

WORLD METEOROLOGICAL ORGANIZATION

AGRICULTURAL METEOROLOGY

CAGM Report No. 66

AGROMETEOROLOGY OF THE PEARL MILLET

Prepared by

V. Mahalakshmi

(CAGM Rapporteur on Agrometeorology of the Pearl Millet)

WMO/TD - NO. 746

Secretariat of the World Meteorological Organization

Geneva, Switzerland

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AGROMETEOROLOGICAL INFORMATION FOR CEREAL CROP

Pearl Millet

CHAPTER 1

INTRODUCTION

Pearl Millet is a widely grown rained cereal crop in the arid and semi-arid regions of Africa and South Asia. It is the staple cereal crop in the subsistence agriculture in these arid and semi-arid regions. It is grown in 15 million ha in Africa and the grain yields average about 500 kg/ha. In the South Asian subcontinent it is grown in 11 million ha and the grain yields average about 660 kg/ha. In other continents it is grown under intensive cultivation as a forage crop. It has numerous advantages that have made it well adapted to these harsh environments; namely, its tolerance to high temperatures, drought, low fertile soils and has high growth rates (Begg, 1965). Pearl millet is capable of producing good yield even under severe environmental conditions, which normally is unsuited for other grain crop. This is the reason why millet is usually referred to as "Camel" crop of the world. Complete failure of crop due to limited rainfall is much less frequent as compared with other crops. Millet is capable of producing significant yield using 200mm of moisture during the growing season (Cocheme and Franguine, 1967). It is commonly known as bulrust or cattail and mil aux chadelles. In Africa it is known as gero, maiwa, souna, dukhn and sanio and in India, bajra and cumbu are a few of the many colloquial names (Andrews and Kumar, 1992).

1.1 Taxonomy and origin

Pearl millet belongs to the genus *Pennisetum* of the paniceae family. Its taxonomic history is extensively variable. It is currently known as *Pennisetum glaucum* (L.) R. Br. It was variously classified as *P. Americanum* (L.) Leeke, *P. Typhoides* Stpf. And Hubb. and *P. Glaucum* (Brunken, 1977; de Wet, 1987).

The genus *Pennisetum* is well distributed throughout the tropics and subtropics. The cross fertile wild and weedy forms of the primary pool include sub-species *stenostachyum* and *monodii*. The secondary pool includes the species *purpureum*. Pearl millet was probably domesticated in Africa in Savannah south of Sahara and west of the Nile, possibly some 5000 years ago (Brunken et al., 1977) from *P. Fallax-P. Violaceum*. These wild forms are still prevalent on the southern fringes of the Sahara (see Andrews and Kumar, 1992; de Wet et al., 1992). The tertiary pool contains many distantly related species of *Pennisetum* with various ploidy levels that do not normally interbreed with the pearl millet. The success of pearl millet as a cereal is due to the adaptive characters of its wild progenitors to heat and drought stress. Wild millets are typically desert type.

1.2 Breeding

Pearl millet is an annual, high tillering diploid ($2n = 14$) and naturally cross-pollinating protogynous crop. This floral biology has permitted various breeding methods for genetic enhancement of the crop. This ranges from population breeding methods to pedigree selection.

Several cytoplasmic male-sterile systems are available and the release of single cross hybrids for commercial use in a coarse cereal was in this crop in the early 1960s in India. Though the initial success of these hybrids was short lived due to their susceptibility to downy-mildew disease during the late 60's, this problem was overcome by the diversification in the male sterile lines. Genetic enhancement through the introduction of single cross hybrids and

improved population has played a major role in improving the grain yield productivity (yield ha⁻¹) of this crop in India. In Africa, there has been no improvement in productivity in the last three decades (Anand Kumar, 1993; Kelly and Rao, 1993). In a study, top-cross hybrids were found to be more responsive than their open pollinated parents in the low -yielding environments (Mahalakshmi et al., 1992; Bidinger et al., 1994). The suitability of top-cross hybrids (line x variety crosses) in West Africa as an alternative to single cross hybrids and open pollinated varieties is being evaluated.

1.3 Physiology

Pearl millet is C₄ (phospho-enol-pyruvate carboxylating enzyme) species with very high photosynthetic rates and dry matter production (Begg, 1965). The crop stages are broadly divided into three growth phases: namely:

- GS₁: Growth stage one or sowing to panicle differentiation
- GS₂: Growth stage two or panicle initiation to flowering
- GS₃: Growth stage three or flowering to grain maturity.

CHAPTER 2

ENVIRONMENT

2.1 Photoperiod

Pearl millet is grown as a rainfed crop during the rainy season (June-Oct.) In India and West and Central Africa. Tailoring the life cycle of the crop to the length of the growing season is the basis of adaptation of pearl millet in these regions. This is achieved by photoperiod sensitivity. Pearl millet is a quantitative short-day crop where flowering is hastened under shorter day lengths (Bilquez, 1963; Burton, 1965). The crop phases, up to flowering, have been divided into juvenile phase: - time during which crop is not responsive to photoperiodic induction; floral induction phase: - the phase following juvenile phase where floral induction under inductive photo periods occur and floral morphogenesis phase: - the phase proceeding floral induction and is not influenced by photoperiod (Belliard et al., 1979).

These two major millet-growing zones of the world lie in different latitude zones, 11 to 14 °N in West and Central Africa and between 25 - 30 °N in north-west India. In both these zones, the length of the growing season varies from 10 to 18 weeks in duration (Kowal and Kassam, 1978; Virmani et al., 1982). In both these regions, the length of growing season is inversely related to the latitude and is more acute in west Africa, where season length changes markedly over a small range in latitude (Figure 1). Therefore, the roles of photoperiodic response differ in these regions. In West Africa, the onset of rains is highly variable between years while the end of rains is sharp (Kowal and Kassam, 1978). In such environments, photoperiodic control of flowering provides an opportunity to sow whenever the rains begin but ensures that flowering and grain filling occur when moisture regime is most favourable (Mahalakshmi and Bidinger, 1985).

2.2 Temperature

It has a base temperature around 12°C, an optimum temperature around 35°C and a lethal temperature around 45°C (Ong, 1983a; Ong, 1983b; Gregory, 1983; Khalifa and Ong, 1990). The germination rate of millet increases linearly with temperature from a base of about 10 to 12°C to a sharp defined optimum of 33°C and sharply declines to zero at 45 to 47°C (Gracia - Huidobro et al., 1982). Fig. 2 gives the root elongation of millet as a function of temperature. It appears that optimum temperature for root elongation is 32°C.

Increasing temperature increases the speed of germination and reduces the spread of population about the modal date, of both germination and emergence (Pearson, 1975). However, high temperatures (>45°C) and soil surface crusting following sowing may result in poor crop establishment due to seedling death (Soman et al., 1987). In West Africa, the problem is further complicated by sand blast that bury the seedling under the sand.

2.2.1 Vegetative growth

Rate of leaf production was accelerated at high temperatures (Pearson, 1975) although the number of leaf primordia on the main stem apex did not change from 18 to 30°C (Theodorides and Pearson, 1981). Tillers appear sooner and they are formed more rapidly as temperature increases to about 25°C (Pearson, 1975; Ong, 1983a). Above 25°C the time of appearance of the first tiller does not change but there is a decline in the number of tillers (Begg and Burton, 1971; Ong, 1983a).

2.2.2 Reproductive stage

High temperature during flowering result in loss of pollen viability and can reduce the receptivity of stigmas and affect grain filling. Grain setting was optimum from 22-25°C and declined at temperatures below and above this optimum while grain mass steadily declined with increasing temperature from 19°C to 31°C (Ong, 1983b). Exposure of plants to prolonged periods of low temperature (< 13°C) during the booting stage resulted in low grain set. This was due to low temperature induced sterility of floret and pollen grains (Fussell et al., 1980; Mashingaidze and Muchena, 1982).

2.3 Rainfall

Rainfall is the main source of moisture supply to the crop. The amount and distribution of rainfall are the most important factor limiting productivity. Poor soil moisture at sowing reduces seedling emergence leading to poor crop establishment. Farmers often resow with subsequent rains. Intermittent break in rainfall is a common feature but the crop is well adapted to water deficits during the GS₂ period (Mahalakshmi et al., 1987). Early flowering and grain filling stages are the most sensitive stages to water deficits (Mahalakshmi and Bidinger, 1985; Mahalakshmi et al., 1987). Both timing of stress in relation to flowering and intensity of stress determine the reduction in grain yield (Mahalakshmi et al., 1988). Most of the variation among environments in a multi-location trial was due to the availability of water at flowering and variation among genotypes was dependent on the temperature during early grain filling.

Agricultural production in rainfed areas depends heavily on the total amount and number of rain-days in the growing season. Under the conditions where millet crops are cultivated, evaluation of rainfall in terms of probability estimates instead of arithmetic means is desirable, since, in most cases, rainfall becomes the key climatological element to determine the suitability of a locality for millet production.

The rainfall derived parameters such as onset of rains, cessation of rains, duration of the rainy season, sowing rains, rainfall probabilities for specific phenological phases (sowing time, flowering, harvesting, etc.) And others can be calculated using the INSTAT programme; which can be run in IBM compatible microcomputers. Rainfall probabilities can be estimated using the gamma distribution since it fits better than other mathematical distribution to observe rainfall data.

2.4 Radiation

Solar radiation is the most important and basic asset in crop production. The amount and distribution of incoming radiation sets the limits for dry matter production. Radiation has two roles in crop production, namely the photosynthetic active radiation (PAR) for photosynthesis and the thermal conditions for physiological processes. Though there are no reports on the effects at different levels of incoming radiation on productivity of pearl millet, this resource is generally not a limiting factor in tropics. Interception of incoming radiation by crop canopy is a limiting factor. Poor crop establishment leading to poor canopy development results in poor interception of the incoming radiation.

2.5 Evaporation

Evaporation related to the evaporative power of the air and the loss of water as vapour into the atmosphere from an open water surface. Evapotranspiration, or the combined transfer

of water from soil by evaporation and from plant by transpiration, is dependent on water availability in the soil, evaporative demand of the atmosphere, crop cover, and stage of growth. Evaporation is dependent on air temperature, wind speed and drying power of the atmosphere; it can be calculated from these meteorological parameters using Penman (1948) equation. One of the main difficulties for the estimation of evaporation using Penman equation in both West Africa and India is not in the computational difficulties but with the ready availability of the input meteorological parameters. Simplified procedures and formulae requiring fewer readily available meteorological parameters are available for India (Mahalakshmi et al., 1993) and West Africa (Anyadike, 1987).

2.6 Windspeed

Little is known on the effect of wind speed on crop production. In West Africa, heavy wind storms associated with thunderstorms are common during the crop season. These winds are laden with dust particles that reduce the visibility and incoming amount and quality of radiation, and form deposits on leaf surface that may affect photosynthesis. Severe winds during seedling stage, bury seedling and lead to poor crop establishment.

CHAPTER 3

WEATHER AND BIOTIC STRESSES

Downy mildew sometimes referred to as the "green ear", smut, ergot and rust are the major diseases of this crop in both continents.

3.1 Downy mildew (*Sclerospora graminicola*)

Downy mildew is the most destructive of the diseases. The sources of primary inoculum for this disease are the soil-borne sexual spores or oospores that can survive in soil for several years. The thick oospore wall protects them from desiccation and serves as an impermeable membrane. There are no published reports on the effects of weather parameters on oospores longevity or their germinability. The asexual spores (sporangia) are the secondary source of inoculum. During cool and humid nights, the systemically infected leaves produce abundant sporangia on the abaxial surface (Singh et al., 1993). However, the hot and dry environmental conditions favourable for pearl millet growth, may not be conducive for sporangial production and survival (Singh et al., 1993). Temperature affects the size of sporangia (Sing et al., 1987). Sporangia liberate zoospores at a wide temperature range (10 to 45°C) and the liberation is maximum at 30°C. The infectivity of zoospores is longer at lower temperature (Sing and Gopinath, 1990). Light does not affect sporangial production (Singh et al., 1987).

3.2 Smut (*Tolyposporium penicillariae*)

Smut is a panicle disease and the primary source of inoculum is spore balls (teletospores) in soil from the previously infected crop and surface contaminated seeds used for sowing which infects young emerging stigmas (Thakur and King, 1988a). Smut is relatively less damaging than downy mildew. Moderate temperatures (20-35°C) rather than cool temperatures, high relative humidity (> 80%) and long days seem to favour disease development (Kousik et al., 1988; Thakur, 1990a; Thakur, 1990b). The secondary spread of the disease within a crop is minimal. This is due to the prolonged latent period for spore production by which time flowering is completed within a crop and pollination interferes with infection of the florets by pathogen spores (Thakur et al., 1983).

3.3 Ergot (*Claviceps fusiformis*)

Ergot is also a panicle disease. The primary source of inoculum is sclerotia in the soil from the previously infected crop or contaminated seeds used for sowing. Disease development and spread depend on the prevailing weather during flowering and the timely availability of pollen (Thakur and King, 1988b). High relative humidities (> 80%), an overcast sky with reduced radiation levels, frequent drizzling rains and cooler nights (18-20 °C) promote disease development (Thakur, 1990a). Secondary spread of the disease occurs through the numerous macroconidia present in the honeydew produced in the infected florets. The latent period (time from primary infection to conidial production) is reduced under 30°C day/25°C night temperatures and panicle wetness (Thakur et al., 1991).

3.4 Rust (*Puccinia substriata*)

Rust is a foliar disease. Occurrence of the disease at seedling stage can result in substantial losses in grain and fodder yield and fodder quality. Cooler temperatures and high relative humidity favour disease development (Singh and King, 1991).

3.5 Striga

Millet is attacked by *Striga asiatica* in India and *hermonthica* in Africa). Low soil fertility and low rainfall favour *Striga* infestation. Soil temperature at 2 cm depth affected germinability and viability of striga seeds (Osman et al., 1989; Osman et al., 1991).

3.6 Insects and Pests

Pearl millet has relatively few menacing insect pest problems. In the Asia sub-continent, white grubs are the major pests (Rachie and Majumdar, 1980). In West Africa, there is a range of insect pests that damage the crop leading to economic losses but the major ones are the earhead caterpillar (*Raghuva*), stem borer (*Acigona*), midge (*Germyia penniset*) and several species of grasshoppers.

3.6.1 Earhead caterpillar (*Raghuva*)

Pest surveys in West Africa indicate that crop was devastated by these head caterpillar infestations. The numbers of surviving diapausing pupae in the soil emerge was associated with soil temperature and moisture at different depths from November to May. There was also a close relationship between moth emergence and onset of rain and soil moisture was the key factor in diapause termination. The increase in soil moisture content and lowering of soil temperature in the upper soil layers was associated with earlier termination of diapausing pupae in this soil layer (Nwanze and Sivakumar, 1990).

3.6.2 Stem borer (*Acigona ignefusalis*)

The time of onset of rainfall and the total amount of rainfall during the crop season was related to the stem borer population (Nwanze, 1989). A knowledge of diapausing populations and the relationship between insects' pests and rainfall during the season in regions where sporadic outbreaks are common, there is need to integrate the weather parameters with population dynamics of the pests.

CHAPTER 4

CONCLUSION

Unlike in other cereals, research on the effect of weather variables on growth and development of this crop is rather limited. In the past, attempts have been made to develop crop models for this crop. Most crop simulation models, assume no biotic stress. The growth and development of the crop and the spread of pathogens and pests are driven by weather variables. When weather is optimum for pathogen or pest development and spread leading to epidemic of disease or pest, sporadic outbreaks of pests and disease occur. It is therefore essential that quantified information on weather and the development of diseases are collected and modeled. Only models can help in forecasting disease or pest epidemics and assist farmers and governments to choose necessary contingent measures to combat them.

REFERENCES

- Anand Kumar, K., 1993. Pearl millet in western Africa. In Sorghum and millets commodity and research environments. Pp 1-15 Ed. Byth, D.E. ICRISAT, Patancheru, India.
- Andrews, D.J. and Kumar, K.A., 1992. Pearl millet for food, feed and forage. *Advances in Agronomy*, 48:89-139.
- Anyadike, R.N.C., 1987. The Linacre evaporation formula tested and compared to others in various climates over West Africa. *Agricultural and Forest Meteorology*, 39:111-119.
- Begg, J.E., 1965. The growth and development of a crop of bulrush millet (*Pennisetum typhoides* S. & H.). *Journal of Agricultural Sciences, Cambridge*, 65:341-349.
- Begg, J.E. and Burton, G.W., 1971. Comparative study of five genotypes of pearl millet under a range of photoperiods and temperatures, *Crop Science*, 11:803-805.
- Belliard, J., Pernes, J. And Sandmeier, M., 1979. Les différentes phases du développement chez le mil (*Pennisetum typhoides* Staf et Hubbard) et la recherche de marqueurs. *Physiol. Veg.*, 17:387-397.
- Bidinger, F.R., Welzien, E.R., Mahalakshmi, V., Singh, S.D. and Rao, K.P., 1994. Evaluation of landrace topcross hybrids of pearl millet for arid zone environments. *Euphytica*, 76:215-227.
- Bilquez, A.F., 1963. Etude du mode d'hérédité de la précocité chez le mil pénicillaire (*Pennisetum typhoides* Stapf et Hubbard). I. Déterminisme génétique des différences de sensibilité à la longueur du jour existant entre les mils du groupe Sanio et ceux du groupe Souna. *Agronomie Tropicale*, 18: 1249-1253.
- Brunken, J.N., 1977. A systematic study of *Pennisetum* sect *Pennisetum* (Gramineae). *American Journal of Botany*, 64:161-167.
- Brunken, J.N., de Wet, J.M.J. and Harlan, J.R., 1977. The morphology and domestication of pearl millet. *Economic Botany*, 31:163-174.
- Burton, G.W., 1965. Photoperiodism in pearl millet *Pennisetum typhoides*. *Crop Science*, 5:333-335.
- De Wet, J.M.J., 1987. Pearl millet (*Pennisetum glaucum*) in Africa and India. In Proc. Of International Pearl Millet Workshop. Eds Witcombe, J.R. and Beckerman, S.R. pp 3-4. ICRISAT, Patancheru, India.
- De Wet, J.M.J., Bidinger, F.R. and Peacock, J.M., 1992. Pearl millet (*Pennisetum glaucum*) - a cereal of the sahel. In Desertified Grasslands: Their biology and management. Ed. Chapman, G.P. Academic Press, London, U.K.
- Fussell, L.K. Pearson, C.J. and Norman, M.J.T., 1980. Effect of temperature during various growth stages on grain development and yield of *Pennisetum americanum*. *Journal of Experimental Botany*, 31:621-633.
- Gregory, P.J., 1983. Response of temperature in a stand of pearl millet (*Pennisetum typhoides* S. & H.). *Journal of Experimental Botany*, 34:744-756.

- Khalifa, F.M. and Ong, C.K., 1990. Effect of supra-optimal temperatures on germination of pearl millet (*Pennisetum glaucum* (L.) R.Br.) Hybrids. *Annals of Arid zone*, 29:279-288.
- Kelly, T.G. and Rao, P.P., 1993. Sorghum and millet in Asia. In Sorghum and millets commodity and research environments. Pp 93-177 Ed. Byth, D.E. ICRISAT, Patancheru, India.
- Kousik, C.S., Thakur, R.P. and Subbarao, K.V., 1988. Influence of environmental factors on production and dispersal of *Tolyposporium penicillariae* sporidia. *Indian Journal of Aerobiology*, 1:85-91.
- Kowal, J.M. and Kassam, A.H., 1978. Agricultural ecology of savanna. A study of West Africa, p. 403, Clarendon Press, Oxford, U.K.
- Mahalakshmi, V. and Bidinger, F.R., 1985. Water stress and time of floral initiation in pearl millet. *Journal of Agricultural Sciences, Cambridge*, 105:437-445.
- Mahalakshmi, V. and Bidinger, F.R., and Rao, G.D.P., 1988. Timing and intensity of water deficits during flowering and grain-filling in pearl millet. *Agronomy Journal*, 80:130-135.
- Mahalakshmi, V. and Bidinger, F.R., Rao, K.P. and Raju, D.S., 1992. Performance and stability of pearl millet topcross hybrids and their variety pollinators. *Crop Science*, 32:928-932.
- Mahalakshmi, V., Ahmed, M.F., Rao, K.P. and Bidinger, F.R., 1993. A test of two empirical evapo-transpirational formulae for semi-arid regions. *Annals of Arid Zone*, 32:89-95.
- Mashingaidze, K. And Muchena, S.C., 1982. The induction of floret sterility by low temperatures in pearl millet (*Pennisetum typhoides* (Burm.) Stapf. & Hubbard). *Zimbabwe J. Agric. Res.*, 20:29-37.
- Nwanze, K.F., 1989. Insect pests of pearl millet in sahelian west Africa I. *Acigona ignefusalis* (Pyralidae, Lepidoptra): distribution, population dynamics and assessment of crop damage. *Tropical Pest Management*, 35:137-142.
- Nwanze, K.F. and Sivakumar, M.V.K., 1990. Insect pests of pearl millet in sahelian west Africa II. *Raghuva albipunctella* De Joannis (Noctuidae, Lepidoptra): distribution, population dynamics and assessment of crop damage. *Tropical Pest Management*, 36:59-65.
- Ong, C.K., 1983a. Response to temperature in a stand of pearl millet (*Pennisetum typhoides* S. & H.) 1. Vegetative development. *Journal of Experimental Botany*, 34:322-326.
- Ong, C.K., 1983b. Response to temperature in a stand of pearl millet (*Pennisetum typhoides* S. & H.) 2. Reproductive development. *Journal of Experimental Botany*, 34:337-348.
- Osman, M.A., Werder, J., Peacock, J.M., 1989. Effect of soil temperature on *Striga asiatica* on sorghum and *Striga hermonthica* on pearl millet. In Proceedings of the Regional Pearl Millet Improvement Workshop, ICRISAT Sahelian Center, Sadore, Niamey, Niger, Eds Fussell, L.K., Werder, J. Pp 34-45. International Crops Research Institute for the Semi-Arid Tropics. Niamey, Niger.

- Osman, M.A., Raju, P.S. and Peacock, J.M., 1991. The effect of soil temperature, moisture and nitrogen on *Striga asiatica* (L.) Kuntze seed germination, viability and emergence on sorghum (*Sorghum bicolor* L. Moench) roots under field conditions. *Plant and Soil*. 131:265-273.
- Pearson, C.J., 1975. Thermal adaptation of *Pennisetum*: seedling development. *Australian Journal of Plant Physiology*. 21:413-424.
- Penman, H.L., 1948. Natural evaporation from open water, bare soil and grass. *Proceedings of Royal Society of London, series A*193:120-145.
- Rachie, K.O. and Majumdar, J.V.K., 1980. Pearl millet. Pennsylvania Univ. Press, University Park, USA.
- Singh, S.D., King, S.B. and Werder, J., 1993. Downy mildew disease of pearl millet, p. 30. Information Bulletin No. 37. ICRISAT, Patancheru, India.
- Singh, S.D., Gopinath, R., and Pawar, M.N., 1987. Effects of environmental factors on asexual sporulation of *Sclerospora graminicola*. *Indian Phytopathology*, 40:186-193.
- Singh, S.D. and Gopinath, R., 1990. Effect of temperature and light on sporangial germination and zoospore infectivity in *Sclerospora graminicola* on pearl millet. *Canadian Journal of Plant Pathology*. 12:25-30.
- Singh, S.D. and King, S.B., 1991. Pearl millet rust - present status and future research needs. *International Journal of Tropical Disease management*. 9:35-52.
- Sivakumar, M.V.K., Konate, M. And Virmani, S.M., 1984. Agroclimatology of West Africa: Mali. Information Bulletin No. 19 p. 72. ICRISAT, Patancheru, India.
- Soman, P., Stomph, T.-J., Bidinger F.R. and Fussell, L.K., 1987. Improvement in stand establishment in pearl millet. In *Food grain production in semi-arid Africa*, pp 159-170, Eds Menyonga, J.M., Bezuneh, T. And Ypodeowei, A. OAU/STRC-SAFGRAD, Burkina Faso.
- Thakur, R.P., 1990a. Basic research on management of pearl millet diseases. In *Basic research for crop disease management* Ed. Vidyasekaren, P. Pp 343-358. Daya Publishing House, New Delhi, India.
- Thakur, R.P. and King, S.B., 1988a. Smut disease of Pearl millet, p 17. Information Bulletin No. 25. ICRISAT, Patancheru, India.
- Thakur, R.P. and King, S.B., 1988b. Ergot disease of Pearl millet, p. 24. Information Bulletin No. 24. ICRISAT, Patancheru, India.
- Thakur, R.P., Subba Rao, K.V. and William, R.J., 1983. Effects of pollination on smut development in pearl millet. *Plant Pathology*, 32:141-144.
- Thakur, R.P., Rao, V.P. and King, S.B., 1991. Influence of temperature and wetness duration on infection of pearl millet by *Claviceps fusiformis*. *Phytopathology*, 81:835-838.
- Theodorides, T.N. and Pearson, C.J., 1981. Effect of temperature on total nitrogen distribution in *Pennisetum americanum*. *Australian Journal of Plant Physiology*. 8:201-210.

Virmani, S.M., Sivakumar, M.V.K. and Reddy, S.J., 1982. Rainfall probability estimates for selected locations of semi-arid India. Research Bulletin No. 1 (2nd edition) p 138. ICRISAT, Patancheru, India.

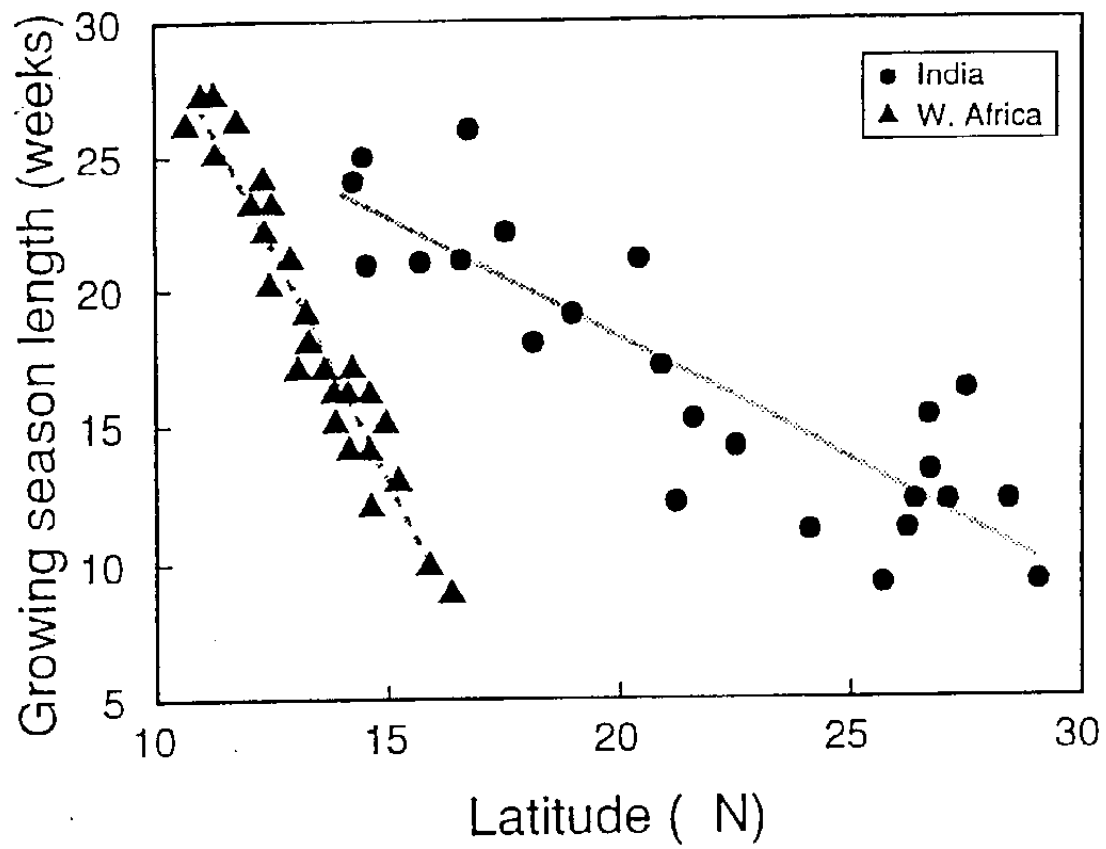


Figure 1: Length of the growing season at different latitudes in India and West Africa (Mali)
 (Source of data Virmani et al., 1982 and Sivakumar et al., 1984)

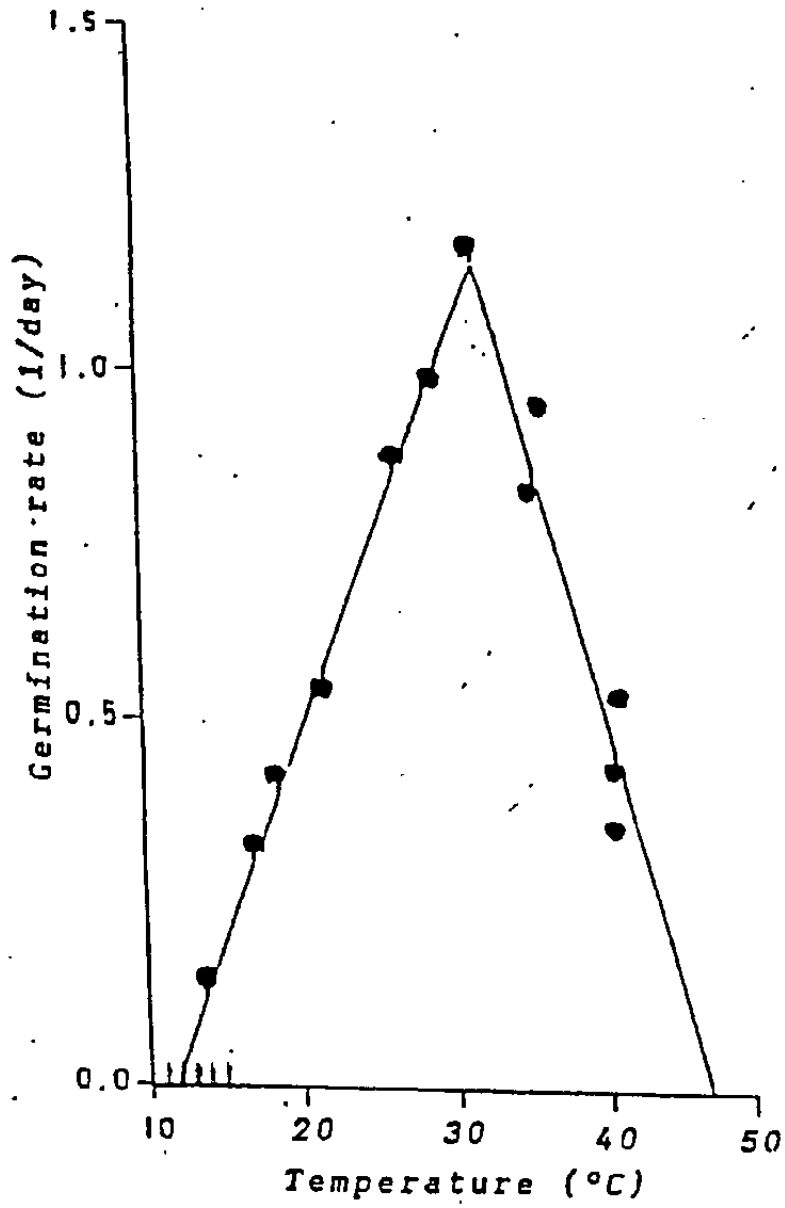


Figure 2 . Germination rate of pearl millet (cv BK-560) as a function of temperature (Peacock, 1982)