantity of grain without affecting the forage production would be welcome. However, it is known that the crop varieties suited for pure stand need not necessarily be suited for inter-cropping.

Among different plant types of *moong* tested as inter-crops over a period of three years, variety 288-8 gave the highest mean grain yield (3.00 q/ha), followed by RS4 (2.33 q/ha) and T44 (2.08 q/ha) in that order, without adversely affecting the forage yield. These varieties were found to possess relatively a higher number of pods than the rest on the three upper nodes of plant. In addition, the incidence of yellow mosaic virus in *moong* was much lesser in association with forage grass, as compared to pure stands.

#### 4.5 Capitalising good rainfall years :

Under the existing conditions of dryland agriculture the cropping intensity is less than even 100 per cent mainly due to the limitation imposed by low and variable rainfall. Analysis of the past 75 years of rainfall data revealed that there were 18 years of good rainfall when double cropping could be a possibility. This possibility can now be achieved with the availability of short duration, high yielding, fertiliser responsive and photo-insensitive crop varieties.

During kharif 1973 two crops were grown in sequence-short duration fodder crop of *bajra* followed by late sown pulse crops (mung or moth) or castor (*Aruna*), yielding 330 q/ha of green fodder and 4-6 q/ha of seed, respectively. In kharif 1975 two crops were

grown successfully in the All Institute Demonstration leading to a very high productivity per unit area (41 q/ha seed), with bajra HB3 for grain (32 q/ha) followed by *raya* (T59) (9.0 q/ha). These results have clearly indicated that growing two crops under rainfed conditions is feasible in years of good rainfall having more than 400 mm rainfall with extended rainy season provided a correct choice of crop varieties is made, coupled with an appropriate soil, moisture and crop management technology.

#### 4.6 Water harvesting systems for drylands :

Preliminary experiments on the evaluation of water harvesting systems-inter-plot and inter-row, against the conventional system (flat) were carried out for two seasons, kharif 1972 and 1973. Under inter-plot water harvesting system, different ratios of catchment to cropped area viz., 1:1 with slope on one side, 1:1 slope on both sides and 1:2 slope on one side only, were studied. The cropped area was 40m × 3m in each treatment. In case of inter-row water harvesting, a 30 cm wide ditch was alternated with 70 cm wide raised beds (Fig. 2).

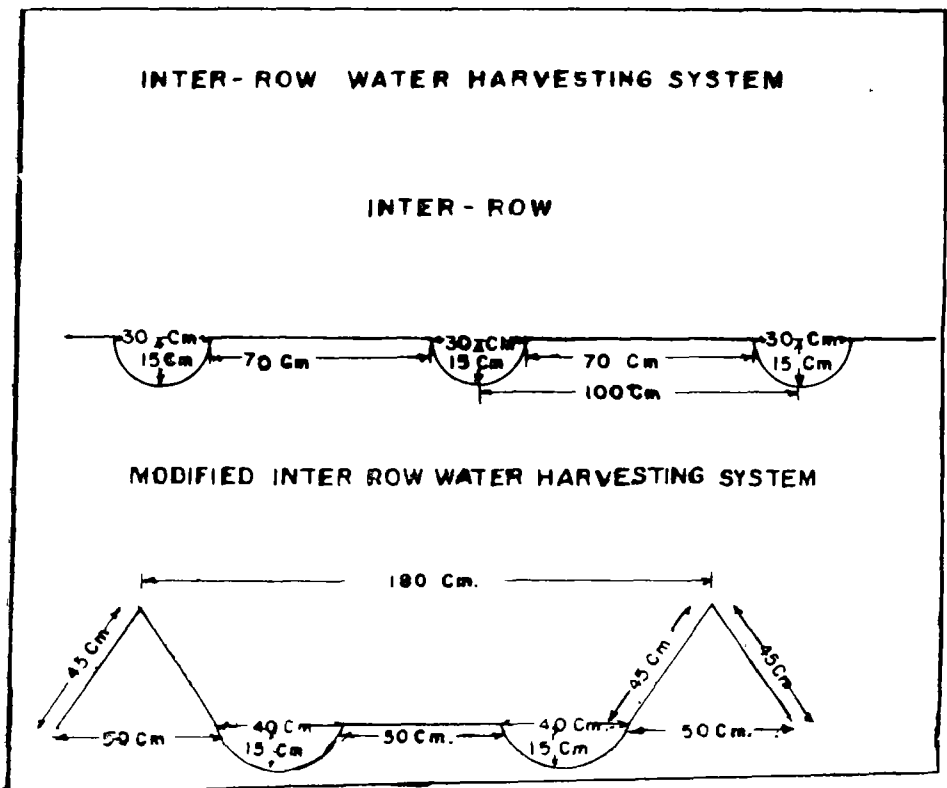


Fig. 2. Inter-row and Modified Inter-row water harvesting systems

Catchment to cropped area ratio of 1:1 with slope on both sides led to the highest grain yield and moisture use efficiency. This was followed by the treatment having catchment to cropped area ratio of 1:1 with slope on one side. All the inter-plot water harvesting treatments showed higher amount of moisture in soil profile initially as well as after four weeks of drought period which was 51 and 20 per cent higher in catchment and cropped area ratio of 1:1 and catchment to cropped area ratio of 1:2, respectively, over the conventional system of planting (flat). However, among the systems of water harvesting, inter-row water harvesting appears to be more practical, feasible and acceptable to farmers, since no land is sacrificed for harvesting water. Thus, full-fledged replicated experiments on water harvesting were taken up in kharif 1975, where the inter-row water harvesting system and modified inter-row water harvesting were tested against the flat system. Modified inter-row water harvesting system (Fig. 2) induced, in general, more run-off than the other two systems viz., inter-row water harvesting and flat. Bentonite application effectively increased run-off in all the systems of water harvesting. The increase in run-off percentage due to bentonite application was maximum in the case of modified inter-row water harvesting system, in general, followed by inter-row water harvesting and flat systems. However, bentonite application was found effective in inducing more run-off in the initial stages only, the effectiveness of bentonite got reduced with each successive rainfall event, the highest being observed in case of modified inter-row water harvesting because of steep slopes provided. Considering the grain yield, though the number of effective tillers was high in the flat systems the corresponding yield per ear was low (3.47 gm/ear), as compared to both inter-row (3.69 gm/ear), and modified inter-row (3.57 gm/ear) systems, thus indicating smaller ear size and lesser number of grains per ear in the case of control.

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## Agricultural Engineering

### 5.1 Tillage practices for bajra (HB3) :

Tillage practices adopted by the farmers of this region are not conducive to uniform crop establishment, consequently resulting in poor yields. An ideal tillage practice should result in uniform initial stand establishment, maximum weed control and should also cover large areas in limited sowing time. Results of the study conducted to evaluate the efficacy of different implements for seed bed preparation have revealed that one sub-surface cultivation with sweep cultivator at the onset of monsoon and again once before sowing resulted in the highest grain yield (12.4 q/ha in 1973 and 17.2 q/ha in 1975). Highest seedling emergence (33.5 per meter row length), highest moisture storage at sowing (81 mm in 90 cm soil profile) and almost complete weed (*Cyperus rotundus*) control and higher MUE (6.5 kg/mm/ha) was obtained in *bajra* with deep discing with heavy duty offset disc harrow, heavy duty mould board plough, and sub-surface cultivation with sweep cultivation, respectively in the experiments carried out in 1975. Use of sweep cultivator also results in coverage of larger area with the same power source.

### Post sowing compaction for better and early seedling emergence :

Investigations on the use of press wheels in the seeding machineries for post sowing compaction have revealed that compaction with narrow iron wheel (5 cm width, 20 cm diameter and 9.0 kg weight) resulted in the highest seedling emergence of mustard and sunflower (83% and 73%, respectively), coupled with the lowest coefficient of variability (20-30%). Post sowing compaction also resulted in the highest coefficient of velocity of seedling emergence.

## 5.2 Evaluation of sowing methods and seeding machinery :

Results of the study conducted to evaluate the efficacy of different seeding machinery models have revealed that sowing with drill having hoe type furrow openers and on the row press wheels can lead to higher grain yields as compared to disc type furrow openers (IHC 510 drill).

## 5.3 Bullock drawn seed-cum-fertiliser drill developed :

A bullock drawn seed-cum-fertiliser drill for sowing of *bajra*, mustard, *mung*, *jowar*, wheat, safflower, sunflower and castor has been developed. The drill consists of a compound seed-cum-fertiliser hoe type furrow opener for band placement of fertiliser with provision for controlled depth of sowing. Replaceable disc with agitator type metering device fixed in hopper facilitates setting of drill for different crops in very short time. A dual purpose press wheel for post sowing compaction and for easy transportation has been provided. The drill can be adjusted to suit bullock pairs of different sizes (Fig. 3).

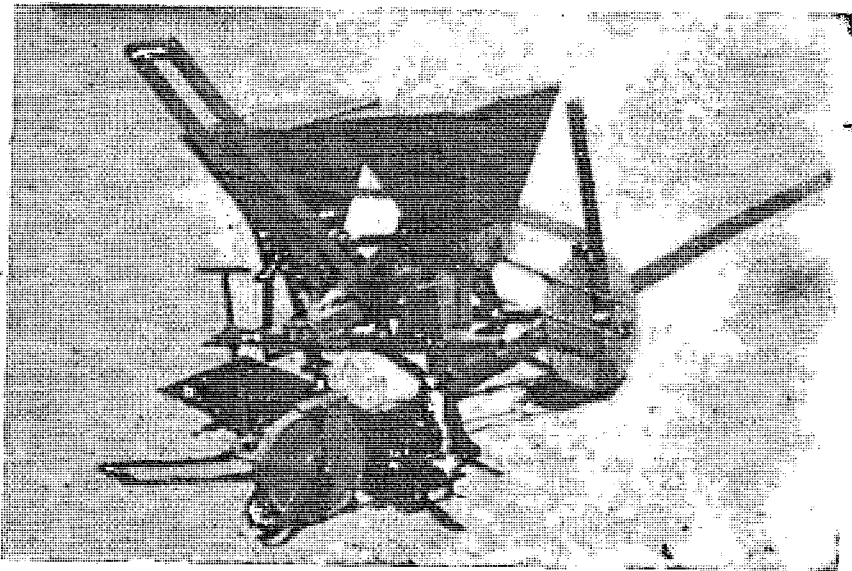


Fig. 3. A bullock drawn seed-cum-fertiliser drill

Depending on the type of crop, sowing in 0.5 to 0.7 ha can be carried out in 10 hours day with this drill. This seed-cum-fertiliser drill costs Rs. 220/-, the lowest price of any drill so far available in the market.



## Summary

Jodhpur is a region of low rainfall receiving 366 mm; most of which is confined to *kharif* (July to September) only. The normal dates of onset and withdrawal of monsoon are 1st July and 15th September, respectively thus restricting the period of moisture availability to 77 days and the mean number of rainy days during the cropping season to 21 only. The various rainfall situations encountered in this region include normal and good rainfall years occurring in one out of two years (48% probability), which are to be capitalised to tide over the years of deficient rainfall (52% probability). One out of four years are quite favourable for double cropping (24% probability), whereas late onset of rains is also possible in one out of four years (27% probability). On the other hand the probabilities of occurrence of prolonged (3 to 4 weeks) drought at seedling stage and flowering and grain formation stages are 20% and 40%, respectively.

Under such conditions it is only through selection of suitable crops and varieties possessing earliness of maturity fitting into the rainfall pattern of the locality, high yield potential and tolerance to conditions of drought, developing appropriate techniques of water harvesting, moisture conservation and management, fertiliser use and planting systems and use of suitable machinery for seeding, dovetailed to variations in agro-meteorological conditions, it would be possible to maximise crop production in years of good rainfall and stabilise in the years of deficient rainfall.

Among various crops and varieties, apart from NHB3 of *bajra*, S8 and M8 (mutant of RS4) of *mung*, FS68 of cowpeas, var4-2 and T13 of *til*, 2470(12) and 4210(26) of *guar*, Aruna and GH3 of castor and EC68414 of sunflower showed promise for the drylands of this region. It has been found that while *bajra* and *til* fail totally under conditions of late onset of monsoon, crops like *mung*, cowpeas, castor and sunflower could give remunerative yield levels. Varieties S8, S9 and RS4 of *mung*, K11 of cowpeas, Aruna and R-63 of castor and EC68414 of sunflower have been found to be promising in this regard.

Use of bentonite as a barrier placed 75 cm deep in pits to prevent losses of moisture due to deep percolation, coupled with a run-off concentration by micro-catchment enabled successful cultivation of vegetable crops like *tinda* on drylands even under conditions of scanty

rainfall. Organic amendments like chopped pieces of *Calotropis procera* and FYM have been found to enhance the water holding capacity and aggregation of these soils as reflected by the yields of *bajra* and *mung* crops.

Soaking of seeds of sunflower, safflower and castor in water for 24 hours before sowing has been found to result in early seedling emergence and good crop stand. Seeding depth of 5 cm for sunflowers and safflowers, and 15 cm for castor have been found to be optimum. A paired system of planting has been found to result in higher yields as compared to uniform system of planting in drought years, in the case of grain legumes, *bajra* and *Cenchrus ciliaris*. Application of 40 kg N/ha to *bajra* crop and 40 kg N+40 kg P<sub>2</sub>O<sub>5</sub> to sunflowers resulted in significantly higher grain yields. Unlike grain legumes, application of fertilisers has been found to be beneficial to fodder and forage crops irrespective of quantum and distribution of rainfall.

Inter-cropping of annual grain legumes like *mung*, cowpeas, *moth* and *guar* with perennial forage grasses, and inter-cropping of *mung* and cowpeas in sunflowers resulted in enhancing productivity without impairing the yields of principal crops. Inter-cropping of *bajra* in double or triple row system of planting *mung* resulted in more than two times the total productivity than the uniform system of planting. Varieties of *moong* such as 288-8, RS4 and T44 possessing a higher number of pods at the upper nodes of the plant have been found to be better suited for inter-cropping with forage grasses. Good rainfall years can be capitalised by increasing the cropping intensity following a sequence of *bajra* or *jowar* (fodders) and *mung* or *moth* or castor. Also it appears possible to take a crop of *raya* and safflower on residual soil moisture after *bajra* and *mung*, respectively. Water harvesting systems like, inter-plot method of water harvesting with a catchment to cropped area ratio of 1:1 with slope on both sides, inter-row method of water harvesting and modified inter-row method of water harvesting have been found to enhance yields of *bajra* by providing additional moisture as compared to flat system of planting. Modified method of inter-row water harvesting induced more run-off than the rest. In a good rainfall year, the yields of succeeding crop of *toria* were higher in the modified inter-row and inter-row water harvesting systems as compared to flat system.

A bullock drawn seed-cum-fertiliser drill consisting of a compound seed-cum-fertiliser hoe type furrow opener for band placement of fertiliser with provision for controlled depth of sowing has been fabricated. A replaceable disc with agitator type metering device fixed in hopper facilitates setting of drill for different crops in very short time.