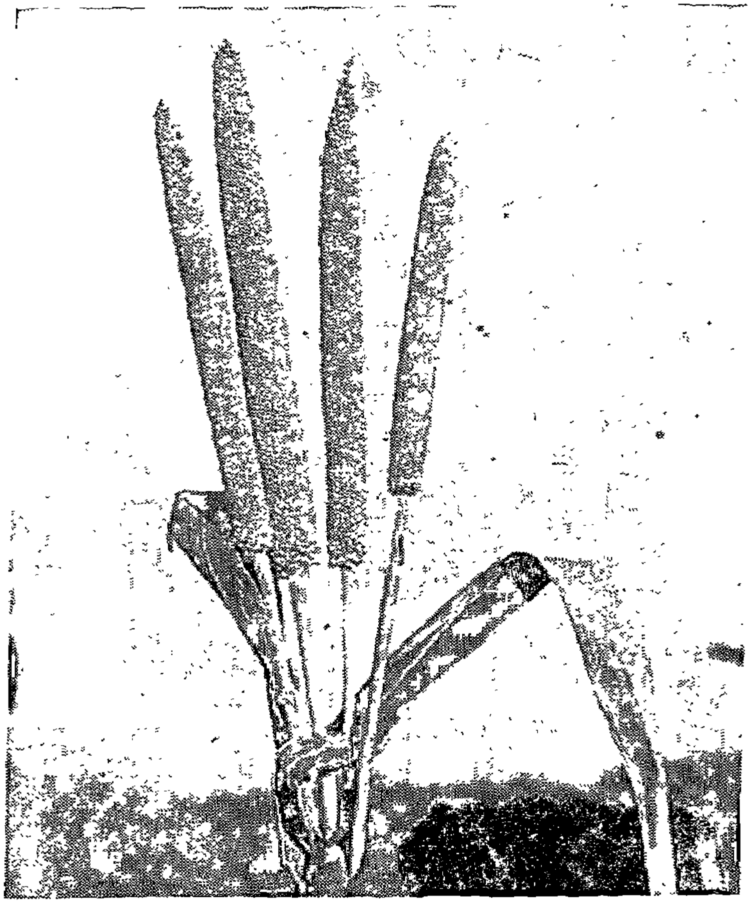
# PEARL MILLET IN ARID ZONE

## A RETROSPECT



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# Introduction

The arid regions of India, spread over 3.2 lakh sq km, account for 12% area of the country. Western Rajasthan alone carries the onus of nearly 62% of arid area. This part of the Indian arid zone is the most thickly populated desert in the world. With over-exploited meagre natural resources, it has a predominantly agrarian base. Farming is almost entirely rainfed. The annual rainfall in the area is precarious (150-400 mm) besides being too aberrant, having coefficient of variability between 40-70 %. Even the onset and recession of monsoon play 'hide and seek' leaving the farmer in the lurch. The monsoon season is characterised by frequent and intemittent droughts. The high solar incidence (450-500 cal/cm$^2$/day), coupled with relatively high wind velocities(10-20 km/h), causes high potential evapotranspiration (6mm/day). The soils, mainly loamy sands (85-90% sand) have low fertility, poor microbial activity and low organic matter content (0.1-0.25 %). Moreover, these soils have a very high infiltration rate (9-10 cm/h) and poor moisture storage capacity(120-135 mm in 1.0 m soil profile) and create a very gloomy scene of poor moisture availability for growing plants. Perhaps in no other habitat plants are subjected to such rigors of fluctuating weather and adverse edaphic conditions as in the arid regions.

Despite all this, pearl millet has continued to be the singular predominant cereal widely grown in these regions. This crop has amazing qualities to withstand long drought, higher moisture utilization efficiency and capacity to extract moisture from deeper soil profile. It also has an excellent photosynthetic mechanism ensuring efficient transfer of energy from leaves to grains. The grains have high nutritive value and form the staple food of the hard working robust people of arid regions. In 1950's it was cultivated in nearly 3 m ha area, constituting about 80 % of the total area of pearl millet cultivation in Rajasthan. But, the average productivity was merely 188 kg/ha against the state and country averages of 215 kg/ha and 310 kg/ha, respectively. Obviously, therefore, research efforts were initiated in the late 50's to meet two diametrically opposite objectives; firstly, developing technologies and management practices to ensure satisfactory yields in below normal rainfall and drought years and, secondly, to obtain the best yields in good rainfall years Considerable research has since been accomplished and published in various scientific journals. Despite all the voluminous research work, pearl millet yields still reel under unstability, largely due to several production constraints like the diseases, lack of resistant cultivars and a lack of region specific production technologies. Most of our farmers cannot afford high cost inputs and yield stabilization needs to be achieved only through suitable cultivars and appropriate management practices. There still exists a large gap between attainable and attained yields. Scientists are continuing their efforts in this direction.

At Central Arid Zone Research Institute (CAZRI), researches on various aspects of pearl millet production have continued for the last three decades and there is no parallel work done on this crop under arid conditions in India. In this publication, an attempt has been made to comprehensively review the entire research work carried out at CAZRI on all aspects of this crop for the benefit of research workers and subject matter specialists concerned with the production technologies of pearl millet.

# Crop Improvement

**Genetic improvement**

Pearl millet, in arid areas, suffers from twin problems of unstable and low productivity Work on genetic improvement of pearl millet was, therefore, initiated in 1972 with dual objectives of achieving stability in production under unfavourable seasons and enhancement of productivity per unit area during favourable seasons. Local germplasm from three districts of Barmer, Jaisalmer and Jodhpur was collected and grouped using metroglyph analysis. It was found that material from Barmer and Jaisalmer districts was early to medium in maturity whereas Jodhpur germplasm had both the types. The Barmer germplasm was found to be yielding higher than that collected from Jaisalmer and Jodhpur. Studies on different germplasm, were also conducted with regard to adaptability, divergence and relative contribution of different components to the divergence. Multivariate analysis showed wider adaptability of the populations collected from Barmer which was characterized with early flowering and maturity, higher tillering and yield potential (Saxena and Subba Rao 1980).

Besides population improvement programmes, efforts to develop hybrids were also made at CAZRI. The stability of male sterility in female parents is one of the important pre-requisites for hybrid seed production. Studies on break-down of male sterility in male sterile lines revealed significant positive correlation with temperature and negative correlation with relative humidity, suggesting rise in percentage of pollen shedders with a rise in temperature and lowering of humidity (Saxena and Chaudhary, 1977). In arid areas, the temperature invariably remains high during flowering time and, therefore, the authors opined that it will be risky to take up hybrid seed production programme in such areas. Chaudhary *et al.* (1981) observed that pearl millet populations were more stable for yield vis-a-vis hybrids under existing conditions.

The selection criteria for yield improvement in pearl millet were developed using the cause-and-effect relationship. Grain yield had significant and positive association with plant height, tillers per plant and ear weight, whilst it showed negative association with days taken to ear emergence (Manga *et al.*, 1985a). Synchrony of ear emergence showed a positive significant association with ear girth, ear weight and yield per tiller, but it showed no relation with grain yield per plant (Manga and Saxena, 1985), revealing that simultaneous improvement for higher synchrony of ear emergence and manifestation of characters (ear girth, ear weight and yield per tiller) could be realized. Good possibility of genetic improvement through selection was indicated for synchrony of ear emergence (Manga and Saxena, 1986a).

The root traits of pearl millet assume great importance in the arid zone where the crop is grown rainfed under limited soil moisture conditions. The nature and magnitude of gene action for root and related traits studies in a diallel cross involving five inbreds revealed the importance of both additive and dominant gene action,with predominance of the latter, for nitrogenase activity of the roots (Manga *et al.*, 1985b). This clearly revealed the possibility of improvement of nitrogenase activity through selection for early plant types with small ears. In another study, the preponderance of both additive and non-additive gene action for dry root weight was observed Non-additive genes were predominantly involved in the expression of root length, root number, dry shoot weight and total dry matter (Manga and Saxena, 1986b). However, additive and non-additive genes played important role in the expression of non-symbiotic nitrogen fixation in pearl millet under existing rainfed conditions of this region.

### *Performance of genotypes*

Role of elite germplasm is as important as any other input for increasing production The yield of a crop can be increased considerably by adopting improved varieties Suitability of a variety may vary with planting time. However, it should be fast growing in nature, responsive to inputs, especially fertilizers, under favourable as well as unfavourable environmental conditions. A variety may not be suitable in all the situations. For instance, the variety RSK performed better than others during early sixties but later on it was replaced by hybrids like HB 1, HB 3, etc. In mid seventies, BJ 104 replaced all other recommended varieties. Contribution of improved varieties or hybrids towards higher production was considered to be significant. In a study conducted by Misra *et al.* (1966), the hybrid HB 1 gave 6% higher grain yield than the variety RSK (Table 1). Daulay *et al.*(1978) also reported better yields of hybrid than local varieties.

Table 1. Comparative study of local and improved variety (Misra *et al.*, 1966).

| Varieties | Ears/plant (no.) | Ear length (cm) | 1000 grain weight (g) | Grain yield (kg/ha) |
|---|---|---|---|---|
| HB 1 | 4.0 | 25.2 | 4.684 | 3522 |
| RSK | 1.5 | 33.8 | 5.138 | 2080 |
| LSD (5%) | 1.1 | 4.2 | 0.300 | 552 |

# Tillage and land preparation

Tillage is not only necessary to prevent or to reduce competition by weeds for moisture, nutrients and light but also to bring about optimum tilth and soil physical environment conducive to proper germination and crop-stand establishment. Soil type is the main factor to determine the kind and the level of tillage operation for field preparation. Characteristics of soils of western Rajasthan have been studied in detail as a part of integrated survey carried out by the institute (Dhir, 1977). Light brown sandy soil (64 6%) was reported as major soil type in the arid region. Brown light loams, grey brown loams, soil with hard pan, sierozems, alluvial soil with dunes and other soil types occur in pockets and occupy 1.7, 13.6, 5 9, 1.6 and 6.8% of the area, respectively.

Light soils require comparatively lesser tillage than heavier soils. Soils with hard pan may require deep tillage for proper crop growth. Studies on preparatory tillage showed that one sub-surface cultivation with a sweep at the onset of monsoon and again prior to sowing was conducive to good crop stand and higher yield of pearl millet (Mann and Singh, 1978). Almost complete control of *Cyperus rotundus* was achieved using a mould board plough for seed bed preparation. Yadav and Singh (1978) recorded the highest yield of pearl millet (36 q/ha) with one deep ploughing followed by one cross harrowing of the field. To evaluate the possibilities of minimun tillage for pearl millet, the plough plant seeding and bed preparation by varying degrees of tillage were compared (Singh *et al.*, 1973). Though plough plant seeding gave grain yield statistically similar to the plots with more tillage, yet, a trend of higher yield was shown by plots receiving two preparatory ploughings. Detailed studies confirmed that seeding after field preparation through harrowing was better than plough plant seeding (CAZRI, 1978a). In plough plant method, higher weed population (344%) and more weed dry weight (243%) as compared to one shallow preparatory tillage caused intense competition for water and nutrients to the pearl millet and consequently resulted in low yields.

Tillage requirement for pearl millet production has been a rapidly changing concept. If weeds could be controlled through chemical means, the practice of plough plant seeding could be advocated or else, one preparatory tillage would be a minimun requirement for satisfactory harvests from pearl millet in light arid zone soils.

# Crop stand establishment

### Time of sowing

Pearl millet is generally sown with the onset of monsoon and seeding is the common practice. However, better results with seed sowing could only be obtained if the rain sets in time (from last week of June to mid-July). Drastic yield reduction has been reported in delayed sowing (CAZRI, 1978d). In delayed condition (after mid-July), transplanting of 21-25 days old seedlings resulted in 22-36% higher grain yield than direct seeded pearl millet (Singh, 1978). For such conditions, transplanting, although labour intensive, has been found to be a superior technique giving reasonably good yield in the years of low or subnormal rainfall. In good rainfall years also, transplanting resulted in more than 30% increase in grain yield over direct seeded crop (1860 kg/ha) planted in the third week of July (Mann and Singh, 1978).

Misra *et al.* (1966), in a laboratory study, reported differential germination response of pearl millet varieties under varying temperatures. The cultivar JJN germinated better at higher temperature and, therefore, was found suitable for pre-monsoon sowing. The dry sowing (pre-monsoon sowing) was reported to be practicable for soils which are not prone to crust formation (CAZRI, 1982). For normal sowing conditions, BJ 104 was found suitable while CM 46 was better for late sowing (CAZRI, 1980).

Plant population per unit area also depends upon the sowing conditions. Under normal sowing, grain yields were similar with different plant populations whereas under late sown condition (transplanted crop), significantly higher yield was obtained with higher plant population (CAZRI, 1977).

### Method of sowing

Two methods of seeding, i. e., *kera* (sowing behind plough) and *pora* (drilling behind plough) are commonly practised for sowing pearl millet, and the latter has been found to be better than the former as, in *pora* method, intimate contact of seed with moist soil and optimum seeding depth are ensured (Singh, 1984). Different makes of tractor-drawn seed drills found large scale adoption for sowing millets. Light planking after drilling the seeds is also a common practice. Yadav (1977) reported that use of packer was advantageous for adequate germination and crop stand establishment. Sowing with seed drill having hoe type furrow openers and on-the-row press wheels has been found to result in a uniform stand leading to higher grain yield of pearl millet compared to using disc type furrow openers (Table 2).

**Depth and rate of seeding**

Adequate plant stand is the first requisite for successful crop production. The primary factors that influence stand establishment are depth and rate of seeding. In arid regions, proper moisture in seeding zone at times becomes the limiting factor for establishment of a good crop stand. Placement of seed at a proper depth would ensure environment conducive to uniform germination. A four-year study (Misra and Vijay Kumar, 1963) showed that the seed placement at 7.5 cm gave the best response in terms of seedling emergence and grain yield, followed by 5.0 cm depth. Use of of 3.36 kg/ha seed gave higher yields than lower or higher seeding rates (CAZRI, 1961). Misra *et al.* (1966) reported variation in germination owing to size of the seed. They screened five varieties (RSK, RSJ, Chadi, T 55 and JJN) with a range of test weight (0 40 to 0.73 g/100 seeds) for germination capability. The medium size seeds (with a mean test weight of 0.62 g/100 seeds) gave the highest germination (93.1%) while the lowest germination (82.1%) was recorded with small seeds. The large and medium size seeds showed equal germination capability.

**Spacing**

Spacing determines the area available to each plant and, consequently, the level of competition for all natural and applied resources between and within the plants. In arid areas competition for moisture is relatively more severe. A preliminary study showed that 45 cm row spacing was optimum (CAZRI, 1961). In another study, 30 and 45 cm spacings gave significantly higher yield than 60 and 75 cm spacings in a normal rainfall year (CAZRI, 1983 a). It is generally believed that a wider spacing may be more

Table 2. Effect of seeding machinery on seedling emergence, coefficient of velocity of emergence and grain yield of pearl millet (Yadav, 1977).

| Treatment | Final emergence (no./metre row length) | Coefficient of velocity of emergence (%) | Grain yield (kg/ha) |
|---|---|---|---|
| Shovel type drill | 11.3 | 22.9 | 828 |
| Shovel type drill with narrow iron press wheel | 23.1 | 23.8 | 950 |
| Disc type drill | 3 0 | 33.2 | 410 |
| Disc type drill with semi-pneumatic press wheel | 8 0 | 27 5 | 1059 |
| Hoe type drill with 'V' shaped solid press wheel | 26.0 | 30.3 | 1195 |
| LSD (5%) | 5.2 | | 234 |

advantageous than narrower ones under moisture stress situation. In a closer spacing, manual weeding is easier than tractor mounted cultivator as operation of tractor is difficult in closer spacing.

**Control of surface crust**

Thin crust formation on the soil surfce is a common phenomenon observed on arid soils. The impact of rain on exposed soil causes structural break down. The dispersed finer fractions of soil deposit on soil surface as well as move downwards with percolating water and impregnate the soil pores. The consequent rapid drying of soil, owing to high radiation intensities available in arid areas, results in surface crust formation. These crusts cause mechanical impedence to the emerging seedling and often result in very poor plant stands or total crop failures Crust is thus a serious problem in the arid zone. Some methods for minimising crust impedence to seedling emergence have been evolved at CAZRI Application of farm yard manure (FYM) on the seeded row after sowing was found helpful in reducing crust strength from 0.74 kg/sq cm to 0.33 kg/sq cm (CAZRI, 1976). Joshi (1987) studied pearl millet seedling emergence under naturally crusted arid soils for four consecutive years. These studies revealed that application of FYM over seed furrows reduced the crust strength to 49 KPa on 3rd day and 69 to 74 KPa on 7th day after sowing as compared to 108-128 KPa on 3rd day and 162-172 KPa on 7th day under drill sowing (Fig. 1). The lower crust strength with FYM allowed higher rate of emergence and greater ultimate emergence with low mean period of emergence (Table 3). The FYM over seed furrows firstly reduced the beating effect of rain drops and thus caused lesser breaking of aggregates. Secondly, FYM being amorphous in nature, absorbed more rain water besides its mulching effect and kept 2.26% higher moisture content of the surface layer Other methods such as use of pearl millet husk as mulch (CAZRI, 1976) and mixing of legume (greengram) seeds with pearl millet seeds (Joshi, 1987) have also been found satisfactory for securing better plant populations and final yields in crusted soils.

Adverse effects of crust could also be minimized by sowing the crop in furrow in ridge-furrow system of land preparation. Ridge-furrow system laid out in N-S direction or with 25° diversion either in west or east (NW-SE or NE-SW) was effective to combat crust problem as it reduced wind action and lowered the soil temperature to result in reduced soil surface drying rate by 25% to 35% (Singh, 1984) Joshi (1987) reported that the success of ridge-furrow system of land preparation was largely dependent on compactness of ridges. The dislodging of loosely packed ridges on light arid zone soils due to high rain intensity after sowing resulted in poor emergence and low yields in two out of four years of study. Packing after sowing offers promise to overcome this problem. Yadav and Singh (1978) reported beneficial effect of packing wheels attached to seed drills on the emergence of pearl millet seedlings when sowing was followed by rains.

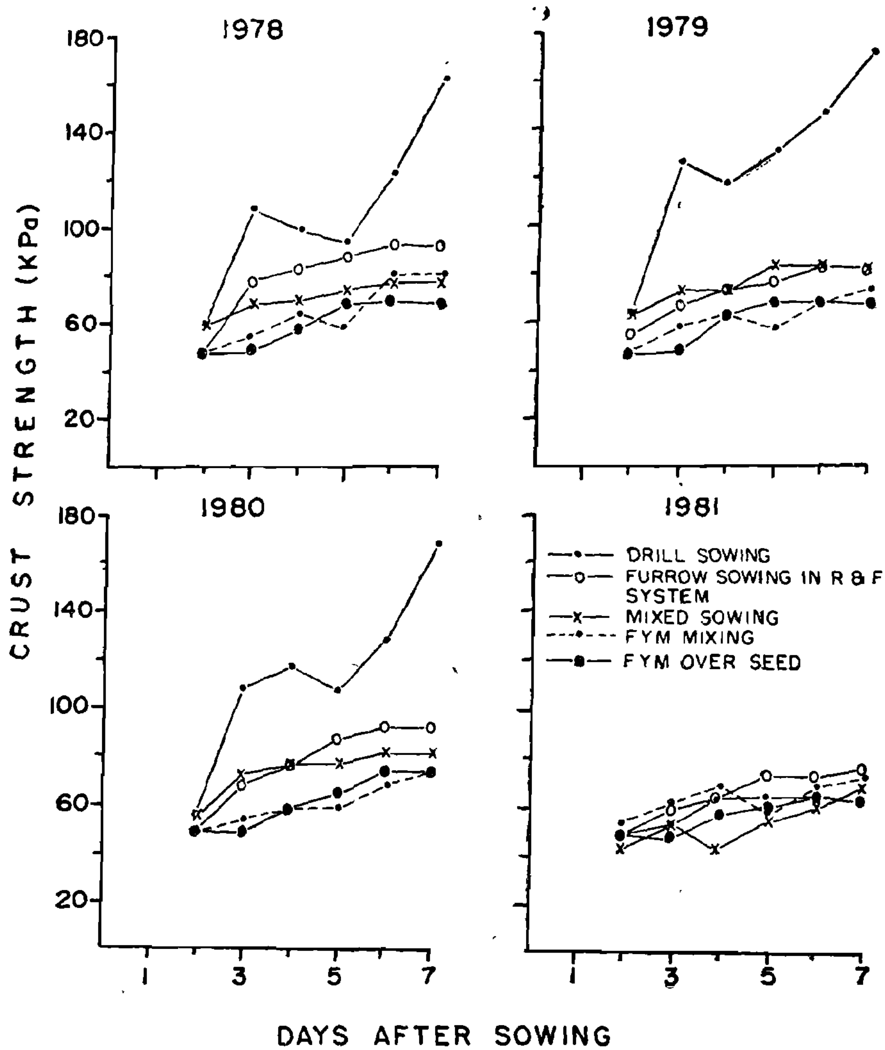


Fig. 1. Effect of sowing and cultural methods on crust formation after planting (Joshi, 1987).

Table 3. Emergence parameters of pearl millet as influenced by various treatments under crusted soil conditions (Joshi, 1987).

| Treatment | Rate of emergence per day | | | | Mean period of ultimate emergence (days) | | | | Ultimate emergence (%) | | | | Seed and seedling mortality (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1978 | 1979 | 1980 | 1981 | 1978 | 1979 | 1980 | 1981 | 1978 | 1979 | 1980 | 1981 | 1978 | 1979 | 1980 | 1981 |
| Seed drill sowing | 6.5 | 3.8 | 4.8 | 20.5 | 5.3 | 4.8 | 5.0 | 3.7 | 33 | 18 | 23 | 74 | 66 | 82 | 77 | 22 |
| Furrow sowing in R&F system | 14 8 | 14.6 | 8.9 | 13.3 | 3.5 | 4.1 | 4.1 | 3.5 | 58 | 58 | 32 | 45 | 41 | 41 | 68 | 53 |
| Mixed sowing with legume | 10.3 | 9.8 | 9 8 | 20.3 | 4.6 | 4.0 | 3.9 | 3.6 | 45 | 38 | 37 | 71 | 54 | 62 | 63 | 25 |
| Seed soaking | 9.9 | 7.2 | 9.0 | 19.6 | 3.9 | 3 4 | 3.6 | 3.4 | 36 | 24 | 31 | 65 | 63 | 76 | 69 | 34 |
| *FYM mixing | 15.8 | 15.5 | 16.0 | 21 6 | 3.5 | 3.4 | 3.5 | 3.6 | 54 | 52 | 54 | 76 | 45 | 47 | 45 | 20 |
| *FYM over seed furrow | 19.1 | 20.3 | 19 6 | 20.3 | 3.5 | 3.6 | 3.5 | 3.5 | 65 | 69 | 67 | 70 | 34 | 30 | 32 | 26 |
| LSD (5%) | 1.39 | 1.72 | 1.23 | 2.21 | 0.73 | 0.52 | 0.46 | NS | 6.3 | 8 0 | 8 1 | 11.3 | 9.6 | 10.4 | 7.8 | 9.4 |

* 10 t FYM/ha

# Soil fertility management

## Fertilizer use

Fertilizer is an important input even in rainfed lands for increasing the crop productivity. Compared to other nutrients, nitrogen was found to influence the pearl millet yields the most (Misra, 1964). Better response of pearl millet to nutrients was obtained when other concomitant factors were well adopted for maximum uptake of nutrients (Joshi and Panjab Singh, 1981; 1985).

Several varieties have been developed in the past due to efforts of breeders engaged in projects on improvement of pearl millet. Varietal response to nitrogen has been studied at CAZRI from time to time. Vyas *et al.* (1972) worked out 23.3 kg N/ha as optimum dose for local varieties. The improved varieties (HB 1, HB 3) were found more responsive to nitrogen application. Singh *et al.* (1974) reported 40 kg N as an optimum dose for these varieties. Panjab Singh (1977) and Singh *et al.* (1978) confirmed this finding in further studies. Joshi (1984) however, reported considerable variation in nitrogen optima between years and among varieties. Based on a two-year study, he reported nitrogen optima for local, BJ 104 and BD 111 as 58.25, 57.14 and 69.25 kg/ha in the first year while 65.53, 62.57 and 80.93 kg/ha in the second year, respectively. The author further reported better production responses in the first year inspite of the fact that rainfall during this year was 60 mm less than the later year. It was argued that it is not only the quantum but the distribution of rainfall during crop growth that influences the production responses. A marginal rise in optimum dose was also observed when rainfall during the crop growth was well distributed. Considering the high variability of response in arid areas due to high risk conditions, Joshi *et al.* (1984) also suggested the use of somewhat lower than optimum doses. Studies based on two similar rainfall years revealed optimum nitrogen levels for local, BJ 104, BD 111, CM 46 and PHB 12 as 63.95, 65.98, 74.37, 84.19 and 82.47 kg/ha, respectively (Joshi and Kalla, 1986).

The recommendations to use physical or economic optima for optimum yield of pearl millet (Singh *et al.*, 1974; Panjab Singh, 1977; Singh *et al.*, 1978 and Joshi, 1984) presupposed no constraint on the availability of fertilizer. In fact, the country is facing a shortage of fertilizer nitrogen. Keeping the fertilizer scarcity in view, Joshi and Kalla (1986) proposed use of pragmatic levels of nitrogen. They worked out a nitrogen curtailing schedule without impairing the production potential where the quantities of nitrogen were allowed to diminish at a fixed interval. The cost reduction and consequent net pay-off incidental to the reduction in the quantities of fertilizer were iterated till the loss in net pay-off was equivalent to the gains in the cost of reduction of fertilizer. This was termed as 'Pragmatic' level of nitrogen.

The results of their studies indicated the possibility of nitrogen curtailment of about 24 kg/ha for CM 46 and PHB 12 (Table 4). Varieties BJ 104 and BD 111 registered saving of 16 and 19 kg N/ha. The authors advocated the desirability of popularization of CM 46 and PHB 12 from the point of view of nitrogen economy. It was suggested that the nitrogen saved by growing these varieties for every 3.0 ha may be utilized for about 1.0 ha additional area which may not have received nitrogen application at all.

Numerous studies on balanced application of nutrients have been carried out to effect efficient utilization of applied inputs and to augment pearl millet productivity. Misra (1971) reported higher yields with the combined application of N and P as compared to application of individual nutrients. *Mann and Singh (1977)* reported yield increase of the order of 35 to 150 per cent with the application of 40 kg N along with 40 kg $P_2O_5$/ha in good rainfall years. A three-year study revealed that maximum grain yield of pearl millet could be obtained when combined application of 60 kg N, 30 kg $P_2O_5$ and 15 kg $K_2O$/ha was made (CAZRI, 1978c).

The investigations on the effect of micronutrients on the pearl millet yield in arid zone have been relatively few Beneficial effects of application of trace elements were observed in a four-year study (Misra and Bhattacharya, 1966). Application of Fe, Zn, Mg and mixture of all resulted in a mean increase in grain yield over control by 21.6, 18.0, 15.0 and 5.4%, respectively (Table 5). The response to Fe and Zn was more confined to development stage and caused significant increases in the kernel weight while beneficial effect of Mg was recorded at all the stages of plant growth and development. Misra (1971) opined that response of micronutrients was more prominent in drought year compared to normal rainfall years. Joshi and Panjab

Table 4. Nitrogen-yield relationship (kg/ha) of pearl millet varieties (Joshi and Kalla, 1986).

| Variety | $N_{max}$ | $Y_{max}$ | $N_{opt}$ | $Y_{opt}$ | Pragmatic nitrogen (kg) | Difference from optimum to pragmatum |
|---|---|---|---|---|---|---|
| Local | 84.44 | 920.93 | 63.95 | 893.34 | 39.4 | 24.55 |
| BJ 104 | 76.52 | 1366.82 | 65.98 | 1352.59 | 50.2 | 15.78 |
| BD 111 | 91.66 | 1105.82 | 74.37 | 1082.49 | 55.0 | 19.37 |
| CM 46 | 104.33 | 1195.25 | 84.19 | 1168 07 | 59.5 | 24.69 |
| PHB 12 | 101.47 | 1261.36 | 82.47 | 1250.12 | 59.4 | 23.07 |

Singh (1985) found 13.1 and 22.5% increase in yields due to application of Zn and B, respectively.

Work on the inter-nutrient relations with respect to pearl millet is also limited. In one such study, application of major nutrients (N, P and K) was found to decrease the copper uptake by pearl millet (Jain et al., 1967). The authors argued that $H_2PO_4$ reduced the uptake of copper by some process external to the plant by copper immobilization. The increased concentration of $NH^+_4$ and $K^+$ ions due to application of fertilizers (N, P and K) caused retention of available copper by soil, thus indicating antagonistic effects of these ions on the uptake of copper (Misra and Tiwari, 1964).

The researches conducted on different aspects of fertilizer use, i.e., optimum and pragmatic levels of N, balanced fertilizer use with respect to major nutrients, response to micronutrient etc. suggest responsiveness of pearl millet to use of fertilizers. Application of fertilizers under arid conditions should, therefore, be given greater emphasis since hungry plant transpires water without producing food. However, to think that use of fertilizers will always result in increased crop yield under arid conditions, is an illusion. For example, if the average and anticipated rainfall (on the basis of last several years) is not received and fertilizer is applied in a manner that leads to its maximum utilization, application of fertilizer may accelerate the initial growth of the crop to the extent that almost all stored moisture is exhausted by the time the crop enters the reproductive phase. Thus, little or no moisture is left to support subsequent growth of the crop, thereby resulting in complete crop failure. To maintain soil productivity, balanced application of fertilizers is necessary. The beneficial effects of micronutrient applications were prominently evi-

Table 5. Effect of micronutrients on grain yield (kg/ha) of pearl millet (Misra and Bhattacharya, 1966).

| Element | Source | Rate (kg/ha) | Grain yield 1958 | 1959 | 1960 | 1961 | Mean |
|---|---|---|---|---|---|---|---|
| Fe | $FeSO_4$ | 32.6 | 969.8 | 813.4 | 657.4 | 847.1 | 821.5 |
| Mn | $MnSO_4$ | 16.8 | 839.6 | 1028.5 | 333.6 | 647.9 | 721.4 |
| Zn | $ZnSO_4$ | 11.2 | 996.9 | 491.5 | 473.2 | 754.8 | 797.6 |
| Cu | $CuSO_4$ | 11.2 | 844.1 | 808.9 | 459 4 | 584.4 | 674.2 |
| B | $Na_2B_4O_7$ | 5 6 | 767.9 | 795.5 | 373.2 | 763.6 | 675.0 |
| Mo | $(NH_4)_6Mo_7O_{24}$ | .14 | 790.2 | 703.6 | 484.1 | 694.2 | 668 5 |
| Mg | $MgSO_4$ | 163.0 | 879.9 | 871.6 | 511.8 | 857.3 | 780.1 |
| Mixture | | | 1113.6 | 899 7 | 414.8 | 685.7 | 778.4 |
| Control | | | 853.2 | 866.1 | 414.8 | 564.2 | 674.6 |
| LSD (5%) | | | NS | NS | 140.7 | NS | NS |

dent in drought years and, therefore, these should be used to reduce the risk of crop failures under arid conditions.

**Nutrient management**

Arid zone soils are low in nitrogen and prone to its losses by leaching and volatilization. Therefore, the management of nitrogen assumes special significance. Broadcasting of urea was found to result in 20% loss through volatilization within 14 days of its application (Aggarwal and Kaul, 1978). Studies have shown that the efficiency of fertilizer nitrogen can be enhanced manifold by integrating the timing and method of its application. Application of 40 kg N, half at sowing and other half after 3-4 weeks to timely sown pearl millet gave as good yield as double the dose of fertilizer, all applied at sowing (Mann and Singh, 1978). Singh *et al.* (1972) reported that placement of ammonium sulphate pellets followed by top dressing after about a month following a rainfall spell gave significantly higher grain yield of 1060 kg/ha, which was 19 to 31% more than other methods of application (Table 6).

The (Table 6) results indicate a general trend of better yield under split application as compared to the application of full dose of N at sowing or after a month Such trend was a manifestation of more productive tillers under split application treatments, possibly because the practice of withholding half of the N during the early part of the season regulates water utilization by limiting the growth of the vegetative parts of the plants, thereby saving greater portion of available water for the later stages of ear emergence, and grain development. Panjab Singh (1977) and Singh *et al.* (1978) confirmed the beneficial effects of split applications of nitrogen doses. Application of nitrogen as top dressing should be made before 45-day crop stage. The delayed top dressing was found to add only to stover production (Panjab Singh, 1977). Singh (1976) advocated the practice of foliar application of 1/3rd dose

Table 6. Effect of different methods of fertilizer application on yield and yield attributes of pearl millet (Singh *et al.*, 1972).

| Methods of N application | Grain yield (kg/ha) | Ears/plant | Length of ear (cm) |
|---|---|---|---|
| Placement of pellets | 820 | 2.9 | 26.9 |
| Drill application | 750 | 2.9 | 26.9 |
| Broadcast at sowing | 730 | 2.1 | 25.0 |
| Top dressing about 30 days after sowing | 750 | 3.2 | 27.3 |
| Half pellets and half top dressed | 1060 | 3.9 | 18.6 |
| Half drilled and half top dressed | 830 | 3.5 | 27.1 |
| Half broadcast and half top dressed | 860 | 2.8 | 29.1 |
| LSD (5%) | 100 | 0.9 | 2.7 |

of nitrogen, should the season turn out moderately dry.

In light soils a part of fertilizer applied through conventional method of broadcasting remains unutilized as the upper 3-5 cm layer dries soon after the rain. A part of it may volatilize upon soil drying, as soils are slightly alkaline and low in cation exchange capacity. In order to derive the maximum advantage out of applied N, studies on methods of fertilizer application were initiated in the early seventies at CAZRI. Singh *et al.* (1972) compared three methods, i.e., placement of pellet, drill and broadcast application of ammonium sulphate and observed that it was not only the method of application that contributed towards the higher yield of rainfed pearl millet but the rational splitting of N was rather more beneficial. In the later studies, Aggarwal and Kaul (1978) found that nitrogen loss was considerably brought down by placing urea in the moist subsurface zone. Singh *et al.* (1978) reported that placement of urea at 10 cm depth or broadcast and mixing with the soil gave significantly higher yield than that 5 cm below the seed and 5 cm to the sides of the seeded rows.

Nitrogen from various sources showed differential response with pearl millet. In a six-year study, various nitrogen sources showed differential responses in different years, but the pooled analysis indicated a trend of slightly higher grain yield (405 kg/ha) due to application of FYM as against 372, 383 and 395 kg/ha with ammonium sulphate, calcium ammonium nitrate and urea, respectively (Vyas *et al.*, 1972). In another long term study conducted from 1975 to 1979 application of sheep manure gave substantially higher productivity of rainfed pearl millet grown in continuous pearl millet - pearl millet system than the application of urea in all the years except first (Singh *et al.*, 1981). The authors opined that in subsequent years N and other nutrients from organic sources became

Table 7. Effect of organic and inorganic source of nitrogen on the yield (kg/ha) of pearl millet (Singh *et al.*, 1981).

| Treatment | 1975 | 1976 | 1977 | 1978 | 1979 | Mean |
|---|---|---|---|---|---|---|
| Control | 2220 | 660 | 1030 | 480 | 250 | 880 |
| 20 kg N/ha inorganic every year | 2940 | 1220 | 1590 | 770 | 450 | 1390 |
| 40 kg N/ha inorganic every year | 3010 | 1670 | 1930 | 900 | 500 | 1600 |
| 40 kg N/ha inorganic once in two years | 3020 | 890 | 2010 | 600 | 540 | 1410 |
| 10 t FYM+10 kg N/ha every year | 2380 | 1650 | 1910 | 1080 | 680 | 1540 |
| 20 t FYM/ha once in two years | 2610 | 1300 | 1780 | 1010 | 840 | 1510 |
| 40 t FYM/ha once in two years | 2700 | 1980 | 2500 | 1080 | 860 | 1780 |

more and more available to the crop due to residual and cumulative effect resulting in sustained higher yield (Table 7). Gupta *et al* (1983) reported that application of FYM in association with urea to supply 50% nitrogen from each improved the soil properties, economised fertilizer use and optimised the production of pearl millet.

Contrary to the above findings, Singh *et al.* (1973) reported ammonium sulphate as slightly superior to FYM on equal N basis. The better efficacy of ammonium sulphate was attributed to additional supply of sulphur to the crop (Aggarwal, 1985).

Urea is extensively used as N source. The nitrogen use efficiency of urea is low due to its higher volatilization losses. Increased uptake of nitrogen and thereby higher N use efficiency of urea was found when it was applied with P and Zn (Aggarwal and Panjab Singh, 1978). Aggarwal (1985) reported N use efficiency of urea, diammonium phosphate, calcium ammonium nitrate and ammonium sulphate as 20.0, 26.0, 30.0 and 36.7%, respectively (Table 8). It was suggested that reduction in the loss of nitrogen and an increase in N use efficiency could be achieved if urea was coated with sulphur in 10:1 ratio (Aggarwal *et al*, 1987).

Effect of different sources of phosphatic fertilizers was studied (CAZRI, 1984a). The results revealed diammonium phosphate (DAP) a better source as compared to dicalcium phosphate, single super phosphate, rock phosphate and NPK compound fertilizer.

Pearl millet is grown in various crop sequences. Pearl millet - pearl millet and pearl millet - greengram or dewgram or clusterbean as two year rotations and pearl millet - wheat as one year rotation are commonly followed in arid areas. Studies on nutrient requirement of crops grown in sequences revealed that application of 40 kg $P_2O_5$ to greengram was beneficial to pearl millet grown in rotation during the next season, giving 200 to 500 and 200 to 350 kg/ha higher grain yield under fertilized (20kg N/ha) and unfertilized conditions, respectively (Singh *et al.*, 1981a). Singh *et al.* (1985) found 36% higher yield of pearl millet when 26 kg P/ha was applied once in two years to legume instead of millet in rotation. For pearl millet-wheat

Table 8. Nitrogen use efficiency of different nitrogenous fertilizers at 60 kg N/ha in pearl millet (Aggarwal, 1985).

| Source of N | Grain yield (kg/ha) | N uptake (kg/ha) | N use efficiency (%) |
|---|---|---|---|
| Control | 450 | 20.5 | — |
| Urea | 650 | 32.5 | 20.0 |
| Urea coated with S | 850 | 50.6 | 50.2 |
| Urea coated with latex of *Calotropis* | 650 | 36.7 | 27.0 |
| Ammonium sulphate | 760 | 42.5 | 36 7 |
| Diammonium phosphate | 600 | 36.0 | 26.0 |
| Calcium ammonium nitrate | 700 | 38.5 | 30.0 |
| LSD (5%) | 49 | 9.3 | — |

rotation, Singh (1985) suggested that application of manure or phosphorus to both the crops was not necessary. To obtain higher grain yield and to maintain the soil organic matter at a desired level, a single application of 26 kg P/ha in addition to 120 kg N/ha to wheat and only 60 kg N/ha to pearl millet in rotation was recommended.

The fertilizer management studies hitherto conducted on pearl millet have generated valuable information. It can be concluded that if application rate, time and method are not followed judiciously application of fertilizer may do more harm than good. Split application of nitrogen should be given due emphasis and the part of nitrogen earmarked for top dressing should be withheld if droughts are anticipated in the later part of crop season. Placement of urea at 10 cm depth was found as superior method but effective administration of fertilizer at such a depth appears to be a difficult task for want of efficaceous and precise implements. Therefore, other methods such as broadcast and mixing in the soil or drill application may be advocated for basal application and losses saved through rational splitting of doses. Application of FYM should find a place in pearl millet cultivation to maintain long term productivity and better soil physical conditions. Integrated fertilizer management should be adopted where phosphatic fertilizer is applied only to legumes in pearl millet - legume rotation and to wheat in double cereal rotation. Such practices would not only help saving the fertilizer input but would also ensure better fertilizer use efficiency.

**Biological nitrogen fixation**

In arid areas where little nitrogen fertilizer is applied the role of various nitrogen fixing bacteria to improve the soil nitrogen status offers considerable potential. Since the identification of *Azospirillum brasilense* as a nitrogen fixing bacterium for cereals, much interest has been generated on this organism from the point of view of nitrogen economy in pearl millet production. Joshi and Panjab Singh (1981) while exploring the possibility of use of *Azospirillum* inoculation in pearl millet suggested that use of biological sources of nitrogen is another bright opening for increasing millets production especially when application of chemical fertilizers is considered risky.

Detailed studies (Joshi and Rao, 1988) on these aspects have shown that inoculation gave an increase of 39 4% in grain yield (718 kg/ha) as compared to uninoculated (Fig. 2). Significant improvement in root dry weight upon inoculation was also recorded. Venkateswarlu and Rao (1983) found that enhanced root growth upon inoculation was due to the production of various growth regulating substances such as indoles, gibberellins and cytokinins by *Azospirillum*.

Studies on associative nitrogen fixation in pearl millet (Fig. 2) revealed that the yield obtained with the application of 13 kg N (716 kg/ha) was similar to that of inoculation treatment alone (718 kg/ha).

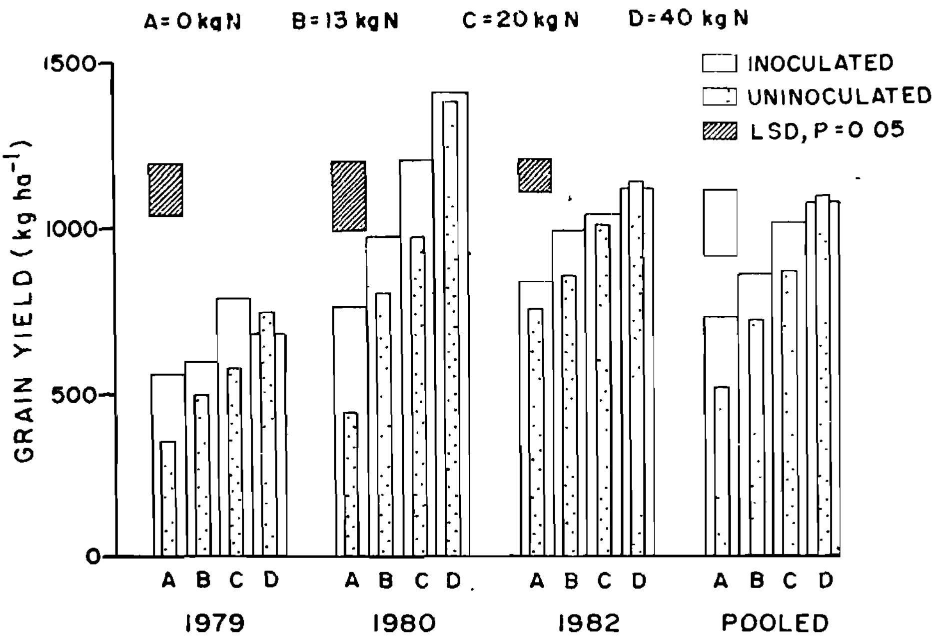


Fig. 2. Effect of inoculation and nitrogen on grain yield of pearl millet (Joshi and Rao, 1988).

This indicated that *Azospirillum* inoculation could contribute an amount equivalent to 13 kg N/ha to the crop nitrogen requirement. The inoculation effect decreased with the increase in external nitrogen application and at 40 kg N the inoculation did not increase the grain yield (Joshi and Rao, 1988). Rao and Venkateswarlu (1982) observed the inhibition of $N_2$-ase activity of *A. brasilense* by addition of both organic and inorganic nitrogen compounds under *in vitro* conditions. These studies confirmed the findings of the field experiments that nitrogenous fertilizer after a threshhold concentration, inhibits the activity of *Azospirillum* and its beneficial effects.

Joshi *et al.* (1984), while suggesting the technologies for higher production in arid zone, advocated the use of *Azospirillum* inoculation as biotic nitrogen source. The authors argued that although the quantum of contribution (13 kg N/ha) by this bacterium may appear low, yet it is significant under arid conditions where monetary inputs are a great constraint in increasing the farm output.

# Weed management

Pearl millet faces a good deal of competition by rainy season weeds for all natural and applied inputs. The competition for resources, especially moisture, is acute during early stages of crop growth as the weeds grow rapidly. Misra and Vijay Kumar (1962) recorded 60% more yield in weeded plots than in control and the effect of weed control on yield was more conspicuous in a season with low rainfall. Joshi and Panjab Singh (1981) and Gupta and Gupta (1982) found over two-fold increase in the grain yield due to efficient weed control measures.

Weeds could either be controlled mechanically or through the use of herbicides. Misra and Vijay Kumar (1962) did not find significant differences amongst different cultural and chemical (2,4-D) weed control methods. In another study, it was found that pre - emergence application of atrazine was as effective as one hand weeding done at 30 days after sowing (CAZRI, 1978b . On the other hand, Joshi and Panjab Singh (1985) reported 40% increase in grain yield due to application of atrazine (1 kg a.i./ha) over one hand weeding at 40 kg N level. Such beneficial effect in yield due to chemical weeding was not observed at 80 kg N level (Table 9). A sizeable population of weeds in the intra-row space escaped manual weeding while the atrazine effectively controlled these weeds. At higher nitrogen rate (80 kg N/ha), it was argued that the plants made faster growth and suppressed the growth of intra-row weeds. This eventually reduced the competition and led to non-significant difference between chemical and manual methods of weed control (Table 9).

Different weedicides were compared for their efficacy to control weeds. Studies by Misra and Mathur (1965) revealed that 2,4-D was more effective at early stages of growth, while 2,4,5-T at later stages of growth. Spraying of three weedicides viz. 2,4-D, 2, 4, 5-T and MCPA at the rate of 1 kg a.i./ha gave significantly higher yields over control, the highest being with MCPA at 30 days after sowing (CAZRI, 1965). Better weed control gave higher protein content in the grain samples owing to higher nitrogen availability to pearl millet.

Table 9. Nitrogen – weed management relationship in pearl millet (Joshi and Panjab Singh, 1985).

| Treatment* | Grain yield (kg/ha) | Weed count/$m^2$ | Weed dry weight ($g/m^2$) |
|---|---|---|---|
| No N + 1 W | 563 | 76 1 | 109.6 |
| 40 N + 1 W | 968 | 75.3 | 124.4 |
| 40 N + 0 W | 412 | 169.3 | 461.1 |
| 80 N + 1 W | 1571 | 71.7 | 139.9 |
| 80 N + 0 W | 448 | 147.5 | 494.0 |
| 40 N + Atra. | 1351 | 32.2 | 68.1 |
| 80 N + Atra. | 1602 | 27.6 | 75.5 |

* W : hand-weeding at 30 days; Atra. : pre-emergence atrazine application @ 1 kg a. i./ha.

# Cropping systems

## Crop rotation

In conservation farming the crop rotation occupies an improtant place. A crop sequence that reduces loss of soil and gives more returns per unit area may be considered more suitable for adoption in arid areas Growing a crop continuously on the same piece of land may have adverse effects on soil fertility because of continuous depletion of nutrients from a particular depth. Adverse effects of such systems have been observed even under good soil fertility management conditions. Mann and Singh (1977) observed 62% reduction in pearl millet yield in pearl millet - pearl millet rotation in comparison to greengram-pearl millet rotation. In traditional cropping, pearl millet is grown either after fallow in two year rotation or monocropped every year. Singh (1980) reported that among single crop systems pearl millet-fallow rotation proved to be the most remunerative from both yield and monetary returns points of views. Among double crop systems, pearl millet-clusterbean gave highest returns per unit area (Misra, 1977) Results of a long term study (Singh *et al.*, 1985) also support pearl millet - clusterbean rotation where 11% higher pearl millet yields were achieved in comparison to continuous growing of pearl millet (Table 10). The system also improved soil organic carbon by 12% and available soil P by 25%.

Table 10. Effect of cropping sequence on the yield of hybrid pearl millet (Singh *et al.*, 1985).

| Crop sequence | Grain yield (kg/ha) |
|---|---|
| Pearl millet — Pearl millet | 2034 |
| Pearl millet — Clusterbean. | 2251 |
| Pearl millet — Greengram | 2217 |
| Pearl millet — Moth bean | 1985 |

## Planting system

Pearl millet is generally grown in uniform planting system. Possibilities of other planting systems were also explored at CAZRI. In a study, Singh *et al.* (1978a) reported 9% higher yield of pearl millet in paired row than in uniform row system under similar set of management (Table 11). In another study, beneficial effects of paired row system were observed during drought year only (CAZRI, 1978a). Conducive micro-climate for plant growth and development, besides efficient use of water, better weed suppression within a row-pair and greater root proliferation in paired rows were some of the reasons attributed for better yields in paired system (CAZRI, 1978a and Ramakrishna *et al*, 1982).

Rao and Joshi (1986) examined the possibility of incorporating such beneficial effects. They tried border cropping by skipping every 4th row in uniform row system with a view to save nitrogen input in pearl millet production. These studies revealed that the border row system (with adjusted population on hectare basis) gave 14% higher yields over uniform row system despite 25% lesser inputs.

**Intercropping**

Growing one or two legumes with pearl millet as mixed crop has been a traditional practice primarily to reduce the risk of complete crop failure in aberrant weather. In the traditional practice, specific row arrangements were not followed which led to low yields of both the mixed crop components. Studies on different aspects of intercropping have since been conducted and attempts made to perfect the technique including the patterns of planting crops in intercropping systems having pearl millet as one of the component crops. It was found that growing pearl millet in association with clusterbean was better in a normal rainfall year while in subnormal rainfall years cowpea was a better associate (Misra, 1971). Singh *et al.* (1978a) did not see any adverse effect of intercropping greengram in the inter-row spaces of pearl millet. In a two-year study (Panjab Singh and Joshi, 1980), double rows of dewgram, clusterbean and greengram planted in the interspaces of paired rows of pearl millet (30/70 cm) yielded 381, 381 and 458 kg/ha additional grain without adversely affecting the yields of the pearl millet (Table 12). The land equivalent ratios (LER) of various intercropping systems were also studied. On the basis of LER, growing dewgram in double rows gave maximum advantage of 54% owing to least competition offered by this crop. Growing two rows of greengram, though resulted in comparatively lower LER (1.19) and only 19% better land utilization, gave the maximum gross returns from the system.

Singh *et al.* (1978b) observed that pearl millet could also be taken as an intercrop in greengram-pearl millet system.

Table 11. Yield and yield attributes of pearl millet as influenced by different planting systems (Singh *et al*, 1978a).

| Planting | Mean grain yield (kg/ha) | Ears (000/ha) | 1000 - grain weight (g) |
|---|---|---|---|
| Uniform rows (50 cm) | 3006 | 282.42 | 6 21 |
| Paired rows (30/70 cm) | 3279 | 311.93 | 6.57 |
| Treble rows (30/90 cm) | 3088 | 298.26 | 6.37 |

They reported higher returns with intercropping than with sole crop of greengram.

Studies on planting systems for pearl millet-greengram intercropping revealed that paired planting (30/70 cm) of base crop was more efficient giving 7-24% higher yield than uniform planting (50 cm) in subnormol rainfall years and as good as uniform planting in normal rainfall years (CAZRI 1984c and 1985b). These studies also showed that yield of principal crop increases with increase in levels of nitrogen but the yield of intercrop (greengram) gets adversely affected. Perhaps at higher nitrogen levels the increased vegetative growth of pearl millet suppressed the growth of intercrop. A three-year study on component populations of pearl millet-greengram revealed that closer spacing of 10 cm for both component crops offered severe competition to the principal crop and gave the lowest yield (202 kg/ha). Keeping pearl millet plants at 15 cm apart with greengram (intercrop) plant spacing of 20 cm resulted in maximum grain yield of 1183 kg/ha (CAZRI, 1985c).

Table 12. Yield and land equivalent ratios (LER) of pearl millet intercropping systems (Panjab Singh and Joshi, 1980).

| Treatment | Mean grain yield (kg/ha) | | Mean total LER |
|---|---|---|---|
| | Pearl millet | Intercrop | |
| Uniform rows ($T_1$) | 1447 | — | — |
| Paired rows 30/70 cm ($T_2$) | 1385 | — | 0.95 |
| $T_2$ + Dewgram SR* | 1249 | 165 | 1.30 |
| $T_2$ + Dewgram DR** | 1274 | 381 | 1.54 |
| $T_2$ + Greengram SR | 1197 | 291 | 1.09 |
| $T_2$ + Greengram DR | 1157 | 458 | 1.19 |
| $T_2$ + Clusterbean SR | 1327 | 268 | 1.14 |
| $T_2$ + Clusterbean DR | 1249 | 381 | 1.21 |
| $T_2$ + Cowpea SR | 1665 | 142 | 0.94 |
| $T_2$ + Cowpea DR | 944 | 273 | 0.91 |
| $T_2$ + Sesame SR | 1049 | 161 | 1.00 |
| $T_2$ + Sesame DR | 1195 | 291 | 1.31 |

* Single row, ** Double row

# Soil moisture conservation and management

With a few exceptions, about 500 mm rainfall is required in a growing season for good harvest. In the Jodhpur region the average seasonal rainfall during growing season is about 298 mm. There is, thus, a large gap between requirement and receipt. *Low moisture retention* capacity of soils, high infiltration rates and high evaporative demand further aggravate the situation. Dry land crops experience moisture stress during early or late stages of growth, leading to low yields or to complete failure of crops. Raising crops under such conditions is a challenging task and needs a good deal of management.

**Surface mulches**

In sandy soils capillary continuity is poor. Water stored in deeper layers, therefore, moves up very slowly in response to the evaporation pull unless conditions are very harsh. After drying, a few centimetres of surface soil act as a mulch and evaporation from soil is negligible. Hence, use of mulches may not be of much practical utility in arid soils. But, many a times drought occurs just after sowing. In such situations covering of soil surface with some mulches like grass waste, pearl millet husk and other organic wastes immediately after sowing may delay the rate of surface drying, promote better establishment of crop and result in higher yields. Singh (1977), discussing the mechanism of moisture loss through evaporation from loamy sand soils, opined that mulches played important role in conserving moisture till the 50% ground area was covered with crop canopy. Daulay *et al.* (1979) reported beneficial effects of mulch in pearl millet crop during drought years. Gupta (1980), while comparing the efficiency of organic and inorganic mulches, reported superiority of polyethylene mulch over organic mulch (Table 13).

The beneficial effects of mulches could be attributed to better moisture conservation and reduced heat load on the surface. Higher albedo and consequent lower soil temperature with the use of wheat straw mulch as against grass mulch was recorded (CAZRI, 1975). In another study, Gupta and Gupta (1985) observed that mulches not only conserved soil moisture by reducing the soil temperature but also considerably suppressed the weed growth.

**Stubble mulching and wind strip cropping**

Wind erosion is a serious problem of

arid regions. Low rainfall, high wind velocity, scanty vegetation and sandy soils are the causes for wind erosion. Wind speed may reach as high as 20-27 km/h in summer months in western Rajasthan. Adverse effect of wind mainly occurs in these months as ground vegetation cover during summer months is minimum. Wind erosion is doubly harmful, as the damage is not only to the area from where the soil is blown but also to the area of its deposition

One of the methods to overcome the problem of wind erosion could be the use of stubble mulch farming and growing wind strips. Misra (1962) reported decrease in wind erosion, and increase in soil organic matter and yield of pearl millet when pearl millet stubbles of 45 cm height were left in the field at harvest. The practice, however, has some limitations to its large scale adoption. The farmers of arid zones are reluctant to leave stubbles in the fields as these are used for animal feeding. Moreover, due to grazing by stray animals, it is difficult to maintain stubbles in the fields. Further, this practice is not so useful as it has nitrogen immobilising effect. Wind strips were found to help in controlling wind erosion (Misra *et al.*, 1966). Comparing the different materials for wind strips, they reported that perennial grass 'Sewan' as wind strip not only increased the yield of pearl millet by 9% over unprotected field but also provided nutritious fodder for animals. Like stubble mulching, this approach also has limited scope to its adoption in the arid zone.

**Soil amendment and subsurface moisture barriers**

Arid soils, being sandy in texture, have low water retention capacity. In normal and good rainfall years, about 30-40% of seasonal rainfall is lost as deep percolation. Thus, there is need to conserve water against percolation loss. Water retention capacity of light soils can be improved to some extent if soil amendments are mixed with these soils. Surface application of FYM and *Calotropis* amendments increased the yield by 30% whereas subsurface application (15-20 cm deep) increased the grain yield by 53% and 58%, respectively, over control (CAZRI, 1973). Singh (1973) reported higher soil moisture status and yield of pearl millet with the use of *Calotropis* as organic amendment. The increase in yield was due to more availability of soil nutrients with the application of *Calotropis* (Aggarwal and Sharma, 1980).

Table 13. Effect of mulches on yield and water use efficiency of pearl millet (Gupta, 1980).

| Treatment | Grain yield (kg/ha) | Water use (mm) | Water use efficiency (kg grain/mm/ha) |
|---|---|---|---|
| Polyethylene | 2900 | 279 | 10.4 |
| Pearl millet husk | 2300 | 269 | 8 5 |
| Control | 1740 | 291 | 6.0 |

Gupta *et al.* (1979) reported 40-50% increase in the grain yield of pearl millet (BJ 104) with the application of 76 t/ha of pond sediments (Table 14). The increase in yield was caused by higher moisture retention, addition of nitrogen and organic matter through the amendments.

Table 14. Effect of pond sediments on yield and water use by pearl millet (Gupta *et al.*, 1979).

| Pond sediments (t/ha) | Grain yield (kg/ha) | Water use (mm) | Water use efficiency (kg/mm/ha) |
|---|---|---|---|
| 0 | 1280 | 228 | 5.73 |
| 38 | 1540 | 247 | 6.30 |
| 76 | 1860 | 283 | 6.76 |
| 114 | 1735 | 322 | 5.67 |
| 152 | 1765 | 286 | 6.28 |

Use of asphalt as a subsurface barrier (2 mm thick at 60 cm depth) increased water and nitrogen retention by 100%, which led to 40-50% increase in the yield of pearl millet over control (Gupta and Aggarwal, 1980).

Large scale use of these barriers has limited scope owing to non-availability of implements with the farmers to incorporate the barriers at the desired depth besides the higher cost of barriers. Availability of suitable implements and cheaper barrier material would enhance the prospects of this practice at least on a small scale.

**Water harvesting**

Water harvesting is the harnessing of rain water from treated or untreated catchments. Its success largely depends on soil, climate, type of vegetation. Owing to low moisture retention capacity and high infiltration rates, the scope of *in situ* water harvesting in desert soils is limited. In the years when rainfall was high or concentrated in a small period during the season the practice did not prove to be advantageous. On the other hand, in the years when rainfall was low to normal, well distributed and the intensity was low, the practice showed promise (Singh, 1982).

Studies conducted at this Institute reveal that there are two efficient systems of *in situ* water harvesting i. e inter-plot and inter-row. Results of these studies have shown that by cropping only two-third of the field and leaving one-third as catchment (75 cm catchment on both sides, with a slope of 5% towards the catchment of 3 metre width) increased the yield of pearl millet by 121% (Singh, *et al.* 1973) and 85% (Singh, 1985) over control in different years with different rainfall intensities. This system of water harvesting also resulted in one-third saving of inputs besides higher yield compared to normal cropping. The inter-row water harvesting system was designed in modification of inter-plot system to save the area under catchment.

The threshold rainfall to produce run-off from the catchment sealed with a layer of pond sediments is 4.5 mm. Average of 85 years rainfall (1901-1985) shows that percentage of showers equal to or less than 4.5 mm is about fifty. The efficient use of these light rains could be achieved by covering the catchment with sealants. Sealants like 'Janta' emulsion, plastic sheet and pond silt were found promising for *pearl millet. Maximum increase was ob*tained with plastic cover over flat surface control (CAZRI, 1985a).

Light rains could further be utilized efficiently with the use of proper planting geometry. Integration of double row planting geometry (DR 25/75 cm) into water harvesting revealed that outer row (adjacent to catchment) gave higher grain yield than the rows located in the centre of cropped area (CAZRI, 1978a). The yield advantage in DR was mainly due to the fact that in this system out of six rows, four rows were benefitted whereas in RR (regular row geometry) only two rows adjacent to catchment got the advantage of runoff from light showers.

Another approach to water harvesting is collection of runoff for recycling as supplemental or life saving irrigations. In the drought prone areas it may be desirable to set apart a portion of the total land for water harvesting. The harvested water can be collected or stored in a pond to give supplemental or life saving irrigation to crop when it suffers from moisture stress (Mann and Singh, 1978). The yield increase due to life saving irrigation varied from 7 to 337% depending upon the severity of drought, method of sowing, depth of water applied and stage of growth at which irrigation was given.

# Stress tolerance

## Drought effects

Occurrence of agricultural droughts is frequent in the arid zone. Although pearl millet is less susceptible to drought than legumes (Ramakrishna *et al.*, 1981; Sastri *et al.*, 1981 and Sastri *et al.*, 1984), its yields are adversely affected (Rao *et al.*, 1984 and 1986). Joshi (1988) reported relatively lower yield reductions in pearl millet than small millets under moderate drought conditions. Ramakrishna *et al.* (1985) reported that mild, moderate and severe droughts reduced the pearl millet yields by 37.7, 72.5 and 82.0%, respectively, from normal average yield of 345 kg/ha as base in western Rajasthan (Table 15).

Table 15. Average grain yield of pearl millet under various intensities of agricultural droughts in western Rajasthan (Ramakrishna *et al.*, 1985).

| Intensity of agricultural droughts | Grain yield (kg/ha) | Yield reduction from normal (%) |
|---|---|---|
| Nil | 345 | – |
| Mild | 215 | 37.7 |
| Moderate | 95 | 72.5 |
| Severe | 62 | 82.0 |

Drought may occur at any stage of growth but the probability of early drought is less (20%) than late drought (40%). The influence of drought on crop yield was found to vary with the age of crop (Lahiri and Kharabanda, 1965 and Lahiri and Kumar, 1966) It was observed that drought had, in general, less adverse effect at early stage of growth as compared to later stages of growth, the highest being at the onset of reproductive stage. Lahiri and Singh (1968) reported that water stress resulted in adverse effects on nitrogen metabolism Garg *et al.* (1981) found considerable reduction of soluble proteins, reducing sugars and enzymes (Table 16)

Apart from water stress, plants grown in arid environment also suffer from the adverse ffects of high temperature Like water stress, high temperature also influences the nitrogen metabolism and effects of high temperature are more significant when plants are exposed to such conditions for more than six hours (Lahiri and Singh, 1969). From these studies it is evident that water and heat stress influnce the activities of enzymes responsible for metabolism. It is, thus, implied that the ability of a plant to endure heat and water stress depends largely on the formation of enzyme systems. Different measures have been tried to evade drought effects. Adequate nutrition and early plant vigour may influence the activities and thermostability of enzymes (Lahiri *et al.*, 1973) and consequently help the plant to endure heat stress. Lahiri and Kathju (1973) reported higher activities and thermostability of hydrolysing enzymes in the leaves of pearl millet under high soil fertility as compared to those obtained from low fertility condition.

Differential varietal susceptibility to drought has also been observed. Misra and Daulay (1963) reported that variety JTR (Jetsar) was more tolerant to drought as compared to other varieties. Studies undertaken by Lahiri and Singh (1970) on different varieties of pearl millet showed that under high critical soil moisture conditions the varietal traits were not discernible. However, in less critical conditions hybrid variety was found more tolerant to water stress than local variety. Thus, choice of variety may play an important role in evading drought effects.

Antitranspirants and reflectants have also been tried to minimise drought effects. Foliar spray of morphactin, claimed to be a promising antitranspirant was found to be ineffective in reducing water requirement of plants under low moisture regimes (Kackar *et al.*, 1978).

Joshi and Panjab Singh (1981) reported that spray of atrazine (100 ppm), when drought sets in, gave significantly higher grain yield than other treatments. Other cultural practices like growing of pearl millet in paired row and removal of every alternate row also gave significantly higher yields than control. Supplemental irrigation, wherever possible, at the onset of drought, is also a remedy for mitigating the effect of drought (Singh, 1984).

**Soil salinity and use of saline water**

In the arid parts of Rajasthan, nearly 84% of the area has groundwater with EC over 2.2 mmhos/cm, unfit for irrigation as per the internationally accepted norms. For want of good quality of water, saline waters remain the main source to supplement crop water requirement under low and erratic rainfall conditions. The techniques for use of saline waters, thus assume great importance. The work on a few

Table 16. Effect of water stress on soluble protein, reducing sugars, starch and activities of certain enzymes in the leaves of pearl millet cv. BJ 104 (Garg et al., 1981).

| Biochemical component | Control | Wilted |
|---|---|---|
| Soluble proteins (mg/g dry matter) | 10.37 | 1.7 |
| Reducing sugars (mg/g dry matter) | 10.73 | 9.2 |
| Starch (mg/g dry matter) | 205.2 | 143.0 |
| Amylase (mg starch hydrolysed/g dry matter/h) | 788.2 | 51.2 |
| Invertase (mg glucose formed/g dry matter/h) | 288.0 | 56.4 |
| Nitrate reductase (mg nitrate formed/g dry matter/h) | 189.1 | 175.6 |

aspects of the use of saline water has been done at CAZRI.

Not only the crops show differential response to saline water but also the varieties of a crop. A pot study (Abichandani and Bhatt, 1965) on the germination of thirty three varieties conducted to determine their salt tolerance showed that the pearl millet cultivar AF3 from Bombay and Cumbu X3 from Madras stood fairly well upto 20 mmhos of water as compared to other varieties. On the other hand, Garg *et al.* (1984a) did not find significant differences in the yield behaviour of cv. BJ 104 and Babapuri. Manga and Saxena (1981) observed that variety BJ 104 did not show any significant decrease in germination upto 5 mmhos/cm EC.

Varieties known for salt tolerance at germination stage may not necessarily be tolerant at later stages of growth. In a laboratory study (CAZRI, 1970), the pearl millet strain No.24 (Raniwas) showed the highest germination in 24 mmhos solution but this trend was not consistent with root and shoot growth of seedlings. In another study, the germination of Babapuri variety was maximum (94%) even at 15 mmhos water while lengths of radical and plumule were maximum for BJ 104 at the same level of saline water (Saxena and Kolarkar, 1981).

In the arid zone, sharp decline in soil moisture after major rainfall incidence in August is often observed. The water stress, thus, coincides with sensitive reproductive stage of pearl millet and affects the yield adversely. Irrigation, if available at this stage, will definitely impart stability to crop production. Irrigation with saline water at this stage needs careful evaluation of the consequences of saline water on the growth and yield of drought affected crop. There are evidences that significantly higher dry matter production and grain yield (Table 17) were achieved when drought at critical stage was avoided by irrigating the crop with saline water having salinity level of 160 me/l (Garg *et al.*, 1984b). Different varieties showed differential responses to saline waters. Irrigation with saline waters of 2.7 to 12 mmhos showed that variety BJ 104 was relatively more tolerant than other varieties (CAZRI, 1983d).

The adverse effect of saline waters could be reduced with the use of soil amendments. Application of gypsum decreased the salt concentration in root zone by 25% and also increased grain yield by 10-30% over control with different varieties (CAZRI, 1983d).

Table 17. Effect of saline waters on dry matter production and grain yield (g/plant) of water stressed and unstressed plants (Garg *et al*, 1984 b).

| Salinity level (me/l) | Dry matter | | Grain yield | |
|---|---|---|---|---|
| | with water stress | without water stress | with water stress | without water stress |
| 0 | 9.50 | 11.93 | 2.19 | 4 71 |
| 80 | 9.00 | 11.50 | 1.92 | 3.26 |
| 160 | 8.71 | 11.08 | 1.48 | 3.69 |
| 240 | 8.10 | 10.84 | 1.10 | 2.90 |
| LSD (5%) | | | | |
| Salinity (S) | 0.77 | NS | 0.87 | 1.14 |
| Drought (D) | 0.55 | 0.72 | 0.61 | 0.80 |
| S X D | 1.09 | 1.43 | 1.23 | 1.62 |

# Plant protection

## Insect pest management

White grubs [*Holotrichia consanguinea* and *H. reynaudi* (synonym *H. insularis*)] and termites (*Microcerotermes tenuignathus* Holmgren) are important soil pests in arid zones. Pearl millet is also attacked by various foliar pests like grey weevil (*Myllocerus maculosus*). delphacids. mirid bugs, leaf roller, blister beetles, red hairy caterpillar and ear worms but none is so serious. The only foliar pests warranting control measures are the grey weevil, red hairy caterpillar, leaf roller and occasionally beetles and worms attacking heads. Among these, grey weevil is the only regular pest whereas other pests appear only in certain years. Apart from insects, the house sparrow [ *Passer domesticus* Linn. (Ploceidae, Aves) ] is also reported to damage pearl millet crop considerably.

Chemical control of white grubs has met with little success, partly because of the size of larvae and their habit of going deeper into the soil and, because of the high cost of effective insecticides. However, studies indicate that the incidence of this pest can be reduced to some extent Pal and Doval (1970) reported that use of lindane and thiodemeton granules (1 kg a.i./ha) was highly successful and economical in controlling *H. reynaudi* (Table 18). In another study, the use of sevidol (Carbaryl : BHC, 4 : 4) at the rate of 25 kg/ha and BHC 10% dust have been found quite effective against white grub (Sachan and Pal, 1976). Verma (1987) discussing the merits and demerits of different methods of controlling white grubs reported that satisfactory and economic control of this insect could be achieved with the drilling of finely ground 60 kg dry FYM and 40 kg BHC dust/ha into seed furrow before sowing. He also suggested that the approach to control white grub should be in the form of a campaign at community level.

Termites are controlled successfully when steps are taken before sowing. Soil treatment with dusts like aldrin (5%), BHC (10%) or chlordane or heptachlor (5%) at the time of land preparation is effective. Seed treatment with aldrin dust (20 to 50 g/kg of seed) or liquid aldrin (5ml 30% EC/kg seed) is also recommended if the termite damage is expected. If soil treatment is not done before sowing, application of 2-4 litres of aldrin (30% EC/ha) with irrigation water in standing crop can be resorted to if irrigation facilities are available. Joshi *et al.* (1984) reported successful control of termite by trèating the soil with BHC dust (10%) @ 25 kg/ha before sowing.

Most of the foliar pests are controlled by dusting BHC or parathion or any other insecticide. Any contact insecticide can control the attack of *Myllocerus* effectively (Pal, 1971). Red hairy caterpillar may be a menace to pearl millet crop only during early stage of the crop. After that, crop can easily withstand the attack. Several control measures have been suggested to reduce the menace of red hairy caterpillar. Vèrma (1980) reported that ethyl parathion (0.05%) caused significantly higher mortality to caterpillars and also brought about significant reduction in the remaining larval population. However, due to its serious handling hazards, spray of other insecticides like quinalphos (0.04%), fenitrothion (0 05%) or methyl parathion (0 05%) was recommended. He also suggested the use of wetting agent in spray to get greater efficiency. Verma (1981), comparing the field efficacy of antifeedant and some contact insecticides, indicated that combined use of antifeedant TPTA and effective insecticides was found promising to control full grown larvae of *Amsacta moorei* Butler.

Among bird pests the house sparrow (*P. domesticus*) as mentioned earlier is most common and destructive. Farmers reduce bird damage by various means of scaring. It is believed that awned varieties and those in which anthers remain stuck to the ears for longer periods are less damaged by birds. But no such observations were pointed by Jain and Prakash (1974). On the other hand, Verma (1984) reported that though the yields of both awned and awnless varieties were statistically similar, the former had relatively less bird damage as compared to the latter, suggesting that awned varieties could be considered bird resistant in arid zone. From these studies it also emerged that hybrids were more susceptible to bird damage than the locals.

**Disease management**

Several diseases are known to infect pearl

Table 18. Relative effectiveness of different insecticides (1 kg a. i./ha) for the control of white grubs (Pal and Doval, 1970).

| Treatment | | Extent of plant infestation at pre-harvest stage | Mean post-harvest population of white grubs/0.3 cu m | Mean grain yield (kg/24 sq m) |
|---|---|---|---|---|
| Thiodemeton | 5% | 30.0 | 1.0 | 4.9 |
| Phorate | 10% | 50.0 | 3.0 | 3.8 |
| BHC | 10% | 40 0 | 1.0 | 3.8 |
| Lindane | 6% | 20.0 | 0.5 | 4.9 |
| Dimethoate | 5% | 30.0 | 1.0 | 4.6 |
| Control | | 70 0 | 5.0 | 3.7 |

millet but downy mildew, ergot and smut are more important which often occur and cause considerable losses to the crop. Downy mildew or green ear disease is caused by *Sclerospora graminicola* (Sacc.) Schroet. High soil moisture has been found to counteract the primary infection of this disease (CAZRI, 1984b). Secondary spread of the disease through sporangia that takes place at a 'simple interest rate' was found to play a major role in spreading the disease further. Sporangial production was nocturnal and maximum number of sporangia (1.3 x $10^5$/$cm^2$ of leaf) were found at 3 a.m. The period for sporangial production from individual plants varied from 4 to 21 days. High relative humidity (90% in the morning and 70% in the evening), moderate temperature (25°C minimum and 31 °C maximum), good sunshine (around 5 h/ day) and mild rainfall favoured rapid secondary spread (CAZRI, 1983c).

Seeds of variety resistant to downy mildew were found to have more sugar and less crude protein content than the susceptible ones. Gupta and Gupta (1984) reported increase of non-reducing sugars and crude protein content in leaves and of reducing, non-reducing and total sugars in the roots of resistant variety due to downy mildew infection. Studies conducted on various management aspects of this disease revealed that soil application of $ZnSO_4$ (15-30 kg/ha) or boric acid (5 kg/ha) and two sprays of sodium molybdate (0.5 kg/ha each) minimised primary infection and secondary spread of downy mildew, respectively (Panjab Singh and Aggarwal, 1979 and CAZRI, 1983b). Application of FYM over seed furrows was also found helpful in checking the primary infection of the disease. Gupta (1984) reported that treatment of seed with systemic fungicide Apron 35 SD (3 g a. i./kg seed) followed by two sprays of Ridomil 25 WP (0.1% a. i.) were effective in controlling the disease. Cultivation of resistant varieties like CM 46, BD 111, WC C 75, MBH 110 and GHB 27 has also been suggested (Joshi *et al.*, 1984).

Ergot disease caused by *Claviceps fusiformis* Loveless was found to have close relationship with the climatological parameters (Saxena *et al.*, 1978). Gupta *et al.* (1983) reported daily optimum weather conditions for the disease development as 12 mm rainfall, 75% relative humidity, 20°C atmospheric temperature and sunshine for 6 hours from protogyny to early anthesis period (Fig. 3).

Smut caused by *Tolyposporium penicillariae* Bref. may cause 40% crop losses under favourable conditions. The disease is favoured by high humidity and high temperature during flowering. Smut management studies revealed that three sprays of calixin (0.1%) or Dithane M-45 (0 25%) were effective in controlling this disease (Gupta, 1984). Varieties CM 46, CJ 104 and MBH 110 have also shown resistance to smut as compared to other varieties developed from 5141A line (Joshi *et al.*, 1984).

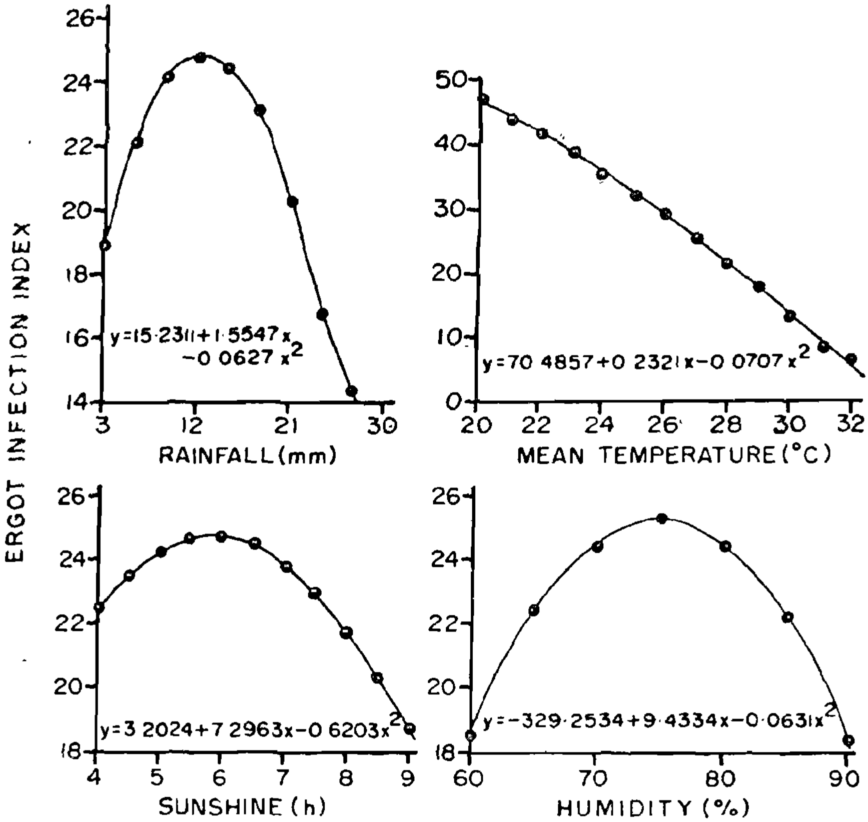


Fig. 3. Relationship between ergot infection index and some climatological parameters (Gupta et al., 1983)

Pearl millet was recorded as a new host for *Aspergillus phoenicis* (Corda) Thom., *Drechslera hawaiiensis* Ellis, *D. colocasiae* Tandon & Bhargava, *D. spicifera* (Bainier) Von. Arx , *Chaetomium globosum* Kunze ex Stendel., *Acremonium strictum* W. Gams, *Fusarium oxysporum* Schlecht., *F longipes* Wollenw. & Reink, *F. equiseti* (Corda) Sacc., *Syncephalastrum racemosum* and *Aspergillus terreus* Thom. (Lodha *et al.*, 1986).

# Crop energetics

The commercial energy input, which largely depends on fast depleting non-renewable sources of energy, has immensely increased crop production in recent years. Despite modest energy use in rainfed agriculture, pearl millet productivity has also become highly dependent on commercial energy inputs. Some of the evolved technologies were, therefore, assessed from energy use efficiency point of view (Joshi, 1988a). The efficient utilization of inputs largely depends on the quantity and distribution of rainfall. The analysis of two typical rainfall years showed that in good rainfall year, pearl millet gave as high as 126852 MJ/ha total energy output while in below normal rainfall year (152 mm), the energy output was 25348 MJ/ha for the same quantum of energy input (9246 MJ/ha). This resulted in higher energy output per unit input ($E_o : E_i$) value of 13.71 in good year compared to $E_o : E_i$ of 2.74 in subnormal rainfall year.

In another study, applicatian of 40 kg N/ha with one manual weeding involving 8034 MJ/ha total energy input resulted in total energy output of 39817 MJ/ha compared to 27226 MJ/ha output without nitrogen. The nitrogen accounted for 12591 MJ and the weeding for 21886 MJ/ha energy output. Combined application of these resulted in complementarity of 15.48% over simple additive effects, thus making integrated use of inputs as more efficient. The least specific energy of 1.76 MJ/kg biomass, with the highest $E_o:E_i$ (7.45) was recorded by the application of 40 kg N/ha together with herbicide application.

Energy output per unit of input varied with the cultivars and BJ 104 was the most efficient. The energy output could be further augmented by intercropping grain legumes with pearl millet (Table 19). The intercrops clusterbean, dewgram and greengram, with only 91 MJ/ha extra energy input resulted in 7938, 3810 and 2215 MJ/ha additional energy output, respectively. The paired planting with $10^5$ plants/ha proved to be energy efficient system for intercropping as it gave significantly higher energy output over uniform row planting in subnormal rainfall year and similar energy output in normal rainfall year.

Joshi (1988b) worked out radiant energy useefficiency (REUE) of pearl millet. The maximum REUE (1.77%) was recorded during 41-50 day period with an overall efficiency of 0 65 per cent.

Table 19. Yield and energetics of pearl millet intercropping systems (Joshi, 1988a).

| Treatment | Grain (kg/ha) | | Stover (kg/ha) | Energy input (MJ/ha) | Energy output (MJ/ha) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Grain | | | Stover | Total biomass |
| | Pearl millet | Inter-crop | | | Pearl millet | Inter-crop | Total | | |
| Uniform row | 1447 | — | 2817 | 8034 | 21270 | — | 21270 | 35212 | 56482 |
| Paired row + dewgram | 1249 | 265 | 3043 | 8125 | 18360 | 3895 | 22255 | 38037 | 60292 |
| Paired row + greengram | 1197 | 291 | 2946 | 8125 | 17595 | 4277 | 21872 | 36825 | 58697 |
| Paired row + clusterbean | 1327 | 268 | 3278 | 8125 | 19506 | 3939 | 23445 | 40975 | 64420 |
| Paired row + sesame | 1049 | 161 | 2866 | 8064 | 15520 | 4025 | 19445 | 35825 | 55270 |
| LSD (5%) | 345 | 61 | 400 | — | 5072 | NS | NS | 5006 | 6858 |

# Research thrusts for future

As a result of almost 30 years of research efforts, the productivity of pearl millet in the arid Rajasthan rose from 188 kg/ha in 50's to 255 kg/ha in 70's but, maladies afflicting crop producton being numerous, lot more of concerted research efforts are needed to arrive at tangible results. Some of important future lines of work are indicated below :

**Crop improvement**

Cultivation of improved varieties/hybrids has contributed less than the expected increase in productivity of arid zone. Unfortunately the hybrids recommended for cultivation in the region do not perfectly match with the rainfall rhythm of the area and often suffer late season droughts. The hybrids, though efficient utilizers of moisture and nutrients and endowed with better productivity, are vulnerable to various pests and diseases on account of their narrow genetic base. Incidence of diseases, especially downy mildew, eroded the faith of farmers to adopt hybrids over existing locals. On the other hand, composites/synthetics, having a broad genetic base, are well buffered against environmental fluctuations but do not have high productivity. The drought and salinity resistance should also receive priority in crop development programmes. Thus, development of a perfect ideotype for the arid conditions is much required for boosting the productivity in the region.,

**Tillage management**

Proper tillage in arid zone is important not only for the control of weeds and preparation of adequate medium for seed a germination and subsequent plant growth but also for conservation of moisture and efficient utilization of energy. Arable lands in arid zones are highly vulnerable to wind erosion and hence conservation tillage, both with respect to water and soil, is essential. The emphasis has to be on reducing the tillage input itself in consonance with other production practices.

**Crop stand establishment**

Soil crusting is a very serious problem in arid regions. Some luke-warm efforts have been made to solve the problem and it is not surprising, therefore, that the problem still persists. Application of FYM over seed furrows has helped in achieving satisfactory plant population on small scale only for want of proper applicators. Mixing of legume seeds with pearl millet appears ameliorative but the technique needs standardization by in-depth studies.

**Soil fertility managements**

Considerable work has been done on soil fertility management aspect but most of it has been done in piece meal. The soil fertility management needs to be considered in a holistic manner for at least five year cropping plan with judicious incorporation of chemical and biofertilizers, manures, crop rotation and intercropping systems. Precise information on the relationship between plant population for sole and intercropping systems and fertilizer use for a given quantum of water available in soil profile is still required to be worked out for improving fertilizer use efficiency. There is great scope for increasing the nitrogen use efficiency as we have not achieved so far further to 50% N use efficiency under the best of arid experimental conditions. Micronutrients, particularly in drought years, have given beneficial effects In-depth studies are needed to explain and quantify such relationships.

**Weed management**

Weed management studies have rather been fragmentary especially for newer more selective herbicides. The aspect of retention of weedicides in soil and the residual effects remained untouched in the past. Proper weed management methods in various intercropping systems involving pearl millet and legumes are yet to be worked out. No work has yet been done on *Striga* sp., the important root parasite of pearl millet. Intensified research efforts in these directions are urgently called for.

**Soil moisture conservation and management**

Water harvesting systems, appropriate to varying land characteristics and rainfall patterns obtained in different agro microclimates of arid zone, are to be perfected to avert crop failures. Crop life saving irrigation research including runoff recycling procedures should form an integral part of any water harvesting research. A relationship between catchment and farm pond size is still to be established. Basic information on moisture retention and its rate of release in respect of major landforms and soil series is lacking. Moisture movement characteristics operative under different agronomic practices should be investigated by soil physicist in detail in collaboration with agronomists. Search for cheaper materials or mulching, soil amendments and subsurface barriers, and development of suitable implements for their proper placement are all the more desirable.

**Tolerance to stress**

Occurrence of drought is not an uncommon phenomenon in arid zone. Some physiological aspects of the effect of drought on pearl millet have been studied but detailed studies on drought evasion using reflectants, antitranspirants and cultural methods are required. Drought evasion studies with regard to plant population in different pearl millet planting systems are required to be taken up. The possibility of using saline waters for life saving irrigations,crop stage-salinity tolerance relationship, soil salinity build up, use of amendments and fertility management relationships are some of the important aspects to be studied.

**Plant protection**

Management of pests and diseases in poor man's crop like pearl millet requires emphasis on cultural and mechanical methods. Varieties resistant to downy mildew and smut have been developed but so far success in practical resistance to ergot appears to be far off Epidemiological and off-season bioecological studies based on edaphic and climatic factors can help forecast and take prophylactic measures to combat foreseen epidemics of pests and diseases. Monitoring of pest outbreaks, resistance to insecticides and fungicides, studies on seed pathology, post harvest studies on varietal reaction to storage pests and effects of various cropping systems and nutrient applicaton levels on the pest incidence are some of the areas requiring greater attention of protection scientists.

**Agrometeorology**

Microclimate studies in relation to pearl millet planting systems and crop management practices evolved for arid zone should be taken up so as to utilize the abundant solar energy and scarce water resources to the best advantage for optimising productivity per unit area, time and moisture.

**Energy management**

Energy is the key factor of concern in agricultural production. We have to develop methods to get larger output of food and biological energy for every input of commercial energy. Huge amounts of non-renewable energy is used even in arid zone agriculture in the form of chemical fertilizers, fossil fuels and electricity. This energy can well be conserved by improving tillage, water and fertilizer use efficiencies.

**Farm implements**

Limited efforts have been made to improve the efficiency of implements already available with arid zone farmer. Though placement of urea in seed furrows in moist zone is essential to increase the fertilizer use efficiency, large scale adoption of this practice remains for want of appropriate bullock drawn seed-cum-fertilizer drills. Similarly, the deep placement of subsurface barriers and water harvesting are not practised for want of suitable implements Research efforts should, therefore, be directed towards improvement of local implements and fabrication of suitable new implements with feasibility and acceptability potential.

**Conservation farming**

Increasing demand for food calls for high emphasis on conservation farming. Time has come to recycle each and every by-product of crop and livestock farming. For each micro-agroclimatic zone of arid region, suitable farming systems including crop, live stock and farm forestry have to be worked out. Agronomists need to interact closely with animal husbandry and farm forestry scientists to develop successful conservation farming systems.

**Systems analysis**

Development of mathematical models is one of the most powerful means known for sorting out and describing complex systems and thereby providing us with a way to evaluate and analyse the various interactions going on within an ecosystem. Simulation modelling is an effective approach to interpreting the inter-relationships between weather and physiological processes leading to final yield. Currently no simulation model for pearl millet is available. A minimum data set required for developing and testing the model should be identified. To make the team efforts successful and to understand the whole system of crop production, it is suggested that the approach of system analysis and modelling should find a place in future research.

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*Note :* This is an incomplete list. A large number of publications, including Annual reports, survey reports, proceedings of symposia/workshops, bibliographies, extension bulletins, etc., have not been included.

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