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Soil Water Balance in the Sudano-Sahelian Zone (Proceedings of the Niamey Workshop, February 1991). IAHS Publ. no. 199, 1991.

Soil water balance in the Sudano-Sahelian zone: need, relevance and objectives of the workshop

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Abstract The Sudano-Sahelian zone extending over several countries in West Africa has an average growing season length varying from 60 to 150 days. Efficient use of the limited rainfall in this region is crucial as future increases in crop production will have to come primarily from increased yields per unit area of land. A complete understanding of the physical and hydraulic properties of the soils and of the different processes of soil water movement including infiltration, redistribution, drainage, evaporation and water uptake by plants is essential in the design of appropriate management practices for increasing water use efficiency. The need and relevance of studies on these aspects is discussed. The objectives and the format for the technical sessions of the workshop are also presented. Finally, the planning meeting at the end of the workshop is discussed with respect to the sharing of knowledge and experience of different disciplines and the training needs for future applications of soil water balance research in the Sudano-Sahelian zone.

INTRODUCTION

On behalf of the co-sponsors of this workshop, we have the honour of being called upon to define broadly the purpose and objectives of this International Workshop on Soil Water Balance in the Sudano-Sahelian zone. Since this workshop is mainly concerned with the Sudano-Sahelian zone (SSZ), it may be useful at the outset to define the geographical extent of this area. Several definitions of the SSZ are available in the literature and there is a wide variation in the rainfall limits used by different authors to delineate the SSZ. Sivakumar (1989) recently reviewed this literature and suggested that the length of growing season is used as the primary criterion for the delineation of the SSZ. On this basis, the Sudano-Sahelian zone extends over several countries from Senegal and Gambia in the west to Chad in the east (Fig. 1). With a growing season length varying from 60 to 150 days, it offers a range of growing conditions, but a large part of the region has a growing season of less than 120 days (Sivakumar, 1989).

The Sudano-Sahelian zone has received a lot of attention in the last two decades because recurrent droughts and successive crop failure have led

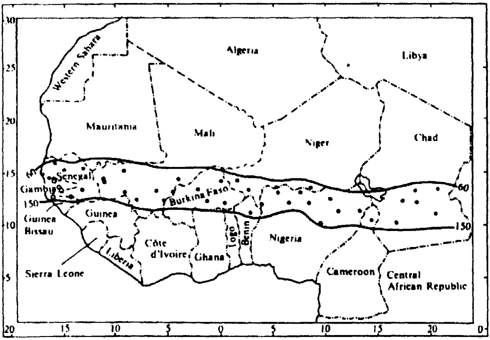

Fig. 1 Geographical extent of the Sudano-Sahelian zone. Growing season isolines of 60 and 150 days are shown (———).

to declining national incomes and decreasing per capita food production. A recent workshop reviewing the soil, crop and water management systems for rainfed agriculture in the SSZ (ICRISAT, 1989) concluded that the entire sub-Saharan region constitutes a highly fragile land resource and environment, and that there is limited knowledge as to the technologies that would be appropriate for these conditions. Drought stress, poor and declining soil fertility, accelerated by degradation of the natural vegetative cover, and lack of efficient soil-water management techniques have been identified as the major constraints to food production in this region (Youdeowei, 1987).

In its projections to the year 2000, FAO (1981) indicated that a bulk of the future crop production increases (60%) in the semiarid regions will have to come from higher yields per unit area of land. Under the rainfed agricultural systems in the SSZ, where rainfall is low, variable and undependable, increases of crop yields per unit area will depend on making the most efficient use of this limited rainfall.

Water related problems in agriculture are not limited to rainfall alone and as Wadleigh *et al.* (1965) pointed out, there is a "many-headed Hydra" emanating from the use and abuse of the soil moisture reservoir. Much of the recent research on the SSZ indicates that rainfall *per se* is not necessarily the crucial limiting factor to agricultural production, rather it is the proportion of rainfall which enters the soil moisture reservoir and its subsequent utilization by plants. Hence we are mainly concerned here with the capacity and preservation of the soil water reservoir, its depletion and replenishment, and its management for efficient use. Numerous examples abound in the literature that show clearly different cropping strategies under the same climatic regime because of differences in soil type and management. For example, in millet water balance trials conducted by the ICRISAT Sahelian Center at Bengou in southern Niger, with a total rainfall of 784 mm during the 1986 growing season, measured soil water profiles in two soil types, a loam and a sandy loam, showed important differences at the time of sowing and at harvest (Fig. 2).

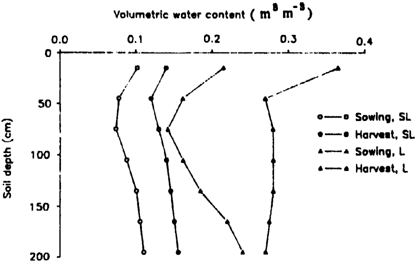

Fig. 2 Soil water content profiles at the time of sowing and harvesting of millet in two soil types, a sandy loam (SL) and a loam (L) during the 1986 rainy season at Bengou, Niger.

We know that the physical processes of soil water movement such as infiltration, redistribution, drainage, evaporation and water uptake by plants are strongly interdependent because they occur sequentially or simultaneously. Hence it is necessary to consider the field water balance as a whole, and the relative magnitude of the various processes comprising it over a period of time.

This brings us to the question of the rationale for our choice of "Soil Water Balance" in the title for this workshop. Arguably, it is difficult to say where in the title the emphasis should be laid. Crops, soils or both? In the SSZ as a whole, one of the major constraints in developing suitable soil and crop management technologies is a lack of complete data on soil physical and hydraulic properties, and on the spatial and temporal variation of water balance components.

Development of management options for sustainable production in the SSZ needs systematic studies of soil water balance. An understanding of the magnitude of different components of the soil water balance and the manner in which they influence crop growth is essential to achieve higher water use efficiency and for managing water resources for their most profitable use in crop production. Information on the water balance of crops, natural vegetation and soil is also very important in the studies of the hydrology of the Sahelian region. Hence we felt that our emphasis on soil water balance is fully justified.

OBJECTIVES

The objectives of the workshop as laid out by the Workshop Scientific Committee are:

* To bring together experts on crop water balance studies to review the present state of knowledge on different components of soil water balance for different vegetation/cropping systems in the SSZ.
* To review, evaluate and disseminate techniques and methods (i) to integrate the soil water balance and plant growth and development and (ii) to develop operational applications of soil water balance monitoring and prediction in real time.
* To identify priority research areas and themes for collaborative work and to formulate recommendations for national, regional and international research.

In this workshop we have scientists from different national programmes of the SSZ with varied backgrounds: agrometeorologists, meteorologists, soil physicists, agronomists, agroforesters, hydrologists, plant physiologists and modellers, all with a common interest in water balance research. This we think is a very positive aspect since it provides us an opportunity to examine this issue from several angles, not just from the soils view point. From the classical studies of Denmead & Shaw (1962) and Philip (1966) we know that plant response can depend as much on the evaporative demand as on soil moisture. In the SSZ, where the soil moisture regime is generally highly variable, crops are influenced more by the extreme values in time and space than by the averages.

NEED AND RELEVANCE

The traditional millet production system in the SSZ, with millet shown in widely spaced pockets (sometimes up to 2 m apart), provides a very interesting case study and it should fully justify the recent interest in partitioning the components of water use into transpiration and evaporation. This is because it is only the transpiration component which is related to yield, the soil evaporation being effectively a "loss" to the system. For example, from our work on millet in Niger (Wallace *et al.*, 1990a) we found that approximately 36% of rainfall in an average year is lost as direct evaporation from the soil. With this knowledge the question is, whether there is a scope for "rerouting" some of this wasted water via plants to improve productivity without an increase in rainfall? Furthermore, under the conditions of decreasing rainfall, particularly in the month of August (as shown for Niger by Sivakumar, 1990), the same strategy may provide a means of sustaining productivity under a lower rainfall regime. A key challenge to agronomists is, therefore, to evolve cropping systems which do not require any more water in total, but which make more efficient use of the limited rainfall by minimizing soil evaporation. These cropping options may include: choice of appropriate varieties in monocultures, intercropping, relay cropping, agroforestry etc. The role of management options such as use of organic matter, mulches, fertilizer (even in limited quantities) and soil tillage etc., in improving water use efficiency should also be carefully considered. We have some very interesting papers covering several of these areas in this workshop and we hope we will be able to develop some useful recommendations after a critical review of these options.

We have hydrologists in this workshop who need evaporation data mainly in the assessment of water resources. Over large areas (catchment scale) and long time periods (ranging from a month to years) the difference between rainfall and evaporation is a primary determinant of other components of water balance such as runoff and drainage. Runoff affects river flows and drainage is a key factor is groundwater recharge. River flows are important for urban and rural water supplies and for irrigated crops along the river banks. Groundwater is an essential resource for people living away from the rivers, again both for human and animal consumption and for (smaller scale) crop irrigation.

In the fragile ecosystems in the SSZ, with vast areas of crusty lands denuded of natural vegetation and ground cover, and with poor soil and water management in the traditional systems of cultivation, poor infiltration and runoff causes severe soil loss and results in degradation of thousands of hectares of land. Soil losses of up to 20 t ha^{-1} $year^{-1}$ have been reported in Senegal and Burkina Faso (Charreau & Nicou, 1971). Clearly, we cannot develop appropriate mechanisms to arrest these losses without an understanding of the magnitude of these runoff losses and how they are related to the soil physical and hydraulic properties.

Another area where evaporation is important is in the understanding of climate change which links two important concepts: water balance, which is a statement of the law of conservation of matter, and energy balance, an expression of the law of conservation of energy. The reduction in evaporation (and the change in the surface energy balance) associated with the removal of vegetation in the Sahel has been shown, via general circulation models (GCMs), to result in reduced rainfall. Our recent studies on energy balance over a fallow bushland and a bare soil at the ICRISAT Sahelian Center (Wallace *et al.*, 1990b) showed significant differences in net radiation over the two contrasting surfaces. Albedo is an important factor controlling the surface energy balance via its effect on net radiation and potential evaporation. However, currently GCMs have very poor representations of the Sahelian land surface, largely because no good comprehensive data exist. There is, therefore, a great need for evaporation (and energy balance) data from typical Sahelian vegetations in order to better understand and hence predict any links between vegetation degradation and climate change. The SEBEX (Sahelian Energy Balance Experiment) project, a collaborative venture between the Institute of Hydrology and the ICRISAT Sahelian Center, is one attempt to provide some of this much needed data. Future projects like HAPEX-II-Sahel (Hoepffner, 1989) should follow with more of this type of information, especially at the larger scale (100 × 100 km) which is relevant to the GCMs.

WORKSHOP FORMAT

We would now like to say something about the workshop format. In this session and in the technical sessions that follow, we have scheduled presentations that will review the current state of research on crop and soil water balance and on the measurement of rainfall, infiltration, runoff, evaporation, soil water, and drainage. For those working in the SSZ it is important to understand the state of the art of research. National programmes operate under severe financial constraints and lack of trained manpower. As Gardner (1987) observed, much of the back-breaking labour required in the past in studying the water balance is now replaced by sophisticated instruments, and, importantly, long columns of figures are replaced with graphs produced electronically and equations derived with computer-aided mathematics. We need to examine the feasibility of introducing such new techniques in the SSZ for use by the national programmes.

We will have the privilege of having keynote addresses from Dr Monteith, Dr Lal and Mr Dancette. Dr Monteith's pioneering work on vegetation–atmosphere interactions is known throughout the world. His presentation will be followed by a review of soil water balance research by Dr Ratan Lal, whose name is now synonymous with soil erosion. Dr Lal has many years of experience working on soil erosion and soil physics in the humid tropics at the International Institute for Tropical Agriculture (IITA) in Nigeria. Some of the pioneering water balance studies in the SSZ have been conducted by Mr Claude Dancette in Senegal, who is now here in Niamey as the Director of Applications Division at AGRHYMET. His review of the water balance studies should help us identify whether we have the necessary information on the crucial components of water balance and where the future emphasis should be. These and other presentations that will follow should provide much food for thought and should help us in our discussions as to how we can incorporate new ideas in our future work plans.

We have two technical sessions on the Soils and Soil Water Balance studies in the SSZ. One of the major constraints in soil and water management research in the SSZ is the lack of published information on the physical and hydraulic properties of different soils. Hopefully, we will be able to bring together some of the available information that should help us evaluate the future research needs.

A major test of the utility of agricultural research results lies in operational applications. Given the variable and unpredictable rainfall in the SSZ, soil water balance research is perhaps one of the most important areas for operational applications in the SSZ. For long-term (strategic) applications such as choice of appropriate cropping systems and cultivars for a given region, farmers must have a knowledge of the length and variability of the growing period which is based on the available soil water. Strategies are normally chosen based on qualitative information or trial-and-error experiences. Models have the potential for providing useful quantitative information while eliminating the costly and time consuming trial-and-error methods. We will examine some such models for operational applications.

Droughts are common phenomena in the SSZ and information dissemination is extremely crucial during the long drought periods. For short term (tactical) decisions concerning crop management, farmers need information on how much water is currently available, how long it is likely to be available and what management options could be used to tide over the situation. Soil water monitoring is very crucial to answer these questions and simulation models incorporating stochastic means could be useful tools.

All the above questions lead us to the serious nature of the planning meeting to be held on the last day. We are asking you to join one of the three groups that would discuss the following issues:

* soil characterization and data bases for water balance studies,
* water balance studies,
* operational applications and modelling.

Water balance research is increasingly being treated in the soil-plant-atmosphere-continuum (SPAC) approach. Data necessary to generate a clear understanding of the SPAC are obviously available, but scattered, and very often not published in the open literature. Clearly this requires the sharing of knowledge and experience of all agrometeorologists, meteorologists, agronomists, soil physicists, plant physiologists, hydrologists, agroforesters and modellers. The research needs of the 1990s call for a much more efficient and concerted effort of the international community of scientists. We need to devise means of pooling our data and research results, not just through workshops of this nature, but also through other more informal avenues.

We hope the planning meeting will also address the question of training which is crucial for long-term growth and development of the national research programmes in the SSZ. AGRHYMET, the WMO regional centre for training in Agricultural Meteorology and Hydrology, ICRISAT and several other regional and international organizations in the SSZ organize training programmes of relevance to water balance. We should examine the possibilities of bringing together the available expertise and resources for the benefit of interested technicians and scientists in this region. Finally, we look forward to a very productive workshop and towards our continued cooperation to help the small farmers of the Sudano-Sahelian zone.

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