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

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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	

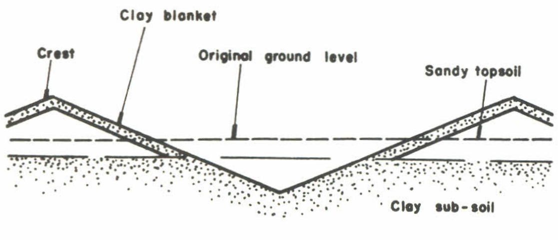

FIG. 1. Cross section through adjacent roads in a roaded catchment.

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

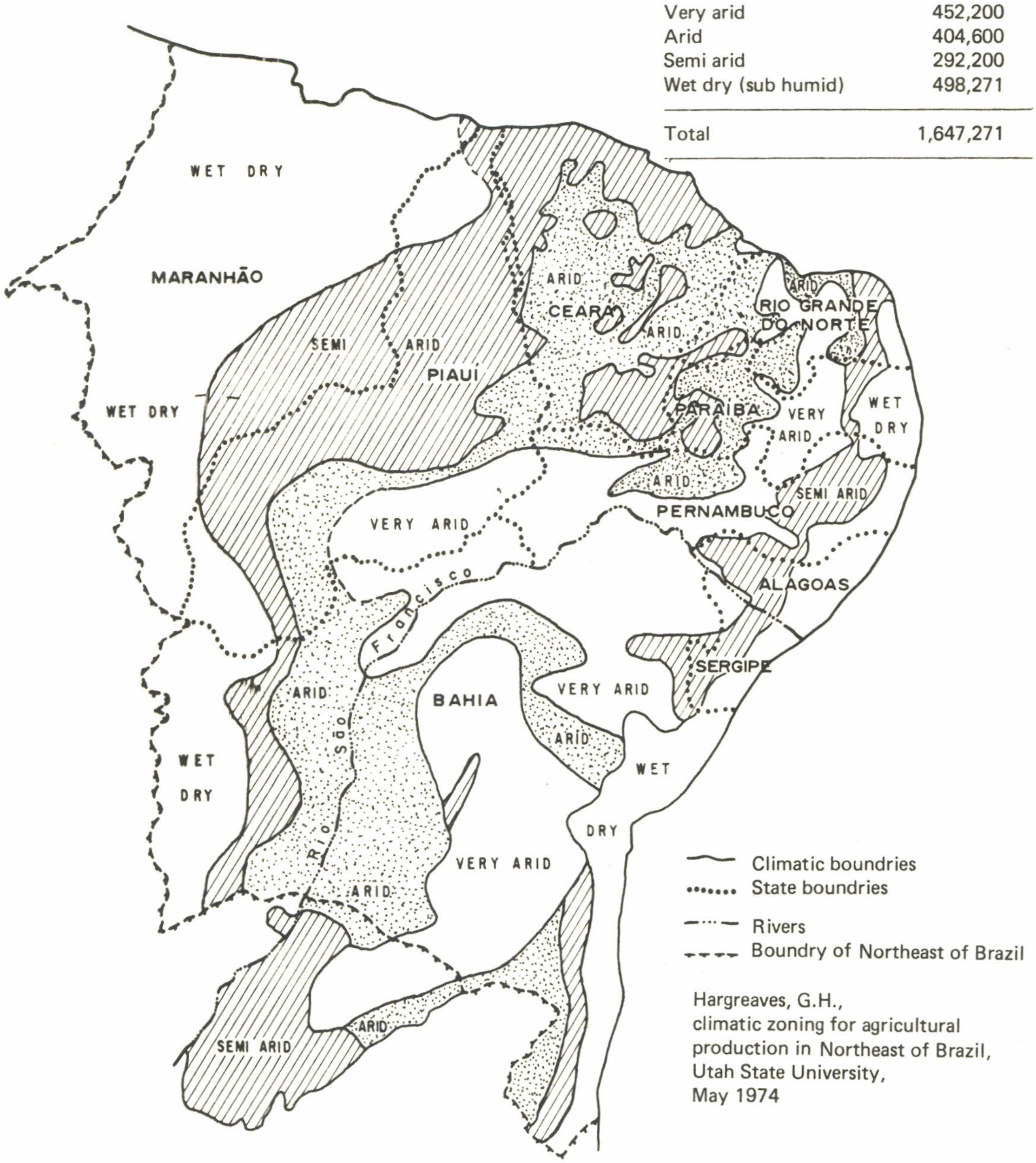

FIG. 2. Climatic classification for Northeast Brasil.

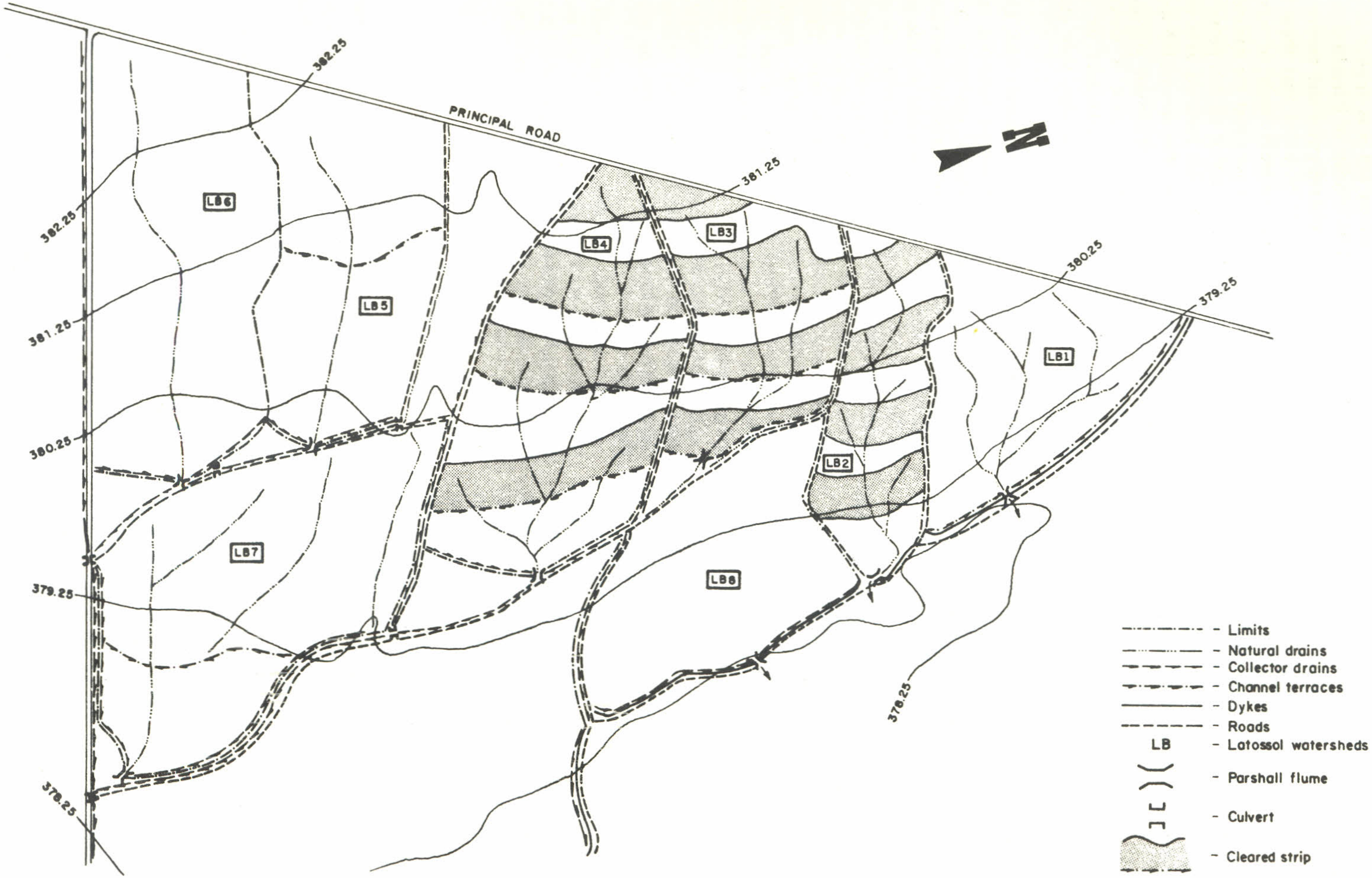

FIG. 3. Latosol watersheds with different runoff inducement treatments, scale 1:4285.

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.

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