Scientific Papers presented at the OAU/STRC-SAFGRAD International Drought Symposium on Food Grain production in the semi-arid regions of sub-Saharan Africa. Nairobi, Kenya. 19-23 May, 1986.

This publication has been supported by the USAID, United States Agency for International Development

An OAU/STRC-SAFGRAD Publication.

Production by: Fourth Dimension Printing Services
7 Glebe Close, Thorpe Bay, Southend-on-Sea, Essex, UK.

ISBN 978-2453-12-9

Printed and bound in Great Britain by
Redwood Burn Limited, Trowbridge, Wiltshire

Proceedings of a[illegible]nternational Drought Symposium
held at the Kenyatta Conference Centre, Nairobi, Kenya
19th to 23rd May 1986.

FOOD GRAIN PRODUCTION IN SEMI - ARID AFRICA

Edited by

J.M. MENYONGA
International Coordinator
OAU/STRC-SAFGRAD,
Ouagadougou

TAYE BEZUNEH
Director of Research
OAU/STRC-SAFGRAD.
Ouagadougou

ANTHONY YOUDEOWEI
Publishing Consultant
University of Ibadan, Nigeria.

Published by

The Coordination Office
OAU/STRC-SAFGRAD
Semi-Arid Food Grain Research and Development
Ouagadougou, Burkina Faso.
BP 1783

use of sorghum to enhance its market opportunity. Beside being used as a malt source by large brewers of traditional beer, Zimbabwe is interested in using sorghum to extend wheat flour and Zambia is planning to construct a plant to make molasses. The dairy industry in Zimbabwe is interested in animal feed and in Botswana there is interest in developing a forage with good resistance to moisture stress. Although it would require study, there may be a place for production of alcohol and biogas.

The programme is at an exploratory stage when attempts are being made to look at an array of opportunities to better utilise the crop traditionally and as a cash crop in the market.

Conclusions

1. While recognizing the importance of resistance to moisture stress, it is important to rank priority traits for the various agro-ecological situations in the SADCC Region to determine research strategies.
2. A regional crop improvement programme can be a cost effective way to undertake many research problems in the region and can contribute to strengthening national research capability. The regional programme develops a network and also participates in a world-wide network of research and development.
3. Education and training programmes are being established to reduce the problem of lack of qualified manpower to undertake crop improvement activities on sorghum and millets..
4. Concern is expressed about conditions for doing quality field research and plans to contribute to improving experiment station development and management, through an educational–training component.
5. In the region, a service will be provided to speed the rate of breeding progress via an off-season nursery – crossing block opportunity, and to continually introduce and evaluate across a range of priority traits.

---

13 Improvement in Stand Establishment in Pearl Millet

P. SOMAN, T.J. SOMPH, F.R. BIDINGER and
L.K. FUSSELL
Pearl Millet Improvement Program, ICRISAT Center, ICRISAT Patancheru P.O., 502 324, A.P., India
and
Pearl Millet Program, ICRISAT Sahelian Center, P.O. Box 12404, Niamey, Niger

Abstract Inadequate crop stands are a common feature of pearl millet fields in arid and semi-arid areas in both Sahelian Africa and in India. Studies in Niger and Rajasthan State (India) indicate that low soil moisture and associated high soil temperature are among the major causes of stand failures; seed quantity and quality are usually not limiting factors.

Field and laboratory screening methods have been developed to evaluate genetic differences in tolerance of high soil surface temperatures and low seedbed moisture levels for both initial emergence of seedlings and for post-emergence survival. Initial results indicate that there is genotypic variation in pearl millet for tolerance to most of these problems. Reasons for differential tolerance are not known at present, but it should be possible in the near future to commence routine screening of selected breeding materials for better stand establishment capability.

The possibility of eventually breeding for better stand establishment capability will depend on (1) field evaluation of the benefits of the differences that exist and (2) the outcome of future studies on the heritability of these differences.

Crop establishment is often cited as a production problem for pearl millet (*Pennisetum americanum (L.) Leeke*) in both arid and semi-arid areas. Farmers are frequently obliged to sow several times to attain an acceptable stand of plants, even with the relatively low plant populations common to these areas, particularly the Sahelian zone of West and Central Africa (Cathernet *et al.*, 1963; ICRISAT, 1983). Resowing increases the labour requirement for the crop, and crops from late sowings often yield less than those from sowings with the first rains (Charreau, 1974). Improved establishment would be a definite benefit if it could be attained, by either improved tillage and sowing methods or by millet cultivars with better tolerance to those factors which cause poor establishment.

Causes of Poor Crop Establishment

Poor crop stands can occur for a variety of reasons: poor seed quality, poor seedbed preparation and sowing methods, failure of emergence, and failure of emerged seedlings to survive (see also table 1). As each of these factors requires a different solution, it is essential to understand the major cause(s) of stand failure in a given location before improvement can be sought. Several studies carried out by the authors to better understand the specific reasons for stand failure (ICRISAT, 1982; ICRISAT, 1986) illustrate the differences which exist.

In studies in several villages in India and in Niamey Department, Niger, the quality of seed of pearl millet sown by farmers has generally been good (Soman *et al.*, 1984b, Soman, unpublished).

With a few exceptions, insect damage is low (<10%) and germination in standard laboratory tests is good (>80%). Seed quality therefore may be only an infrequent cause of poor stands. Similarly sowing rates were generally adequate (Fig. 1)

Actual field emergence percentages in these same studies however were low, often in the range of 25% or less of seeds sown. In Dhandhan village, Sikar District, Rajasthan in 1983, for example, actual plant stands at 5 days after sowing (DAS) represented less than 10% of the seeds sown (Fig. 1), which resulted in plant populations well below recommended ones in all cases, and stand failures in many cases. Even under optimal conditions on research stations emergence rates for pearl millet are seldom more than 50% of the seeds sown (Lawan *et al.*, 1985, Soman, unpublished), although laboratory germination rates of 90% are regularly reported. Emergence rates of 50% can be easily compensated for by adjusting sowing rates, but emergence rates of 10% can seldom be, as emerged seedlings in these conditions are frequently too unevenly distributed to provide even stands.

Analyses of seedbed environmental data from the Dhandhan study suggested that low soil moisture and high soil temperature in the seed zone during germination/early emergence (1 – 2 DAS) were at least partly responsible for the poor emergence observed. Mean seed zone moisture ranged from 1 to 6% (in soils with >90% sand) at 1 DAS, accompanied by midday soil temperatures of 36 to 44°C.

Post-emergence death of seedlings is also a common problem, particularly in the Sahel, and can reduce acceptable plant stands at emergence to stand failures within one to two weeks time (ICRISAT, 1986). In the study in Niamey Department, emergence calculated on a hill basis (at least one emerged seedling per hill) averaged 80%; but hill populations declined from a mean of 4900 hills ha^{-1} at 5 DAS to 2300 hills ha^{-1} at 12 DAS, with stands failing completely in nearly half of the fields (Fig. 1). An analysis of environmental conditions measured during the period indicated that high soil surface temperatures (>50°C at midday) were primarily responsible for the stand loss. Such temperatures are common in this area if the initial sowing rain(s) are followed by a period of dry, clear weather and surface soil moisture evaporates (ICRISAT, 1983).

Table 1 Factors affecting crop establishment of pearl millet in farmers' fields.

Factors Affecting Seedling Emergence:

Seed Factors
- Seed viability and dormancy
- Seed size and density
- Plumule length/growth rate

Management Factors
- Timeliness of sowing
- Sowing depth
- Seed-soil contact

Environmental Factors
- Soil moisture
- Soil temperature
- Soil crusting and compaction

Factors Affecting Post-Emergence Survival:

Seedling Factors
- Vigor and growth rate
- Root establishment

Environmental Factors
- Soil moisture
- Soil temperature
- Soil fertility

Figure 1 Distribution of seeds sown (bottom), emerged seedlings (center), and surviving seedlings (top) in farmers' fields in Sikar District, Rajasthan India in 1983, and Niamey Department, Niger in 1985

Improvement in Stand Establishment

The origin of a stand establishment problem obviously determines the appropriate solution. Seed quality can be improved by selecting better seed material from the previous crop (Okonkwo and Vanderlip, 1985), and by improved storage conditions. Poor emergence due to incorrect sowing depth, poor seed soil contact, etc., can be improved by better sowing equipment and/or methods. Stand loss due to covering of seedlings by wind or water transported soil materials can be reduced by land surface treatments, wind breaks, etc. to reduce such covering (ICRISAT, 1985)

Stand failures or losses due to unfavourable seedbed moisture and temperature conditions are less feasible to control by cultural methods, and improvement must be sought through genetic tolerance of the factor responsible for the stand failure. Breeding for such tolerance is a relatively ew area, but the procedure for doing so is similar to that for breeding for resistance to pests or diseases (Bidinger *et al.*, 1986). This necessitates an understanding of the problem, the development of screening methods and the assessment of genetic variability for tolerance, and an evaluation of the response to selection for improved establishment ability.

This paper will review the results of the authors' research, which has been designed to lay the foundation for future efforts in breeding for improved crop establishment ability. Emphasis is on the development of screening methods for specific problems, and on the assessment of genetic variation for tolerance to the causes of the problems.

Seedling Emergence from Low Moisture, High Temperature Seedbeds

Screening Techniques

A field screening technique has been developed to simulate the low moisture, high temperature conditions which can occur in a seedbed following sowing done on an isolated, light, rainfall (15 – 20 mm) which is then followed by clear dry weather (Soman, unpublished). The screening is done in the hot dry season before the beginning of the monsoon (March – May) when atmospheric conditions result in rapid drying and heating of the seedbed soil.

Seeds are sown into dry soil on raised beds 1.2 m wide with 4 rows to a bed. The soil surface is smoothed and a gradient irrigation applied using the line source technique (Hanks *et al.*, 1976). This produces a linear gradient of applied water from about 30 mm closest to the sprinkler line to 5 mm at the farthest point, covering seven beds. The beds are sown such that each test entry appears in each position (bed) along the gradient in the useful range of 10 to 25 mm of applied water. Seedbed temperature (2 cm) is monitored hourly by an automatic data logger and seedbed moisture (0 – 5 cm) is measured daily by gravimetric means (Fig. 2). Test entries are replicated either once or twice on both sides of the line source. Comparisons are made of genotype emergence in several beds, including both adequate (wet) and inadequate (dry) moisture for full emergence. Data are expressed as emergence in the dry seedbed conditions relative to that in the wet conditions.

A second, laboratory-based method to assess germination response to high temperature has also been developed (Soman and Peacock, 1985). In this method seeds are sown in closed but unglazed clay pots which are placed in a water bath with the water level controlled to maintain an optimum (not saturated) soil moisture in the seed zone of the pot. A bank of infra-red lamps are placed above the water bath; these are used to heat the soil surface in the pots in a simulated natural diurnal temperature cycle (Fig. 3). The maximum temperature of the cycle is adjustable from <40 to 50°C, thus allowing any degree of temperature stress to be put on germinating/emerging seeds without the common confounding effects of inadequate seedbed moisture. Data are expressed as a percent emergence (of the seeds sown).

Evidence for Genetic Variation

Differences between both landrace and improved varieties have been found in ability to emerge in low moisture, high temperature seedbeds. In fact in

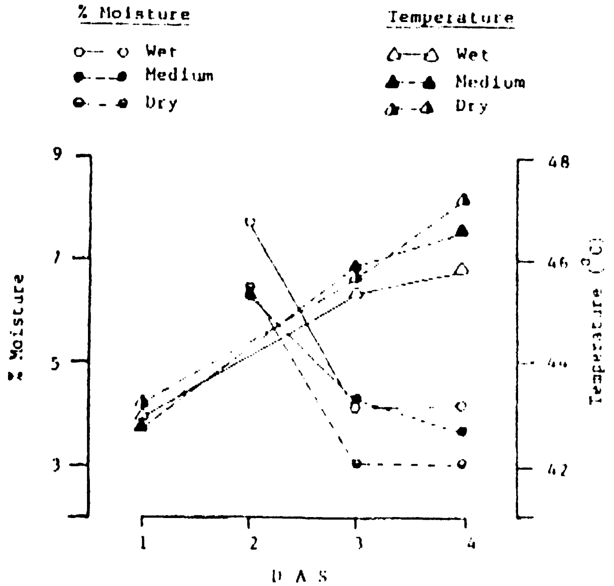

Figure 2 Changes in surface soil moisture (0 – 2.5 cm) and temperature (2 cm depth) with days after sowing (DAS) in a field screening for emergence under high temperature, low moisture seedbed conditions

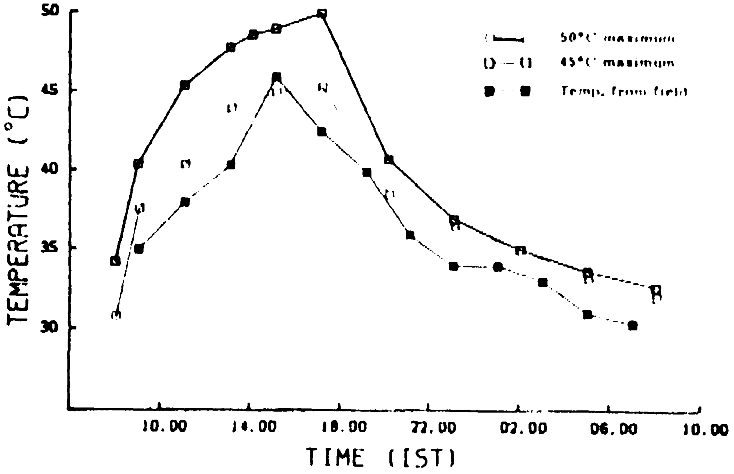

Figure 3 Diurnal variation in soil surface (2 cm depth) temperature under infrared lamps, in comparison to diurnal variation in soil surface temperature (2 cm depth) under field screening conditions

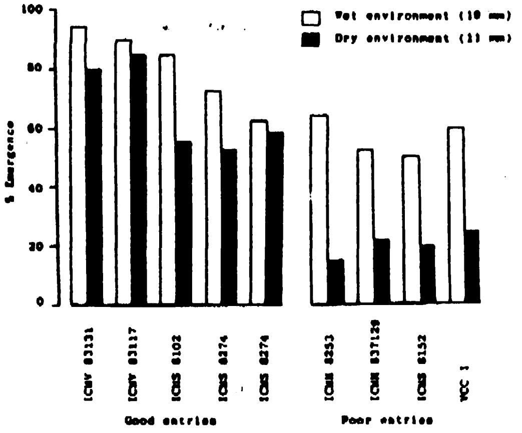

Figure 4 Percentage emergence of selected entries from the International Pearl Millet Adaptation Trial, 1985, under high temperature, low moisture seedbed conditions in the field.

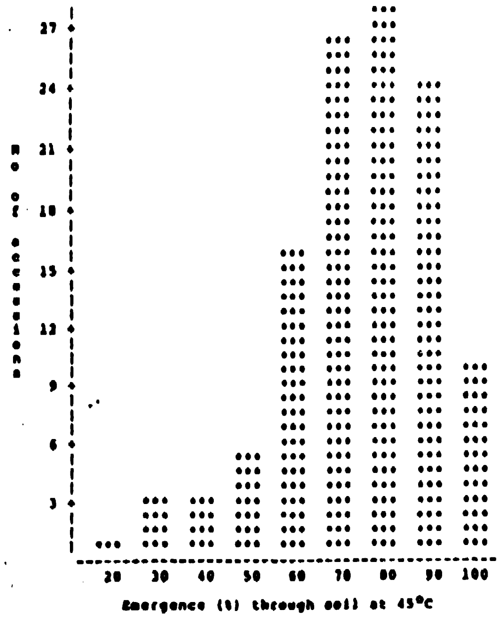

Figure 5 Percentage emergence of germplasm accessions at a soil surface temperature of 45°C, under infrared lamps.

certain cases the differences have been surprisingly large. In a recent evaluation of entries in the International Pearl Millet Adaptation Trial, 1985, the range of emergence in the drier end of the moisture gradient (11 mm of water applied) was from 11 to 85%. Six entries had greater than 50% emergence in these conditions and two emerged as well in the dry as in the wet (19 mm water applied) environment (Fig. 4).

These results were considered encouraging as no previous effort had been made to select these entries for emergence ability. If this amount of variation is a general pattern, early screening of varieties under consideration for wider testing may be sufficient to eliminate those with poorer emergence capability from further consideration. This would simplify the procedure for improving stand establishment capability considerably.

More experience is available in screening pearl millet for the ability to emerge in high temperature conditions alone, as the technique using the infra red lights has been available longer. A comparison of 117 genetic resources accessions from the state of Rajasthan (India), six Sahelian and two Southern African countries indicated considerable genetic variation for emergence ability at a moderately high (45°C) daily maximum soil surface temperature (Fig. 5). Increasing this temperature to 50°C reduced the mean per cent emergence from 71% at 45 to 36% at 50°C, and the range from 20 – 100% to 0 – 30%. Eight per cent of the entries however still achieved a satisfactory (>60%) emergence at 50°C. This suggests that if there were a need to breed for emergence capability from such extreme temperatures, sources of tolerance are available.

Seedling Emergence from a Crusted Soil Surface

Screening Techniques

This technique (Soman *et al.*, 1984a) is done in the field in the dry season as in the previously described seedling emergence technique. Seeds are sown on adjacent pairs of 1.2 m wide beds in a dry soil, which has been worked to a very fine tilth to favour surface crust formation. The tops of the beds are smoothed with a bed shaper following sowing and a uniform sprinkler irrigation of approximately 30 mm is given using two sets of overlapping line source systems placed at the edges of the test area. The action of the sprinkler-applied water drops on the smooth soil surface provides the conditions necessary for crust formation during the following 2 – 3 days, if evaporation rates and temperatures are high. One day before the expected time of seedling emergence the surface crust on one of the pair of beds is broken using a rolling crust breaker; this provides a control treatment to measure the potential maximum emergence under the experimental conditions, but in the absence of the crust. Soil temperature and moisture are monitored and crust strength assessed daily (Fig. 6). Genotype emergence is expressed as the ratio of seedlings emerged in the crusted treatment to those emerged in the control (c/u ratio).

Evidence for Genetic Variation

Pearl millet in general does not emerge well in crusted soil conditions compared (for example) to sorghum as the millet seedling is smaller and less capable of actually breaking a surface crust. There are, however, some differences among lines, and a recent test of germplasm accessions from

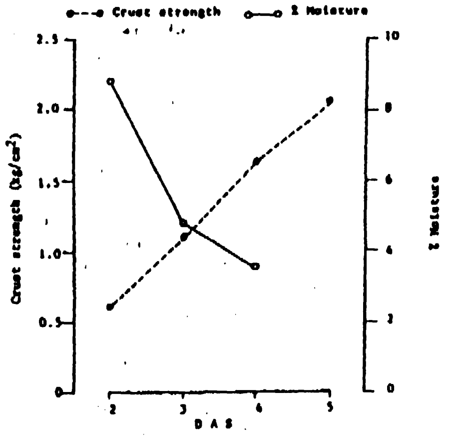

Figure 6 Changes in crust strength and soil surface moisture (0 – 2.5 cm) with days after sowing (DAS) in a field screening trial for seedling emergence in crusted soil conditions.

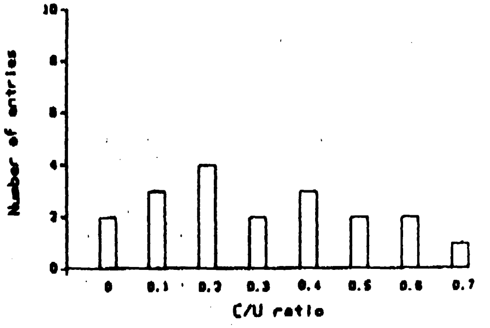

Figure 7 Emergence of entries in the International Pearl Millet Adaptation Trial, 1985, under crusted soil conditions. Data are the ratio of emergence in the crusted to the noncrusted conditions (C/U ratio).

Southern Africa has identified some lines with a reasonable emergence ability.

The same International Pearl Millet Adaptation Trial reported in the previous section was also screened for emergence in crusted soil conditions (Fig. 7), the results typify those generally observed with pearl millet. The majority of the entries failed to achieve a satisfactory emergence, only five reached 50% and one, 70% emergence. Breeding to improve emergence ability in crusted conditions would probably require a greater effort, perhaps including crosses with the existing lines showing the best capability and intensive screening of progeny. Nothing is known however of the inheritance of the ability of emergence from a crusted soil or the mechanisms by which some few lines are successful.

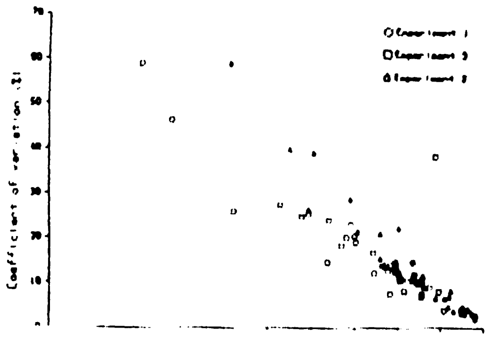

Figure 8 Relationship of percent seedling survival and experimental coefficient of variation for three field experiments on seedling survival in high temperature, low moisture conditions.

Seedling Survival in High Temperature, Low Soil Moisture Conditions

Screening Techniques

Screening for seedling survival in combined high soil temperature, low soil moisture conditions is done under field conditions in the latter part of the dry season, prior to the rains. Seeds are planted and given 25 mm of irrigation by sprinkler, which is adequate for 100% emergence. Control plots (wet plots) continue to be irrigated as required. Stress plots (dry plots) receive no further irrigation. Under such conditions, there is a strong inverse relationship between coefficient of variation (CV) and the mean percentage survival in the dry plots (Fig. 8). The time of release of the stress (when an irrigation of 25 mm is given to the dry plots to accurately determine the number of surviving plants) has been experimentally determined in terms of the estimated percentage survival in a standard resistant check at which the expected CV will allow the desired degree of discrimination among entries. (This is about 70% with local Heini-Kheri landrace as the resistant check). Soil surface temperatures are monitored regularly in both treatments and data are expressed as per cent survival and seedling growth in the dry as compared to the wet plots.

An attempt is also being made to modify the laboratory technique used to evaluate emergence under high soil surface temperature, in order to evaluate the ability to survive high soil temperatures following emergence, without the associated effects of a rapid loss of soil moisture. Plastic pots containing 10 seedlings each are set in a water bath placed under a bank of infra-red lamps. Seedlings are subjected to various periods of high (45 – 50°C) soil surface temperatures, both continuous and with alternating non-stress periods, as would occur in field conditions. Additional work is

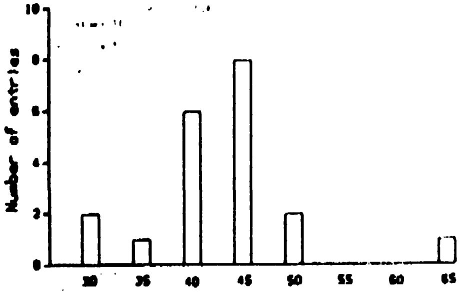

Figure 9 Seedling survival of entries of the Pearl Millet Multilocation Drought Trial, 1985, under high temperature, low moisture conditions.

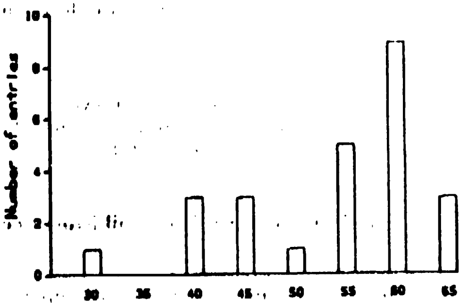

Figure 10 Seedling survival of a collection of landrace varieties from West Africa under high temperature, low moisture conditions.

required on this methodology, but initial results (see below) have been promising.

Evidence for Genetic Variation

A number of comparisons of materials of Sahelian-origin with non-Sahelian materials have demonstrated the clear superiority of the former in surviving long periods of stress at the seedling stage. For example, a group of Indian lines under evaluation for drought tolerance (at the adult plant stage) were all markedly inferior to the local Heini-Kheiri landrace at Sadore, Niger in ability to survive a period of seedling stress (Fig. 9). The landrace had 65% stand survival compared to 51% for the next best entry and a 42% average of all lines. Similar differences exist between African varieties of Sahelian and non-Sahelian origin; nearly all of the entries with less than 50% survival in the comparison of mostly Sahelian landraces shown in Fig. 10 are of African but non-Sahelian origin. Whether or not there are important differences among Sahelian landraces is not known.

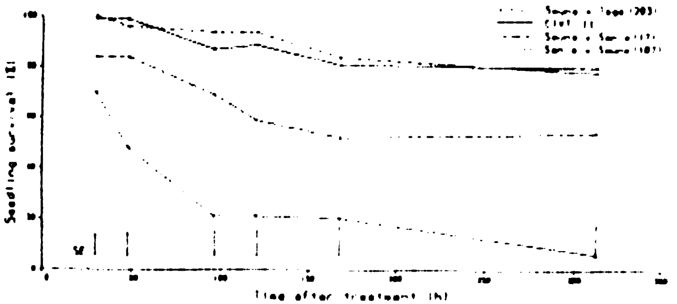

Figure 11 Seedling survival of selected pearl millet lines following the initiation of a 48 hour period of high temperature (48°C) treatment under infrared lamps

Limited experience in screening new breeding program products indicates that there may be large differences in such materials, and that those including parents from non-Sahelian areas may have poor seedling survival capabilities under Sahelian conditions (ICRISAT, 1986). Results were generally encouraging however, in that some new varieties did have a tolerance equal to that of the local Sadore' landrace, which was used as the tolerant check. New varieties for the Sahelian zone clearly need to be screened for establishment capability as early as possible in the breeding process to discard those which are not able to tolerate seedling stress conditions.

Results from the laboratory infra red screening system for high temperature tolerance are limited, but have indicated that clear differences exist among the limited number of genotypes tested, (Fig. 11). As in the case of the field screening, certain lines were found with a tolerance equal to that of the check variety (CIVT in Fig. 11). Further experience with this technique is necessary however to confirm that the direct measurement of heat tolerance does predict the field tolerance of the combined temperature and moisture stress.

Breeding for Improved Crop Establishment Capability

It is clear from results reported in the previous sections that there are often significant differences among released or advanced varieties in crop establishment ability. Where crop establishment is a problem, it would seem that routine screening of advanced varieties for establishment ability should be initiated, mainly to discard those entries which do not establish as well as the varieties commonly grown by farmers. The number of varieties in the advanced stages of testing is often small, so the resources required for such screening are not large. As the objective of such final evaluation is generally to reduce the number of varieties to one or two for on-farm testing, any evaluation procedure (e.g., consumer acceptance, pest resistance, establishment ability, etc.) which assists in this is useful. This is particularly true if the yield differences among entries are small/non-existant, and cannot therefore be used to eliminate entries.

Some additional field evaluation of the differences among varieties identified in the screening procedures would probably be advisable before routinely using these procedures, however. The performance of the tolerant d susceptible checks in several of the procedures has been confirmed in field plantings, as part of the procedure of selecting these as checks. These represent extreme differences, however, and it could be useful to determine how well intermediate entries in the screening tests perform under natural field conditions. Such information would assist in evaluating the significance of small (but statistical) differences recorded among entries in the screening procedures.

The longer term use of these screening procedures for direct selection for seedling establishment ability in the early stages of a breeding program will depend on the results of future studies on the heritability of differences in establishment among genotypes. Early generation selection requires screening a much greater number of lines, over more than one generation, and requires that screening must fit into a fixed calendar determined by other selection procedures. Seedling establishment must be sufficiently heritable to justify this increased expenditure of time and resources. Nothing is known of the heritability of seedling establishment at present; work is just beginning to assess this. The results will determine how (and if) selection for establishment ability can be best integrated into the early stages of a breeding program.

References

Bidinger, F.R., V. Mahalakshmi, P. Soman, and B.S. Talukdar. 1986. Breeding for adaptation to environmental stress? *In* Proceedings of the International Pearl Millet Workshop, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, 7-11 April. *International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.*

Catherinet, M.-D., S. Dumont and A.A. Mayaki. 1973. Le mmil et le sorgho dans l'agriculture du Niger. A) Cultivars. Besoins. Soil et climat. Facteurs limitatants. *Agron. Trop. 18:108-113.*

Charreau, C. 1971. Soils of tropical dry and dry-wet climatic areas of West Africa and their use and management. *Cornell University. Ithaca, New York.*

Hands, K.R., J. Keller, V.P. Rasmussen, and G.D. Wilson. 1976. Line source sprinkler for continuous variable irrigation, crop production studies. *Soil Sci. Soc. Am. Proc. 40:424-429.*

International Crops Research Institute for the Semi-Arid Tropics. 1982. pp. 59-61. *In Annual Report for 1981. Patancheru, India.*

International Crops Research Institute for the Semi-Arid Tropics. 1982. pp. 360-362. *In Annual Report for 1982. Patancheru, India.*

International Crops Research Institute for the Semi-Arid Tropics. 1985. pp. 303-305. *In Annual Report for 1984. Patancheru, India.*

International Crops Research Institute for the Semi-Arid Tropics. 1986. *in press. In Annual Report for 1985. Patancheru, India.*

Lawan, M., F.C. Barnett, B. Khaleeq, and R.L. Vanderlip. 1985. Seed density and seed size of pearl millet as related to field emergence and several seed and seedling traits. *Agron. J. 77:567-571.*

Okonkwo, J.C. and R.L. Vanderlip. 1985. Effects of cultural treatment on quality and subsequent performance of pearl millet seed. *Field Crops Res.* 11:161-170.

Soman, P., J.M. Peacock, and F.R. Bidinger. 1984a. A field technique to screen seedling emergence in pearl millet and sorghum through soil crust. *Expt'l. Agric. 20:327-334.*

Soman, P.R. Jayachandran, F.R. Bidinger, and J.M. Peacock 1984b. Factors affecting seedling emergence and stand establishment – Studies on farmers' fields in Aurepally and Dhandhan during 1981, 1982 and 1983. *Sorghum and Millet Physiology Program Progress Report, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.*

oman, P., and J.M. Peacock. 1985. A laboratory technique to screen seedling emergence sorghum and pearl millet at high soil temperatures. *Expt'l. Agric. 1:335-341.*