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SIMULATION OF POTENTIAL BENEFIT OF WATER CONSERVATION IN THE NORTH EAST ARID ZONE OF NIGERIA

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Abstract

An agro-climatic model was used to predict the potential benefits of water conservation (runoff control and runoff harvesting) to upland millet systems in the North East Arid Zone of Nigeria in wet, average and dry years. The results showed that on land presently prone to runoff, there are likely to be significant benefits from runoff control in all years, however, there is little benefit from runoff harvesting in all but the driest years, as the light soils of the uplands are unable to hold the extra water and hence drainage losses increase.

1. Introduction

The North East Arid Development Programme (NEAZDP) area lies within the Sudano-Sahelian Zone of Nigeria and covers an area of about 25,000 km^2. The long term (1961 - 1990) mean annual rainfall ranges from 660 mm in the south west, to 340 mm in the north east, although it has been declining throughout the last three decades (Hess *et al.*, 1994). The published mean for Gashua is 420 mm (NEAZDP, 1991). Most of this rain falls between July and September and rainfall events are characterised by high intensities. According to Kowal and Kassam (1976), the peak intensity may be as high as 200 mm hr^{-1}. As a result of the high intensity rain and the seemingly low infiltration rate of the soil in some parts of the area, runoff is a common feature. In a catchment in Northern Nigeria, Kowal (1970) estimated that more than 20 per cent of the rainfall may be lost as runoff.

It is widely held that water is one of the most limiting factors of crop production in the semi-arid tropics (IFAD, 1992; Huibers and Stroosnijder, 1992) and the Sahel in particular (Mortimore, 1989). The inadequacy of rainfall poses a serious constraint to crop production in the NEAZDP area. Simple, easy and cheap ways of water conservation that can be adopted by the local farmers should be sought.

One of the ways to improve the supply of water for crop production in the North East Arid Zone is by conserving and efficiently utilising the limited available water supply (precipitation). In areas with similar soil and climate characteristics to the North East Arid Zone, water conservation has been shown to be successful. For example, stone terraces, pitting and planting pits (*tassa*), have been used in Burkina Faso, Mali, and Kenya to grow crops like sorghum, millet and maize (Roose, 1990; IFAD, 1991; Ayers, 1989; Simiyu, *et al.*, 1992). However, water conservation techniques will only show a benefit if the soil is able to hold the extra water within the root zone of the crops. Where the available water capacity of the soil is low, or the rainfall events are closely spaced, encouraging extra infiltration may only result in increased drainage losses. This paper seeks to use agro-climatic model (PARCH) to evaluate the potential benefit of water conservation for maximum utilisation of rainfall in upland pearl millet production systems in the NEAZDP area.

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2. An overview of the PARCH model

The model has the acronym PARCH (Predicting Arable Resource Capture in Hostile environments) because it has been developed for applications in the dry tropics. The PARCH model (Bradley and Crout, 1993) is used for predicting the growth of crops in semi-arid areas in response to environmental influences. It considers the effects of solar radiation, atmospheric humidity, temperature, soil water availability and nutrition on crop growth and development. The model uses a multi-layer water balance to simulate vertical redistribution of soil water, infiltration, drainage and soil evaporation on a daily time step and converts intercepted available light and extracted water into assimilated dry matter. Depending upon the availability of these resources and the crop's ability to intercept them, its growth is considered as either light or water 'limited'. Partitioning of resources between crop organs is calculated by empirically derived fractions which are adjusted according to growth stage and level of stress. Full details of the model are given in the PARCH Technical Manual.

PARCH requires four sets of input data to predict crop growth and yield. These relate to the climate, soil, crop and management practices. For the climate, the model requires daily data on maximum and minimum temperature, solar radiation, saturation deficit, rainfall and pan evaporation. The minimum soil specific inputs are fractions of silt, clay and sand, soil strength, soil depth and starting water content. For the crop, the major requirements are cultivar type and planting parameters (planting density and sowing date). The management practices can be represented using the interventions menu. Here, soil evaporation can be reduced by a given percentage, while runoff can be captured or lost above a given magnitude of rainfall.

As the model works through the season, an animated graphical simulation of the crop growth and water balance is shown. The output given by the model include final grain yield, above ground dry weight, transpiration and evaporation.

3. Methodology

Annual rainfall data were collected for the period 1960 - 1992 for the meteorological station at Nguru (12.53°N, 10.28°E, alt. 343 m). Six years were selected corresponding to typical wet (20% probability of exceedance), average (50%) and dry (80%) years. For each of these years, the daily rainfall for period 1 June - 31 October was used. As daily data for the other meteorological parameters were not always available, monthly means were replicated for each day of the month. Solar radiation was estimated from recorded sunshine duration, latitude and date using empirical coefficients for Maiduguri, Nigeria (Grema and Hess, 1994).

Soil physical data were selected from literature and local observation to represent a typical upland fine sandy loam soil. Although the PARCH model has default data for a millet crop, some of the cultivar parameters were modified to reflect the characteristics of the local landrace (*ex-Borno*) following discussions with local agronomists (A K Grema, personal communication). The soil and cultivar parameters were validated against soil water and grain yield data from Maiduguri in 1992 (Grema and Hess, 1994) and the agreement was good. For each year of the simulation, the soil was taken to be at permanent wilting point on 1 June and planting at 30,000 plants per hectare was assumed to take place at the onset of the rainy season (as defined by Stern *et al.,* 1982).

The PARCH model allows the simulation of runoff control and water harvesting by varying the fraction of rainfall, above a given threshold, that infiltrates into the soil. For each year, the model was run with runoff varying from -50% (i.e. half of the rainfall is lost to runoff) to +50% (i.e. runoff harvesting (runon) results in infiltration equal to one and a half times the rainfall) at intervals of 10%. Crop yield and soil water responses were monitored and analysed.

4. Results and discussion

Table 1 shows the annual rainfall and predicted planting dates for the six years chosen.

Table 1: Annual rainfall and predicted planting dates for selected wet, average and dry years for Nguru

Type	Year	Annual Rainfall (mm)	Planting Date
Wet	1975	557	1 July
	1965	563	10 June
Average	1971	446	7 July
	1976	431	13 July
Dry	1984	332	11 July
	1989	339	14 July

4.1 Grain yield predictions

Figure 1 shows the predicted yield response obtained for different runoff / runon percentages in each of the years. In all years there was a decrease in yield with increasing runoff. If a figure of 20% is taken as the typical runoff from farmed uplands, then the results suggest that eliminating runoff would result in yield increases of between 45% in wet years and 100% in dry years (Table 2). Similarly, Table 3 shows the predicted benefit of runoff harvesting assuming that infiltration could be increased to 150% of rainfall.

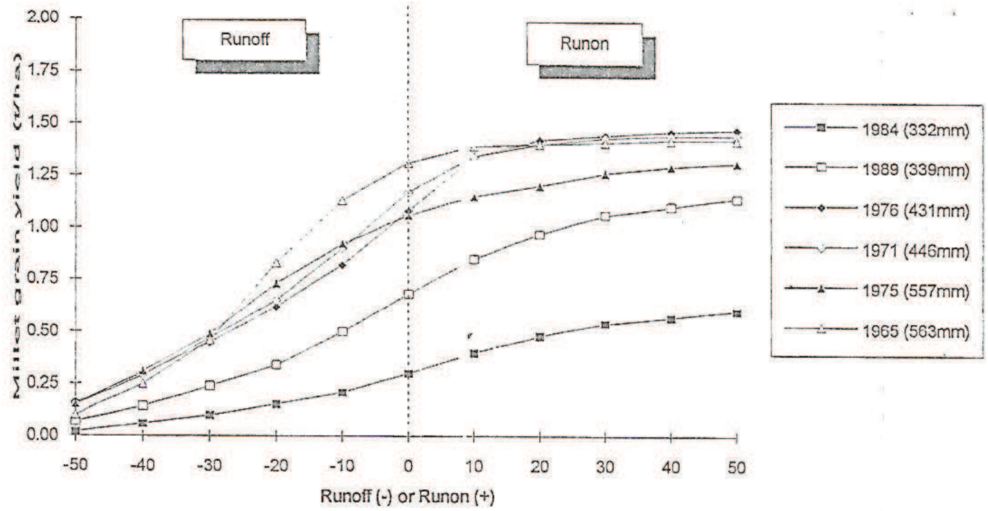

Figure 1: Predicted millet grain yield response to runoff control and water harvesting

Table 2. Predicted millet grain yield (t ha^{-1}) and relative benefit of reducing runoff from 20% to zero in wet, average and dry years

	Wet		Average		Dry	
Year	1965	1975	1971	1976	1984	1989
20% runoff	0.83	0.73	0.65	0.62	0.15	0.34
Zero runoff	1.31	1.06	1.17	1.08	0.30	0.68
Benefit	58%	45%	80%	74%	100%	100%

Table 3: Predicted millet grain yield (t ha^{-1}) and relative benefit of runoff harvesting in wet, average and dry years

	Wet		Average		Dry	
Year	1965	1975	1971	1976	1984	1989
Zero runoff	1.31	1.06	1.17	1.08	0.30	0.68
50% runon	1.42	1.31	1.44	1.47	0.60	1.14
Benefit	8%	24%	23%	36%	100%	68%

4.2 Soil water storage and drainage

Figure 2 shows the seasonal variation in the water content of the root zone under conditions of 20% runoff, zero runoff and 50% runon in a wet and a dry year. It can be clearly seen that whilst runoff harvesting has a positive effect on stored soil water in both years, it also results in the soil being above field capacity water content for much of the season. This is particularly true in the wet year when most of the extra water harvested will move down the soil profile and be lost to drainage.

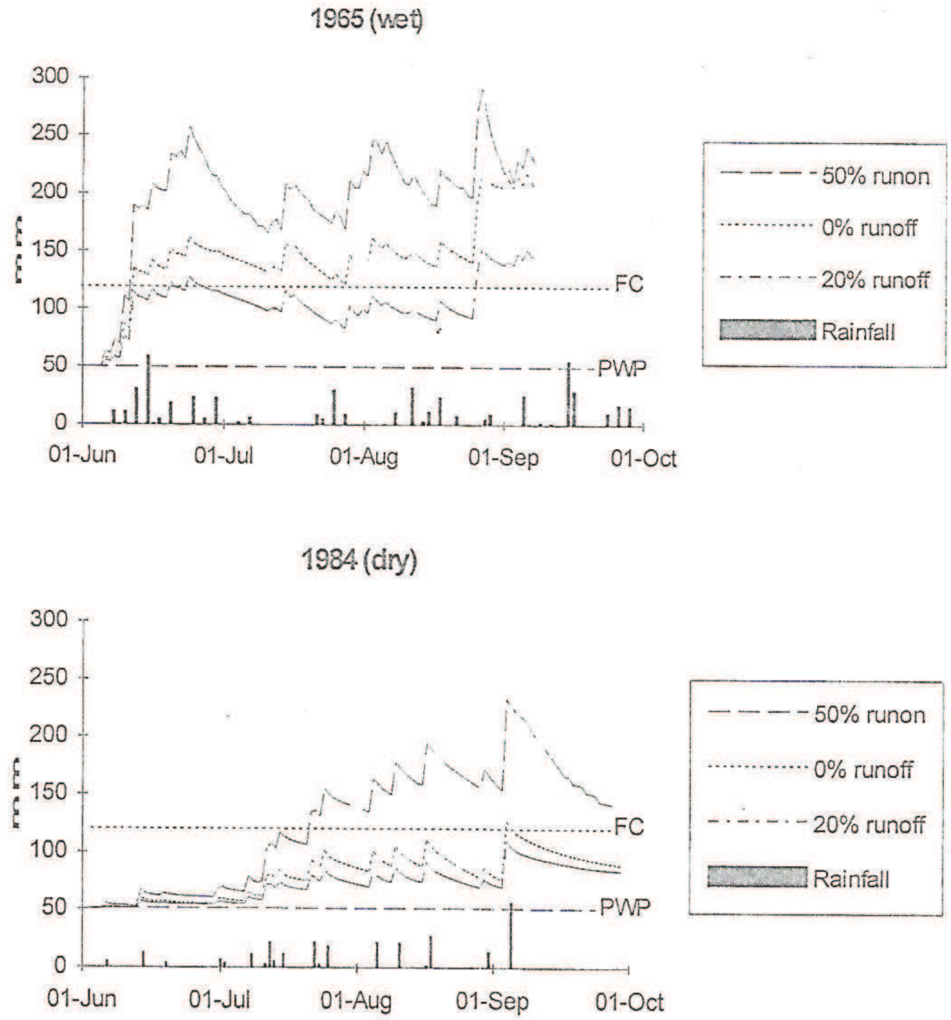

Figure 2: Predicted seasonal variation in soil water content with varying levels of runoff for a wet and a dry year showing field capacity (FC) and permanent wilting point (PWP) water contents and rainfall

5. Conclusion

The simulation has shown that for millet grown on light soils in the uplands of the North East Arid Zone, where there is presently runoff occurring, there is likely to be a benefit from runoff control measures (such as contour ploughing and tied-ridging) in all years irrespective of annual rainfall. In the drier years this could result in yield increases, which although small in absolute terms, would be equivalent to a doubling of the cropped area. The curves of grain yield response to runoff, however, flatten markedly when considering runoff harvesting in excess of 10% of rainfall as excess water cannot be held in the soil profile, resulting in increased drainage losses. Given that runoff harvesting also requires the runoff area to be left unplanted, it is unlikely that it would be a worthwhile technology for upland farming systems in the region in the future as the demand for land will increase due to increase in population.

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