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BY

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ORGANIZATION OF REPORT:

This is the final report of work for the 1984. The report has been organized such that it gives the strategy of research adopted and the justification as to why the reported work is being carried out. Then based on this suggested strategy and taking into consideration the limited financial resources made available to me by EMBRAPA and the very little field assistance available, the following research projects were approved for execution:

1. Runoff inducement for supplemental irrigation and soil conservation under alternate micro watershed management strategies.
2. Water Production function of major dry land crops of NE Brazil for establishing timing and quantity of supplemental irrigation projects.
3. Optimization of small reservoir systems for minimizing investments in small irrigation projects and maximizing the benefits from such systems.
4. To search and evaluate various locally available cheap seepage control materials for reducing seepage losses from existing or future small reservoir irrigation projects so that full benefit of these systems can be achieved.

In writing this report I have utilized the various papers that were published by me during the period of report. In addition upto date results have been provided where addtional results are available.

In the end of the report a brief summary of training and diffusion activities has also been provided. It should be noted that EMBRAPA has exclusively tried to use my services for research work at its headquarters in Petrolina.

CHAPTER I

RESEARCH STRATEGY FOR THE IMPROVEMENT OF LAND AND WATER RESOURCES OF THE SEMI-ARID TROPICS OF NORTH-EAST BRAZIL*

PREM N. SHARMA**
E. R. PORTO***

1. INTRODUCTION:

The semi-arid tropics (SAT) of the world are fragile ecosystems which are being substantially modified by the activities of mankind. Increasing human populations have resulted in greater demand on semi-arid regions for providing human substance and the possibility that this may enhance desertification is a grave concern (Hall et al, 1979). These zones are harsh habitats for humans. Water is the single most important natural constraint to agricultural production and human welfare in these regions. However, human tragedy of the drought in North-East Brazil is due as much to the social and economic organization of the region as to climatic vicissitudes (Hall, 1978). When feasible, irrigation by imported water could be used to increase and stablize agricultural production of these regions. However, because of very limited availability of the surface and ground water resources,

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majority of the areas in the semi-arid tropics will continue to depend on direct rainfall for agriculture and livestock, for example, in the North-East Brazil, except for São Francisco and the Parnaiba river basins, opportunities for irrigated agriculture are limited in extent. In addition, traditional irrigation, so far has not been able to make any dent in solving the problem for a vast majority of populance due to a variety of socio-economic and political reasons (Hall, 1978).

The climate of semi-arid tropics (SAT) is characterized by limited, erratic and undependable distribution of rainfall. In North-East Brazil, sometimes a whole year may pass without rain in certain locations. When the rains do occur, the whole year's precipitation may fall in 4 to 5 days. Although the rainy season in normally during the high sun period, any month may have downpours or be completely dry. Variations within a given month of from 0.00 to as much as 1335 mm have been recorded (Hargreaves, 1974). The situation is further exaggerated by poor soil resources and their poor distribuition in this regions.

Bowden (1974) claims that the original vegetation has been perhaps clearad several times in the last 400 years in North-East Brazil, often by 'slash and burn' techniques, which has reduced humus levels and left the soil more infertile. This has also resulted in accelerated erosion leaving soils with cropped rocks and gulley formations in the upper reaches of watersheds. This can be confirmed by visiting already cleared lands. Thus better management of water and soil resources is of paramount importance to the North-East region of Brazil. This region has wide variations in its climate, soils and socio-economic status of its population hence any technology that is to be developed or recommended should suit its variable needs. In the following sections a brief description of climate, soils and socio-economic conditions of the North-East region is included. Based on this, priorities for research in the area of land and water management and supplemental irrigation are developed.

2. CLIMATE:

A detailed analysis of the climate of North-East Brazil have been reported by Hargreaves (1973). He has delineated the North-East Brazil into various zones as very arid, arid, semi-arid and wet-dry (Fig. 1) based on moisture availability indices* (MAI) as following (Hargreaves, 1974):

CRITERIA	CLIMATIC CLASSIFICATION	REMARKS
All months with MAI in the range of 0.00 to 0.33	Very arid	Very low rainfall zones
One or two months with MAI of 0.34 or above	Arid	Low rainfall zones
There or four consecutive months with MAI of 0.34 or above	Semi-Arid	Medium rainfall zones
Five or more consecutive months with MAI of 0.34 or above	Wet-dry	High rainfall zones

The Wet-Dry areas are out of the scope of this report. The very arid zones are areas of very low rainfall and in general not suited for rainfed agriculture but water can be harvested for livestock use/or very limited agriculture. The arid zones, are areas receiving 500 to 750 mm rainfall and

*Moisture Availability index defined as ratio of amount of monthly rainfall at 75% probability level (PD) with the amount of monthly potential evapotranspiration (PET).

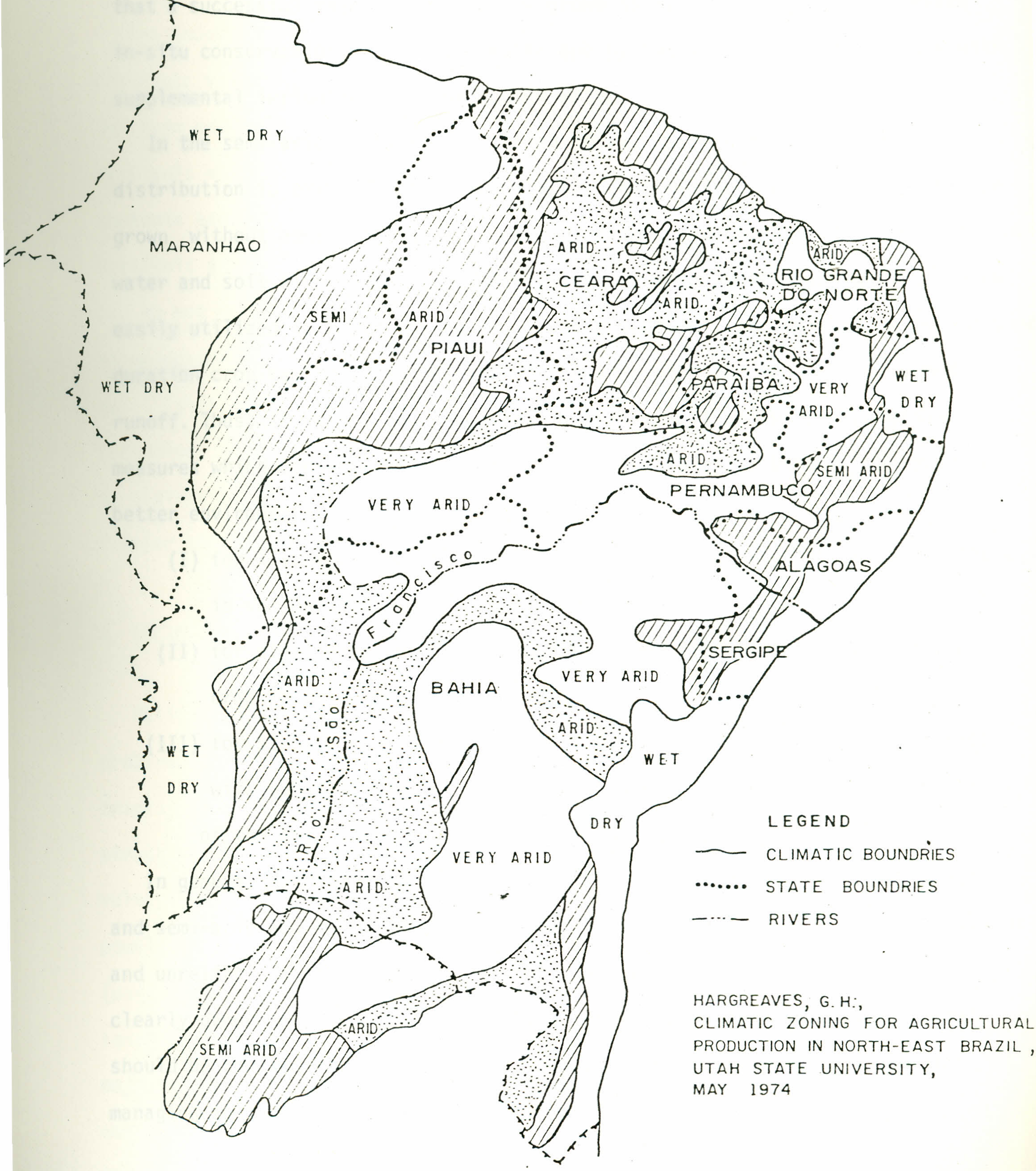

FIGURE. 1 CLIMATIC CLASSIFICATION FOR NORTH-EAST BRAZIL.

have limited suitablity for rainfed agriculture. It is this author's belief that a successful rainfed crop can be grown in many years with appropriate in-situ conservation of soil and water and by backing up the agriculture with supplemental irrigation from harvested water.

In the semi-arid areas as classified above, more rainfall with better distribution is expected and appropriately chosen short duration crops can be grown without additional water. However, proper management and conservation of water and soil along with water harvesting for supplemental irrigation can be easily utilized to boost the agricultural production. In addition, a second short duration crop may be grown on part of the area with the help of collected runoff. Thus, it can be concluded that suitable soil and water management measures which conserve and utilize the limited rainfall better, can provide better environment;

(I) for livestock and fodder production and some very limited agriculture in very arid zones

(II) for stablizing and increasing the production of one short duration crop in arid zones, and

(III) for stablizing and increasing production of one short duration crop with possibilities of producing another short duration crop in part of the area of a catchment in semi-arid zones.

In general descripitions, all these zones classified as very arid, arid and semi-arid are referred to as semi-arid tropics due to similarity in erratic and unreliable distribution of rainfall. But as the climatic classification clearly demonstrates, the capability of each zone varies. Hence these zones should be treated separately for the purpose of developing techniques for managing their soil and water resources.

3. SOILS:

The important soils of North-East Brazil (in SAT region) consist of Planosols solodized, Non Calcic Brown Soils, Solonetz, Vertisols, Latosols and some Regosols (Dematte, 1981). The Planosols Solidized, Solonets Solidized, Vertisols and Non Calcic Brown soils are poor in drainage due to higher clay contents and presence of higher quantities of exchangable sodium (except in Vertisols & Non Calcic Brown Soils). Latosols & Regosols are relatively sandy and do not pose any drainage problems. Thus it can be inferred that problems of management of soil and water for better utilization, are of different nature on different type of soils. However, it can be anticipated that a technology (for soil & Water management), developed for a given soil type with in a given climatic classification can be approximately duplicated on areas of similar soils within same climatic zones (Hargreaves, 1974).

4. SOCIO-ECONOMIC CONDITIONS

Hall (1978) has successfully argued and demonstrated that the 'drought problem' in North-East Brazil is not only a climatic problem. The human tragedy of the drought is a direct result of the way in which the rural structure of the Sertão places thousands of peasants at the economic margin, vulnerable to even the slightest climatic vicissitude. The majority of population directly effected by the climatic vicissitudes are the sharecroppers (parceiros), small holders (minifundistas), tenant farmers (arrendatários) squatters (ocupantes) and wagelabourers (assalariados or diaristas). At best, majority of these people are primarily subsistance farmers in the sense that most of their produce is consumed by the farmer and his family rather than entering the market. In table 1, which is based on the Brazilian Census division (IBGE) study, 1970, breakdown of rural properties into size

Table 1: Distribution of landholdings, sertão, 1970.

States	Size of landholdings (ha): 0-1.9 N	0-1.9 A	2-9.9 N	2-9.9 A	10-99.9 N	10-99.9 A	100-999.9 N	100-999.9 A	1,000+ N	1,000+ A	Total N	Total A
Pernambuco	15.91	0.50	41.89	5.46	34.98	31.03	6.91	46.03	0.31	16.98	100	100
Paraība	9.90	0.30	42.62	5.46	40.32	31.16	6.70	29.91	0.46	33.17	100	100
R.G. do Norte	16.39	0.26	34.06	3.03	39.50	21.24	9.24	43.43	0.27	32.04	100	100
Ceară	9.24	0.19	36.71	3.41	40.78	27.16	9.62	44.23	3.65	25.01	100	100
Piauī	44.25	0.98	25.69	2.41	21.91	18.18	7.08	43.20	1.07	34.16	100	100
Bahia	22.00	0.95	42.79	7.98	30.79	36.13	4.22	40.29	0.20	14.65	100	100
Sergipe	19.43	0.38	26.24	2.78	45.57	31.84	8.38	42.96	0.38	22.04	100	100
Alagoas	39.24	2.14	34.89	9.30	22.78	36.70	2.91	38.97	0.18	12.89	100	100
TOTAL SERTÃO	22.24	0.54	35.88	4.07	32.28	26.33	7.27	43.56	1.33	25.50	100	100

Source: IBGE, Agricultural Census, 1970 (Quoted from Hall, 1978).

Notes: N = % of rural establishments

A = % of area covered

categories for the "Sertão" as for 1970, is given. It shows that 58% of holdings are under 10 hectares and occupy less then 5% of the total area. At the other end of the scale, properties of over 100 hectares account for only 8% of the total number but cover 69% of area. (These figures have later been further confirmed by independent studies of selected areas). The 1970 study also suggests that the real income of properties below 25 hectares suffered most during the drought. Holdings of between 25 and 1000 hectares, on the other hand, seemed to be least affected. Thus the land ownership in the interior is very heavily skewed and smaller a farmer more his vulnerability. The vulnerability of particular groups to the drought is a direct product of the landownership structure in the Sertão and the system of tenancy relationships which has grown up around it. The commercializable rural surplus (cattle, cotton and some staple foods) is extracted by a relatively small minority of large and medium-size landowners as well as a variety of merchants or middlemen, while a large part of the poorer population remain dependent on a precarious, largely subsistence agriculture susceptible to minor reductions in rainfall (Hall, 1978).

One of the major conclusion that can be drawn from the thesis of Hall (1978) is that a better redistribution of rural property in the "Sertão" of North-East Brazil will bring a stablizing effect for the majority of the population. For similar reasons many developing countries are infact already taking up redistribution programs. But since redistribution is a socio-political issue it is being presumed for the purpose of this paper that existing land ownership structure will continue for a long time. However, in the present context, if any resource development is to bring any visible effect on solving the problems of the majority of rural populations, it should expressly be directed towards small farmers holding less then 25 hectares of land. Since resource development work is done on natural catchment units, from here it follows that a mini-catchment should be taken as a unit of development.

5. THE APROACH TO DEVELOPING A TECHNOLOGY FOR MANAGMENT OF WATER & SOIL RESOURCES IN NORTH-EAST BRAZIL:

The goal of any proposed technology for managment of soil, water and crop system is to achieve a highest possible water utilization efficiency (WUE) by conserving and utilizing the water and soil resources for highest beneficial use. This aim is to be achieved in collaboration with nature rather than by disturbingor destroying the natural ecosystem. The movement of water follows soil topography in a watershed (Or catchment). The socio-economic conditions of the North-East dictate that the small farmer should be the target of development. Thus, a small watershed or a mini-catchment becomes the natural unit for developing the soil and water resources. This concept has been amply demonstrated at ICRISAT where the first author alongwith Drs. Krantz and Kampen has the credit of developing a small watershed based technology for managing soil and water resources of Vertisols (Sharma and Kampen, 1975, Sharma and Kampen, 1976, Sharma and Kampen, 1977, and Krantz and Kampen, 1978). The recent work of the author on optimization of small reservoir irrigation System for Semi-Arid Tropics (Sharma, 1981), also very clearly demonstrates that a small watershed should be chosen as unit of development of soil and water resources, if optimum benefits of the system are to be achieved. The recent work carried out at CPATSA (Silva and Porto, 1982) in last 3 years has generated some lead data base for such an approach and shall prove useful in generating an integrated technology for soil and water management and supplemental irrigation systems in North-East Brazil.

CPATSA is located in a very arid zone (Petrolina) according to Hargreave's (1974) classification. Thus it becomes responsible for developing a range of technologies to serve very arid, arid as well as semi-arid zones in North-East Brazil. It should be pointed out here that technologies developed for a particular zone (and a particular soil type) can not be transferred in total to other zones. Similarly efforts at transferring technologies for management of soil and water from other countries with disregard to the conditions of N-E Brazil will prove futile. The approach should be to adapt and modify the available technologies to suit the needs of North-East Brazil without compromising on the principles and concepts.

It is concluded from the above discussion that approach to generating an integrated technology for soil and water management and supplemental irrigation should be:

(1) A small watershed is to be taken as a unit of planning and development of soil and water resources.

(2) The research on development of a technology for soil and water management & utilization should be conducted at atleast 3 locations, namely:

(a) in very arid zones

(b) in arid zones, and

(c) in semi-arid zones

This is to be done in the most predominent soil type of a zone in collaboration with the State agencies and other local agencies.

(3) The development of a technology should be in an integrated manner rather than in components. This should result in development of appropriate models of the proposed systems to facilitate fast transfer of the technology.

(4) After the technology has been developed at research stage; it should be tested at a pilot project stage at operational scale at a number of locations among small farmers before it can be recomended for use, and before heavy investments are made in transfering and executing the technology at farmers level.

Keeping the above discussion in mind, a summary of recent research and findings for management of land and water resources under semi-arid environments is presented first and then some specific research priorites in the area of supplemental irrigation and soil and water resource development, are presented.

6. A BRIEF REVIEW OF RECENT RESEARCH:

CPATSA is located in a very arid area receiving only about 400 mm rainfall. Based on one of the crop water simulation models (Porto et al, 1982), which quantifies the risk involved in rainfed agriculture, it is estimated that the chances of growing a successful crop at Petrolina (PE) are only 10%. Even at a place like Jaicos (PI) which receives an average of 700 mm rainfall, the chances of growing a successfull crop do not exceed 60%. The viability of life saving or supplemental irrigation is by now well estabilished in many semi-arid regions to reduce the risk involved in rainfed agriculture. At CPATSA recent experiences also show how excess runoff can be used to raise crops in limited area even in very arid conditions like that at Petrolina. (Silva et al, 1981). The major questions still to be resolved are related to optimization of small reservoir systems which is also a topic of another paper (Sharma and Helweg, 1982) in this symposium and has been earlier reported by Sharma (1981).

Some of the recent lead work on resource development under semi-arid conditions have been carried out at ICRISAT (India). ICRISAT has tried a system of broad bed and furrows along with drainage ways and graded terraces for soil conservation and better rainfall utilization. However while this system performed very well on medium and deep Vertisols, it was not effective on Alfisols. Also its viability under very arid conditions has never been confirmed. This demonstrates that the techniques of managing soil and Water resources may be different under different soil and climatic conditions.

The following section deals with the priorites in research which should be soon carried out for North-East Brazil in order to make a strong foundation for future supplemental irrigation and land and water resource development projects.

The first proposal is on optimization of small reservoir irrigation system and the second proposal is on development of an appropriate technology for management of soil and water resources in various zones in N-E Brazil. The third research proposal is for defining appropriate water production functions for important dry land crops under high uncertainity. The fourth and final project proposal deals with the rainfall-runoff relationships for small watersheds. The last two projects (third and fourth) are basic in nature. This basic information is needed for planning and designing any land and water resources development works.

5.1. RESEARCH PROPOSAL I:

TITLE: OPTIMIZATION OF SMALL RESERVOIR SUPPLEMENTAL IRRIGATION SYSTEM FOR THE NORTH-EAST BRAZILIAN REGION:

OBJECTIVE:

To develop methods for making better use of the existing system of small reservoirs and to develop a model for optimization of small reservoir supplemental irrigation system for stabilizing and increasing the agricultural production of the North-East Brazilian Region.

SPECIFIC OBJECTIVES:

1. Improvement of existing system of small reservoirs:

(a) To study the hydrologic water balance of a few representative existing small reservoirs in three distinctly different agroclimatic zones of semi-arid tropics of North-East Brazil. The three distinct areas should be in the very arid, arid and semi-arid zones of the North-East Brazil.

(b) To adopt, modify and to develop methods for improving the water utilization efficacy for agricultural production and/Or livestock of the existing small reservoirs in various zones of the Semi-Arid Brazil.

(c) To test and demonstrate the developed methods under on-farm conditions at a few representative locations in North-East Brazil and develop detailed guidelines for use of the execution agencies for modification of the existing small reservoirs such that these reservoirs can be converted into productive agricultual systems.

2. Development of an optimization model for small reservoir systems on small watershed basis:

(a) To adapt and/or develop a generalized mathematical model for optimization of storage capacity, location and design of small reservoir (also called farm ponds or tanks) systems for supplemental irrigation by maximizing net benefits and water use efficiency, and by minimizing investment associated seepage and evaporation losses, and land occupied by the reservoir. This model should become a tool to provide general guidelines for planning of small reservoir water resources systems in the North-East region of Brazil.

(b) To search, gather and develop the input data needs of the proposed model for a no. of representative locations in N-E Brazil which will be required by the model to be useful as a guiding technique in aiding water resources planning of the proposed region for rainfed agriculture.

The important data needs are rainfall-runoff relations for various zones in North-East Brazil, water production function of various crops grown in the region, cost of excavation as related to lift and lead (cost functions), agroclimatic data e.g. evaporation & seepage rates of various zones in the region, watershed contour maps, information on agricultural input & operations cost for crop production, and knowledge of market conditions of the region.

(c) To test and search locally available cheap seepage and evaporation control materials and methods for controlling seepage and evaporation losses in small reservoirs which in turn will increase the water use efficiency of the small reservoir irrigation systems.

(d) To test the model results under research station & later under on-farm conditions to establish the viability of the model and develop generalized guidelines for the development of small reservoir systems in North-East Brazil.

5.2. RESEARCH PROPOSAL II

TITLE: DEVELOPMENT OF SUITABLE LAND & WATER MANAGEMENT TECHNOLOGY FOR VARIOUS ZONES IN THE SEMI ARID TROPICS OF NORTH-EAST BRAZIL.

OBJECTIVE: Adaptation and Development of suitable technologies for better management and utilization of the water & soil resources in the semi-arid tropics (SAT) in N-E Brazil for stabilizing and increasing the agricultural production of the region on small watershed basis.

SPECIFIC OBJECTIVES:

1. FOR VERY ARID ZONES

(a) To establish a technology for soil conservation in already cleared areas.

(b) To evaluate & develop runoff inducement systems for increasing the available runoff yield from a catchment for water harvesting.

(c) To select and establish appropriate technology for conservation of soil & water and for facilitating supplemental irrigation on the down stream areas of small reservoirs to stablize & increase agricultural production (and/or livestock).

2. FOR ARID ZONES:

To adopt and develop technology for conservation of soil & water on a watershed to stablize and increase agricultural production. The approach here will differ from the approach in (1). Here the major emphasis will be on in-situ conservation of water and soil and suitable arrangement for supplemental irrigation.

3. FOR SEMI-ARID ZONES:

To develop a land & water management technology for soil & water conservation and appropriate surface drainage to create an optimum environment for plant growth for increasing and stablizing the agricultural production of these zones. Here the emphasis will be on in-situ moisture and soil conservation, appropriate surface drainage & supplemental irrigation.

5.3. RESEARCH PROPOSAL III

TITLE: WATER PRODUCTION FUNCTIONS OF IMPORTANT DRYLAND CROPS FOR NORTH-EAST BRAZIL.

OBJECTIVE:

To develop water production function which relate yield, quantity of water and growth stages of important dry land crops of North-East Brazil under high uncertainity.

SPECIFIC OBJECTIVES:

(1) To develop generalized water production functions relating yield and quantity of water use (evapotranspiration) for important dry land crops of North-East Brazil.

(2) To establish the relative yield deficits as effected by relative evapotranspiration deficits at different important crop growth stages for important dry land crops of North-East Brazil.

(3) To establish a criterion for timing and quantity for supplemental irrigation as well as full irrigation projects in North-East Brazil.

(4) To develop a model for minimizing the inherent uncertainities in water production function.

5.4. RESEARCH PROPOSAL IV

TITLE: HYDROLOGY OF SMALL WATERSHEDS

OBJECTIVE: To develop suitable models for predicting runoff under alternate management practices for small watersheds.

SPECIFIC OBJECTIVES:

1. To develop rainfall-runoff relationship under native cattinga conditions for important soil types.

2. To develop rainfall-runoff relationship for cleared lands for important soil types.

3. To develop rainfall-runoff relationship for cleared lands with alternate soil and water conservation practices on important soil types.

6. CONCLUSIONS:

1. The soil and water are national resources. Appropriate development and optimum utilization of these resources will result in the welfare of small farmers in general. These are the farmers which are badly hit by the vagaries of rain. The small wateshed based approach suits the small farmer's requirements.

2. The information which will be generated by research proposals developed here is essential for the development of soil and water resources. Hence these projects should be carried out by CPATSA (EMBRAPA) as a priority.

3. An integrated approach to the solution of the problems of water & soil management can bring visible benefits to the small farmers by increasing and stablizing their agricultural (including livestock) production.

4. To develop technology for management of soil and water resources in N-E Brazil, the technology development research should be carried out in most representative soils of at least the three suggested (very arid, arid & semi-arid) zones in collaboration with state agencies. This will ensure appropriate technology for the whole of North-East Brazil.

5. After a technology has been developed it should be tested at Pilot project scale where selected farmers participate in the adaptation of the developed technology. Only after successful pilot project level testing, it should be recommended for general use.

Research Proposals Now Being Executed:

Based on the financial resources made available by EMBRAPA and the limited technical and field assistance available, the following research projects are being executed:

1- Runoff inducement for Supplemental irrigation on micro watershed basis and soil conservation under alternate management treatments

2- Water Production Function of major dry land crops of NE Brazil

3- Optimization of small reservoir irrigation systems for NE Brazil

4- Seepage control methods for small reservoir systems in NE Brazil

The following chapters give a report of work carried out on these projects.

CHAPTER II

RUNOFF INDUCEMENT FOR AGRICULTURE IN VERY ARID ZONES OF THE NORTHEAST OF BRAZIL[1]

PREM N. SHARMA[2], FAUSTINO B.ALONSO NETO[3], EVERALDO R. PORTO[4] and ADERALDO DE S. SILVA[4]

ABSTRACT - The concept of runoff inducement for agricultural purposes is discussed in detail. Its implications to the Northeast Brazilian conditions and necessity for additional research is explained. An exaustive review of the research at various places in the world is included. The latest work being carried out at the Centro Nacional de Pesquisa do Trópico Semi-Árido (CPATSA/EMBRAPA) (Center of Agricultural Research for Semi-Arid Tropics) is explained in detail. This work included development of eight small watersheds varying in size from 1.0 ha. to 2.7 ha. for hydrologic evaluation of various simple low cost runoff inducement methods under natural "caatinga" conditions on shallow to medium deep Latossols. The various methods of runoff inducement include combinations of intensified grassed waterways, strip clearing of caatinga, narrow based channel terraces (or graded bunds) for soil conservation, salt treatment on cleared strips and complete clearing of caatinga with grass cover.

Index terms: water harvesting, small watershed hydrology, caatinga forest management.

INDUÇÃO DE ESCOAMENTO SUPERFICIAL COM FINS AGRÍCOLAS PARA AS ZONAS MUITO ÁRIDAS DO NORDESTE DO BRASIL

RESUMO - Discutem-se, em detalhes, os conceitos de indução do escoamento superficial de água de chuva com fins agrícolas e são explicadas suas implicações para o Nordeste do Brasil e a necessidade de pesquisas adicionais. Inclui-se uma revisão exaustiva das pesquisas em vários países. É apresentado o trabalho mais recente atualmente conduzido no Centro de Pesquisa Agropecuária do Trópico Semi-Árido (CPATSA/EMBRAPA). Este trabalho inclui a criação de oito pequenas bacias hidrográficas variando de 1,0 ha a 2,7 ha, para a avaliação hidrológica de métodos simples e de baixo custo de indução do escoamento superficial da água de chuva em condições de caatinga natural e de latossolos rasos a medianamente profundos. Os vários métodos estudados incluem a combinação de linhas de drenagens como gramíneas, faixas desmatadas das caatingas, terraceamento, tratamentos com sal, total desmatamento e cobertura com gramíneas.

Termos para indexação: captação de água de chuva, hidrologia de pequenas bacias, manejo de "caatinga".

INTRODUCTION

Water harvesting has been practiced in the arid and semi-arid regions of many countries for centuries. Mention of tank irrigation systems can be found in historic books that are thousands of years old in India (Oppen & Subba Rao 1980). These tanks were built by throwing a dyke across a valley thus catching water from upstream catchments. Evenari et al. (1971) have described water harvesting systems in the Negev desert of Israel, which are thought to have been built about 4,000 years ago. These systems involved clearing hillsides to smooth the soil and increase runoff which is guided by contour ditches to lower fields for raising irrigated crops. Cisterns have been used to harvest water from roof tops in Brazil for drinking water supply for a long time. A brief history of water harvesting has been given by Myers (1975). During the past 25 years, water harvesting has been receiving renewed attention. A brief review of rain water harvesting was recently presented by Boers & Ben-Asher (1982).

Water harvesting was first defined by Geddes (1963) as, "the collection and storage of any farm waters for irrigation use". Myers (1975) defined water harvesting as, "the practice of collecting water from an area treated to increase runoff from rainfall and snowmelt". Currier (1973) generalized

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the definition as, "the process of collecting natural precipitation from prepared watersheds for beneficial use". These definitions show that water harvesting encompasses methods to induce, collect and store runoff from various sources and for various purposes. This paper deals specifically with the runoff inducement aspect of water harvesting only. The objective is to present a detailed review of various methods of runoff inducement, discuss their applicability to Northeast Brazilian arid zones and make a report of the recent work that is now being carried out at the Centro Nacional de Pesquisa do Trópico Semi-Árido (CPATSA/EMBRAPA) at Petrolina, Brazil, for the arid zones of the Northeast of Brazil.

REVIEW OF RUNOFF INDUCEMENT METHODS

The success of a water harvesting system depends mainly on the runoff efficiency of a catchment which can be defined as the runoff produced per unit of precipitation on a given piece of land. The runoff efficiency of a runoff inducement method depends on land factors like vegetal cover interception, depression storage on land, infiltration rate of soil, antecedent soil moisture and precipitation factors like threshold quantity of precipitation, its intensity, amount and duration. Since manipulation of precipitation is a very difficult process, most runoff inducement methods are different ways and means of manipulating and modifying the land surface. These methods can be divided into the following two categories: vegetation management, and land surface management.

Vegetation Management

In general vegetation clearing and soil surface conditions can have more influence on infiltration rate than do the soil type and texture (Frevert et al. 1955). When vegetation is removed the fine soil particles that are detached due to rain drop impact help seal the surface which results in reduced infiltration and increased runoff. The effect of vegetation clearence on runoff efficiency has been summarized in Table 1 for a few locations. The sources of data are also shown.

In an experiment on small runoff plots on Oxisols (Latossols) at Petrolina, Brazil, the annual runoff was increased from 8% to 24% of annual rainfall by removing the native caatinga, under well drained conditions (Silva & Porto 1982). At ICRISAT, India (International Crops Research Institute For Semi-Arid Tropics 1977), the annual runoff was 33.5% of annual rainfall on bare Vertisol watershed as compared to 10.2% on a similar watershed with native vegetation. Similarly in the Negev desert (Migda location) of Israel on deep sandy loess loamy soils the runoff efficiency was increased from 7% to 21% by removing native vegetation only. Similar findings have been reported by Frazier (1975) for Phoenix, Arizona. These results clearly demonstrate that runoff efficiency can easily be increased up to 3 times just by vegetation clearing. However, soil erosion also increases after vegetation clearance. Hence this method should invariably be accompanied by appropriate soil conservation methods. The method is one of the cheapest ways of inducing runoff. The efficiency can further be increased if this method is combined with some land treatment.

Land surface management

The land surface management treatments can be classified into two types. Those that involve mechanical treatment of land surface only like stripping, leveling, smoothing, stone clearing, compaction, inversion of soil and land surface configuration treatments. These methods increase runoff by reducing surface storage. The second category of land surface treatment includes chemical treatment of land surface which increases runoff by reducing infiltration rate. The chemical materials so far tried include sodium salts, petrolium products application, bitumen, paraffin, wax application etc. The two types of treatments can also be applied in conjunction. A detailed review of these methods is given below.

Mechanical treatments

Table 2 summarizes some of the results quoted from different sources showing the effect of different mechanical treatments on runoff efficiency. The runoff efficiency of similar treatment on different locations is difficult to be generalized because it depends on such factors as soil types, antecedent soil moisture, storm intensity, storm duration, catchment size and years after treatment (Frazier 1975).

Evenary et al. (1971) have demonstrated how the ancient farmers in Negev desert of Israel used the technique of clearing stones to increase runoff. The runoff was increased from 13.65% to 17.05% on treatment with stone mounds (an ancient practice) and to 22.06% when stones were completely removed and the surface was rolled after wetting. In western Australia roaded catchments were developed by their Public Works Department during 1949-52. The roaded catchments consist of 6 to 15 m wide roads made at a gradient and with side slopes of 1 in 8 to 1 in 12 (Laing 1981). The subsurface clay is inversed to provide a blanket on the surface of the roads. Thus roaded catchments increase runoff by reducing both surface storage and the infiltration rate. A typical cross section of a roaded catchment is shown in Fig. 1. The runoff efficiency of clay covered roaded catchments has been found to vary from as low as 9% to as high as 60% as shown in Table 2 (Burdass 1975, Laing & Prout 1975, Laing 1981).

In experiments with compacted earth catchments on sandy loam soils Cluff (1975) was able to obtain runoff efficiencies in the range of 30 to 60% (Table 2). Frazier

TABLE 1. Effect of vegetation clearing on runoff efficiency.

Location/Years of data (in Brackets)	Soil type	Watershed conditions	Runoff efficiency, %	Source of data
CPATSA/EMBRAPA, Petrolina, PE, Brazil (1981)	Oxisols (Latossols)	Native vegetation (about 50% by 2 year old Caatinga), small runoff plots, 2% slope	8.0	Silva & Porto (1982)
		Bare, small plots, 2% slope, well drained by ridges & furrows	24.0	
ICRISAT, Patancheru, A.P., India (1976)	Vertisols	Native vegetation (Dense tall grass), Small watersheds, Field bunds, 1-2.5% slope	10.2	International Crops Research Institute For Semi-Arid Tropics (1977)
		Cropped, small watershed, field bunds, 1-2,5% slope	10.3	
		Bare, field bunds, small watershed, 1-2.5% slope	33.5	
Migda, Breershada, (Negev Desert), Israel (1975-76)	Deep Sandy Loess Loams	Native Vegetation (60-80% cover by Herbaceous Annuals), Small runoff plots, 7.5% slope	7.0	Shanan & Tadmor (1979)
		Bare, 7.5% slope	21.0	
Granite Reef Test Site, Phoenix, Arizona, USA (1961-72)	Granite Reef Soils	Native vegetation	22.0	Frazier (1975)
		Bare (Similar slope for both but unknown)	32.0	

(1975) was able to increase runoff efficiency to 36% and 42% by smoothing and ridging respectively (Table 2) as compared to 32% on bare soils and 22% on catchments with native vegetation (Table 1). The above discussion implies that more runoff can be induced by various mechanical treatments on cleared lands. However, it involves additional costs of heavy earth moving machinery for land development.

Chemical treatments

By late sixties the emphasis started shifting to searching different hydrophobic materials (Myers & Frasier 1969) and chemical treatments including polyethylene, wax and asphalt which would reduce infiltration and increase runoff efficiency at low cost. A summary of the results of these searches is given in Table 3. In western Australia when the roaded catchments were treated with petrolium products (Petroset) and bitumen, 41.5% and 39% efficiency was obtained (Burdass 1975). However, in absence of appropriate experimentation it is not possible to compare these results with the results of roaded catchments in Table 2 as quoted from Burdass (1975). Laing & Prout's (1975) data gives a comparison for sandy soils in western Australia where bitumen emulsion primed and oil primed treatments increased runoff to 18.67% and 25% respectively as compared to 17% for clay covered treatments. Aldon & Springfield (1975) were able to increase the efficiency to 68% and 62% on Paraffin and Polyethylene treatments as compared to 28% for the control on silt loam soils at Santa Fe in New Mexico (USA).

Cluff (1975) compared compacted earth (Table 2), sodium treated compacted earth treatment, gravel covered plastic cover on soil surface and asphalt embedded plastic--chip coated cover on soil surface (Table 3), and obtained increasingly better efficiencies reaching to a range of 85% to 95% on the asphalt embedded plastic-chip coated treatment. However, application of gravel covered plastic or chip coated asphalt embedded plastic needs specialized machinery which might restrict the use on larger catchments in developing countries due to its availability

TABLE 2. Runoff efficiency of different mechanical treatments for land surface management.

Location/years of data (in Brackets)	Soil type	Treatments	Runoff efficiency, %	Source of data
Avdat (Negev Desert) Israel, (1966-67)	Shallow sandy Loess soil	Control, natural desert surface strewn with stones (10% slope in all treatments)	13.65	Evenary et al. (1971)
		Mounds (stones headed at 5 m interval), smoothed between intervals	17.05	
		Bare (stones raked and removed completely)	19.94	
		Mounds, wet rolled	21.4	
		Bare, wet rolled	22.06	
Western Australia-	Sandy	Clay covered roaded catchments		Burdass (1975)
Dalwallinu (1952)			9.0	
Narrogin (1954)			35.0	
Mc Andrew (1973)			60.0	
New Degate (1974-77)			33.0 (average)	Laing (1981)
University of Arizona, Tucson (1970)	Sandy loam	Compacted earth	30-60	Cluff (1975)
Granite reef test site, Phoenix, Arizona (1961-72)	Granite reef	Cleared and smoothed	36.0	Frazier (1975)
		Ridges and furrows	42.0	

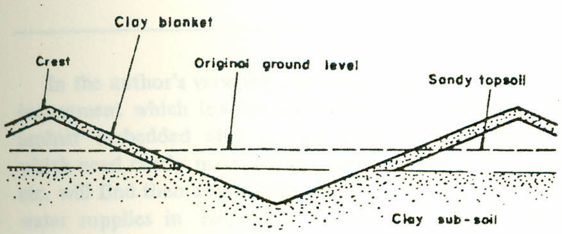

FIG. 1. Cross section through adjacent roads in a roaded catchment.

and high cost. Frazier (1975) has summarized the results of his comparison of different chemical and mechanical treatments (Table 2 and 3) at Granite Reef test site in Phoenix (Arizona). The paraffin wax which melts by the solar radiation could be treated as a breakthrough as the efficiencies in the range of 60-90% can be obtained.

THE APPLICABILITY OF RUNOFF INDUCEMENT CONCEPT TO AGRICULTURE IN THE NORTHEAST OF BRAZIL

The agriculture in the Northeast of Brazil suffers from climatic variability, poor soil resource base and heavily skewed social structure of its farmers. The effects of these factors are more acute on the very arid and arid zones of the Northeast of Brazil (Fig. 2) which consist of 452,200 and 404,600 square kilometers of area respectively out of a total area of 1,647,271 square kilometers (Hargreaves 1974). Small farmers move away from their lands as soon as there are signs of a drought, often in vain since opportunities to earn livelihood in cities are rather limited. Soon there are some rains these farmers return back to their land to take some meager crops but often this also proves to be in vain as these rains very rarely suffice for growing any kind of crops. The raising of animals is also directly effected by these variations. Often animals die due to lack of water and fodder. Runoff inducement for water harvesting is a method to reduce these imbalances for very arid and arid zones.

TABLE 3. Runoff efficiency of different chemical treatments for land surface management.

Location/years of data (in Brackets)	Soil type	Watershed conditions	Runoff efficiency, %	Source of data
Western Australia (1973)				Burdass (1975)
Sounness	Sandy	Roaded catchment with Petroset	41.5	
De Grossa		Roaded catchment with Bitumen	39.0	
Western Australia, New Degate (1972-73)	Sandy	Oil primed	25.0	Laing & Prout (1975)
		Bitumen emulsion primed	18.67	
		Clay cover	17.0	
Santa Fe, New Mexico, USA (1973)	Silt loam	Paraffin	68.0	Aldon & Springfield (1975)
		Polyethlene	62.0	
		Control	28.0	
University of Arizona, Tucson (1971)	Loam	Compacted earth Sodium treated (CEST)	40-70	Cluff (1975)
(1965-74)	Sandy loam	Gravel covered Plastic (GCP)	60-80	
(1971)	Sandy loam	Asphalt-Plastic-Asphalt-chipcoated (APAC)	85-95	
Granite Reef site, Phoenix, Arizona, USA (1961-72)	Granite reef	Sodium carbonate	47.0	Frazier (1975)
		Silicon water		
		Repellents	50-80	
		Paraffin wax	60-90	
		Concrete	60-80	
		Gravel covered sheeting	70-80	
		Asphalt fiber glass	85-95	
		Artificial rubber	90-100	

In the author's view the chemical treatments of runoff inducement which involve higher cost of machinery e.g. asphalt embedded chip coated plastics, or treatments which need costly materials like wax, asphalt or fibreglass etc. will find their applicability only to augment domestic water supplies in Northeast Brazilian arid zones. Such chemical treatments will find only restricted use for raising agricultural crops. Since land availability is not a limiting factor, a combination of land clearing, appropriate drainage relief and cheap salt treatments with appropriate soil conservation methods hold promise for developing life saving irrigation systems and water supply for livestock. This is true for areas which have shallow to medium soils having relatively low water holding capacity. For deep soils having sufficient water holding capacity a combination of runoff inducement coupled with "in situ" moisture conservation methods holds promise for raising short duration crops successfully. To evaluate the hydrologic potential of different low cost alternatives, recently a project was executed in shallow to medium deep Oxisols (Latossols) at the experiment station of CPATSA/EMBRAPA in 1982-83. The following is a report of this work.

RECENT RESEARCH ON RUNOFF INDUCEMENT FOR SHALLOW AND MEDIUM DEEP LATOSSOLS (OXISOLS)

Recently eight small watersheds were developed at CPATSA/EMBRAPA, Petrolina (PE) for hydrologic evaluation of alternate low cost methods of runoff inducement for shallow and medium deep Latossols. These watersheds varying in size between 1 ha and 2.7 ha on a 15.2 ha land consist of different combinations of intensified drainage, land clearing, channel terraces and salt treatments. Table 4 gives the exact areas of different watersheds with their treatments. Fig. 3 shows the layout of these experimental watersheds.

N-E zones	Area, km²
Very arid	452,200
Arid	404,600
Semi arid	292,200
Wet dry (sub humid)	498,271
Total	1,647,271

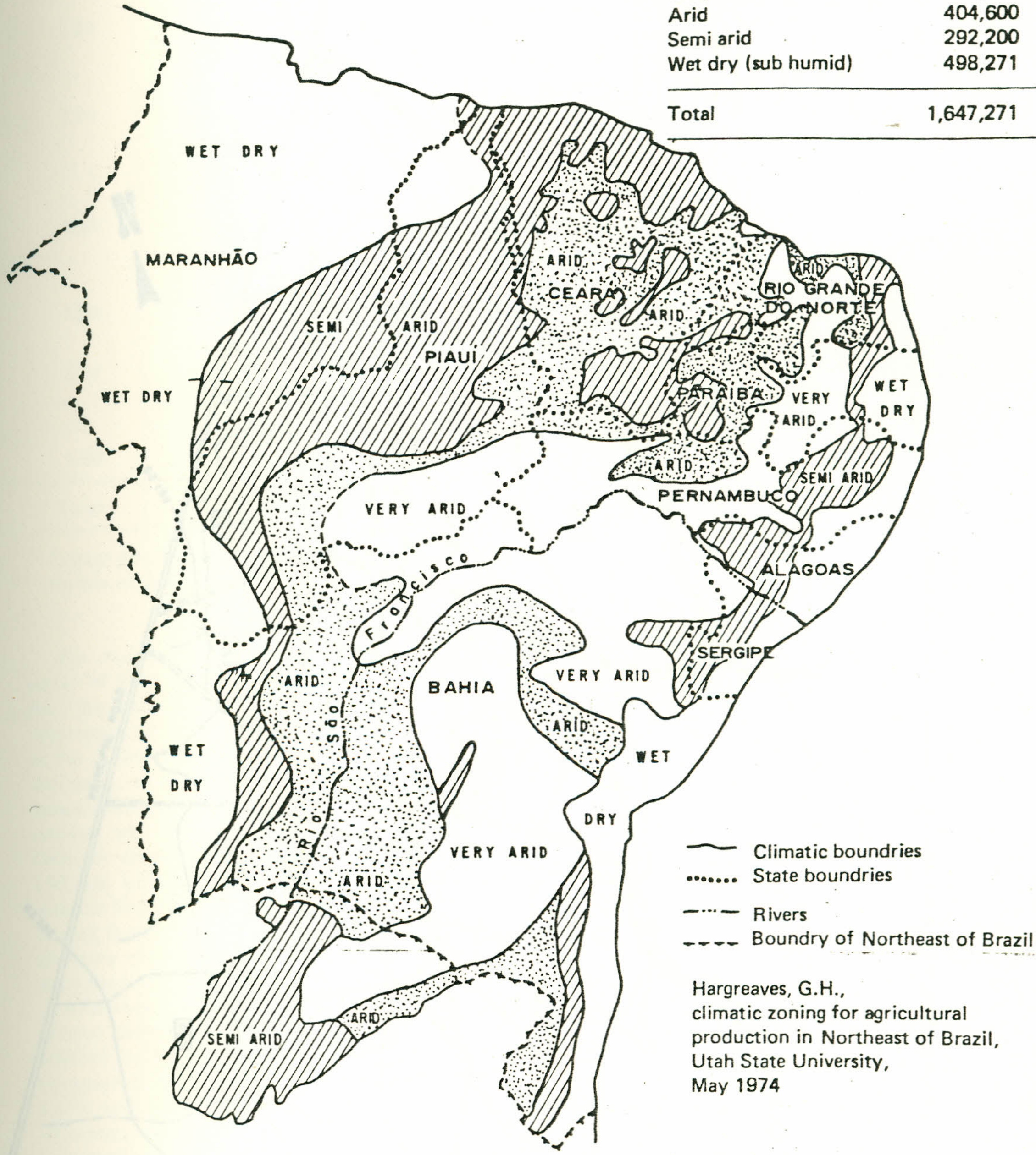

FIG. 2. Climatic classification for Northeast Brasil.

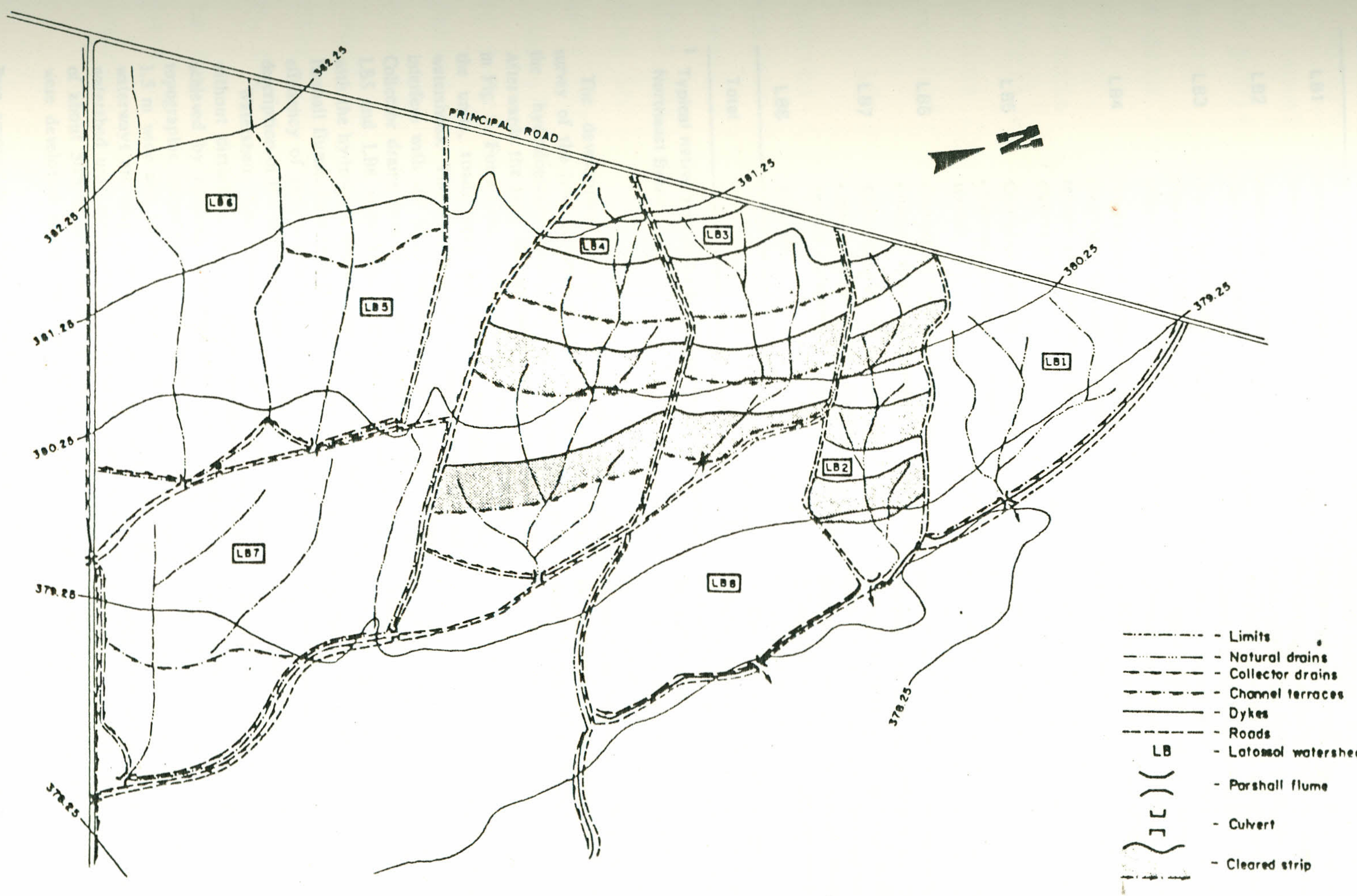

FIG. 3. Latosol watersheds with different runoff inducement treatments, scale 1:4285.

TABLE 4. Description of Latossol (Oxisol) watersheds.

Watershed No.	Description	Area, ha
LB1	Intensified drainage within Caatinga[1]	1.481
LB2	Intensified drainage + strip clearing of Caatinga	1.063
LB3	Intensified drainage + strip clearing of Caatinga + channel terraces	1.402
LB4	Intensified drainage + strip clearing of Caatinga + channel terrace + salt treatment on cleared strips	2.384
LB5	Complete clearing of Caatinga + natural drainage + channel terrace	2.088
LB6	Complete clearing of Caatinga + natural drainage + grasses	2.466
LB7	Complete clearing of Caatinga + intensified drainage + channel terrace + grasses	2.653
LB8	Control	1.609
Total		15.146

[1] Typical native vegetation of arid and semi-arid zones of Northeast Brazil.

The development work consisted of topographic survey of the land before any land clearing to delineate the hydrologically independent watershed units. Afterwards the land was opened according to the design in Fig. 3. For a closer surveillance and easy approach to the units, roads were laid on the boundries of the watersheds. These roads drain separately and do not interfere with the water balance of the watershed units. Collector drains were developed to remove the water of LB5 and LB6 watersheds so that it does not interfere with the hydrologic water balance of the LB7 watershed. Parshall flumes have been installed to monitor the runoff efficiency of various treatments. Following is a detailed description of the various watershed units.

Watershed LB1 consists of intensified drainage without disturbing caatinga native vegetation. This was achieved by opening waterways manually according to topographic depressions. The main drain consists of 1.5 m wide and 15 cm deep waterway while the lateral waterways are only 1 m wide and 15 cm deep. On LB2 watershed unit, strips of land were cleared which consist of about 50% of the area of the watershed. Waterways were developed as on LB1. On LB3 watershed channel terraces were laid below the cleared strips at 0.3% slope. In LB4 watershed common salt was applied at a rate of 300 gm/m^2. Thus LB4 consists of intensified drainage as in LB1, salt treated cleared strips and narrow based channel terraces. It should be noted that these first 4 treatments are basically different ways of managing the caatinga native vegetation such that the natural plant cover which acts as the best way of erosion protection is preserved. The cleared strips are fortified with channel terraces for soil conservation. The intensified drainage system is aimed at relieving the depression storage of a catchment. Thus in a nutshell these 4 watersheds represent incremental levels of techniques of runoff inducement namely intensified drainage, strip clearing, channel terraces and salt application.

The next three watershed units namely LB5, LB6 and LB7 are treatments after completely removing caatinga native vegetation. LB5 includes provision of main waterway and channel terraces for soil conservation on completely bare soil. In LB6 watershed Buffalo grass is to be planted to protect the soil and make the system productive. The LB7 watershed consists of narrow based channel terraces in addition to intensified waterways relieving depression storage and Buffalo grass. Thus these three treatments are treatments after completely removing the caatinga native vegetation and represent different levels of drainage, channel terraces and grass for soil protection.

The 8th and last watershed unit is a control. The natural vegetation (caatinga) is maintained without any disturbance. The runoff is monitored with the help of a Parshall flume.

After a few years of data collection these treatments can be evaluated for their runoff efficiency and the best method can be selected. Additionally the runoff data will be used to calibrate some of the existing water balance model for runoff predictions.

CONCLUSIONS

The detailed review of the data on various runoff inducement methods in various countries clearly demonstrates that these methods have a great potential for helping solve the imbalances of natural water supply for agriculture, animal and domestic use in the very arid zones of the Northeast of Brazil. The present research efforts at CPATSA, Petrolina, Brazil, on hydrologic evaluation of cheap runoff inducement methods will help establish the best combination of vegetation management and land surface management treatments for runoff inducement for the arid zone agriculture in the Northeast of Brazil.

Analysis of Runoff data from various microwatersheds during 1984:

Watershed Management for Runoff Inducement: In total there were 19 runoff producing events here. Total rainfall was 600.9 mm. In this project we have 8 micro watersheds consisting of various treatments. Table 1 gives the details of the 8 watersheds. The runoff data for the rainfall year 1983-84 was analysed and is given in Table 2. In general recommendations shoued not be based on one year of data in this kind of experimentation due to stochastic nature of rainfall and runoff relationships. However preliminary indications from Table 2 are that annual runoff efficiency is in the order of:

LB5 > LB4 > LB3 > LB2 > LB1 > LB8

The control (complete cattinga) did not produce any runoff (0.028%). The maximum runoff was in completely denuded treatment (annual runoff efficiency = 28.07%). LB1 which is only drainage channels is Cattinga gave 0.12% runoff efficiency. The contribution of strip clearing in LB2 increased runoff to 3.72% annually (partial results). The most stricking results are of LB3 & LB4. When channel terraces were installed in LB3 along with strip clearing and drainage the runoff increased to 10.77% annually. Even when the runoff events of the period for which there are no records in LB2, are removed for LB3 also, the annual runoff efficiency will be 8.37%. This indicates that when channel terraces are introduced, which stop water from entering the cattinga strips thus avoiding infiltration of this water, the over all runoff of a strip cleared watershed increases.

The contribution of salt treatments is of the order of 0.85% (compare LB3 & LB4). I want to caution that these results are preliminary and shoued not yet be treated as recommendations.

Table 1: Description of various treatments in mini watersheds.

Watershed No.	Treatment	Area Ha	Area under Cattinga, %	Drainage Density, %	Watershed slope, %
LB1	Intensified drainage in Cattinga	1.481	99.5	263.47	1.43
LB2	Strip Clearing in Cattinga	1.063	49.3	310.44	1.16
LB3	Strip Clearing + Drainage + Terraces	1.402	44.0	233.95	0.75
LB4	Strip Clearing + Drainage + Terraces + Salt	2.384	53.8	270.05	0.77
LB5	Completely denuded + Drainage + Terraces	2.088	0.0	91.0	0.89
LB6	Completely denuded + Grass	2.466	0.0	103.97	1.20
LB7	Completely denuded + Grass + Drainage + Terraces	2.653	0.0	224.27	0.66
LB8	Control, No disturbance in Cattinga	1.609	0.0	0.0	1.181

Table 2: Runoff efficiency of various runoff inducements treatments on micro watersheds at CPATSA/EMBRAPA, for rainfall year 1983 - 84.

			Watershed Treatment																	
			LB1			LB2			LB3			LB4			LB5			LB8		
Date	Rainfall Responsible for runoff on the date, mm	Total Rainfall to date, mm	Runoff, mm	Runoff efficiency, %	Erosion*, T/ha	Runoff, mm	Runoff efficiency, %	Erosion*, T/ha	Runoff, mm	Runoff efficiency, %	Erosion*, T/ha	Runoff, mm	Runoff efficiency, %	Erosion*, T/ha	Runoff, mm	Runoff efficiency, %	Erosion*, T/ha	Runoff, mm	Runoff efficiency, %	Erosion*, T/ha
28.11.83	36.70	43.90	0.265	0.72		No	Records		3.997	10.89		4.525	12.32		9.120	22.12		0.0	0.0	
30.01.83	43.90	87.5	1.483	3.38		No	Records		10.439	23.78		5.61	12.78		11.338	25.83		0.0153	0.035	
04.12.83	10.60	98.1	0.0	0.0		No	Records		0.0	0.0		0.169	1.59		0.23	2.17		0.0	0.0	
10.03.83	38.20	155.2	0.312	0.8		0.667	1.75		3.522	9.22		3.797	9.94		15.736	41.2		0.0	0.0	
12.03.84	46.00	206.9	0.697	1.5		1.439	3.13		5.475	11.9		8.222	17.87		25.239	54.97		0.0	0.0	
14.03.84	80.00	286.9	1.919	2.4		8.68	10.85		8.472	10.59		11.690	14.61		35.127	43.9		0.153	0.19	
14.03.84	13.00	299.9	0.134	1.03		0.928	7.14		1.763	13.56		2.810	21.61		5.28	40.6		0.0	0.0	
15.03.84	11.60	222.8	0.306	2.60		2.171	18.72		3.142	27.08		4.190	36.12		11.108	95.7		0.0	0.0	
16.03.84	35.20	257.9	0.08	0.22		1.285	3.67		3.941	11.2		5.642	15.03		13.153	37.36		0.0	0.0	
17.03.84	3.60	262.3	0.0	0.0		0.0	0.0		0.183	5.08		0.151	4.20		0.0	0.0		0.0	0.0	
25.03.84	5.50	377.9	0.0	0.0		0.0256	0.46		0.399	7.25		0.578	10.5		0.805	14.6		0.0	0.0	
30.03.84	25.80	403.7	0.0	0.0		0.0528	0.2		0.52	2.01		1.224	4.74		1.625	6.30		0.0	0.0	
31.03.84	23.40	427.1	0.0	0.0		0.0335	0.14		0.845	3.61		2.286	9.77		3.989	17.05		0.0	0.0	
04.04.84	12.20	441.8	0.0	0.0		0.254	2.08		1.681	13.77		1.564	12.81		2.428	19.90		0.0	0.0	
06.04.84	75.00	515.8	1.989	2.64		6.574	8.76		18.957	25.27		15.343	20.45		41.044	54.73		0.0	0.0	
07.04.84	7.0	524.3	0.0	0.0		0.0	0.0		0.0534	0.76		0.231	3.3		0.0738	1.05		0.0	0.0	
13.04.84	16.10	548.9	0.0	0.0		0.291	1.8		1.321	8.20		1.654	10.27		3.27	20.3		0.0	0.0	
21.04.84	5.60	562.8	0.0	0.0		0.0	0.0		0.0	0.0		0.0204	0.36		0.0	0.0		0.0	0.0	
24.04.84	8.60	572.3	0.0	0.0		0.0	0.0		0.0	0.0		0.0803	0.93		0.0[illegible]3	0.71		0.0	0.0	
30.05.84		600.7																		
Annual		600.7	7.18	0.12		22.4	3.72**		64.71	10.77		69.7867	11.62		1[illegible]3.8	29.07		0.158	0.023	

[1] Rainfall started on 6.11.83.

*The erosion data are now being analysed.

**Partial

Annual Runoff efficiency: LB5 > LB4 > LB3 > LB2 > LB1 > LB8

CHAPTER III

WATER PRODUCTION FUNCTIONS OF SORGHUM FOR NORTH EAST BRAZIL[1]

BY

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[1]A contribution of IICA/EMBRAPA/CPATSA presented at the XIV Brazilian Agricultural Engineering congress to be held in Fortaleza (Brazil) from July 23-27, 1984.

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WATER PRODUCTION FUNCTION OF SORGHUM FOR NORTH EAST BRAZIL

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ABSTRACT

Sharma, P.N. and Alonso Neto, F.B., 1984. Water production function of sorghum for North-East Brazil.

The results of the experiment to determine the water production function of sorghum for North East Brazilian conditions are reported. The experiment was designed in random blocks consisting of four growth stages for irrigation deficit and 4 levels of nitrogen (N). The growth treatments consisted of vegetative stage, flowering stage, grain formation stage and no deficit treatment. The nitrogen levels were 0 kg/ha, 45 kg/ha, 90 kg/ha and 135 kg/ha for each treatment. Six levels of irrigation and soil moisture up to 120 cm soil depth were monitored at 1.25 m, 3.75 m, 6.25 m, 8.75 m, 11.25 m and 13.75 m perpendicular to sprinkler line source, to give exact actual evapotranspiration (ETa). The experiment consisted of 2 replications layed out in the direction of the wind perpendicular to sprinkler line source.

In total 8 irrigations were given. First 3 irrigations totaling 84.2 mm were given uniformly for establishing the crop. All the irrigations were scheduled by Pan Evaporation method. The pan coefficients and crop coefficients were tentatively taken as recommended by FAO for calculating timing and quantity of irrigation at the point of maximum water application. Irrigation quantity was monitored by cans and soil moisture was monitored in one replication of each of the 4 growth stages by neutron probe at the 6 places. The daily rainfall (which was very little except one event in the maturity period), soil moisture balance and quantity of irrigation were summed up to give the values of ETa. Crop yield samples of 3 m x 1 m size for grain and fodder were collected at the same 6 places of each treatment.

The nature of crop response to water was found to be of quadratic nature. Regression equations are developed for each nitrogen and growth stage treatment between water use and grain yields. Then nitrogen and growth stage (in terms of days to irrigation after planting) has been introduced for multiple regression analysis of quadratic nature. The most critical stage was found to be flowering stage followed by vegetative and grain formation stages. The crop response factors, Ky were found to be always greater than, 1.9 for flowering stage, 1.4 for vegetative and grain formation stages and always more than 1.23 for total growing period when nitrogen level was 0 kg/ha. The Ky factors at N= 45 kg/ha are respectively; > 1.73 (flowering), > 1.62 (grain formation), > 1.46 (vegetative) and > 1.52 for total growth period. These factors are much above the generalized estimates of the FAO. The highest obtainable yield was observed to be 4.92 metric ton/ha at 424.6 mm of actual water use at N= 45 kg/ha for the no deficit case.

The crop coefficients (Kc) calculated from observed data by pan evaporation method are; 0.40 for initial period (0-17 days), 0.74 for crop development period (18-44 days), 0.81 for mid season (45-68 days), 0.73 for late season (68-85 days) and 0.5 for harvest period (86-106 days), respectively for N= 45 kg/ha. The Kc value for total period is 0.75. These coefficients are in general around the range suggested by the FAO except in the mid season (Kc= 0.81) where the value in lower than the FAO value of Kc= 1.05.

The information reported can immediately be utilized for irrigation scheduling and for supplemental irrigation project planning in North East Brazil.

INTRODUCTION

North East Brazil is climatically one of the most erratic regions of the world. Water often is not available in sufficient quantity at right time and right place. Supplemental irrigation projects are being proposed in general to minimize these imbalances in natural water supply for rainfed areas. These irrigation projects usually involve high expenditures. Most often, in past, these supplemental irrigation projects have been planned without adequate knowledge of water production functions of the dry land crops. To fill this gap in information a research project for determination of water production functions of major N-E Brazilian dry land crops was started here in 1983. This paper reports the results of the experimentation for sorghum. The water production functions for various levels of irrigation deficit at different phenological stages and with no irrigation deficit, at various nitrogen levels, are reported. In addition the crop response factors (Ky) based on the crop yield response to water model of the FAO (Doorenbos and Kassam, 1979) have been determined to aid future irrigation project planning and crop coefficients based on pan evaporation method have been determined for proper irrigation scheduling.

MATERIALS AND METHODS

The experiment was conducted on Latossols. The physical and hydraulic characteristics of these soils have been described in detail (Choudhury and Millar, 1981) in Table 1. The experiment was designed in randomized blocks consisting of 4 growth stages for irrigation deficit and 4 levels of nitrogen. The 4 growth stages were; vegetative, flowering, grain formation and no deficit treatment. The 4 levels of nitrogen applied were 0 kg/ha, 45 kg/ha, 90 kg/ha and 135 kg/ha. Uniform basal doses of 30 kg/ha K_2O and 90 kg/ha of P_2O_5 were applied. The nitrogen was applied in two parts, half as basal and remaining half as top dressing after 3 weeks of germination. The method of line source sprinkler as described by Hanks et al. (1976) was utilized for giving continuously variable irrigation. The perpendicular plots of 15 m x 4.5 m for each of the treatments were layed out to give 4 replications by locating two replications on either side of the sprinkler line. However as the wind velocities often exceeded 300 km/day, the two replications against wind direction were rejected due to poor distribution of water. Thus only two replications of each treatment were utilized for final analysis.

Table 1: Physical and hydraulic characterization of the Latossols of the experimental site (Choudhury and Millar, 1981).

Characteristics	Depth , cm			
	0 - 30	30 - 60	60 - 90	90 - 122
Texture:				
Gross Sand (%)	4	5	3	3
Fine Sand (%)	87	81	79	76
Silt (%)	4	5	6	8
Clay (%)	5	9	12	13
Textural Classification (USDA)	Sandy	Sandy Loam	Loamy Sand	Loamy Sand
Apparent Density (g/cm^3)	1.62	1.68	1.64	1.62
Real Density (g/cm^3)	2.72	2.74	2.74	2.82
Field Capacity (%)	8.94	9.00	9.20	9.00
Permanent Wilting Point (15 atm), %	1.84	2.52	3.07	3.22
Available Water, cm	3.45	3.27	3.00	3.01

The experimentation was carried out for the IPA 7301011 granifero variety of sorghum as this variety is one of the highest grain yielding varieties of the region. The plant population was maintained at 100,000 plants/ha. Each plot consisted of 6 rows spaced at 75 cm. Two of these 6 rows on the sides were borders. Six levels of irrigation and soil moisture up to 120 cm soil depth were monitored at 1.25m, 3.75m, 6.25m, 8.75m, 11.25m and 13.75 m perpendicular to line source. Climatic data on wind velocities, rainfall, daily evaporation rates and mean relative humidity were obtained from the nearby meteorological station of the irrigation research center for irrigation scheduling.

In total. 8 irrigations were given. First 3 irrigations totaling 84.2 mm were given uniformly for establishing the crop. All the irrigations were scheduled by Pan Evaporation method. The pan coefficients and crop coefficients were tentatively taken as recommended by FAO (Doorenbos and Kassam, 1979) for calculating timing and quantity of irrigation at the point of maximum water application. Irrigation quantity was monitored by cans and soil moisture was monitored in one replication of each of the 4 growth stages for each nitrogen treatment by neutron probe at the 6 places. The daily rainfall (which was very little except one event in the maturity period), soil moisture balance and quantity of irrigation were summed up to give the values of actual evapotranspiration (ETa) i.e. water use, presuming no deep percolation losses. Crop yield samples of 3 m x 1 m size for grain and fodder were collected at the same 6 places of each treatment.

RESULTS AND DISCUSSION

The observed sorghum grain yield (y) at different water use (Q) levels for the 4 stages (T) and for all the 4 nitrogen levels (N) are given in Table 2. The water use was calculated by summing up the irrigation quantity applied at the 6 locations from the line source, soil moisture contribution calculated by substracting the value of soil moisture before previous irrigation from the value of soil moisture before an irrigation is to be given and rainfall. Deep percolation losses were assumed to be negligible. The irrigation scheduling was done by pan evaporation method at 50% moisture depletion level. A total of 61.9 mm rainfall took place during the period of the experiment. Except for one event of 39 mm in the last week of the experiment, all other rainfall was in small quantities. There was no runoff loss from any rainfall event. The growth stages have been represented by number of days, T from planting to the day when water deficit started (or irrigation omitted).

Six samples of yield were taken for each nitrogen treatment for all the stages however some of the data in Table 2 have been omitted since these omitted points either had severe bird damage or suffered from poor pollination for some unknown reason.

Yield response to various variables

The nature of crop response (yield) to water use was found to be of quadratic nature. The observations that have an asterisk (*) on the values of water use in Table 2 were deleted in the regression analysis as some of them are very much off the general nature and some removed to avoid negative predictions at lower values of water use. Regression equations developed for different stages (T in days) at

Table 2: Observed sorghum grain yield at different water use levels for various stages and nitrogen levels, and calculated values of crop response factors and water utilization efficiency.

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency (kg/ha-cm of water)
VEGETATIVE STAGE (T= 30 days)			
At N= 0 kg/ha;			
Rep. I:			
130.6	93.3	1.42	7.14
155.6*	626.6	1.38	40.27
291.9	436.6	2.92	14.95
343.0	760.0	4.41	22.15
Rep., II:			
141.1	0	1.50	0.00
183.5	113.3	1.72	6.17
250.0	353.3	2.26	14.13
338.5	806.6	4.12	23.83
388.5	1420.0	8.37	36.55
409.4	1186.6	21.20	28.98
At N= 45 kg/ha;			
Rep. I:			
132.7*	0	1.46	0.00
151.9	16.6	1.55	1.09
178.8	120.0	1.69	6.71
254.2	886.6	2.04	34.88
330.5	603.3	3.96	18.25
394.5	1053.3	11.09	26.70
Rep. II:			
151.2	36.6	1.54	2.42
178.6	93.3	1.69	5.22
259.0	386.6	2.36	14.93
322.1*	1953.3	2.50	60.64
400.6	1066.6	13.86	26.63
At N= 90 kg/ha;			
Rep. I:			
158.9	0	1.60	0.00
171.9	46.6	1.65	2.71
268.7	136.6	2.65	5.08
331.9*	426.6	4.18	12.89
392.1	1170.0	9.96	29.84
Rep. II:			
150.7	46.6	1.54	3.09
184.9	46.6	1.76	2.52
253.1	443.3	2.25	17.51
325.5	800.0	3.59	24.58
391.5	2286.6	6.86	58.41
400.0	1593.3	11.67	39.83
At N= 135 kg/ha;			
Rep. I:			
129.5*	0	1.44	0.00
156.6	43.3	1.57	2.77
185.3*	40.0	1.76	2.16
265.1	393.3	2.45	14.84
340.2	603.3	4.41	17.73
388.1	823.3	9.69	21.21
Rep. II:			
144.2	36.6	1.51	2.54
320.2	686.6	3.50	21.44
385.6	1046.6	8.55	27.14
401.0	713.3	15.27	17.7[illegible]

Table 2: Continuation

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency, (kg/ha-cm of water)
FLOWERING STAGE (T= 56 days)			
At N= 0 kg/ha;			
Rep. I:			
179.4*	0.0	1.73	0.00
213.0	0.0	2.01	0.00
277.4	470.0	2.61	16.94
349.9	920.0	4.62	26.29
393.8	1070.0	10.79	27.17
Rep. II:			
179.4*	460.0	1.57	25.64
213.0	253.3	1.90	11.89
277.4	826.6	2.40	29.80
349.9	1446.6	4.01	41.34
393.8	1703.3	9.01	43.25
412.5	1903.3	21.52	46.14
At N= 45 kg/ha;			
Rep. I:			
185.1*	0.0	1.77	0.00
219.7	0.0	2.07	0.00
287.1	170.0	2.98	5.92
353.7	736.6	5.09	20.83
420.5	1003.3	82.44	23.86
422.6	936.6	171.88	22.16
Rep. II:			
185.1*	103.3	1.74	5.58
219.7	120.0	2.02	5.46
287.1	866.6	2.54	30.19
353.7	1070.0	4.69	30.25
420.5	1636.6	69.11	38.92
422.6	1686.6	139.50	39.91

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency, (kg/ha-cm of water)
At N= 90 kg/ha;			
Rep. I:			
177.1	0	1.72	0
213.1	16.6	2.00	0.78
283.3	36.6	2.98	1.29
356.8	320.0	5.86	8.97
415.1	1153.3	34.20	27.78
418.7	836.6	59.71	19.98
Rep. II:			
177.1	80.0	1.69	4.52
213.1	70.0	1.98	3.29
283.3	820.0	2.50	28.94
356.8	1470.0	4.39	41.20
415.1	1820.0	28.13	43.84
418.7	1880.0	44.46	44.90
At N= 135 kg/ha;			
Rep. I:			
168.6	0.0	1.66	0.00
225.8*	70.0	2.11	3.10
287.6	970.0	2.49	33.73
357.0*	870.0	5.18	24.37
403.2	1076.6	15.50	26.70
422.0	1460.0	114.87	34.60
Rep. II:			
168.6	20.0	1.65	1.19
225.8	463.3	1.94	20.52
287.6	1103.3	2.41	38.36
357.0	1103.3	4.87	30.91
403.2	1136.6	15.26	28.19
422.0	1220.0	122.88	28.91

Table 2: Continuation

GRAIN FORMATION STAGE (T= 68 days)

At N= 0 kg/ha;

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency, (kg/ha-cm of water)
Rep. I:			
171.1*	803.3	1.40	46.95
172.0	100.0	1.65	5.81
260.1	1403.3	1.85	53.95
282.5	2520.0	1.46	89.20
297.5	3193.3	1.17	107.34
332.7	2833.3	1.96	85.16
Rep. II:			
171.1*	26.6	1.67	1.56
172.0	60.0	1.66	3.49
260.0*	553.3	2.30	21.27
282.5	3520.0	0.85	124.60
297.5	2866.6	1.40	96.36
332.7	3333.3	1.50	100.19

At N= 45 kg/ha;

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency, (kg/ha-cm of water)
Rep. I:			
171.2	0.0	1.68	0.00
194.0	50.0	1.82	2.58
244.0*	66.6	2.32	2.73
275.3	1400.0	2.03	50.85
335.8	2453.3	2.40	73.06
343.0	2403.3	2.67	70.07
Rep. II:			
156.5*	0.0	1.59	0.00
175.0	226.6	1.62	12.95
229.4	620.0	1.90	27.03
269.2	993.3	2.18	36.90
347.9	2120.0	3.14	60.94
369.9	2086.6	4.47	56.41

At N= 90 kg/ha;

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency, (kg/ha-cm of water)
Rep. I:			
171.7*	66.6	1.66	3.88
231.9	836.6	1.83	36.08
273.5	813.3	2.35	29.74
311.0	1786.6	2.38	57.45
325.2	2200.0	2.36	67.65
368.7	1870.0	4.70	50.72
Rep. II:			
171.7*	40.0	1.66	2.33
231.9	50.0	2.18	2.16
273.5	136.6	2.73	5.00
311.0	2733.3	1.66	87.89
325.2	1636.6	2.85	50.33
368.7	2720.0	3.39	73.77

At N= 135 kg/ha;

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency, (kg/ha-cm of water)
Rep. I:			
157.7*	0.0	1.59	0.00
189.0	136.6	1.75	7.23
259.7	666.6	2.23	25.67
299.5	1300.0	2.50	43.41
338.1	2036.6	2.87	60.24
Rep. II:			
189.0	333.3	1.68	17.64
231.9	386.6	2.03	16.67
259.7	1786.6	1.64	68.80
299.5	2486.6	1.68	83.03
338.1	1536.6	3.37	45.45
370.6*	3666.6	2.01	98.94

Table 2: Continuation

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency, (kg/ha-cm of water)
NO DEFICIT STAGE (T= 100 days)			
At N= 0 kg/ha;			
Rep. I:			
205.1	853.3	1.60	41.61
257.2	236.0	1.32	91.76
366.2	4086.6	1.23	111.60
413.9	3060.0	15.00	73.93
419.1	3833.3	17.00	91.47
426.8	3433.3	58.30	80.44
Rep. II:			
205.1	10.0	1.93	0.49
257.2	270.0	2.40	10.50
366.2*	333.3	6.75	9.10
413.9	2033.3	23.29	49.13
419.1	3653.3	19.85	87.17
426.8	3903.3	39.36	91.46
At N= 45 kg/ha;			
Rep. I:			
200.4	666.6	1.638	33.27
250.8	1853.3	1.523	73.90
339.3	4366.6	0.562	128.70
424.6	4366.6	∞	102.84
434.8*	2520.0	- 20.33	57.96
462.1	2600.0	- 5.35	56.27
Rep. II:			
220.4	106.6	1.85	5.32
250.8	786.6	2.05	31.37
339.3	2100.0	2.85	61.89
424.6	4920.0	0/0	115.87
434.8*	1833.3	- 26.13	42.17
462.1	3453.3	- 3.38	74.73

Water Use, Q, (mm)	Grain Yield, y, (kg/ha)	Crop Response factor, Ky	Water utilization efficiency, (kg/ha-cm of water)
At N= 90 kg/ha;			
Rep. I:			
192.1	133.3	1.78	6.94
230.4	270.0	2.07	11.72
347.2	1770.0	3.52	50.98
421.5*	2950.0	54.80	69.99
422.5	3036.6	77.37	71.87
441.7	3000.0	-9.68	67.92
Rep. II:			
160.6*	0.0	1.61	0.00
166.5*	16.6	1.64	1.00
176.9	86.6	1.68	4.90
233.4	160.0	2.15	6.86
300.2	1753.3	2.20	58.41
386.0	2420.0	5.58	62.69
At N= 135 kg/ha;			
Rep. I:			
153.5*	0.0	1.57	0.00
160.6	16.6	1.60	1.04
223.5	33.3	2.10	1.49
302.7	1420.0	2.48	46.91
386.8	3186.6	3.96	82.39
449.0	3066.6	- 7.89	68.93
Rep. II:			
Rejected completely due to heavy bird damage.			

different levels of nitrogen (N, kg/ha), between grain yield, y in kg/ha(dependent variable) and water use, Q in mm (independent variable) and the value of R^2 for each regression equation are as following (all equations significant at 1% level except where otherwise marked):

Vegetative Stage (T= 30 days):

At N= 0, $y = 267.359 - 3.73186Q + 0.0155982Q^2$, $R^2 = 0.94$

At N= 45, $y = -943.719 + 7.18158Q - 5.63288 \times 10^{-3}Q^2$, $R^2 = 0.86$

At N= 90, $y = 892.674 - 9.67966Q + 0.0274038Q^2$, $R^2 = 0.91$

At N= 135, $y = -538.874 + 4.00191Q - 1.1981 \times 10^{-3}Q^2$, $R^2 = 0.90$

Flowering Stage (T= 56 days):

At N= 0, $y = -1126.83 + 5.06409Q + 4.27556 \times 10^{-3}Q^2$, $R^2 = 0.84$

At N= 45, $y = -1534.86 + 7.84808Q - 2.58923 \times 10^{-3}Q^2$, $R^2 = 0.75$

At N= 90, $y = 151.184 - 3.67749Q + 0.0161397Q^2$, $R^2 = 0.69$

At N= 135, $y = -2403.02 + 18.1206Q - 0.0225658Q^2$, $R^2 = 0.94$

Grain Formation Stage (T= 68 days):

At N= 0, $y = -7721.99 + 58.1631Q - 0.0758758Q^2$, $R^2 = 0.87$

At N= 45, $y^* = -2515.14 + 15.3217Q - 0.0051198Q^2$, $R^2 = 0.93$

At N= 90, $y = -760.476 + 45.0886Q - 0.0485702Q^2$, $R^2 = 0.65$[a]

At N= 135, $y = -4362.19 + 30.3986Q - 0.0345647Q^2$, $R^2 = 0.71$[a]

No Deficit Stage (T= 100 days):

At N= 0, $y = -8265.87 + 55.0203Q - 0.0647574Q^2$, $R^2 = 0.73$

At N= 45, $y = -9919.42 + 66.0057Q - 0.0789173Q^2$, $R^2 = 0.76$

At N= 90, $y^* = -1834.3 + 8.77258Q + 5.70488 \times 10^{-3}Q^2$, $R^2 = 0.96$

At N= 135, $y^* = -2013.1 + 10.2593Q + 4.29153 \times 10^{-3}Q^2$, $R^2 = 0.92$[b]

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[a]significant at 5% level

[b]significant at 10% level

The equations which have an asterisk (*) on y are those equations which give negative value of y for the first point in Table 2 hence should not be used at such low values of Q. In general these equations are valid within the range of data set only.

When nitrogen (N in kg/ha) is introduced as another independent variable, the multiple regression analysis gives the following equation for different stages (all equations significant at 1%-level):

Vegetative Stage (T= 30 days):

$$y = -83.2419 + 2.05688\,N - 0.107914\,N^2 - 0.747286Q + 0.0100705Q^2 - 5.62799 \times 10^{-3}\,NQ, \quad R^2 = 0.86$$

Flowering Stage (T= 56 days):

$$y = -1778.82 + 0.214481\,N + 0.0461677\,N^2 + 9.61182Q - 3.35078 \times 10^{-3}\,Q^2 - 0.207424\,NQ, \quad R^2 = 0.76$$

Grain Formation Stage (T= 68 days):

$$y = -4855.47 - 16.2039\,N + 0.141945\,N^2 + 35.5054Q - 0.0334574Q^2 - 0.0372201\,NQ, \quad R^2 = 0.80$$

Total Growth Period (T= 100 days):

$$y = -4677.61 + 3.92332\,N - 0.0263966\,N^2 + 30.3803Q - 0.0254922Q^2 - 0.0148113\,NQ, \quad R^2 = 0.77$$

Finally the growth stage represented by time of beginning of deficit (Vegetative T= 30 days, Flowering T= 56 days, Grain formation T= 68 days and No deficit T= 100 days) was also introduced as an independent variable along with nitrogen and water use. The multiple regression analysis of quadratic nature gives the following equation (significant at 1% level):

$$y = -1526.55 - 26.714\ T - 0.0295695\ T^2 - 2.65839\ N + 0.0408066\ N^2 + 14.1741Q - 0.0280272Q^2 - 0.0511639\ T N + 0.172276\ TQ - 0.0076658\ T NQ\ ,\ R^2 = 0.75$$

These multiple regressions in general are valid within the range of data set. However some times these equations do give negative values of y for the lowest values of water use in the data set and should be utilized with this caution in mind.

Water utilization efficiency (WUE)

The water utilization efficiency is calculated by dividing the grain yield by the quantity of water use in kg/ha-cm of water and is given in Table 2. The highest values of the WUE were for no deficit case followed by the grain filling stage. The WUE for both vegetative and flowering stage were low. The highest average (of the two repetitions) water utilization efficiency was observed to be 109.3 kg/ha-cm of water at 424.6 mm water use for 45 kg/ha applied nitrogen and the no deficit stage. The average (of the two repetitions) highest grain yield was also obtained at the same point. It can be generalized from the values of the WUE in Table 2 that if quantity of water available is limited the deficit should not be allowed to occur during vegetative and the flowering stages otherwise the WUE can drastically fall.

Crop response factors (Ky)

Doorenbos and Kassam (1979) have developed the following model for predicting relative actual yield decrease for relative actual evapotranspiration deficit:

$$\left(1 - \frac{ya}{ym}\right) = Ky \left(1 - \frac{ETa}{ETm}\right)$$

Where:

ya= actual yield, kg/ha

ym= maximum obtainable yield, kg/ha

ETa= actual evapotranspiration, mm

ETm= maximum evapotranspiration for maximum obtainable yield, mm

Ky= crop response factor

The term (1 - ya/ym) becomes the relative actual yield decrease and (1 - ETa/ETm) becomes the relative actual evapotranspiration deficit. The factor Ky relates the two.

The maximum obtainable yield was taken as 4.92 ton/ha (= ym) at 424.6 mm (ETm) of water use. Based on this the values for Ky have been calculated for all levels of nitrogen for the 4 growth stages and are given in Table 2. The values of (1 - ETa/ETm) and (1 - ya/ym) have been plotted as shown in Fig. 1(a), (b), (c) and (d). In general, there is a wide spread in the values of Ky. The values are always above one (slope > 45°). The minimum values of Ky are shown by a line through the center for different stages and different nitrogen levels. From Fig. 1, the most critical stage was found to be

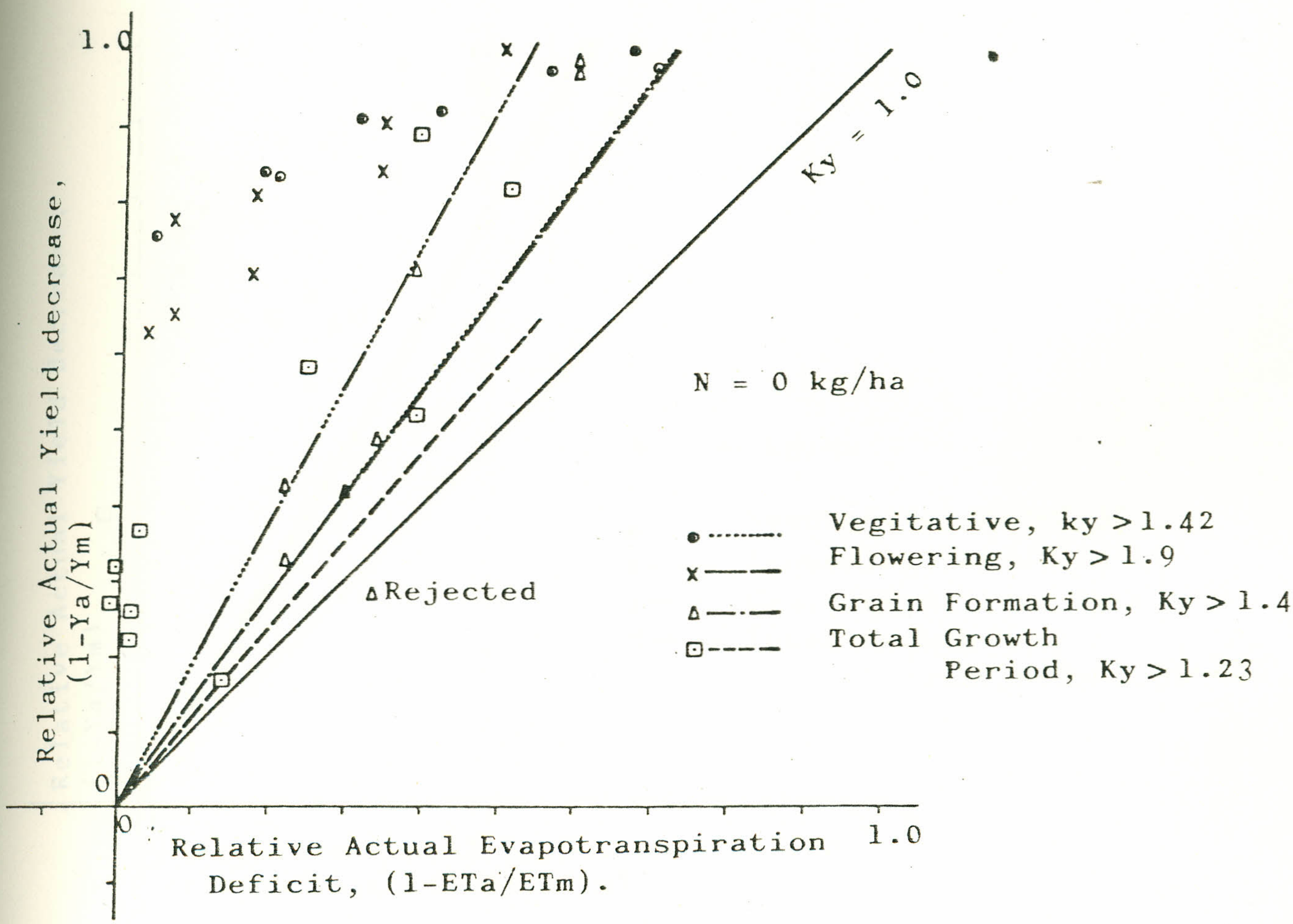

Fig. 1 (a): Relationship of relative actual evapotranspiration deficit with relative actual yield decrease at 0 kg/ha nitrogen level.

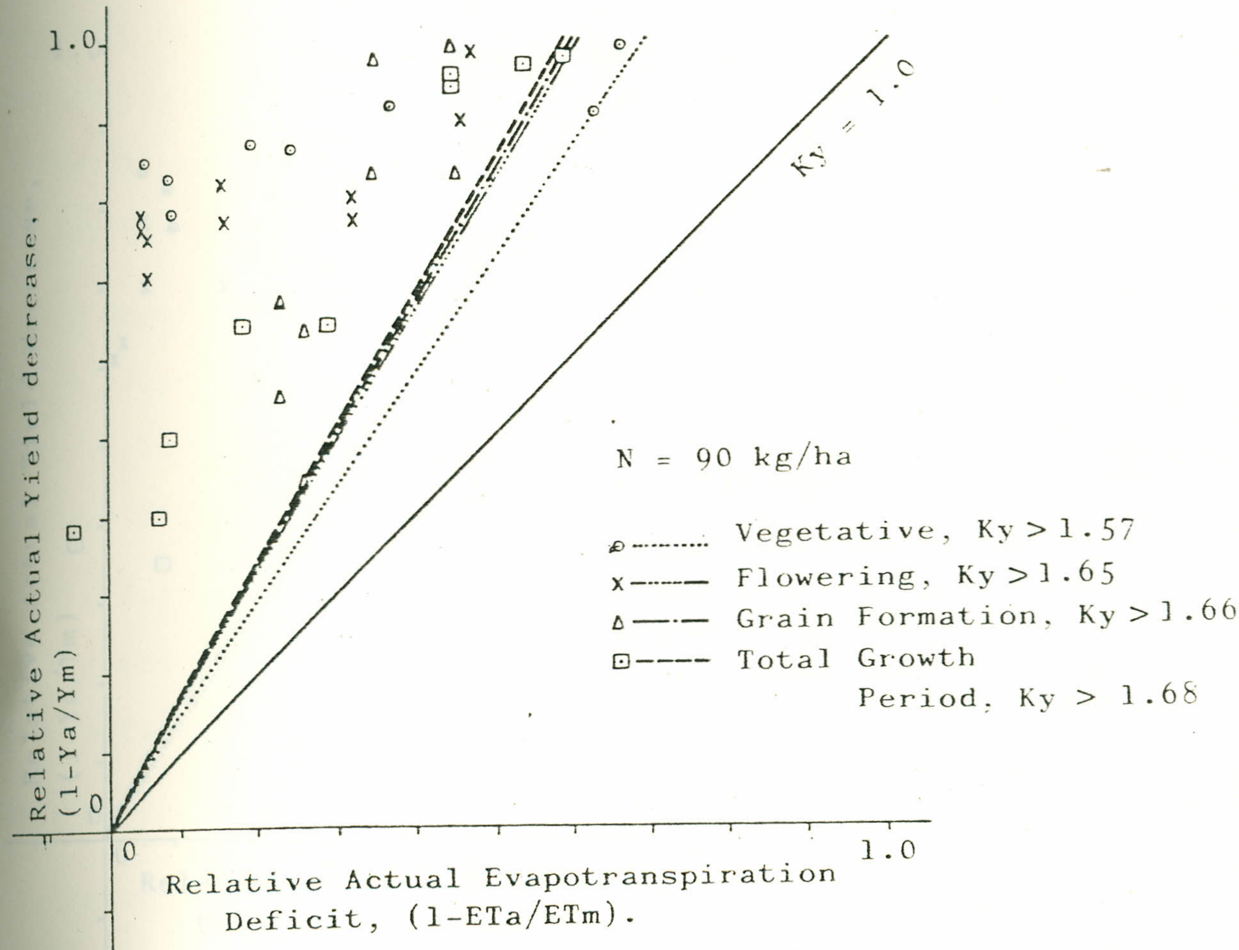

Fig. 1 (c): Relationship of relative actual evapotranspiration deficit with relative actual yield decrease at 90 kg/ha nitrogen level.

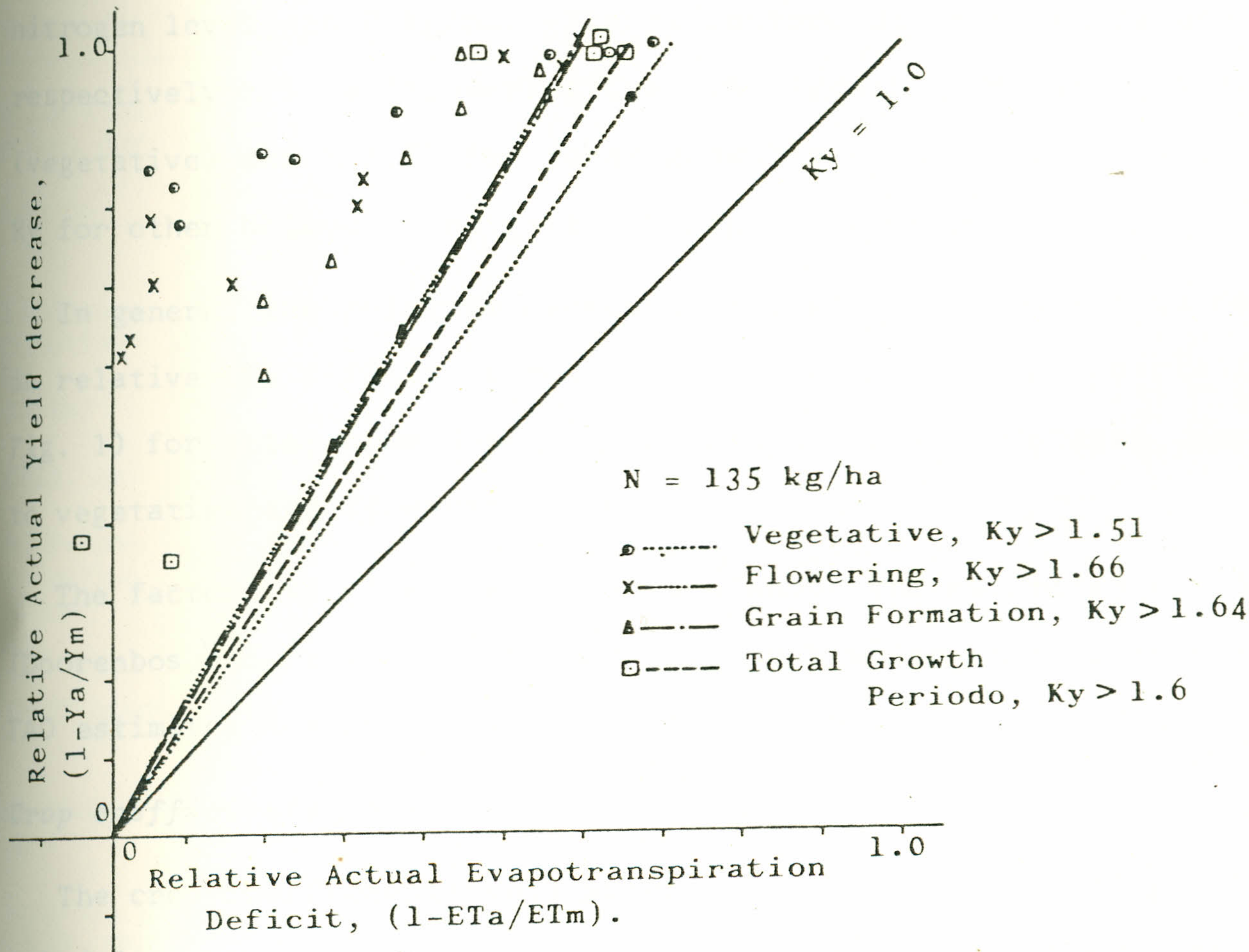

Fig. 1 (d): Relationship of relative actual evapotranspiration deficit with relative actual yield decrease at 135 kg/ha nitrogen level.

flowering stage followed by vegetative and grain formation stages. The crop response factors, Ky were found to be always greater than, 1.9 for flowering stage, 1.4 for vegetative and grain formation stages and always more than 1.23 for total growing period when nitrogen level was 0 kg/ha. The Ky factors at N= 45 kg/ha are respectively > 1.73 (flowering), > 1.62 (grain formation), > 1.46 (vegetative) and > 1.52 for total growth period. The minimum values of Ky for other N levels are given in Fig. 1 (c) & (d).

In general the relative decrease in yield with respect to decrease in relative ETa deficit is much lower (see the band of points in Fig. 1) for total growth period and grain formation stages compared to vegetative and flowering stages.

The factors Ky given here are much above the estimates of FAO (Doorenbos and Kassam, 1979) and have much wider scatter than the FAO estimates due to different climatic conditions.

Crop coefficients (Kc)

The crop coefficients (Kc) which are used for irrigation scheduling have been calculated by Pan Evaporation Method. The pan coefficients were taken as given by FAO (Doorenbos & Kassam) for the climatic conditions of the location of the experiment. The sample calculations for Kc at N= 45 kg/ha for no deficit growth stage and water use (ETa) = 424.6 mm case are shown in Table 3. This case was chosen as it gives the maximum WUE and yield and hence the optimum water use level. The water balance data for calculating the actual evapotranspiration (ETa) during different growth periods are also given in Table 3.

Table 3: Calculation of crop coefficients (Kc) for sorghum at N= 45 kg/ha, No deficit stage and maximum average water utilization efficiency and yield location.

Crop Development Periods	Initial	Crop Development	Mid-Season	Late Season	Harvest	Total
Duration from planting, day	0 - 17	18 - 44	45 - 68	69 - 85	86 - 106	0 - 106
Irrigation, mm	59.13	95.6	123.0	69.3	54.6	401.7
Soil moisture contribution to ETa (at N= 45)	-17.4	10.7	10.2	-3.2	- 48.0	- 39.0
Rainfall, mm	—	—	2.6	11.4	47.9	61.9
Actual Evapotranspiration (ETa)[1], mm (N= 45)	41.73	106.3	135.8	77.5	54.5	424.6
Pan Coefficient, K_p[2]	0.65	0.65	0.65	0.65	0.65	0.65
Evaporation, Ev, mm	158.94	221.34	256.84	162.36	168.63	868.11
Ref.Crop ET, $ETo = K_p Ev$, mm	103.31	143.87	166.95	105.53	109.6	564.27
Kc= ETa/ETo (Calculated)	0.40	0.74	0.81	0.73	0.5	0.75
FAO, Kc values	0.3	0.7	1.05	0.75	0.5	0.75

[1] ETa= (Irrigation + Soil Moisture Contribution + Rainfall), assuming no deep percolation and there was no runoff.

[2] For moderate wind velocities (175-425 km/day) and high mean relative humidity (RH_{mean} > 70%), FAO source, Doorenbos and Kassam (1979). The pan is located in the green grass cover (< 1 m).

The crop coefficients (kc) for the N= 45 kg/ha for optimum water level are 0.40 for initial period (0-17 days), 0.74 for crop development period (18-44 days), 0.81 for mid season (45-68 days), 0.73 for late season (69-85 days) and 0.5 for harvest period (86-106 days), respectively. The Kc value for total period is 0.75. These coefficients are in general around the range suggested by the FAO except in the mid season (Kc= 0.81) where the value is lower than the FAO value of Kc= 1.05.

Table 4 gives the values of Kc calculated for different N levels at their optimum water use levels. Crop coefficients for N= 0 kg/ha and N= 45 kg/ha for different growth periods are about equal. The Kc values for N= 90 kg/ha and N= 135 kg/ha are generally lower than the Kc values for N= 0 kg/ha and 45 kg/ha except for initial period and mid season in the case of N= 90 kg/ha. This explains why the yields were lower at these higher N levels though over all the value of Kc for total period may be equal as in the case for N= 90 kg/ha.

CONCLUSIONS

The multiple regression equations developed here can be utilized for economic analysis of new supplemental irrigation projects. The crop response factors Ky developed here can also be utilized for irrigation project planning or for decisions on the choice of sorghum as a crop in the cropping mix of an irrigation project to predict in advance the effect of limited quantities of water for irrigation. The crop coefficients developed can be utilized for irrigation scheduling. The highest average water

Table 4: Values of Crop Coefficients (Kc) for Sorghum at different nitrogen levels.

Nitrogen level, (kg/ha)	Value of Kc at different growth periods					
	Initial (0-17 days)	Crop development (18-44 days)	Mid Season (45-68 days)	Late Season (69-85 days)	Harvest (86-106 days)	Total period
0	0.4	0.74	0.86	0.74	0.45	0.76
45	0.4	0.74	0.81	0.73	0.5	0.75
90	0.4	0.59	0.91	0.64	0.58	0.75
135	0.4	0.65	0.59	0.65	0.68	0.68
FAO Values	0.3	0.7	1.05	0.75	0.5	0.75

utilization efficiency of 109.3 kg/ha-cm of water and highest grain yield of 4.92 tons/ha was obtained at 424.6 mm of water use at 45 kg/ha of applied nitrogen for no water deficit in total growth stage case of which the value of Ky is always > 1.52 and the value of Kc for total period is 0.75. The value of Kc for initial period is 0.4, for crop development period is 0.74, for mid season is 0.81, for late season is 0.73 and for harvest period is 0.5 (at N= 45 kg/ha). The recommendations can immediately be used.

Water Production Function of Maize for NE Brazil:

The field experimentation for maize was completed on 15 Dec. 1984. The methodology used was same as for sorghum. The analysis of data is now being carried out hence it is too early to give final results of this experiment. The results will be given in Jan-March, 1985 trimestral report.

CHAPTER IV

Optimization of Small Reservoir Systems for NE Brazil

The mathematical part of the model for optimizing small reservoir systems for NE Brazil was developed in 1982-83 and was reported to IICA in 1983 (see trimestral report of April-July, 1983). The input data for the model are now being collected. The input data of the model basically come from the project on runoff inducement reported here in chapter II and water production functions data reported here in chapter III. Soon sufficient data is generated, the model shall be operational.

For understanding the details of the model following references are sited:

1. Sharma, P.N, trimestral Report of Activity (IICA), April-July, 1983.

2. Sharma, P.N, & O.J Helweg, "A non-linear model for optimization of small reservoir irrigation systems in SAT", paper presented in I simposium on Semi Arid Tropics, Olinda, July 1982.

3. Sharma, P.N, & O.J Helweg, "Optimal Design of small Reservoir Systems, Jr. of Irrigation & Drainage, ASCE, Dec, 1982.

4. Helweg, O.J and P.N. Sharma, optimum Design of small Reservoir (Tanks), American Geophisical Union, July 1983.

4. Sharma, P.N, & O.J. Helweg, "Problems with Traditional small Reservoir Irrigation Systems in SAT, Trans. ASAE, Dec, 1984.

5. Sharma, P.N. & O.J, Helweg, "An Evalutation of Small Reservoir Irrigation Systems", Jr. of Agricultural Engg., ISAE, Nov, 1983.

6. Helweg O.J. and Sharma, P.N. "Optimum Design of Small Reservoir", Water Resources Journal, ESCAP, UNO, Dec, 1984.

CHAPTER V

SEEPAGE CONTROL:

This research project consists of a replicated experiment to study the effectiveness of various locally available cheap materials for seepage control. The materials include various combinations of soil-cement (10: 1 and 15: 1), plastics (covered by soil-cement, asphalt and soil only), clay covered blancket with and without salt, asphalt treatment and control. These materials are to be tested in pits of 7m³ capacity. All the treatments and installation of instrumentation is ready now. The delay in experiment so far took place as it depended at permission of CODEVASF to draw water from their canal which have now been granted. In the coming year this experiment shall be completed. No results are yet available as data collection is now to start.

CHAPTER VI

MISCELLANEOUS ACTIVITIES

(a) Training:

(i) Completed on the job training of Mr. Faustino, a CNPq agricultural engineering trainee. The training included; research methodologies, experiment designs & field layouts, scientific report and paper writing and use of scientific instruments in the area of soil & water managements, irrigation and hydrology.

(ii) Worked as a faculty member for the irrigation management training program of CODEVASF (San Francisco Valley Development Authority, Brazil) for lectures on irrigation scheduling, and operations and maintenance (O & M) of lift irrigation systems, as a IICA/EMBRAPA representative, Feb. 20-25, 1984.

(iii) Provided training to the soil and water management researcher of IPA-Serra Talhada on research methodology in Soil & Water Management.

(b) Seminar:

Delivered a seminar on the progress of the 4 research projects being carried out by me, Aug 8, 1984 .

(c) List of Publications:

(a) Journal Articles:

1- Sharma, Prem N. and Otto J. Helweg. "Optimum Design of Small Reservoir Systems", Journal of Irrigation and Drainage Division, ASCE, Vol. 108, No IR4. pp. 250-264, Dec. 1982.

2- Sharma, Prem N. and Otto J. Helweg. "An Evalutaion of Traditional Small Reservoir Irrigation Systems in

Semi-Arid India", Journal of Agricultural Engineering, ISAE, Vol. XX, No. 3 & 4, pp. 101-110, Sept. & Dec. 1983.

3- Helweg, O.J. and Prem N. Sharma. "Optimum Design of small Reservoirs (Tanks)", Water Resources Research, American Geophysical Union, Vol. 19, No. 4. pp. 881.885, Aug.1983.

4- Sharma, Prem N. and E. R. Porto. "Research Strategy for the Improvement of Land and Water Resources of Northeast Brazil", Journal of Rural Development of the Americas (DRELA), Dec. 1983.

5- Sharma, Prem N., et al., "Runoff Inducement for Agriculture in very Arid Zones of the Northeast of Brazil", Brazilian Journal of Agricultural Research (PAB), Brasilia, Vol. 19, Nº 8. pp 1011-1019, 1984.

6- Sharma, Prem N. and O.J, Helweg, "Problems with traditional Small Reservoir Irrigation Systems in Semi-Arid Tropics", Transactions of American Society of Agricultural Engineers, ASAE, Vol. 27, No. 6, Nov.-Dec. 1984.

7- Helweg, O.J. and Prem N. Sharma. "Optimum Design of Small Reservoirs", Water Resources Journal, United Nations Economic and Social Commision for Asia and Pacific, Natural Resources Division (to be reprinted), Dec, 1984.

(b) Conference Papers:

8- Sharma, Prem N. and O.J. Helweg, "A Nonlinear Model for Optimization of Small Reservoir Irrigation Systems for Semi-Arid Tropics", 1st Brazilian Symposium on Semi-Arid Tropics, held at Olinda (PE), Brazil, Aug. 1982.

9- Sharma, Prem N. and Faustino B. Alonso Neto, "Water Production Function of Sorghum for the Northeast Brazil", A paper presented at the XIV Congress of Brazilian Society of Agricultural Engineers, held at Fortaleza, CE Brazil, from July 23-27, 1984.

10- Helweg, O.J. and Prem N. Sharma, "An Aprroach to Economic Analysis of Water Resources Systems Under High Rainfall Uncertainity", 1st Brazilian symposium on Semi-Arid Tropics, Olinda (PE), Brazil, Aug.1982

(c) Reports

11- Annual Report of the 4 research projects-submitted to EMBRAPA, Aug. 1984

12- Various trimestral reports submitted to IICA quarterly, 1984.

(d) List of Collaborating Personnel of EMBRAPA/CPATSA:

The following personnel of EMBRAPA/CPATSA have collaborated at same stage or other of the research work reported here:

Collaborators :

Aderaldo de S. Silva - Researcher

Everaldo R. Porto - Researcher (up to July 1984)

Partial Collaborators:

Eliane N. Choudrury - Researcher (up to July 1984)

Ribamar Pereira - Researcher

Carlos A. Oliveira - Statisticion

Field Assistance:

Silvio Clementino da Cruz - Agricultural Technician

Faustino B. A. Neto - Agricultural Engineering Trainee
(up to Oct. 1984)

Administration:

Clovis Guimarães Filho - Coordinator PNP 030

Edson Lustosa de Possídio - Tecnical Chief - CPATSA

Pedro Maia da Silva - Adm. Chief - CPATSA

Renival Alves de Souza - Director - CPATSA

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