Agroclimatic Environment of Chickpea and Pigeonpea

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Abstract

Chickpea and pigeonpea are grown in a wide range of agroclimatic environments. Chickpea is produced in 37 countries, and pigeonpea in 14. India accounts for 74% of total world chickpea production (6.2 million t) and 90% of the world pigeonpea production (1.2 million t). Chickpea is usually grown after the rainy season on stored soil water—during winter in the tropics and in the spring in the temperate and Mediterranean regions. Pigeonpea is usually sown at the beginning of the rainy season, as either a mixed crop or an intercrop.

To verify the performance of promising genotypes and recommended management practices, identification of a few benchmark locations is useful. Meteorological data for four contrasting chickpea-growing locations—Hisar and Hyderabad in India, Aleppo in Syria, and Khartoum in Sudan—are given.

In India, pigeonpea-growing areas are usually located in regions with a 600–1400 mm annual rainfall and a growing period of 90–180 days. Chickpea is usually grown where mean daily maximum temperatures are 22.5–30° C and mean daily minimum temperatures 7.5–13° C during January, when flowering begins. The soils on which the two crops are grown are predominantly Alfisols, Entisols, Inceptisols, and Vertisols.

Quantitative information on the effect of environmental factors on growth and development of these crops is useful in building models for simulating yields. Using historical weather data, cumulative probabilities of simulated available soil water at sowing were computed for ICRISAT Center (Patancheru) and Hisar. At Patancheru, in a medium-deep Vertisol having 150 mm water-storage capacity, the simulated available soil water in 70% of the years studied was 120 mm under rainy-season fallow and 80 mm under rainy-season sorghum. At Hisar, the simulated available soil water after rainy season fallow in 70% of the years was more than 120 mm in soils with 150 mm water-storage capacity. Using the water use and yield relationship, cumulative probabilities of chickpea yields and phosphorus requirements were computed for both ICRISAT Center and Hisar. Although simulated yields were higher than farmers' yields, the water use and yield relationships can be used to compute the probabilities of potential yield at various locations. In some instances, simulated yields were lower than actual yields on experimental fields, and the reasons for this are explored. The delineation of the isoclimes of pigeonpea-growing areas in West Africa is also reported.

Introduction

Chickpea and pigeonpea are grown in a wide range of agroclimatic environments (Sinha 1977), and their yield potential exceeds 4 t ha^{-1} (Nene 1987). However, the yields achieved by farmers are quite low and variable. For example, in India, average yields of chickpea obtained by farmers are often only about 25% or less than can be achieved under nonirrigated conditions at experiment stations within the

1. Resource Management Program, ICRISAT.

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Adaptation of chickpea and pigeonpea to abiotic stresses. Proceedings of the Consultants' Workshop, 19–21 December 1984, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

same region with similar cultivars (Sheldrake and Saxena 1979). The reasons for such low yields are:

- Poor plant stand from failure of many seeds to germinate and of seedlings to become established because soil moisture is inadequate in the seed zone.
- Drought in the growing season, particularly at the flowering and pod-filling stages.
- Biotic constraints.

To develop suitable agronomic practices and to select genotypes that can cope with existing situations, it is necessary to know the range of the agroclimatic environments in which these crops are grown. Promising genotypes and recommended improved agronomic practices can be verified at a few benchmark locations representing the environment range.

Thus, the objectives of this presentation are:

1. To describe the agroclimatic environment of areas growing chickpea and pigeonpea, with emphasis on a few contrasting environments.
2. To review the available information on the effect of water, temperature, and solar radiation on the growth and yield of chickpea.
3. To discuss cumulative probabilities of simulated chickpea yield using the relationship between water use and chickpea yields.

Chickpea

World chickpea production data (FAO 1982) indicate 37 chickpea-growing countries. Total chickpea production in the world for 1982 was 6.2 million t. The chickpea-growing countries are grouped into four categories:

- India, which produced 74% of the world production.
- Pakistan, Turkey, and Mexico; production of individual countries ranged between 2.6 and 5.0% of world production, and together these countries contributed 13% of the world production.
- Burma, Ethiopia, and Syria, which contributed 1.0-2.5% individually and together contributed 6% of the total production.
- Other countries, in which individual production was below 1.0% and which together contributed 7% of the total production.

Chickpea is usually grown after the rainy season on stored soil moisture—during winter in the tropics and in the spring in temperate and Mediterranean regions. Recently chickpea has been grown in the temperate and Mediterranean regions as a winter crop when rainfall is well distributed during the growing period (Saxena 1984). The major part of West Asia and North Africa is characterized by a Mediterranean type of climate with large variations stemming from proximity to the sea, latitude, and altitude. In West Asia and North Africa, chickpea is grown mostly in areas where winter precipitation is more than 400 mm (Saxena 1987). In areas with less precipitation, but with a thermal regime permitting an adequately long growing period for economic yields, the crop is grown with irrigation (supplementary or total). The Nile valley of Egypt and Sudan is a good example. In areas receiving adequate winter rain, however, the crop is sown at the end of the rainy period (Saxena 1987).

Precipitation and evapotranspiration, maximum and minimum temperatures, and photoperiod for four contrasting environments representing the environmental range in which chickpea is grown were presented in detail by Saxena (1984). These four locations are Hisar (29°10'N) and Hyderabad (17°32'N) in India, Aleppo (36°11'N) in Syria, and Khartoum (15°36'N) in Sudan.

At Hisar, where the maximum temperature declines from 35° to 20°C, and the minimum from 17° to 5°C, between sowing in October and flowering in January, pod set begins when minimum temperatures rise above 8°C in February. The rapid rise in maximum/minimum temperatures (from 25/8° to 37/20°C) and in evaporation (from 1-2 mm day^{-1} in December and January to 4-5 mm day^{-1} in late March and early April) hastens senescence and forces maturity. Growth duration is long, usually from 150 to 160 days. Daylength decreases from 11 h 16 min to 10 h 10 min between sowing and flowering, and increases to 12 h 44 min at maturity. On average, 370 mm of rainfall is received before sowing and 80-90 mm during crop growth.

At Hyderabad, the crop is sown at about the same time as at Hisar, but seasonal variations in mean maximum and minimum temperatures and in daylength are smaller than those at Hisar. The maximum temperature declines from 30° to 28°C and minimum from 20° to 13°C. Maximum/minimum temperatures and evaporation increase in late January and, at maturity, maximum/minimum temperatures are around 32/16°C. The growth duration is short, usually about 100 days. Daylength decreases from 11 h 34 min at sowing to 11 h 09 min at flowering, and then increases to 11 h 24 min at maturity. On average, 600 mm of rainfall is received before sowing, and another 40-100 mm during crop growth.

The climate for spring sowing at Aleppo resembles that of Hyderabad in many respects. Between sowing in February-March and harvest in June-July, maximum temperature increases from 17° to 36°C, minimum temperature from 5° to 18°C, and daylength from 11 h 0 min to 14 h 33 min. About 300 mm of rainfall is received before sowing, and another 25 mm during crop growth. In winter sowings (November-December), rainfall is well distributed during the growing period, and minimum temperature ranges between 1° and 4°C from December to March. Daylength increases from 10 h 33 min at sowing in November-December to 14 h 17 min at harvest in May-June. Growth duration is long and comparable to that at Hisar.

Climate during crop growth between October and April is less favorable at Khartoum than at Hyderabad. In Khartoum, the crop is grown with irrigation and receives practically no rainfall. Maximum/minimum temperatures are 36/20°C at sowing in November, but drop to 30-33/14-16°C at flowering and then rise again.

Since 74% of the world chickpea production comes from India, we have studied the distribution, area, production, and agroclimate of the chickpea-growing environment in India (Fig.1). The states of Madhya Pradesh, Rajasthan, and Uttar Pradesh contributed 70% of the chickpea production in India (Bose 1981). Easter and Abel (1973) demarcated the chickpea-growing regions into "core" and "satellite." A core region was one that had at least 5% of the total cropped area under chickpea and contributed at least 1% to total national production. A satellite region was one that had less than 5% but at least 2% of gross cropped area under chickpea and produced at least 0.5% of the national total.

To clarify this picture, the air temperature isotherms for October, January, and April were superimposed on the maps of core and satellite chickpea-growing regions in India (Figs. 2-4). In October, when chickpea is usually sown, the mean daily maximum temperature ranges between 32.5° and 35.0°C, while the mean daily minimum temperature ranges between 20.0° and 22.5°C. In January, when flowering usually begins, the mean daily minimum temperature ranges from as low as 7.5° to 15.0°C; the mean daily maximum temperature ranges between 22.5° and 30.0°C. As pod filling begins, the temperature starts rising and, by the time chickpea is harvested, the air temperatures rise very high. For example, in April, the mean daily minimum temperature ranges between 20.0° and 25.0°C, and the mean daily maximum temperature ranges between 37.5° and 40.0°C.

Similarly, the benchmark soils map of India (Murthy et al. 1982) was superimposed on the map of core and satellite chickpea-growing regions of India (Fig. 5). The soils are Alfisols, Inceptisols, Entisols, and Vertisols.

Alfisols are usually neutral to slightly acidic in reaction (pH 6.5-7.0), are relatively shallow (<1 m deep), have less clay content, are usually sandy loam in texture, and can retain less than 100 mm available water. Entisols are deep loams, slightly alkaline (pH 7.5-8.5), with about 150-200 mm available water-storage capacity in about 2 m soil depth. Inceptisols are mineral soils, more highly developed than Entisols, with a clay content in the surface soil ranging from 30 to 50%, and a pH ranging from 7.5 to 8.0; these soils are usually less than 1 m deep, and the available water-holding capacity is less than 150 mm. Vertisols are characterized by 40-60% clay in the surface soil horizons, with a pH of about 8.0, and they can store between 150 and 300 mm available water in the 1.5-2 m soil depth.

Effect of Environmental Factors on Chickpea Yield

Seed yield in grain legumes depends upon both vegetative and reproductive components, which are markedly affected by environmental factors (Summerfield et al. 1980, 1987). In a study on photothermal effects on flowering in chickpea, we pooled the phenology data (n = 7) for two chickpea cultivars, Annigeri and K 850, from Hisar and ICRISAT Center, Patancheru, to calculate the growing degree days (GDD) (data supplied by N.P. Saxena, ICRISAT). In the absence of defined base temperatures for different growth stages, such as sowing to 50% flowering, 50% flowering to pod initiation, and pod initiation to physiological maturity, we used 6, 8, and 10°C as base temperatures. The 8°C base temperature gave the lowest coefficient of variation from sowing to 50% flowering in both cultivars (18% in Annigeri and 16% in K 850), and the mean GDD values were 540 for Annigeri and 675 for K 850. The base temperature of 6°C gave the lowest coefficient of variation (27%) from pod initiation to physiologi-

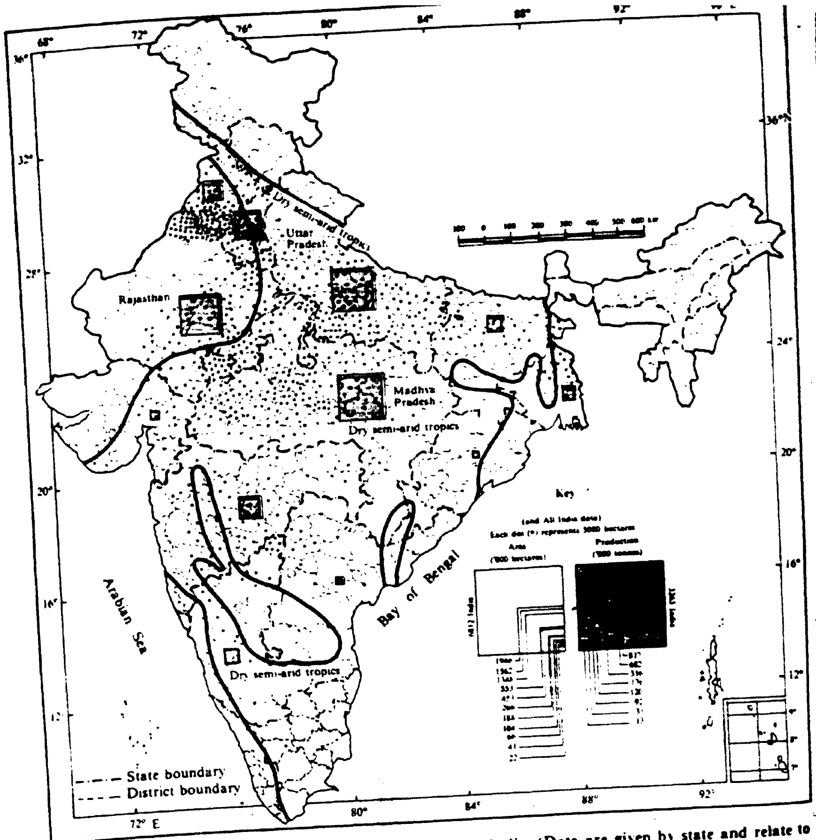


Figure 1. Distribution, area, and production of chickpea in India. (Data are given by state and relate to 1979/80).

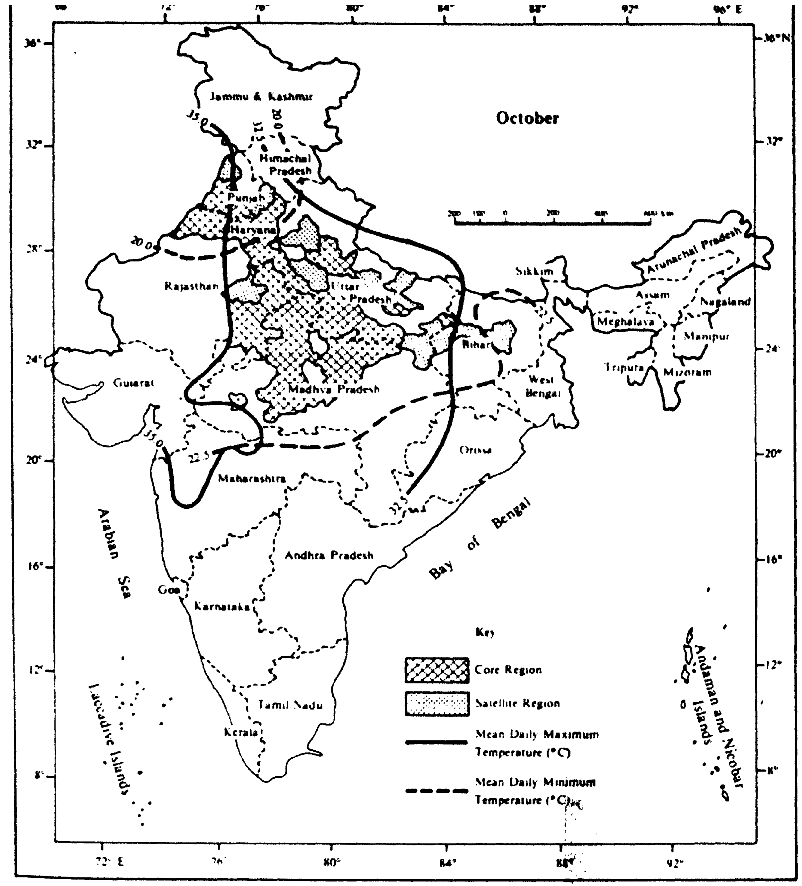


Figure 2. Mean daily maximum and minimum air temperature (° C) for October in chickpea-growing regions of India.

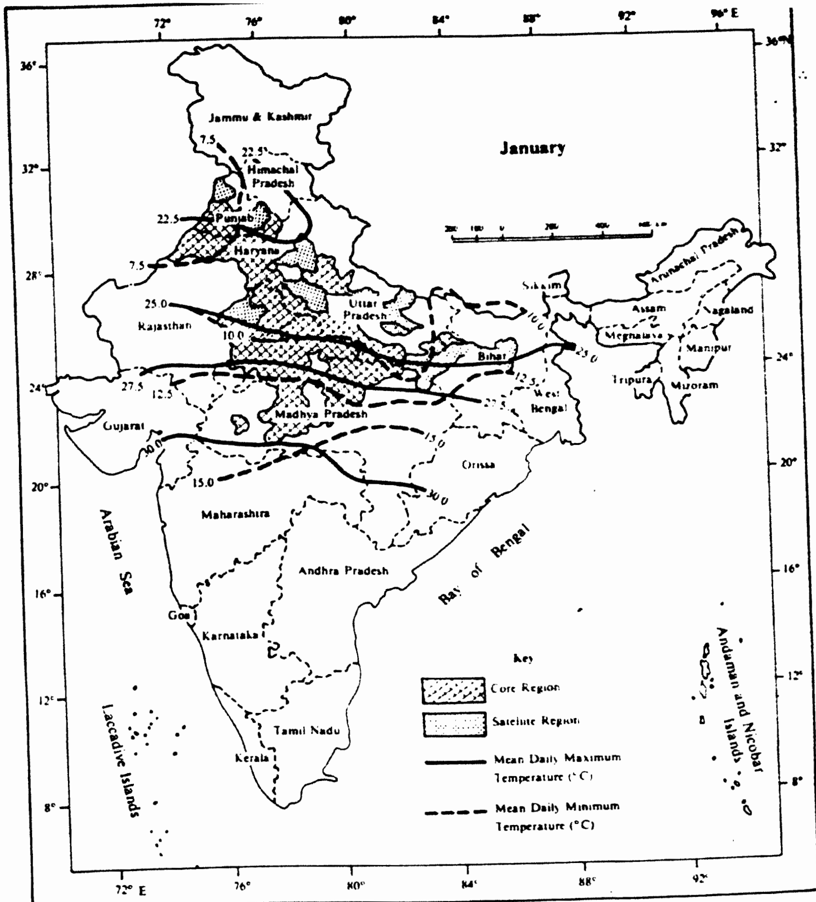


Figure 3. Mean daily maximum and minimum air temperature (°C) for January in chickpea-growing regions of India.

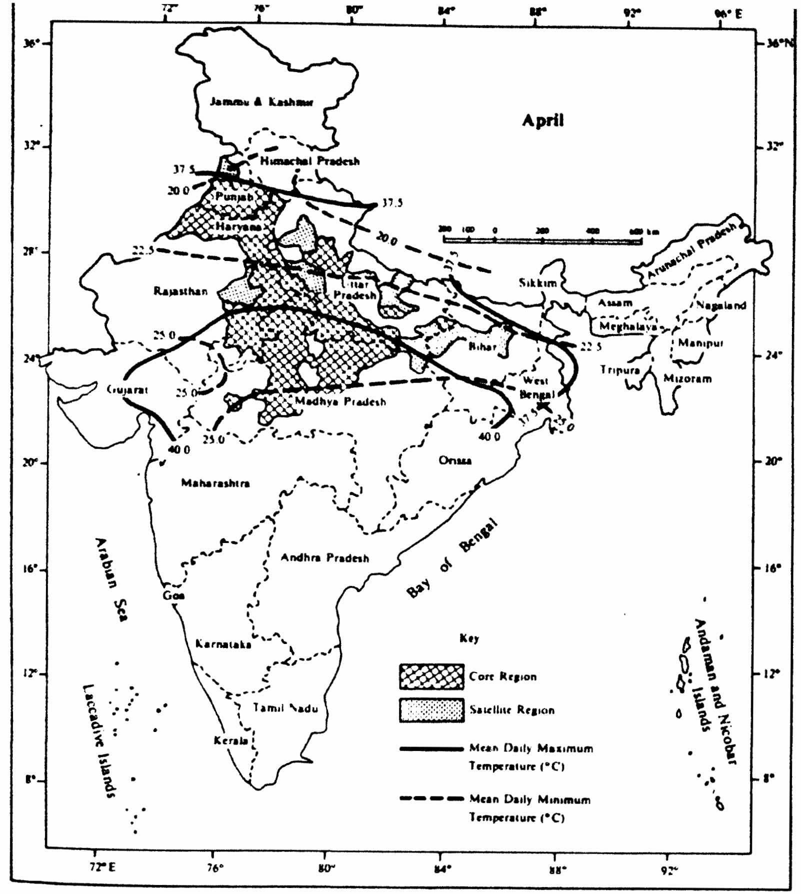


Figure 4. Mean daily maximum and minimum air temperature (°C) for April in chickpea-growing regions of India.

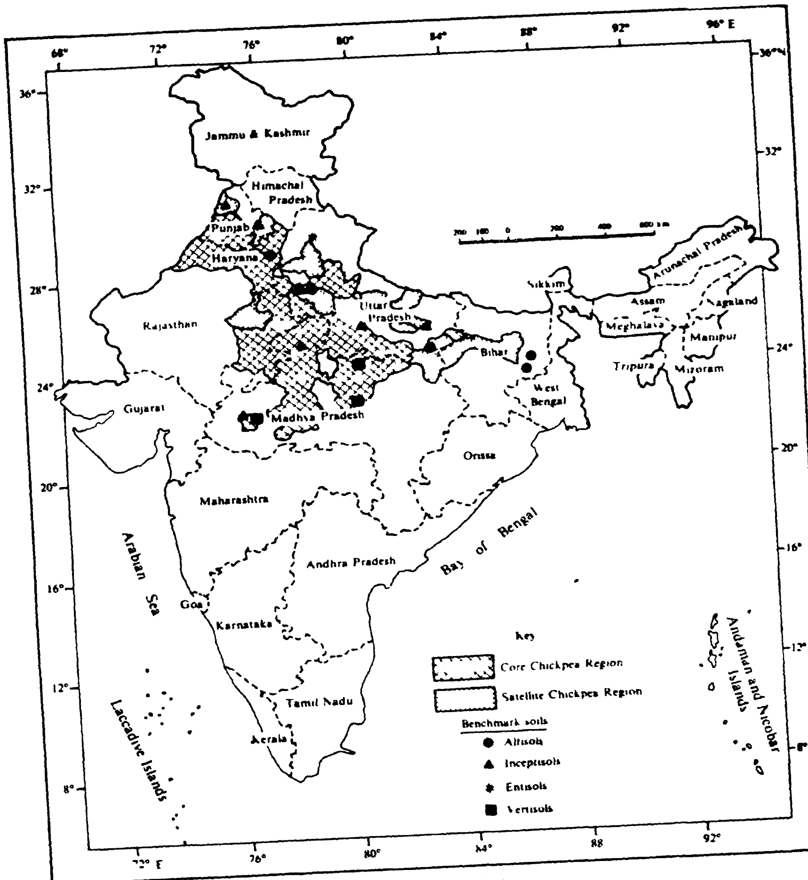


Figure 5 Benchmark soils in chickpea-growing regions of India

cal maturity in Annigeri and the mean GDD value was 775, there was no difference in coefficients of variation (33%) using 6 8 and 10°C as base temperatures for pod initiation to physiological maturity in K 850 It may be noted that these values for coefficient of variation are too high The mean GDD value for K 850 using 6°C as the base temperature was 745 which is similar to that of Annigeri The coefficients of variation using 6 8 and 10°C as base temperatures from 50% flowering to pod initiation ranged from 60 to 90% in both cultivars indicating that pod initiation is determined by environmental factors other than temperature alone

The relationship between intercepted solar radiation and total dry matter production has been studied for different crops for example for wheat and barley (Gallagher and Biscoe 1978) sorghum (Sivakumar and Huda 1985) pearl millet (Huda et al 1984) and pigeonpea (Natarajan and Willey 1980) About 0 46 g of total dry matter was produced for each MJ of radiation intercepted by chickpea cv Annigeri (Fig 6 M Natarajan ICRISAT personal communication) The experiment was conducted at ICRISAT Center Patancheru under nonirrigated conditions This relationship could be used to simulate chickpea total dry-matter production but it is necessary to establish whether this relationship changes with season location and cultivar

Quantified information on the effect of environmental factors on chickpea yield should be useful for building models that can be used to simulate growth and yield of chickpea However the impact of environmental factors on the development of diseases and pests should also be considered For example development of ascochyta blight in chickpea (cv ILC 464) was closely related to increased temperature at Tel Hadya Syria (Fig 7 ICRISAT 1984) the disease began to develop when average minimum temperature exceeded 5°C and the average maximum temperature was 15 C The disease killed almost all plants during a 3 week period when maximum temperature rose from 15° to 25°C

Simulated Soil Water

Chickpea is able to extract moisture from deep layers of the soil profile An adequate supply of soil moisture at the time of sowing and winter rains nearing 60-80 mm (in the Indian subcontinent) are essential for a successful chickpea crop (Singh and Das 1987) Because it is difficult to measure soil water at the time of sowing a soil water-balance

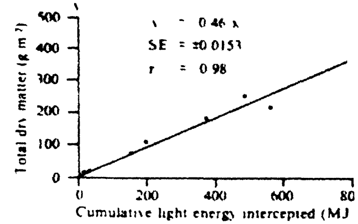


Figure 6 Relationship between intercepted s radiation and dry-matter production for chickpea Annigeri) at ICRISAT Center, Patancheru p rainy season 1982 83

model can be used to estimate available soil wat The soil water balance model developed by Ritcl (1972) was used to simulate soil water for ICRISA Center and Hisar (Fig 8) The available wat holding capacity of a medium-deep Vertisol ICRISAT Center and an Entisol at Hisar is 150 m Normal rainfall from June to October is 653 mm f ICRISAT Center and 366 mm for Hisar Sowings chickpea were assumed on 15 October at ICRISA Center and on 1 November at Hisar Historic weather data for 1901-70 for Hyderabad an 1951-82 for Hisar were used to compute cumulativ probability of simulated available soil water at sowing for the two locations For ICRISAT Center simulation of soil water was done for both rainy season fallow and rainy-season sorghum For Hisar this was done only for rainy-season fallow At ICRISAT Center in 70% of the years there is at least 120 mm of available water under rainy season fallow conditions and 80 mm under rainy-season sorghum (Fig 8) Considering that normal rainfall is 42 mm and potential evaporation (PE) is 442 mm from November to February supplemental irrigations are obviously required to achieve a reasonably good chickpea yield after rainy-season sorghum in a medium deep Vertisol At Hisar the simulated available soil water after rainy-season fallow was more than 120 mm in 70% of the years From November to February normal rainfall there is 64 mm and normal PE 235 mm, thus good yields of chickpea can be expected at Hisar without supplemental irrigation

The information on simulated soil water at sowing is important, but the simulated daily/weekly soil water balance during the growing season would help

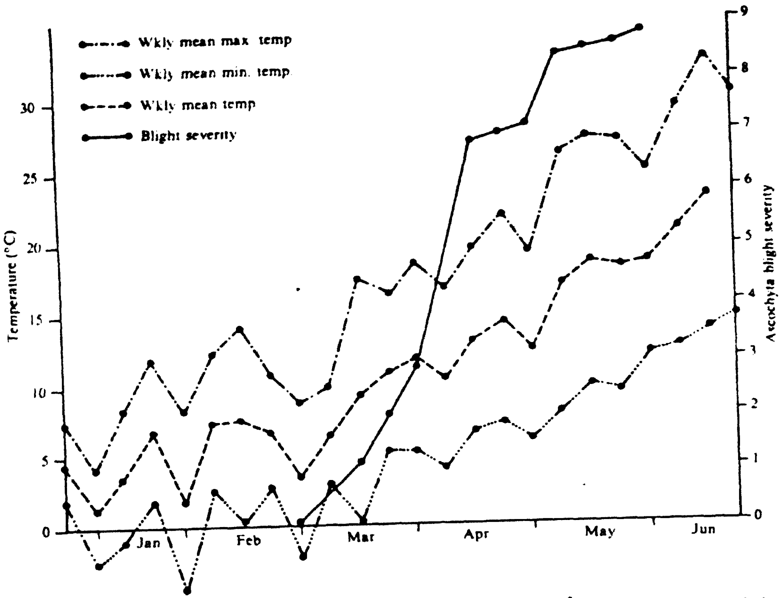


Figure 7. Development of ascochyta blight in chickpea (cv ILC 464) in relation to temperature, Tel Hadya, 1982/83 (Source: ICRISAT 1984).

us better understand whether the crop suffers from water deficits at any growth stage. Additional information on canopy development would be required to calculate the evapotranspiration component of daily soil water balance.

Simulated Grain Yield

Chickpea grain yield could be simulated on the basis of stored available soil water plus winter rains (Singh and Das 1987). Singh and Bhushan (1979) reported the following regression equation from their experimental results of 1972-73 to 1975-76 at Dehradun, using cv H 208, where experimental yield ranged between 800 and 3000 kg ha^{-1}:

$$Y = 13.1\ X - 456,$$

where Y = chickpea yield (kg ha^{-1})
and X = water use (mm), i.e., soil water at sowing plus rainfall during growing season.

We used this relationship to compute the cumulative probability of chickpea yield for Hisar (Fig. 9). Sowing date was assumed to be 1 November and historical weather data for 1951-82 were used. Phosphorus requirements to achieve these yields were also simulated assuming that 5 kg of phosphorus are required to produce 1 t of chickpea (Saxena 1984). In 70% of the years, simulated chickpea grain yields were at least 1.5 t ha^{-1}, and simulated phosphorus requirements were 7.5 kg ha^{-1} (Fig. 9). The simulated yields were compared with the actual yields quoted in the estimates of area and production reports. Two points were noteworthy: (1) farmers were achieving less than 1 t ha^{-1} chickpea yield in 80% of the years; (2) the simulated maximum yield (2800 kg ha^{-1}) was similar to the experimental yield as reported by Singh and Bhushan (1979); this was much higher, however, than the mean maximum yield of 1800 kg ha^{-1} obtained by farmers. This yield gap could be reduced if proper management such as timely planting, fertilizer application, and plant protection were undertaken.

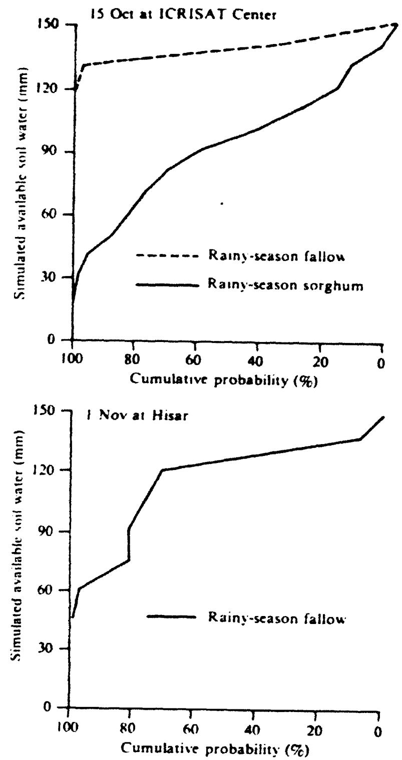


Figure 8. Cumulative probability (%) of simulated available soil water (mm) at sowing for ICRISAT Center, Patancheru (using historical data for Hyderabad, 1901-70), and Hisar (using historical data, 1951-82).

The water-use efficiency (WUE) of nonfertilized chickpea crops grown on stored soil water at ICRISAT Center, Patancheru, is between 7.6 and 9.2 kg grain ha^{-1} mm^{-1} (Saxena 1984). We have used the WUE value of 8 kg of grain ha^{-1} mm^{-1} to compute cumulative probability of chickpea yield for ICRISAT Center under both rainy-season fallow and rainy-season sorghum (Fig. 9). Historical weather data for 1901-70 were used and the sowing date was assumed to be 15 October. Maximum yields under both rainy-season fallow and rainy-season sorghum were about 3 t ha^{-1}. The percentage of maximum yield was computed by dividing individual-year simulated value by the maximum simulated yield. In 70% of the years, at least 40% of the maximum yield was simulated under rainy-season fallow and 35% of the maximum yield under rainy-season sorghum. Phosphorus requirements for achieving these yield levels were also simulated (Fig. 9).

Using the WUE value of 8 kg grain ha^{-1} mm^{-1}, chickpea yields were also simulated from 1974-75 to 1982-83 for ICRISAT Center. Simulated yields were compared with actual yields reported in ICRISAT Annual Reports for these years (Table 1). Simulated values were within ± 20% of actual yields in 50% of the years. The lowest chickpea yields were simulated for 1976/77 and 1980/81 under rainy-season sorghum. These are due to low winter rainfall from November to February, which was 30 mm in 1976/77 and 24 mm in 1980/81.

Table 1. Actual and simulated chickpea yield at ICRISAT Center, Patancheru, under residual moisture for 1974/75 to 1982/83.

	Chickpea yield (kg ha^{-1})		
		Simulated	
Year	Actual	After rainy-season fallow	After rainy-season sorghum
1974/75	2596[1]	3024	2928
1975/76	1878[1]	2248	2176
1976/77	2654[1]	1258	578
1977/78	1963	1805	1238
1978/79	1342	1715	1459
1979/80	1015	1743	1447
1980/81	1499	1265	658
1981/82	1250	1232	1104
1982/83	2460	1636	1268

1. Cultivar other than Annigeri; all other results reported here are from cv Annigeri.

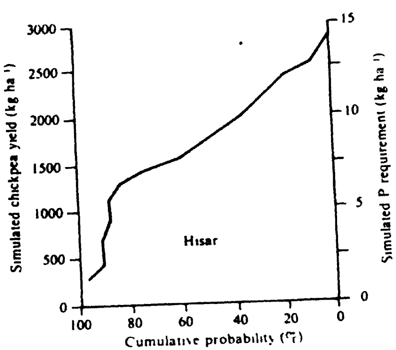
The water-use and yield relationship studies discussed above can be used to screen environments for production potential. Simulated data in Table 1 show, for example, that in a medium-deep Vertisol, sequential crops (sorghum in rainy season and chickpea in postrainy season) are possible in three years out of nine without loss in chickpea yield.

Simulated chickpea yields were lower by 3-52% than actual experimental yields in four years, particularly so in 1976-77 when rain during October-February was low (30 mm). It is possible that in such low-rainfall years, supplemental irrigations were applied in field experiments, but these were not considered in the simulation because actual data were not available on date and amount of irrigation. This suggests that such minimum essential information from field experiments should be recorded, so that they can be included in the simulation and the results can be generalized.

Pigeonpea

World pigeonpea production data (FAO 1982) indicate 14 pigeonpea-growing countries which are grouped into four categories:

- India, which produced 90% of the world production.
- Kenya and Uganda, which individually contributed 2-3% and together contributed 5% of the world production.
- Burma, the Dominican Republic and Malawi, which individually contributed 1-2% and together contributed 4% of the total world production.
- Other countries, in which individual and total share of world production was below 1%.



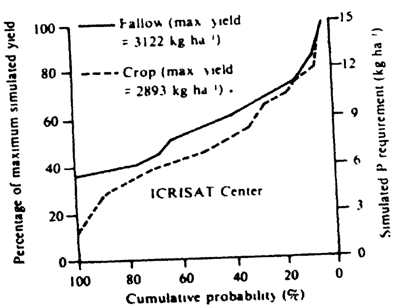
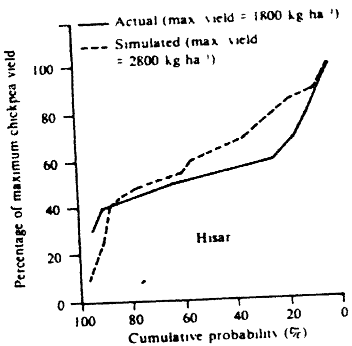


Figure 9. Cumulative probability (%) of simulated chickpea yield and simulated P requirements for Hisar and ICRISAT Center, Patancheru. Sowing dates assumed: for Hisar, 1 November; for ICRISAT Center, 15 October. Historical weather data used: 1901-70, Hyderabad, for ICRISAT Center; 1951-82 for Hisar.



The agroclimatic environment of pigeonpea has been discussed by Reddy and Virmani (1981). Chickpea is usually grown under stored soil moisture whereas pigeonpea is sown mainly as a mixed crop or as an intercrop at the beginning of the rainy season. Thus the soil becomes charged as the rainy season advances and as the crop grows. Intermittent wetting and drying, including periods of waterlogging are experienced by pigeonpea which, however, continues to grow after the rains stop, with pod filling continuing under progressively depleting soil moisture.

Since 90% of the world pigeonpea production comes from India, we have studied the distribution, area, production, and agroclimatic environment of the pigeonpea-growing regions in India (Fig. 10). Uttar Pradesh, Maharashtra, Karnataka, and Madhya Pradesh contributed about 80% of the pigeonpea production in India (Bose 1981). Easter and Abel (1973) demarcated pigeonpea growing regions into "core" and "satellite", which were defined earlier for chickpea. Pigeonpea-growing areas are located within the 600-1400 mm annual rainfall zone (Reddy and Virmani 1981).

Average length of the growing season in India was prepared by the Agroecological Zones Project of FAO (1979) (Fig. 11). Growing period is defined as the number of days during a year when precipitation exceeds half the potential evapotranspiration, plus a period required to evaporate an assured 100 mm of water from excess precipitation stored in the soil. The lengths of pigeonpea-growing periods for core districts in Uttar Pradesh, Bihar, Madhya Pradesh, and eastern Maharashtra are between 120 and 180 days (Fig. 11). Most of the satellite pigeonpea-growing regions in the states of Karnataka, Andhra Pradesh and Maharashtra have growing periods of 90-120 days. The benchmark soils map of India (Murthy et al. 1982) has been superimposed on the map of the pigeonpea-growing regions (Fig. 12). The predominant soils in these regions are Alfisols, Inceptisols, and Vertisols.

Isoclimes of Pigeonpea-Growing Areas in West Africa

The Inter-African Committee for Hydraulic Studies (CIEH 1979) defined three major bioclimatic zones in West Africa:

a. The Southern Sahelian zone with a growing season of 75-90 days.
b. The Sudanian zone, with a growing season of 90-165 days.
c. The Northern Guinean zone with a growing season of 165-210 days.

Based on a study of the monthly moisture availability index for rainy season cropping at 15 locations (Virmani et al. 1980) representing five West African countries, Reddy and Virmani (1981) suggested that the southern part of the Sudanian bioclimatic zone, with a growing season of 120 days and the Northern Guinean zone with about 180 days are likely to provide a suitable growing environment for pigeonpea. The crop is likely to do well on deep, heavy-textured soils in these regions.

Future Research Needs

- To delineate the isoclimes for regions growing chickpea and pigeonpea.
- To identify a few benchmark locations that represent a wide range of agroclimatic environments in which the two crops are grown, for testing improved management practices and promising genotypes.
- To compute the frequency of different water availabilities in space and time, using simple soil water-balance models.
- To generate cumulative probabilities of yield potential of the two crops, using water-use and yield relationships for various locations, and thus to help expedite the transfer of technology.
- To collaborate with different national and international institutes to document the existing knowledge on these crops, which can be used for building crop simulation models.

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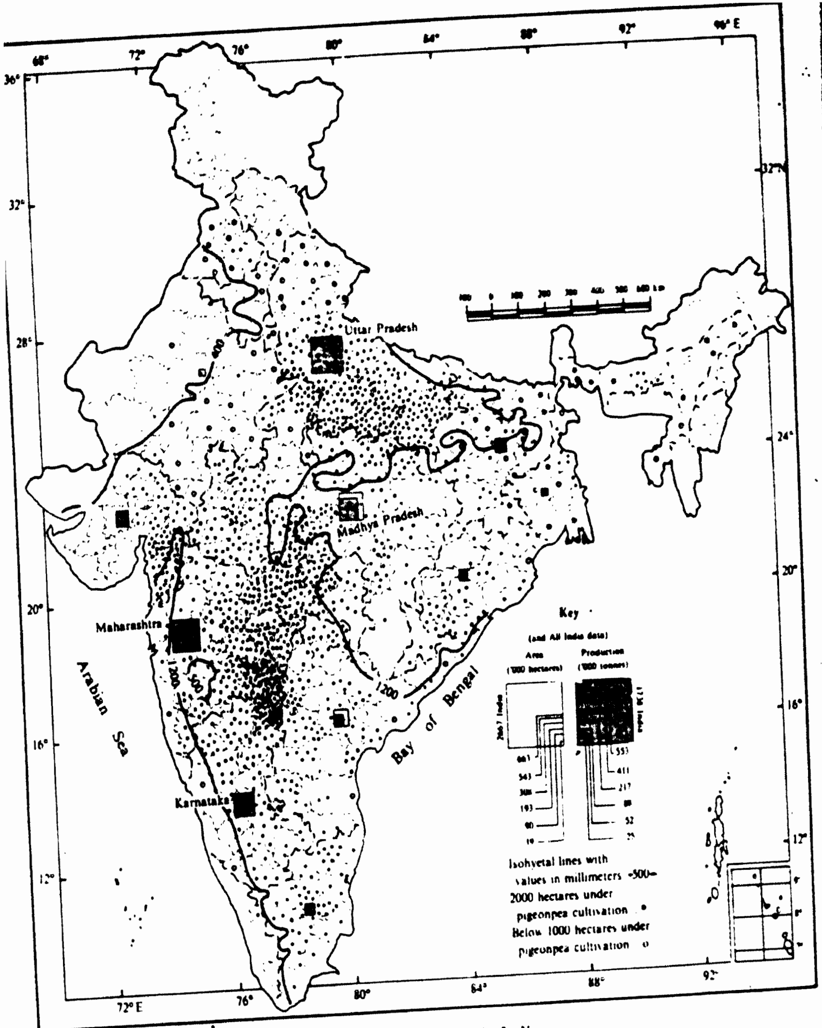

Figure 10. Distribution, area, and production of pigeonpea in India.

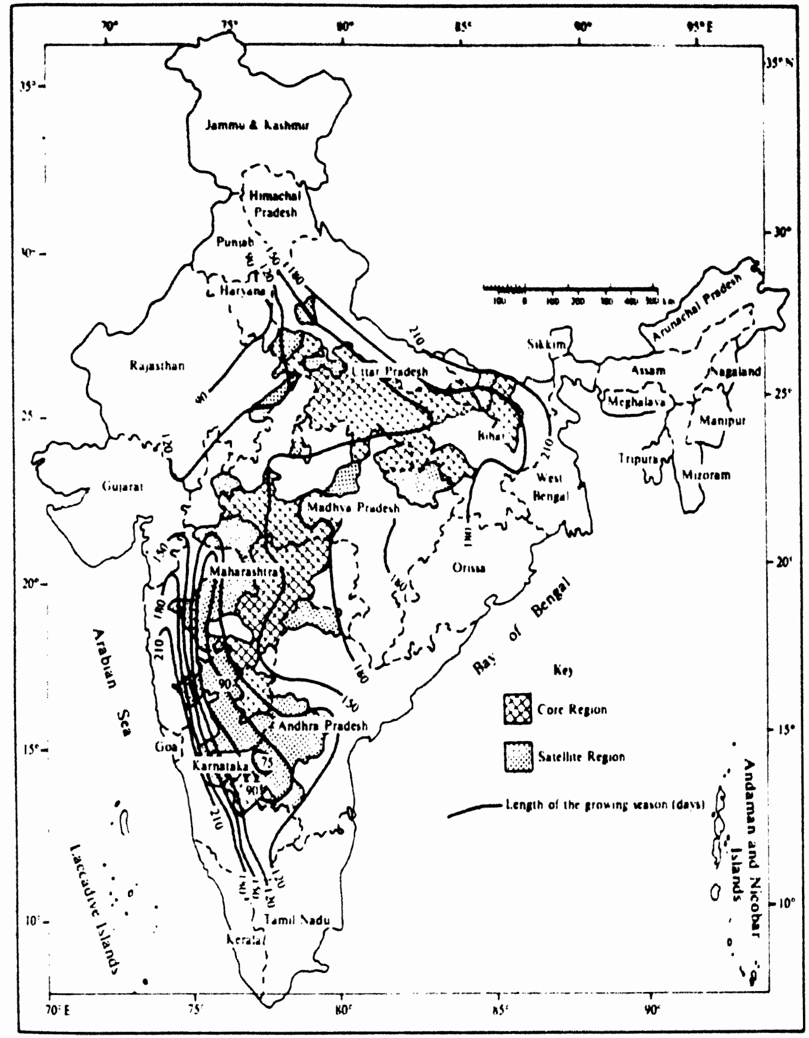

Figure 11. Length of the growing season in pigeonpea-growing regions in India.

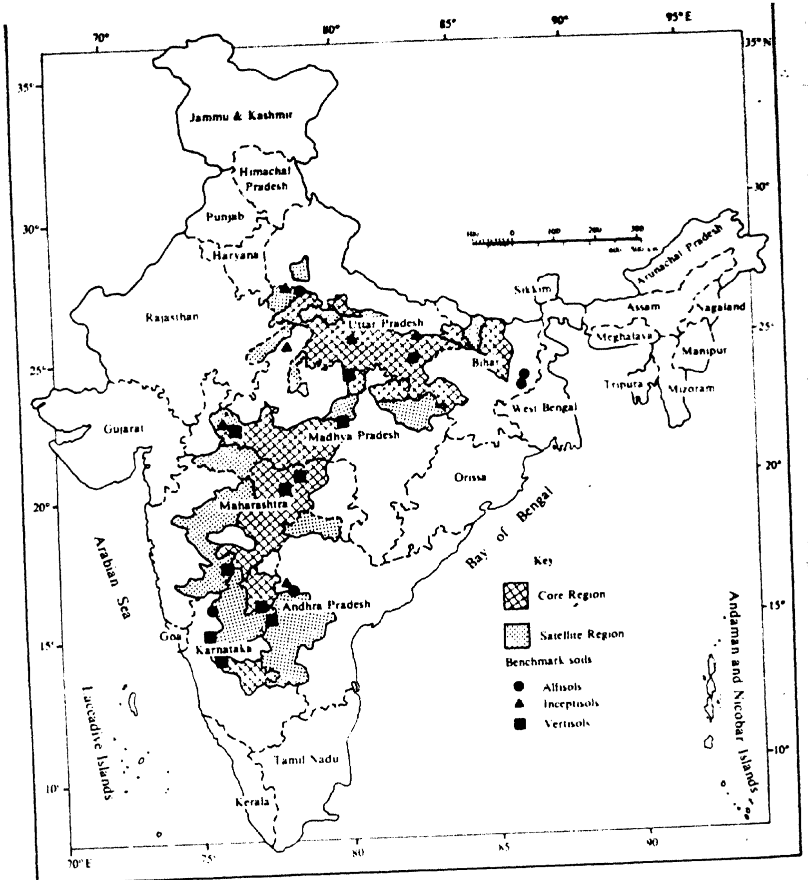

Figure 12. Benchmark soils of pigeonpea-growing regions in India.

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