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Chapter 32

Global Climate Change and Crop Production in the Sudano-Sahelian Zone of West Africa

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No other issue in the recent past has generated so much interest and concern, and so much press coverage as climate change. This topic is finally bringing together the developed and developing countries to one summit with the realization that there are finite limits to the ecological exploitation within national boundaries, and that it is time that we regard planet earth as a common resource. This is because greenhouse gases released any where in the world dispense rapidly in the global atmosphere. Neither the location of the release nor the activity resulting in their release makes much difference (NAS, 1991a).

Waggoner (see Ch. 30, this book) appropriately emphasized the impact of projected climate change on crops. While there is universal agreement that the direction of climate change, especially at the regional scale, is somewhat uncertain, there should be no degree of complacency that adaptation to climate change will be easy. The importance of the rate of climate change must be assessed by comparing the rate at which the systems that might be affected change and adapt (Ausubel, 1991). Adaptations are expensive and the level of technological and economic development of a country determines the extent to which countries can cope with climatic changes. Two dissenting voices in the Reports of the Synthesis Panel and the Adaptation Panel of the National Academy of Science (NAS, 1991a,b) highlight this issue. People, economic activity, infrastructure and natural context cannot be dissociated. Jessica Mathews (NAS, 1991a) cautions that costs that are indisputably enormous (including human suffering) begin to appear deceptively manageable when viewed solely from the perspective of their impacts on a multitrillion dollar economy. Jane Lubchenco (NAS, 1991b) echoes the same view by saying that we have to worry about the costs of adaptation and that substantial difficulties are anticipated for developing nations to adapt to climate change. The objective of this chapter is to examine possible impacts of climate change on crop productivity in the Sudano-Sahelian zone (SSZ) of West Africa.

32–1 SUDANO-SAHELIAN ZONE OF WEST AFRICA—A VULNERABLE REGION

Although Waggoner (see ch. 30, this book) does not prefer the term vulnerability since it is pejorative, several reports (IPCC, 1990a,b; Parry et al., 1988) refer to countries in the arid and semi-arid regions, especially in West Africa, as being vulnerable to projected climate change. Recently, IPCC (1992) reinforced the concern that climate change resulting in increased frequencies of drought poses the greatest risk to agriculture. Consequently the arid and semi-arid regions which are already having difficulty coping with environmental stress, are likely to be most vulnerable to climate change. The report cautions that the accelerated reduction of tropical forest with climate change on the African continent could result in an encroachment of the Sahel syndrome into the now productive savannas.

The SSZ extends over several countries from Senegal and Gambia in the west to Chad in the east. The growing season varies from 60 to 150 d, but most of the region has a growing season $<$ 120 d (Sivakumar, 1989). Subsistence agriculture is the main mode of livelihood and 90% of the population lives in villages. Extended droughts since 1969 and successive crop failures resulted in a decline in the per capita food production. The following are some of the reasons why the SSZ of West Africa is vulnerable.

32–1.1 Prevailing Low Rainfall and High Temperatures Increase the Risk with Climate Change

Agriculture in the SSZ, which is predominantly rainfed, is finely tuned to climate as it relies on the timely onset of rainfall and its regular distribution through the rainy season. Hence even a slow, small change towards a worsening cli-

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mate can increase climatic risks. Waggoner (see Ch. 30, this book) concluded that if the present climate is a productive one, warmer and drier will hurt. In the SSZ, however, the present climate itself is marginally productive, and this introduces a much greater risk if climate worsens further.

The monomodal rainfall in the SSZ, concentrated in a short period of 3 to 4 mo is low, variable and undependable. With the large temporal and spatial variations in rainfall, the traditional systems of crop production are often very vulnerable. Below normal rainfall could persist for 10 to 20 yr. For example, it has been established that at several locations in Niger, a significant decline in the annual and August rainfall has occurred since 1966 (Sivakumar, 1992).

Air temperatures in the SSZ are usually high because of the high radiation load. From south to north temperatures increase and rainfall decreases. Environmental conditions during the stage of crop establishment in the SSZ, especially in the low rainfall areas, are usually harsh since the sowing rains follow a long and hot dry season. Mean maximum temperatures could exceed 40°C at the time of sowing and absolute temperatures could be much higher (Sivakumar, 1989). Diurnal variations in the air temperature and soil temperatures at the surface and 5-cm depth before the onset of rains (Fig. 32–1) show that the surface soil temperatures can increase rapidly from 27°C at 0700 hr to 56°C at 1400 hr. Although the surface soil temperatures decrease after a rain, with a short dry period and clear skies, atmospheric conditions can quickly return to those described in Fig. 32–1.

32–1.2 Climatic Extremes Under Projected Climatic Change Can Pose Serious Problems

In view of the disagreement on the extent of future warming, Waggoner (see Ch. 30, this book) favors an intermediate realm of 1 to 2°C warming. Even under this modest warming scenario, the nature, frequencies and sequences of extreme events may have a significant impact on crop production in the Sudano-Sahelian zone. Episodes of higher temperature are likely to become more frequent. The number of days with temperature above a given value at the higher end of distribution will increase substantially and there will be decrease in the days with temperature at the lower end of the distribution (IPCC, 1990a). Data presented in Fig. 32–1 raise an important question. How would the intermediate realm of warming of 1 to 2°C in the *mean* affect the *maximum* temperatures at the soil surface? It is conceivable that surface soil temperatures could exceed even 60°C.

Under higher air temperatures, enzyme degradation will limit photosynthesis and growth. Increased temperatures will result in increased rates of potential evapotranspiration. In the long term, the very establishment and survival of species in both the managed and unmanaged ecosystems in this region may be threatened resulting in a change in the community structure.

Although the direction of change in precipitation with climate change in West Africa is unclear, episodes of extreme events such as droughts and high intensity rainfall are likely to increase (IPCC, 1990a). Rainfall decline and droughts of the past two decades in the SSZ have already affected crop production. In the Sahelian region, where the rainy season is already short, further increase in the frequency of droughts will have serious consequences.

Fig. 32–1. Diurnal variation in the air temperature and soil temperatures at the surface and 5-cm depth before the onset of rains on 10 May 1992 at Sadore, Niger.

32–1.3 Poor Soil and Crop Management Make Quick Adaptation Difficult

The sensitivity of a crop to climate change depends not only on its physiological response to temperature or moisture stress, but also on other components of the system. The poor soils of SSZ with low native soil fertility are a major component affecting this sensitivity. Arenosols and Luvisols are the two major soil types in the SSZ accounting for 56% of the total area (Sivakumar, 1989). Arenosols are sandy, acidic, and low in organic matter, cation exchange capacity, N and P. With the reduced ratio of the length of fallow to cropping years in the SSZ, soil fertility has been declining. According to Mudahar (1986), average use of fertilizers in the sorghum [*Soghum bicolor* (L.) Moench] and pearl millet [*Pennisetum glaucum* (L.) R.Br.] growing countries of West Africa was only 5 kg/ha. In the absence of added manure or fertilizers on these poor soils, the nutrient reservoir of the soil under continuous cropping is dropping to levels which can no longer sustain the desired yield levels.

The lack of suitable fertility management is further aggra-ted by the limited, untimely soil management practices. infall intensities in the SSZ are much greater than in the temperate and subtropical zones and pose special problems in agricultural management and soil conservation. Although appropriate soil and water management practices are crucial for making efficient use of the limited rainfall, adoption of such soil management practices at the farm level are virtually unknown. In a major part of the millet growing region in the SSZ, use of animal traction for preparatory cultivation is not common and the soils are seldom plowed (Spencer & Sivakumar, 1987). On soils that are hard and crusty, non-adoption of soil tillage results in low infiltration rates and runoff, and in low water use efficiencies.

32-1.4 Deforestation, Land Degradation and Wind Erosion Threaten Sustainable Agriculture

The traditional shifting cultivation system in the SSZ was sustainable. Fallowing allowed for nutrient buildup which was used during subsequent cropping seasons. Since only the fallow was cleared, the C balance was maintained. However, with increasing population pressure, large scale clearing of marginal areas and biomass burning has become more common and monocropping has come to replace the shifting cultivation. The widespread deterioration of large areas of savannah in the semi-arid regions of Africa is believed to be associated with the overexploitation of marginal land via the removal of wood and overgrazing (Barrow, 1987). While the clearing of closed tropical forests in Africa accounts for 18% of the world clearing (FAO, 1988), the open forests in Africa are disappearing at an alarming rate and contribute to 62% of the total destruction of open forests worldwide. Because the open forests are mainly an unmanaged ecosystem, their regeneration may pose problems.

Deforestation and changes in the land surface conditions can also have an important influence on rainfall. Our studies in Niger have shown that on bare soils that result from such degradation, evaporation rates are much lower compared to the fallow bushland (Wallace et al., 1990) thereby disturbing the natural hydrological cycle. The feedback effects could be important as Laval and Picon (1986) have shown that an increase in albedo can inhibit rainfall. The feedback implies that deforestation may be difficult to reverse.

Increasing land degradation leaves the bare surface soil susceptible to wind erosion. Data collected in Niger show that the increasing wind erosion is leading to decreased visibility (Fig. 32–2). As compared to the 1960s, during the 1980s there was a significant increase in the number of days with poor visibility (<5 km). The problem is becoming particularly serious at the beginning of the rainy season, when rains are usually preceded by dust storms with violent winds. Moving sand particularly affects crop establishment by damaging the seedlings by "sand blasting" and the high soil temperatures during this period cause further damage. Lack of adoption of appropriate strategies at the farm level, especially in the Sahelian zone, to reduce wind erosion and sand blasting is leading to suboptimal plant stands and replanting over large areas. This has a feedback effect on land degradation.

Figure 32-2 Changes in the visibility from the 1960s to 1980s at Niamey, Niger. (Data source: National Meteorological Services of Niger.)

32-1.5 Demographic Pressures, Declining Productivity and Low Per Capita Incomes Raise Difficult Questions of Tradeoffs

Population growth rate in West Africa is one of the highest in the world. Unfortunately this growth has put stress on the natural resource base and increased environmental degradation, making it even more difficult to obtain the required production gains to sustain the growing populations. While population has been growing at close to 3% annually, there has been a declining trend in the quantity and quality of cultivable land area per inhabitant. If these trends are allowed to continue, FAO (1981) projects that by the year 2000, per capita food production will decline by 30% and cereal self-sufficiency from 85 to 65%.

Average productivity of the cereal crops in the SSZ has remained stagnant over the past two decades. For example, average yields of millet in Niger declined from 570 kg ha^{-1} in 1964 to 340 kg ha^{-1} in 1987 (Fig. 32–3a). In comparison, during 1950 to 1980 wheat yields in USA increased annually by 50 kg ha^{-1} (Fig. 32–3b).

Gross national product (GNP) and per capita incomes of countries in the SSZ are among the lowest in the world. With such poor per capita incomes, the Sudano-Sahelian region faces difficult trade-offs between stimulating economic development and alleviating environmental problems.

32-1.6 Poor Research Infrastructure Limits Innovative Adaptations

One of the most important prerequisites for the success of the adaptation strategies recommended by several forums (IPCC, 1990b; NAS, 1991b) is to ensure that the inventive genius that makes the many technologies useful in adapting to climate is available to most people. The rate of adoption of new cultivars at the farm level could be used as an example. In the USA, the estimated life span of cultivars is 7 yr for maize (*Zea mays* L.), 8 for sorghum [*sorghum bicolor* (L.) Moench] and cotton, (*Gossypium hirsutum* L.), and 9 for

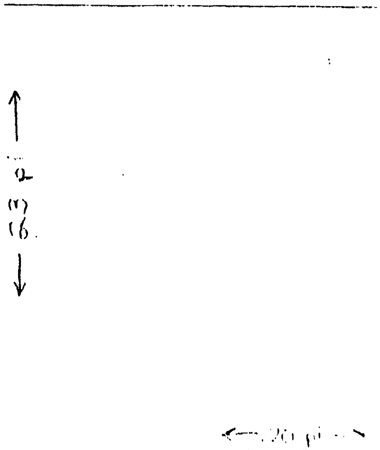

Fig. 32-3. Variations in the average yields of a) pearl millet in Niger and b) wheat yields in USA. (Data source: FAO Year Books.)

wheat (*Triticum aestivum* L.) and soybeans [*Glycine max* (L.) Merr.] (Duvick, 1984). It is no surprise that with 60,000 maize cultivars and hybrids in preliminary trials in 1980 compared to 454 in commercial uses (Wilkes, 1984), the average life span of a corn cultivar is only 7 yr. For pearl millet [*Pennisetum americanum* (L.) Leeke] in the SSZ, it is estimated that in 1990, only 70 to 100 cultivars of pearl millet were tested in preliminary trials (K. Anand Kumar, 1992, personal communication). In Niger, the pearl millet cultivar CIVT, developed in the early 1970s, is still being used as the improved check in breeders trials and is the most important improved cultivar recommended for general cultivation. Use of such improved cultivars at the farm level is still very low.

32-2 COPING WITH CLIMATE CHANGE IN THE SUDANO-SAHELIAN ZONE

Whether or not there will be a significant climatic change, the inherent climatic variability in the SSZ makes the need for adaptation unavoidable. Environmental problems facing this zone are serious and certain. The need for development and implementation of sustainable agricultural strategies on a regional scale is crucial in this marginal region that is already threatened by environmental degradation. Premeditated adaptation that begins with anticipation and information (NAS, 1991b) is a good strategy for this region. The approaches should be prescriptive and dynamic rather than descriptive and static.

32-2.1 Use the Analogue Approach and Strengthen International Research

One of the characteristic features of the SSZ is a north-south gradient in temperature and rainfall. This offers an advantage in the sense that the climates that may be experienced at a given site in future for the most part, are climates that are being experienced already somewhere along this gradient. Although there are some differences in soil types along this gradient, crop responses to a given range of temperatures and rainfall could still be examined since all occurrences of a defined class (rainfall and temperature) should respond to management in a similar way.

Effective implementation of the analogue approach requires the cooperation and coordinated action of all the countries in the SSZ. Hence, it is necessary to create a network of research and experimental sites. Fortunately, for millet and sorghum, the most important cereal crops in the SSZ, the West and Central African Millet Research Network and the West and Central African Sorghum Research Network are already functioning. Activities of these two networks are coordinated by ICRISAT. An international perspective is a prerequisite in the implementation of the analogue approach since it is difficult for any one national program to keep abreast of all developments across this vast climatic zone. From the climate change perspective, it is necessary to further strengthen the research of the International Agricultural Research Centers and the networks in West Africa.

32-2.2 Improve Monitoring

To carefully assess the impact of future climate change on the managed and unmanaged ecosystems in the SSZ, it is crucial to monitor local climate, and natural changes in species adaptation. It will be necessary to install improved methods of climate monitoring by taking advantage of recent developments in automatic weather stations which enable easy recording of the occurrence of extreme events on a routine basis. Recent advances in satellite technology also offer the possibilities for better monitoring of the managed and unmanaged ecosystems. For species adaptation, it will be useful to set up phenological gardens at bench mark sites in the SSZ to carefully assess the changes in their adaptation and in the duration of the developmental stages.

32-2.3 Use Strategies for Efficient Natural Resource Use

Increasing the promotion and strengthening of resource conservation is the first step in coping with the climate change. These strategies will include, for example, soil and moisture conservation, better moisture use efficiency, collection and recycling of runoff, reducing deforestation, increasing reforestation, and reduction of biomass burning. Strategies that can increase the water use efficiency, such as relay cropping during years with early onset of rains, are now available and should be transferred to the farm level.

32–2.4 Implement Sustainable Agricultural Practices

It is important to increase the emphasis on the development and adoption of technologies that increase the productivity or efficiency of crops consistent with the principles of sustainable deve
possible strategi
the SSZ includi
tems, traditional agro-silvi-pastoral systems, choice of appropriate crop varieties, intercropping/relay cropping of cereals with legumes, *Faidherbia albida* systems, mixed tree/grass/crop systems, rotations, use of manures with a limited quantity of fertilizer, and use of crop residues.

32–2.5 Enforce Effective Intervention Policies

One of the adaptation strategies recommended by NAS (1991b) is the intervention by governments to manipulate the circumstances of choices. The criteria laid down for government action (NAS, 1991b) apply to the SSZ even now:

1. Amount of time needed to carry out the adaptation is so long that we must act now.
2. Action is profitable even when climate does not change.
3. Penalty for waiting a decade or two is great.

The need for good, timely climate information in the drought-prone regions is too well known to be stressed. Recent developments in the information technology now make it possible to quickly acquire and sort the enormous amount of information into items relevant to the end user. Implementation of policies to provide timely information, improved weather and climate forecasts and good markets should help the farmer adapt quickly.

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REFERENCES

Ausubel, J.H. 1991. A second look at the impacts of climate change. Am. Sci. 79:210–221.

Barrow, C.J. 1987. Water resources and agricultural development in the tropics. Longman development studies. John Wiley and Sons, New York.

Duvick, D.N. 1984. Genetic diversity in major farm crops on the farm and in the reserve. Econ. Bot. 38:161–178.

FAO (Food and Agriculture Organization). 1981. FAO Production year book 1980. FAO, Rome.

IPCC (Intergovernmental Panel on Climate Change). 1990a. Climate change, The IPCC scientific assessment. Cambridge Univ. Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change). 1990b. Climate change, the IPCC response strategies. World Meteorological Organization/United Nations Environment Programme, Geneva, Switzerland.

IPCC (Intergovernmental Panel on Climate Change). 1992. IPCC supplement. World Meteorological Organization/United Nations Environment Programme, Geneva, Switzerland.

Laval, K., and L. Picon. 1986. Effect of a change of the surface albedo of the Sahel on climate. J. Atmos. Sci. 43:2418–2429.

Mudahar, M.S. 1986. Fertilizer problems and policies in sub-Saharan Africa. pp. 1–32. *In* A. Mokwunye and P.L.G. Vlek (ed.) Management of nitrogen and phosphorus fertilizers in sub-Saharan Africa. Martinus Nijhoff Publ., Dordrecht, Netherlands.

NAS (National Academy of Sciences). 1991a. Policy implications of greenhouse warming. Report of the Synthesis Panel. National Academy Press, Washington DC.

NAS (National Academy of Sciences). 1991b. Policy implications of greenhouse warming. Report of the Adaptation Panel. National Academy Press, Washington DC.

Parry, M.L., T.R. Carter, and N.T. Konijn. (ed.). 1988. The impact of climatic variations on agriculture. Kluwer Academic Publ., Dordrecht, Netherlands.

Sivakumar, M.V.K. 1989. Agroclimate aspects of rainfed agriculture in the Sudano-Sahelian zone. pp. 17–38. *In* Soil, crop and water management systems for rainfed agriculture in the Sudano-Sahelian zone: Proc. Int. Workshop, ICRISAT/Sahelian Center, Niamey, Niger. 7–11 Jan. 1987. ICRISAT, Patancheru, A.P. 502324, India.

Sivakumar, M.V.K. 1992. Climatic change and implications for agriculture in Niger. Climatic Change 20:297–312.

Sivakumar, M.V.K., C. Renard., and J.M. Powell. 1991. Agroclimatic considerations for sustainable agro-silvi-pastoral systems in the Sudano-Sahelian zone. Invited Scientific lecture, Tenth Session of the Commission for Agricultural Meteorology of WMO, Florence, Italy. 2–13 Dec. 1991. World Meteorological Organization, Geneva, Switzerland.

Spencer D.S.C., and Sivakumar, M.V.K. 1987. Pearl millet in African agriculture. pp. 19–31. *In* Proc. Int. Pearl Millet Workshop, ICRISAT Center, India, 7–11 Apr. 1986. ICRISAT, Patancheru, A.P. 502324, India.

Wallace, J.S., J.H.C. Gash, and M.V.K. Sivakumar. 1990. Preliminary measurements of net radiation and evaporation over bare soil and fallow bushland in the Sahel. Int. J. Climatol. 10:203–210.

Wilkes, G. 1984. Germplasm conservation towards the year 2000: Potential for new crops and enhancement of present crops. *In* C.W. Yeatman et al. (ed.) *Plant genetic resources*. Am. Assoc. Adv. Sci. Selected Symp. 87. Am. Assoc. Adv. Sci., Washington DC.

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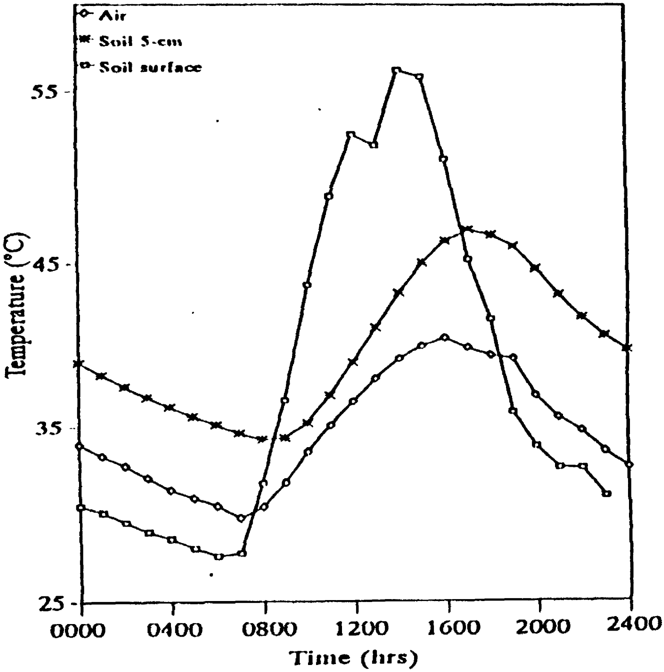

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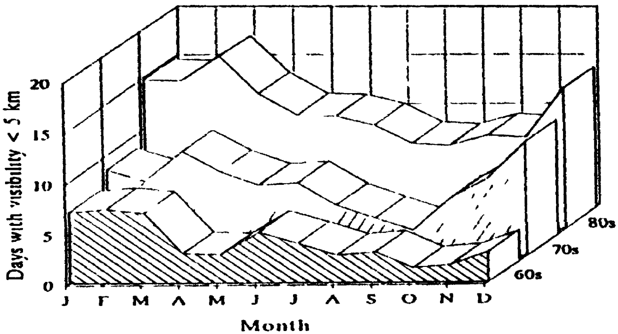

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