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Elements of Climate – Their Relevance to Crop Productivity and Fertilizer Use Planning in the Semiarid Tropics[1]

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Abstract

High-yielding varieties, balanced fertilizer application, and adequate water supply are the three important factors for higher crop production. In the semiarid tropics (SAT), water is the primary constraint for crop production mainly in shallower soils having low water-holding capacity. The problem is further aggravated by variability in quantity and distribution of rainfall and by high evaporative demand. Based on the experiments conducted at ICRISAT Center, we have developed a program for N fertilizer application for cereals. Split application of N fertilizer is useful for both Vertisols and Alfisols. In Vertisols, water does not become a limiting factor for N response because of their high water-holding capacity, whereas in Alfisols, water is the main factor dictating crop response to N. Based on an analysis of long-term (1901-87) rainfall received during the crop growing season, the probability of fertilizer N required to optimize sorghum production has been estimated. These data can be used to assess risks to fertilizer N application and differences in fertilizer N needs from year to year in a semiarid tropical environment.

Introduction

In many parts of the semiarid tropics (SAT), great advances in agricultural productivity along with the introduction of modern agronomic practices have been witnessed in the last few decades. These advances have been possible mainly because of a remarkable fusion of the introduction of high-yielding varieties (HYVs) and improved agrotechnology. In particular, controlled use of irrigation and application of balanced amounts of fertilizers have contributed significantly to increased agricultural production. However, this impressive growth has not taken place across all of the semiarid tropics. Unirrigated, dryland areas, which are characterized by uncertain rainfall and a poor resource base, have largely remained neglected. The adoption of improved practices such as the use of HYVs, application of balanced doses of fertilizers, and crop protection measures is fairly low across the SAT. This paper attempts to examine the climatic constraints of some typical SAT locations in relation to their current and potential fertilizer use practices.

1. Submitted as CP #523 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Climatic Characteristics of SAT

Seasonality of Rainfall

The SAT regions are characterized by a seasonal rainfall. The rainy season varies from 2 to 4.5 months in the dry SAT and from 4.5 to 7 months in the wet-dry SAT. The distribution of rainfall is generally unimodal in areas lying >15° north and >15° south of the equator; it is bimodal in equatorial regions. The SAT exhibits a wet rainy season followed by a distinct dry season. About 90% of the total annual rainfall is received during the rainy season (Figure 1).

Variability of Rainfall

The amount of annual rainfall received in SAT areas varies greatly from year to year; its coefficient of variability (CV) is 20%-30%. For example, the mean annual rainfall at Hyderabad based on 1901 to 1987 rainfall records is 781 mm with a standard deviation of ±212 mm and a CV of 27%. At Hisar, the mean annual rainfall is 456 mm (1930-70) with a standard deviation of ±149 mm

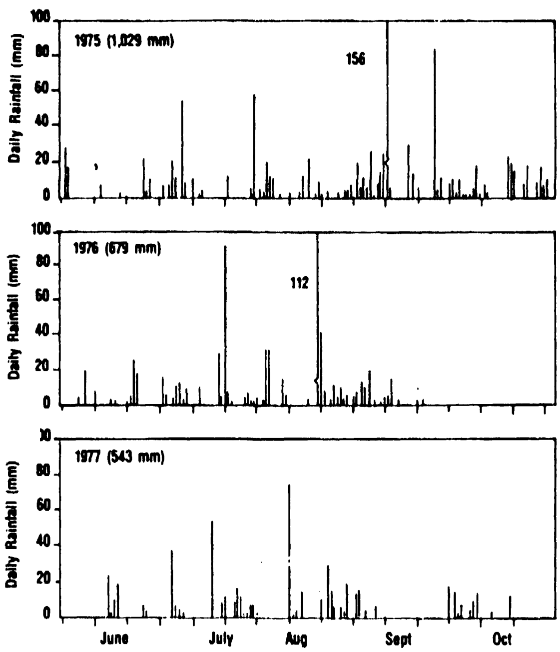


Figure 1. Rainfall Distribution at ICRISAT Center, 1975 to 1977.

and a CV of 33%. Thus, large variations in interannual rainfall are observed. The range of annual rainfall observed at Hyderabad is 950 mm for the period 1901-87. The annual rainfall may be as low as 450 mm or as high as 1,400 mm – about 90% of which is received during the 4-month rainy season.

Another characteristic of tropical rainfall is that the bulk of the seasonal rainfall is received during a few (generally 5-10) rainy days. The 24-hour total rainfall on each of such torrential rainy days may exceed 100 or 150 mm (Figure 1). At ICRISAT Center, it has been observed that in 43% of the rainy days, the rainfall storm intensity exceeded 20 mm hour^{-1}. In Niamey, this characteristic was observed in 72% of the rainy days. In about 10% of the days, rainstorm intensities as high as 120-160 mm hour^{-1} are not uncommon (Hoogmoed, 1981). Hence there is a considerable loss of water due to surface runoff and soil erosion. Miranda et al. (1982) observed that at the ICRISAT Center in traditionally managed Vertisols, 28% of the total seasonal rainfall was lost as surface runoff. This runoff carried away 7 tonnes of surface soil per hectare.

The convective nature of rain-producing storms in the tropics means that the rainy periods are interspersed with dry periods. During the rainy periods, when the soil profile is fully charged, a portion of the soil water is lost as deep drainage. The proportion of total seasonal rainfall lost by this pathway ranges from about 20% in light-textured soils to 10% in heavier soils. Thus the amount of effective seasonal rainfall in the tropics is about 50%-60% of the total annual precipitation.

Evaporation

The SAT areas are characterized by a high water demand due to intense radiation and uniformly high temperatures throughout the year. Sivakumar and Virmani (1987) calculated potential evapotranspiration (PE) statistics for 169 locations in rainfed India and found that the total annual PE was about 1,550 mm with a standard deviation of 196 mm and a CV of 13%. The PE in the months just prior to the rainy season is relatively high – about 200 mm month^{-1}; sometimes the PE exceeds 15 mm day^{-1}. The climatic data for the SAT regions show that the variability in PE is much lower than the rainfall variability and that the atmospheric demand for water is consistently high.

Length and Characteristics of the Growing Season in the SAT

Length of the growing season is defined as the period during which the availability of moisture in the root zone of the crop is adequate to meet the crop's water needs. Because the soil is practically dry prior to the onset of the rainy season, almost all activities related to land preparation for seeding are undertaken when the surface soil is moist enough for ploughing. As a rule of thumb, sowing is done within a week of the onset of the main rainy season in sandy soils and within 2-4 weeks in heavier soils.

The moisture in the soil is enough to sustain crop growth for about 4 weeks after the cessation of rains in lighter soils and about 8-12 weeks in the heavier soils. Thus the length of the growing season in SAT areas receiving rainfall for 2 months will be of the order of 80 days in light-textured soils and about 100 days in soils with clay or clay loam textures. Similarly, in areas with 5 rainy months, the growing season varies between 180 days in light-textured soils and 210 days in clayey soils. Because the amount and distribution of rainfall vary considerably from year to year, the length of the growing season also varies. This variability is higher in the dry SAT than in the wet-dry SAT. The risk to dependable crop production is least for short-duration crops like pearl millet, mung beans in lighter textured soils, and sorghum or maize in heavier soils. The length of the growing season exceeds the average in at least half the years, and the soil water remains relatively underutilized after the harvest of the short-duration crops. In the SAT, therefore, intercropping of short-duration and long-duration crops is recommended. This practice helps stabilize the yield (Willey et al., 1982) and increase rainfall use efficiency (Virmani, 1982).

Climate Analysis and Fertilizer Use Development

Climate analysis is an essential part of technology development and the technology transfer process in the semiarid tropics. For example, by classifying a set of climatic parameters relevant to the definition of adequacy of soil moisture for crop establishment, a region can be defined in which it is assumed that basal dressing of fertilizers would be relatively safe. Virmani et al. (1982) have demarcated the Vertisol region of India into regions with a dependable onset of seasonal rainfall and those with a relatively undependable onset.

The SAT climates encourage surface runoff of rainwater, deep drainage losses, and soil erosion. All of these losses of water lead to fertilizer losses–in particular, losses of applied N. In the SAT, it is best to apply split doses of fertilizers and to adapt the fertilizer applications to the moisture storage capacity of the soil profile and the progress of the seasonal rainfall. The information on rainfall probabilities could be used with advantage in scheduling fertilizer application.

Suggested Fertilizer Use Practices for SAT Dryland Areas

The risks to dependable crop production in the SAT are high. Because fertilizers are costly, the farmers do not use applied nutrients in sufficient quantities. Water is the main limiting factor in the dryland areas of the SAT; therefore, the application of fertilizers will be most advantageous where water conservation methods are used. In the Indian SAT, fertilizer use is currently limited to cash crops like cotton, groundnuts, chilies, etc., and, to some extent, post-rainy-season sorghum. Fertilizer use efficiency, however, is low.

The practice of intercropping is common in the SAT, where about 44% of the cropped area is devoted to intercropping. Legume is one of the important crops in about 50% of the intercropped plots. The practice of intercropping cereals with legume crops leads to the buildup of soil nitrogen. Because intercropping leads to a substantial reduction in risk to dependable crops, the adoption of intercropping encourages fertilizer use for cereal production (Table 1).

Table 1. Some Important Indicators of Fertilizer Use in Three Villages of India's Semiarid Tropics (Average of 1981-83)

Particulars	Nonirrigated	Irrigated	Total
% of total cropped area	81.1	18.9	100
% share of total nutrient (NPK) used	33.7	66.3	100
Fertilizer Use by Crop (%)			
Cotton	39.5	15.3	23.4
Wheat	2.7	32.5	22.4
Paddy	5.2	19.8	14.9
Sorghum	34.0	1.4	12.4
Pearl millet	4.0	13.0	10.0
Castor	6.7	7.5	7.3
Groundnut	3.0	2.7	2.8
Others	4.9	7.8	6.8
Total	100.0	100.0	100.0
Use of Nutrients (NPK) in Relation to Farm Size (kg ha^{-1})			
Small farm	6.1	29.1	8.5
Medium farm	4.8	48.5	14.6
Large farm	6.7	56.8	15.9
All farms	6.3	53.5	15.1

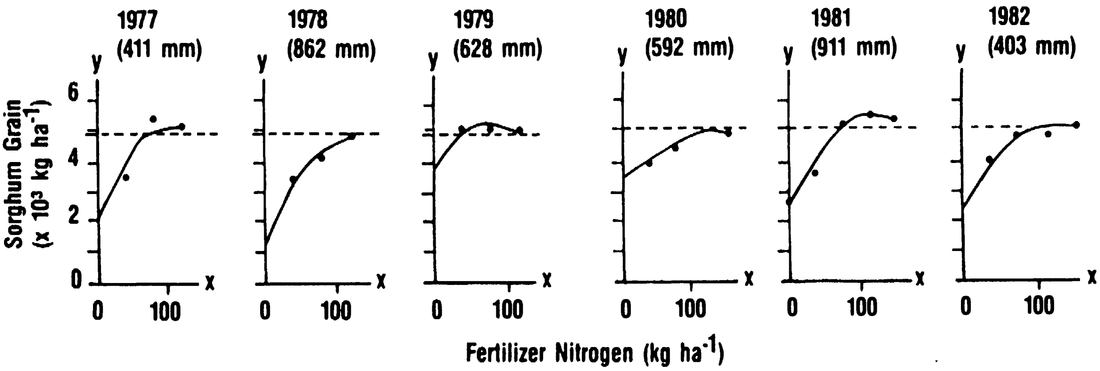
Source: Data collected from ICRISAT's village-level studies.

The production of short-duration pigeon peas is becoming popular. The crop needs application of phosphorus; however, critical soil test values for available P have not been well defined for the various soil orders in India. This is an important area of future research.

Rainfall Amount and Possible Fertilizer Use

Huda et al. (1988) demonstrated the use of agroclimatic analysis for improved soil and water management and efficient fertilizer use in semiarid India. These researchers analyzed seasonal rainfall (June to October) data of Hyderabad from 1901 to 1987 to relate rainfall and possible past fertilizer use. Nitrogen response data at ICRISAT Center from both Vertisols (1977-82) and Alfisols (1979-81) were used (Figures 2a and 2b). In Vertisols, grain yields of rainy-season sorghum (CSH 6) grown in small-plot research experiments at ICRISAT Center exceeded 5,000 kg ha^{-1} in each of the six rainy seasons from 1977 to 1982, provided adequate N was applied. In the absence of added N, grain yields were as low as 1,300 kg ha^{-1}. Seasonal rainfall varied from 474 mm to 907 mm. This did not markedly affect yields, nor were the responses of yields without N closely related to rainfall. For example, the two seasons in which responses were highest (1977 and 1978) were those with extremes in seasonal rainfall. These experiments were conducted on Vertisols nearly 1.5 m deep, which thus had a high water-holding capacity. Variations in nutrient supply apparently are much more important than variability in seasonal rainfall in determining the yields of improved rainy-season sorghum on Vertisols.

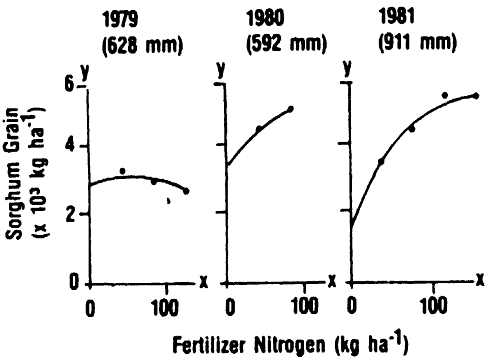
The ICRISAT data base for Alfisols is smaller than that for Vertisols. In the years of moderate and high seasonal rainfall (1980 and 1981), maximum yields exceeded 5,000 kg grain ha^{-1}. But in droughty 1979, the maximum was only 3,400 kg ha^{-1}, and yields were further depressed when applied N exceeded 40 kg ha^{-1}. It seems that maximum yields (when N supplies are adequate) will vary more on Alfisols than on Vertisols. On these Alfisols, which have low water-holding capacity, and on similar soils (in terms of water storage), maximum yields are determined by both rainfall and nutrient supplies. Thus the critical factor determining differences between Vertisols and Alfisols in responsiveness to added N is the moisture-holding capacity of the soil. Alfisols, as well as similar shallow soils, store insufficient moisture to



Regression Equations:

1977: $y = 1{,}920 + 62.4x - 0.28x^2$ R = 0.81 rse = 1,063
1978: $y = 1{,}310 + 53.3x - 0.19x^2$ R = 0.97 rse = 386
1979: $y = 3{,}920 + 37.8x - 0.23x^2$ R = 0.92 rse = 280
1980: $y = 3{,}340 + 19.6x - 0.59x^2$ R = 0.99 rse = 123
1981: $y = 2{,}580 + 44.3x - 0.17x^2$ R = 0.97 rse = 358
1982: $y = 2{,}340 + 40.8x - 0.15x^2$ R = 0.91 rse = 510

Figure 2a. Response of Sole Cropped Hybrid Sorghum (CSH 6) to Applied N on Deep Vertisols, ICRISAT Center, Rainy Seasons 1977-82. Seasonal Rainfall Given in Parentheses After Year.



Regression Equations:

1979: $y = 2{,}950 + 12.9x - 0.11x^2$
$R = 0.51$ $rse = 351$

1980: $y = 3{,}590 + 36.2x - 0.18x^2$
$R = 0.90$ $rse = 400$

1981: $y = 1{,}620 + 54.9x - 0.18x^2$
$R = 0.99$ $rse = 187$

Figure 2b. Response of Sole-Cropped Sorghum (CSH 6) to Fertilizer N on Alfisols, ICRISAT Center, Rainy Seasons 1979-81. Seasonal Rainfall (sowing-harvest) Given in Parentheses After Each Year.

maintain plant growth during droughty, rainless periods, especially when growth is stimulated by addition of fertilizer N. Therefore, if the rainfall is < 500 mm, fertilizer N application is a great risk in these types of soils. For maximum yield of sorghum, the recommended rate of nitrogen application is about 40 kg N ha^{-1} if rainfall is 500-700 mm, about 80 kg N ha^{-1} if rainfall is 700-900 mm, and 120 kg N ha^{-1} if rainfall exceeds 900 mm (ICRISAT, 1984). Analysis showed (Figure 3) that from 1900 to 1941 there were many years when nitrogen would not have been added because of low rainfall, whereas from 1942 to 1987 there was only one such year (1972).

Conclusions

The climatic environment of the semiarid tropics is characterized by variability of amount and distribution of rainfall from year to year. This leads to variations in the length and quality of the growing season. It is suggested that a basal dose of fertilizers be applied in those regions of the SAT where the onset of the rainy season is dependable. Fertilizers should be applied in split doses - not on a fixed schedule but according to the progress of the rainfall and the crop. Practices like intercropping, growing of legumes, and application of fertilizers on the basis of soil test and rainfall probability estimates are likely to lead to the efficient use of applied nutrients in the dryland areas of the SAT.

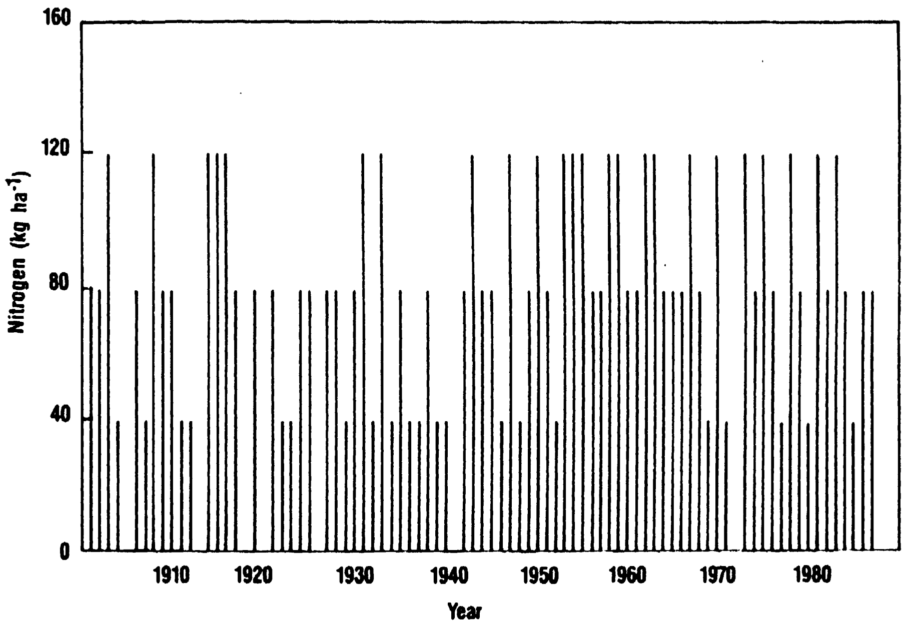


Figure 3. Amount of Nitrogen Fertilizer That Should Have Been Added (based on rainfall analysis) for Sorghum in Hyderabad During 1901-87.

References

Hoogmoed, W. B. 1981. "Analysis of Rainfall in Some Locations of West Africa and India," Appendix 5, Agricultural University, Tillage Laboratory, Wageningen, Netherlands, and Hebrew University, Rehovot, Israel.

Huda, A.K.S., P. Pathak, T. J. Rego, and S. M. Virmani. 1988. "Agroclimatic Considerations for Improved Soil and Water Management and Efficient Fertilizer Use in Semi-Arid India," *Fert. News*, 33(4):51-57.

ICRISAT. 1984. *Annual Report 1983*. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Miranda, S. M., P. Pathak, and K. L. Srivastava. 1982. "Runoff Management on Small Agricultural Watersheds-The ICRISAT Experience," IN *National Seminar on a Decade of Dryland Agriculture Research in India and Thrust in the Eighties*, Hyderabad, India.

Sivakumar, M.V.K., and S. M. Virmani. 1987. "Climate and Production in the Semi-Arid and the Humid Tropics," IN *Global Aspects of Food Production*, pp. 129-169, M. S. Swaminathan and S. K. Sinha (Eds.), Tycooly Publishing Ltd., London, United Kingdom.

Virmani, S. M. 1982. "Increased and Stabilized Production of Sorghum/Millet Based Farming Systems in the Semi-Arid Tropics: Role of Agroclimatic Studies," Paper presented at the ICRISAT-WMO Symposium/Planning Meeting on the Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics, November 15-19, 1982, ICRISAT, Patancheru, India.

Virmani, S. M., K. L. Sahrawat, and J. R. Burford. 1982. "Physical and Chemical Properties of Vertisols and Their Management," IN *Vertisols and Rice Soils of the Tropics*, pp. 80-93, Symposia Papers II, 12th International Congress of Soil Science, New Delhi, India.

Willey, R. W., M. S. Reddy, M. Natarajan, and M. R. Rao. 1982. "Improved Intercropping Systems for the SAT," Paper presented at the IRAT/ICRISAT Meeting on Soil Fertility and Nitrogen Management, April 13-15, 1982, ICRISAT, Patancheru, India.