PN-ABK-282

C7-021

FINAL REPORT
SEPTEMBER 1987 TO JANUARY 1992

Submitted to the Office of the Science Advisor
U.S. Agency for International Development

YIELD IMPROVEMENT OF UPLAND RICE THROUGH MORE EFFICIENT UTILIZATION OF RAINFALL IN COSTA RICA

J. Lomas
TAHAL Consulting Engineers Ltd.
H. Herrera
National Meteorological Institute

Project No: 936-5544
Grant No.: DPE-55-44-G-SS-7026-00/01

A.I.D. Grant Project Officier: Ms. Joyce Frame
Project Duration: September 1987 to January 1992

R-91-29
November 1991

Rec'd in SCI JAN 3 1992

FINAL REPORT
SEPTEMBER 1987 TO JANUARY 1992

Submitted to the Office of the Science Adviso:
U.S. Agency for International Development

YIELD IMPROVEMENT OF UPLAND RICE THROUGH MORE EFFICIENT UTILIZATION OF RAINFALL IN COSTA RICA

J. Lomas
TAHAL Consulting Engineers Ltd.
H. Herrera
National Meteorological Institute

Project No: 936-5544
Grant No.: DPE-55-44-G-SS-7026-00/01

A.I.D. Grant Project Officier: Ms. Joyce Frame
Project Duration: September 1987 to January 1992

R-91-29
November 1991

TAHAL CONSULTING ENGINEERS LTD

AÑO DEL CENTENARIO 1888-1988
INSTITUTO METEOROLOGICO COSTA RICA

TABLE OF CONTENTS

1. Executive Summary
2. Research Objectives
3. Methods and Results
3.1 Methods
3.2 Results
3.2.1 Rainfall Characteristics
3.2.2 Rainfall - Runoff Relationships
3.2.3 Rainwater Gain Due to Ridging
3.2.4 Effect of Ridging on Soil Moisture
3.2.5 The Growth, Flowering and Ripening of the Rice Crop and Its Yield
3.2.6 Discussion
4. Impact, Relevance and Technology Transfer
5. Project Activities
6. Project Productivity
7. Future Work

APPENDIX

1. Monthly Rainfall Amounts (mm) during Experimental Season at Liberia.
2. Agriculture
2.1 Physical Environment
2.2 Climate

1. Executive Summary

Ridging of rainfed - upland rice reduced runoff. The amount of rainfall "saved" for the rice crop will be a function of both rainfall intensity (mm/h) and daily rainfall amounts (mm/d). The rainfall intensity threshold value at which runoff occurs is approximately 10 mm/h at the control plot and approximately 25 mm/h at the ridged plots. Ridging reduced runoff. At rain intensities of 20-40 mm/h by 5-10 mm and at 40-60 mm/h by 10-25 mm. The rainwater saved by ridging will be approximately 55-146 mm calculated from the frequency distribution of long term rainfall intensities, during the rice growing season (July-November).

Reduced runoff increases soil moisture during the reproductive period by some 5-15% (soil moisture by volume) and increased in rice yields. The increase ranged from 10% during a drought year to 29% during a year with average rainfall.

This technology required little, if any capital investment and it can be applied in relatively flat agricultural areas (slope up to 1.5%) for which rainfall intensity data are available.

2. Research Objectives

The objective of this research was to determine the amount of rainfall that could be saved for the rice crop by reducing runoff. It was assumed that reduced runoff would increase soil moisture and consequently rainfed rice yields.

A theoretical growing season water balance indicates that out of seasonal rainfall of some 1.225 mm some 440 mm may be lost to the rice crop. The runoff lost to the crop could be saved by suitable agrotechnology and it was estimated that rice yields be increased by some 200-400 kg/ha. (Lomas and Herrera, 1985).

This project was supported by the rice growers association, as well as the agricultural extension officers of the Ministry of Agriculture.

Most of the rice growing farmers are smallholders that can benefit considerably by an increase in yield provided that no large capital investment is necessary. Small ridges aimed at reducing runoff, increasing soil moisture and final crop yields are a technology that can easily be applied.

3. Methods and Results

3.1 Methods

1. A detailed study of the rainfall intensities for 3 stations with 12 years of rainfall records was carried out in order to establish rainstorm characteristics.

2. Field Experiments during three growing seasons, were undertaken to determine the effect of ridging on the reduction of runoff and rice yield responses. The experimental plots consisted of a ridged basin plot of 100 sq.m and a control plot of 100 sq.m, separated by a small plot of 2 m where the runoff studies and observations on rice growth and development took place.

3. The field data obtained from the runoff experiment, the measurements of soil moisture and the observations and measurements of the rice crop were analysed. The data obtained from the ridged plot was compared to that obtained from the control plot.

   The pooled 3 year data on runoff was analysed statistically and a non-linear multiple correlation was used between rainfall intensities and daily rainfall amounts as independant variables and runoff as the dependant variable to establish a model. This model was then used to calculate runoff differences. The scatter diagram shows the range of observational data.

4. Training seminaries and field days were held to explain and to demonstrate the new technology.

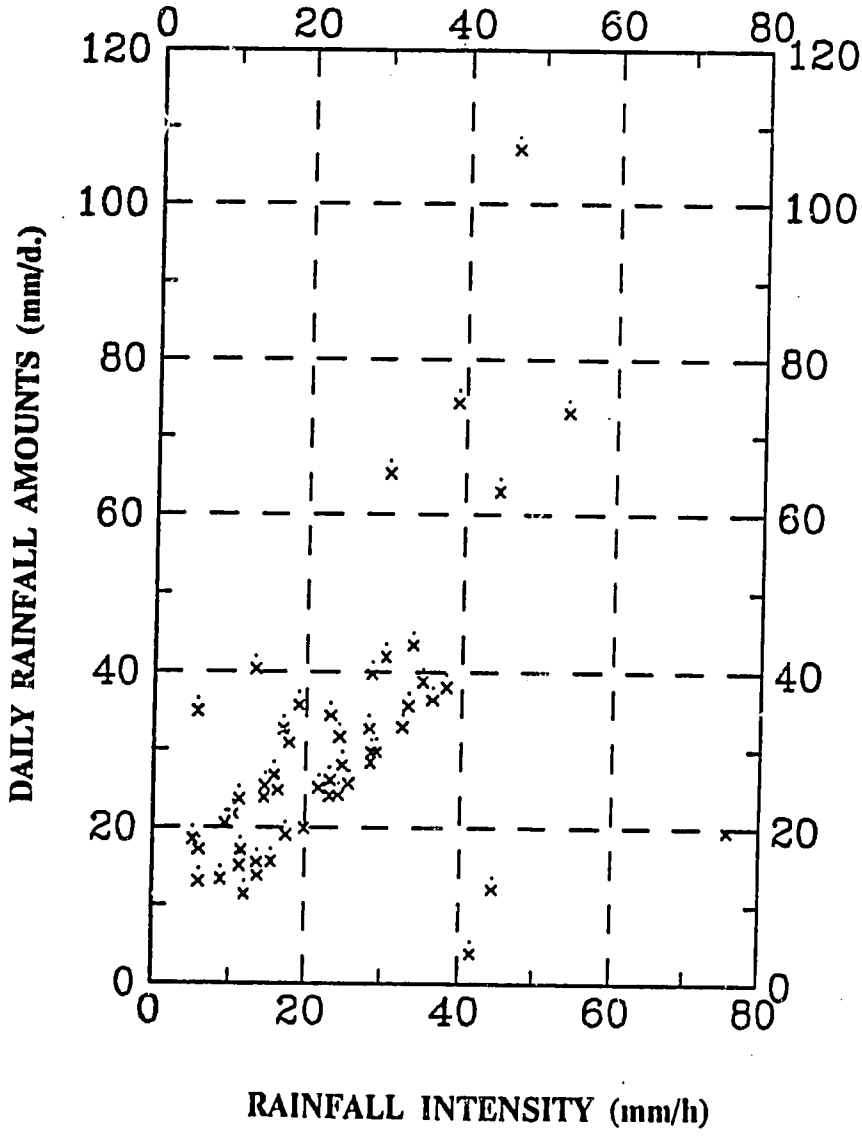
3.2 Results

3.2.1 Rainfall Characteristics

Rainfall during the rice growing season for the three experimental years 1988-1990 was very different. 1988 was a wet year, 1989 was a normal year with well distributed rainfall, while in 1990 drought conditions occurred early in the rice growing season. For the monthly rainfall amounts see Appendix 1.

During the 3 year experimental period there were 93 rainfall days of which nearly half (41 rain days) had rainfall intensities of 0.1 to 4.0 mm/hour and had no runoff. On 52 rain days with rainfall intensities of 4.1 mm/hour and above runoff was measured. The average expected rainfall intensity distribution of a three year period based on an analysis of 12 years 1975-1987, and the rainfall intensity distribution measured during 1988-1990 are shown in Fig. 1.

Figure 1



Scatter diagram showing the rainfall intensities (mm/h) and the daily rainfall amounts (mm/d) at which runoff measurements were made.

There is fairly good agreement between the expected mean rainfall intensity distribution, based on long term climatic analysis of rainfall intensity measurements at Liberia, and those measured during 1988-1990. Indeed at the higher rainfall intensities of 24.1 mm/hour and above the number of measured occurrences during the experimental period were 24 as compared with 12 expected in an average 3 year period. The daily rainfall amounts (mm/day) and the maximum rainfall intensities (maximum mm/hour) correlated poorly (r2 = 0.233).

3.2.2 Rainfall - Runoff Relationships

Measured runoff correlated poorly with rainfall intensities or daily rainfall amounts. Table 1, presents the correlations obtained. The best correlation was obtained between the log of runoff and the log of rainfall intensities, accounting for some 23% of the variance of runoff from the control plot and some 35% of the variance of runoff from the ridged plot.

TABLE 1: CORRELATIONS BETWEEN RUNOFF AND RAINFALL INTENSITIES, DAILY RAINFALL AMOUNTS AND BOTH INTENSITIES AND AMOUNTS FOR THE CONTROL AND RIDGED PLOTS (n = 52)

TREATMENT / CORRELATIONS	CONTROL r^2	RIDGED r^2
Runoff (mm) - Rainfall Intensity (mm/h)	0.219	0.140
Runoff (mm) - Log Intensity	0.201	0.104
Log Runoff - Intensity (mm/h)	0.135	0.240
Log Runoff - Log Intensity	0.227	0.349
Runoff (mm) - Rainfall Amount (mm/d)	0.262	0.176
Runoff (mm) - Log Amount	0.228	0.134
Log Runoff - Rainfall Amount (mm/d)	0.303	0.321
Log Runoff - Log Rainfall Amount	0.353	0.409
Multiple Regression* (non linear)		
Runoff (mm) - Rainfall Intensity (mm/h) and Daily Amount (mm/d)	0.647	0.574

*Z = ai + bi + cj + dj2 + eij + f
where:
Z = runoff
i = rainfall intensity
j = rainfall daily amount
a,b,c,d,e and f regression coefficients

Correlation between runoff and daily rainfall amounts gave only slightly better results. The best correlation was obtained between the log of runoff and the log of rainfall amounts, accounting for 35% of the variance of runoff from the control and some 41% of the variance of runoff from the ridged plot. The best results were obtained with non linear multiple correlations between both rainfall intensities and daily rainfall amounts and runoff, accounting for some 65% of the variance from the control and 57% of the variance from the ridged plot.

Making use of the above relationship runoff values were plotted using rainfall intensities and daily rainfall amounts as independent variables and runoff as the dependent variable. The results are presented in Fig. 2 for the control (A) and ridged (B) plots. The difference in runoff between the control and ridged plots were then calculated by grid points from Fig. 3A and Fig. 3B and is presented in Fig. 3C.

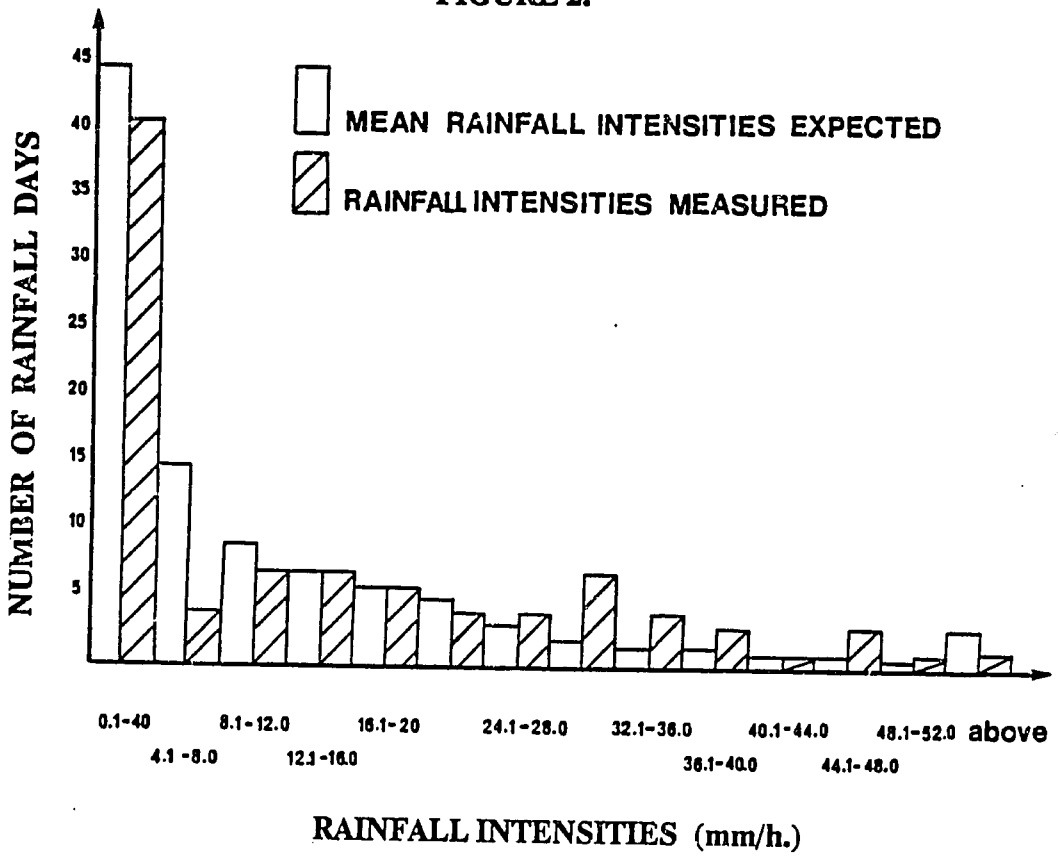
Runoff at the control plot will occur once rainfall intensities reach 10 mm/h and at least 10 mm of rainfall was recorded on that day. As rainfall intensities and daily rainfall amounts increased so will runoff. It seems that increased rainfall intensities only but no increase in daily rainfall amounts will have little, if any, effect on runoff. At rainfall intensities of 45 mm/h or more provided there is 40 mm or more of daily rainfall, nearly all the rainfall is lost to runoff.

Ridging of the ground significantly reduced runoff. In the first place runoff only occurs when rainfall intensities where 25 mm/h or more and at least 20 mm of rainfall was recorded on that day. As in the control plot, increasing rainfall intensities only, do not increase runoff. However as rainfall intensities and the daily rainfall amounts increase so does runoff. At rainfall intensities of 60 mm/h or more provided there is above 60 mm of daily rainfall, nearly all the rainfall is lost to runoff.

3.2.3 Rainwater Gain Due to Ridging

The expected gain in rain water due to reduced runoff from the ridged plot is presented in Fig. 3C. The greatest rainwater gain occurs at rainfall intensities of some 50-55 mm/h and daily rainfall amounts of some 70-85 mm/d. However such rainfall events occur only once in a year or so. The greatest real rainwater gain will be due to the great numbers of rainfall events at relatively lower rainfall intensities. The runoff gain due to ridging is presented in Table 2.

FIGURE 2:



The average expected rainfall intensity distribution based on 12 years of measurements (1975-1987) compared with rainfall intensities measured during the experimental period (1988-1990)

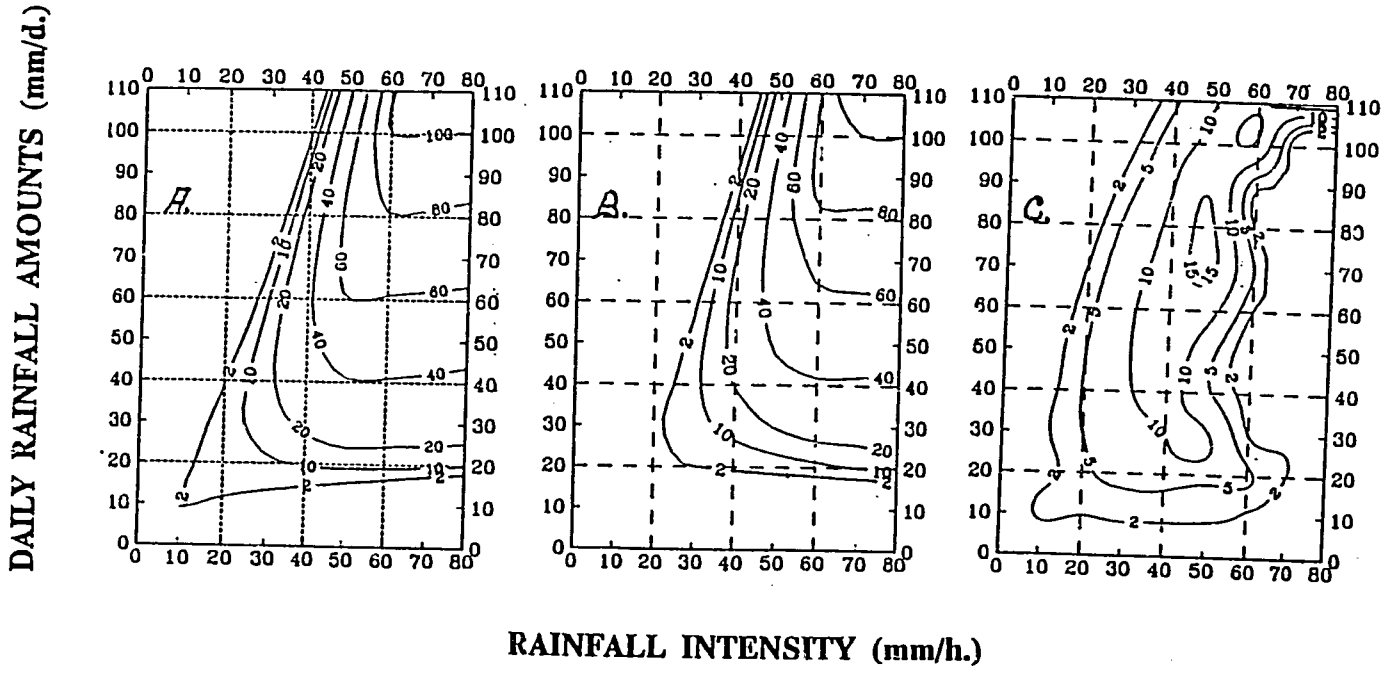


FIGURE 3:

Calculated values of runoff (mm) from the Control Plot (A) and the Ridged Plot (B) based on non-linear multiple regressions between runoff and rainfall intensities and daily rainfall amounts. Experimental data, Liberia 1988-90. Runoff gain calculated by means of smoothed differences in runoff between control and ridged plots by grid points (C).

CN/210/FRCDR-2

TABLE 2: RUNOFF GAIN DUE TO RIDGING CALCULATED FROM THE MEAN EXPECTED RAINFALL EVENTS AND THE REDUCTION OF RUNOFF AS SHOWN IN FIG. 2c FOR THE RICE GROWING SEASON
July-October

Rainfall Intensity mm/h	No. of Mean Rainfall Events	Rainfall Gain mm	Total Gain mm
0.1 - 12.0	43.7	0	0
12.1 - 24.0	11.7	2 - 5	23.4 - 58.5
24.1 - 40.0	5.3	5 - 10	26.5 - 53.0
40.1 - 60.0	2.3	15 - 20	4.6 - 34.5
Total	62.7		54.5 146.0

As can be seen from Table 2, most of the runoff gain is due to rainfall intensities of 12.1 to 40.0 mm/h. The total expected rainwater gain will be some 55-146 mm during the rice growing season of July to October in an average rainfall year.

The average calculated rainfall gain is some 55-146 mm compared to an average measured runoff gain of some 148 mm. Actual measured runoff during the 3 year experimental period is presented in Table 3.

TABLE 3: SUMMARY OF THE RUNOFF MEASUREMENTS DURING EXPERIMENTAL PERIOD 1988-1990, LIBERIA

Year	Planting Date	Period of Runoff Measurement	No. of Raindays With Measured Runoff	Runoff mm	Source Progress Reports
1988	10 July	10 Sept - 3 Nov	14	73.4	Table3.1 Report 5
1989	12 June	22 July - 26 Sept	18	159.9	Table 3.1 Report 5
1990	4 July Replanted	17 June - 21 Oct	19	210.0	Table 3.2 Report 6

3.2.4 Effect of Ridging on Soil Moisture

Rice requires ample and a regular moisture supply because of its semiaquatic nature and because of the relative shallowness of its root system. During the 3 year experimental period the soil has been carefully removed around the rice plants on 6 occasions to show that some 92- 96% of all the roots are to be found in the top 30 cm of soil.

The effect of ridging on soil moisture during the reproductive period of the rice crop for 1988 and 1990 is shown in Fig. 4. Large and consistent differences of some 10-15% of soil moisture by volume can be seen during the reproductive stage in 1988 up to a depth of some 30 cm. During the reproductive period of 1990 consistent but rather smaller differences in soil moisture of some 5-6% by volume can also be seen. Significant differences in soil moisture were measured up to a depth of some 30 cm. At depth greater than 30 cm there seems to be no significant difference in soil moisture.

3.2.5 The Growth, Flowering and Ripening of the Rice Crop and Its Yield

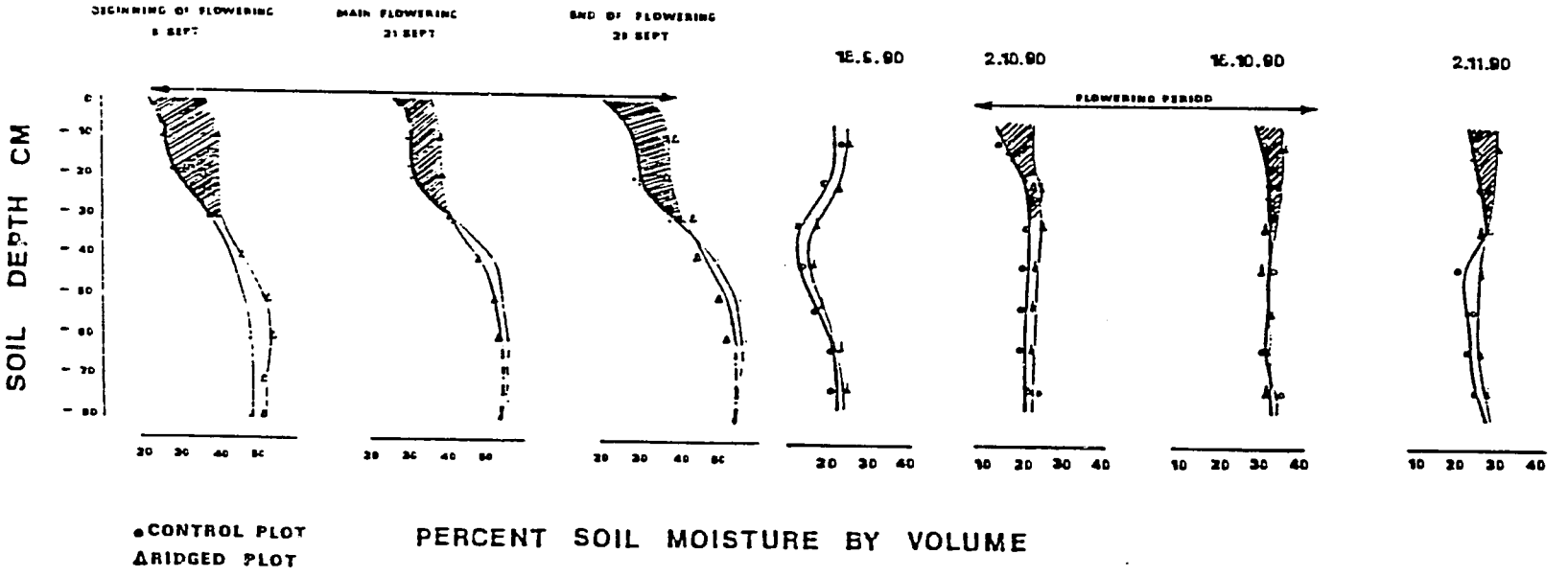
The rice crop is usually planted during the month of June, following some adequate rainfall at the end of May, flowering at the end of September and being harvested during November. The development stages of the rice crop during the experimental period is shown in Table 4.

TABLE 4: PLANTING, FLOWERING, RIPENING AND THE DURATION OF THE RICE GROWING SEASON FOR 1988-1990, LIBERIA

Phenology / Year	Planting	Flowering	Ripening	Duration Days
1988	July 10	Sept 5	Nov 11	123
1989	June 12	Aug 19	Oct 21	123
1990	June 27/July 4	Oct 10	Nov 21	140

During the three year experimental period only in 1990 was the rice crop replanted. Drought conditions continued during July, August and half of September. Once replanted there was a very poor plant stand and little if any growth until the end of September. The rice was only 48-50 cm high when flowering and had an extremely poor stand (130-145 plants/m2). Table 5 presents some of the basic rice crop data for the control and ridged plots.

FIGURE 4:



Soil moisture profiles comparing ridged and control plots of rice during the reproductive period, Sept. 1988 and Oct. 1990 at Liberia.

RICE CROP DATA
FOR EXPERIMENTAL PERIOD 1988-1990, LIBERIA

Years / Crop Components	1988 Control	1988 Ridged	1989 Control	1989 Ridged	1990 Control	1990 Ridged
Final Crop Height (cm)	78 - 81	80 - 83	71 - 74	73 - 75	48 - 50	48 -51
No. of Leaves/Plant	5.2	5.3	5.4	5.4	4.7	4.9
Average Leaf Area (cm2)	25.1	26.4	26.8	26.7	23.7	24.1
No. of Plants/m2	227	247	530	540	129	146
Lai at Maturity	2.96	3.46	7.67	7.78	1.44	1.72
No. of Grains/Plant	103	109	92	88	37	38
Mean Weight/1000 grains	21.1	21.5	15.7	21.0	20.9	22.6
Yield of Grains t/ha^{-1}	4.94	5.78	7.68	9.90	2.26	2.48
Differences in Yield						
kg/ha	+840		+2220		+220	
%	+17.0%		+28.9%		+9.7%	

There was no significant difference in plant height between the control and ridged plots, or the onset of the major phenological stages, vegetative, reproductive and maturity. There was also no significant difference in the number of leaves per plant, or the leaf area per plant. However, there was a significant difference in the number of plants per m2 for 1988 and 1990 (but not for 1989) and in 1989 in the mean weight of 1000 grains. Finally, the ridged plot gave higher yields every year. Differences in yield ranged from nearly 10 to 29%.

3.2.6 Discussion

Ridging reduced runoff from the rice crop at rainfall intensities ≥12.0 mm/h, except on extreme rainfall events when rainfall intensities exceeded some 65-70 mm/h. The amount of rainwater gained increases with rainfall intensity and daily rainfall amounts, and is greatest at some 50 mm/h of rainfall intensities with some 65-85 mm of daily rainfall, when runoff can be expected to be some 15 mm. However, the number of such rainfall events is very small. Table 6 presents the calculated rainwater gain due to ridging at 3 rainfall intensity levels for the whole rainfall season.

TABLE 6: THE AVERAGE NUMBER OF RAIN DAYS AT LIBERIA FOR THE DIFFERENT RAINFALL INTENSITIES AND CALCULATED REDUCTION OF RUNOFF.

Month	Number of Raindays at Given Rainfall Intensities			
	10.1 - 20.0 mm/h	20.1 - 40.0 mm/h	40.1 - 60.0 mm/h	
May	2.0	2.0	0.2	
June	2.8	2.4	0.2	
July	1.6	1.3	0.7	
Aug	1.9	1.6	0.7	
Sept	3.0	2.8	0.2	
Oct	4.2	2.2	0.7	
Nov	1.0	0.8	0.2	
Total No. of Raindays	16.5	13.1	2.6	
Expected Average Rainwater Gain/Day/mm	2 - 5 mm	5 - 10 mm	2 - 15 mm	
Expected Total Gain in mm	33 -82.5	65.5 - 131	5.2 - 39.0	=103.2-252.5

The growing period of the rice crop is of course of some 120- 140 days only and consequently the amount of water gained will be less than that for the whole rainfall season. The calculated values of runoff gain during the rice growing season and the measured values are presented in Table 7.

TABLE 7: CALCULATED AND MEASURED RUNOFF FROM THE RIDGED PLOT

Year	Period of Measurement	Calculated		Measured	
		No. of Raindays	Runoff mm	No. of Raindays	Runoff mm
1988	Sept - Oct	13.2	41.4 - 99.0	14.0	73.4
1989	July - Sept	13.5	46.5 - 102.5	18.0	159.9
1990	June - Oct	19.6	62.0 - 157.5	19.0	210.0

The measured values for 1989 and 1990 exceed the calculated values due to one rainfall event each year with considerable rainfall amounts and intensities.

The higher yields obtained with ridging are due to the lower soil moisture stress experienced by the plants in the ridged plots, as well as the higher photosynthetic potential, due mainly to a larger plant population.

4. Impact, Relevance and Technology Transfer

During the project a number of meetings and a workshop took place where and opportunity was taken to present the provisional result to the agriculture extension officers and the large rice growers. In addition the methodology used in this project has been amply demonstrated to the Ministry of Agriculture and the University. Indeed in an ongoing project some of this technology is already being applied.

Herrera, H. and Rojes, O. of the National Institute of Meteorology and the University of Costa Rica are using now similar technique of runoff measurement to investigate the water balance of maize crop at the experimental farm of Favio Baudrit in the Central Valley of Costa Rica.

Due to the project experience has been gained by Costa Rican scientists and technicians in the field measurements of the water balance especially runoff. Before this experiment there was no practical experience in field installation, measurement and management of sets of runoff batteries under tropical rainfall conditions. This expertise will remain in Costa Rica.

The Camara de Granos Basicos supported the project offering sites for field measurements. The National Meteorological Institute provided long term rainfall data. The application of the results of this project seemed to justify large scale trials in the dryer regions. Some of the large rice growing farmers are already applying ridging. The application of the results by the small farmers is more doubtful due to the lack of extension facilities.

5. Project Activities

The following meetings with institutions (1. 2.) farmers (5.) and technology transfer courses (3. 4.) were held during the project.

Institution	Date	Objective
1. Camera de Gramas Basicos Director H. Cappela	19/1/1998 25/1/1988	Explain experiment and benefits, obtained assistance with experimental sites.
2. Officina de Arroz Lic. L. Ploinaris	3/8/1988	Present project objectives, explained possible benefits
3. Short course on Climate and Rice Production in Guanacaste	June 1989	Presentation of partial results. Relationship between climatology and rice production.
4. Conference for professionals and technicians of Ministry of Agriculture and MET service and other agricultural interest. The Agroclimate of Guanacaste H. Herrera The Water Requirements of Rice J. Lomas Rainfall Intensity Analysis of 3 Stations Guanacaste H. Herrera Cultivation Methods, Water Conservation and Rice Yields J. Lomas	July 1989	Presentation of Partial Results
5. Meeting with many individual farmers in Guanacaste	Feb 1988 to March 1990	Presentation of Partial Results

6. Project Productivity

The project accomplished most of the proposed goals. The basic field data obtained was of high quality at Liberia and 3 years of experimental data was obtained (1988-1990) and not 2 years as planned (1989-1990). However, we were not successful in obtaining reliable experimental data from Santa Cruz due to the very heavy soil which made the installation of the runoff batteries under local conditions impossible. The distances of the field experimental sites from San Jose also presented some operational difficulties.

7. Future Work

The project could lead to the testing of the technology proposed under commercial field conditions. Many of the countries of Central America experience drought conditions on the Western Coast and this method could be tried. A preliminary rainfall analysis could indicate the approximate rainfall runoff that is likely to be saved for the rice crop.

APPENDICES

APPENDIX 1

Monthly rainfall amounts (mm) during the three experimental seasons at Liberia, Costa Rica.

	June	July	August	Sept.	Oct.	Total
1988	475.3	172.1	378.4	364.5	405.9	1796.2
1989	119.3	127.1	292.0	499.8	100.7	1138.9
1990	71.4	100.1	112.8	185.1	325.3	794.7

APPENDIX 2

AGRICULTURE

Agriculture in Costa Rica contributes about 25 percent of the Gross National Product, accounts for more than 90percent of all exports and employs about half of the labour force. Major food crops are: coffee, banana and cacao.

The success of cropping practices depends on climatic condition, soil, genetic potential of the plant and improved technology. Adverse climate and weather and the occurence of flooding, droughts and plagues, may cause crop failures and a decline in production which affects the national economy and the prosperity of the population. Severe drought during 1982 on the Pacific region had a disastrous impact on the local agriculture. Significant year-to-year variations in seasonal rainfall can be expected to continue and to be a dominant factor in determining the level of food production.

1. PHYSICAL ENVIRONMENT

Costa Rica is located in the Central American Isthmus betwee 8 and 11 north latitude and between 83 and 86 west longitude. It is bordered on the north by Nicaragua and on the south-east by Panama. The total land area of the country is 51,000 sq.km. The mountain ranges extending from the north-west to the south-west nearly form a continuous divide between the narrow strip of lands on the Pacific coast and the broad extension of the Caribbean coast.

The Pacific coast is 965km long, and marked by two mountain peninsulas: the Nicoya Peninsula in the north-west and the Osa Peninsula in the south-west. Rivers in this region are characterized by high water flow variability due to the seasonal precipitation regimen.

The Atlantic region occupies about 30 percent of the total land area, the 200km long coast is level and open to the sea, contrasting sharply with the Pacific coast.

The Central Mountain region makes up about 20 percent of the country's area. The major mountain ranges are: the Volcanic range which includes Guanacaste mountains, with a high elevation of about 2,000m; Tilarin mountains, with the highest point being 1,633m; the Central Mountain chain reaching 3,400m and the Talamanca range that reaches 3,819m.

The population of Costa Rica (2.6million in 1980) is mainly concentrated on the Meseta Central where the capital city of San Jose and four other major cities are located.

2. CLIMATE

The climate of Costa Rica is tropical humid (Trewartha, 1968) and is mainly determined by: latitude, topography and large scale atmospheric circulation systems, such as the trade winds which are associated with the Intertropical Convergence Zone (ITCZ) seasonal migration. Also local winds such as mountain-valley and sea-land breeze circulation and atmospheric disturbances such as hurricanes, eastern waves and cold fronts, developed in the Caribbean Sea, play an important role in regional climate conditions.

Taking into consideration the major climate components, the territory can be divided into four regions: Norther Pacific region, Southern Pacific region, Central region, and Atlantic region (Figure 2.5).

A. NORTHERN PACIFIC REGION

This region has two rainfall seasons, a dry season from December to April and a wet season from May to November. The wettest months are June and September. From July to August there is a period known as "veranillo" when there is relatively little rain. The mean annual rainfall is about 1,400mm in the low-land areas and 2,500mm in the high- lands. The mean annual temperature is between 23 and 24C in the low-lands and around 21C in the Guanacaste mountains. The relative humidity varies from 65 percent during the dry season to 90 percent in the wet season. The trade winds are weaker during the wet season and the penetration of winds and sea breeze from the Pacific Ocean provides more moisture to the region.

B. GUANACASTE PROVINCE

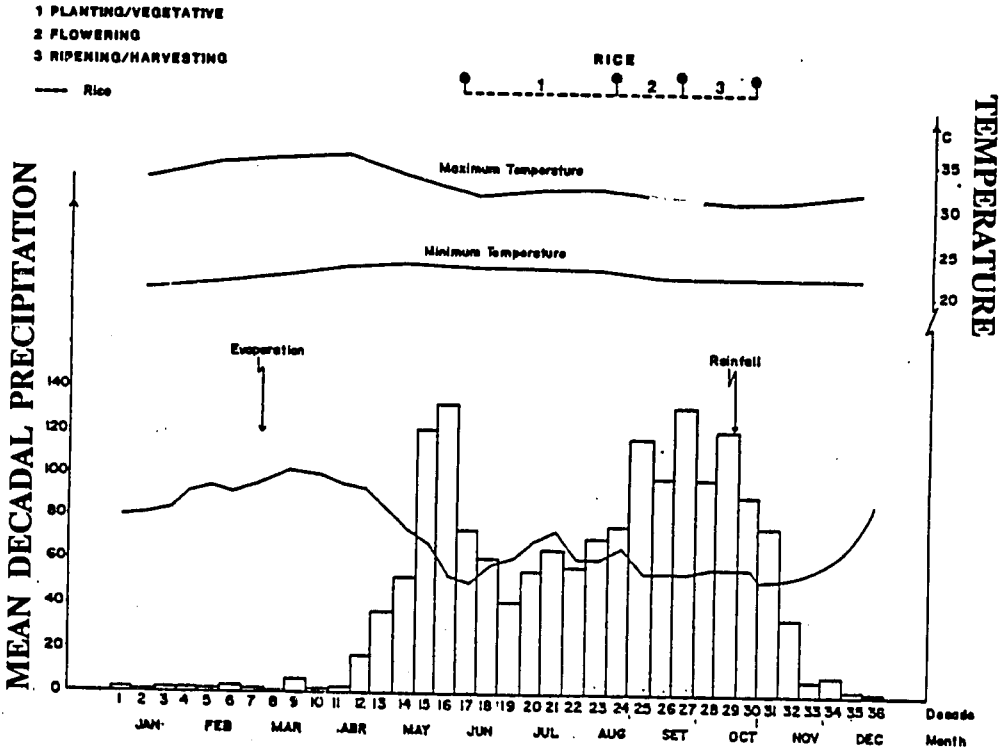
The Guanacaste province is located in the north-west corner of the territory of Costa Rica between 931' and 11 north latitude and between 85 and 86 west longitude. The total area is about 10,000km2 and comprises approximately 20 percent of the total country area.

Parallel to the Guanacaste Plain, the Cordillera de Guanacaste stretches for 112km from the western border with Nicaragua to the Cordillera Central from which it is separated by low mountains. The highest peak in the Guanacaste chain is the Miravalles volcano (2,200m above sea level).

Most soils in the Guanacaste area are fertile. Those of the northern plain and the areas east of the Tempisque River valley are of recent volcanic origin, while those of the Tempisque River valley itself are alluvial. Soils on most of the Nicoya Peninsula, however, are intensely weathered soils of the lateritic (iron and aluminum bearing) groups. The vegetation of the plain was once predominantly open deciduous forest, but most of this has been transformed into tropical savanna grasslands by slash-and-burn cultivators.

The eastern slope of the Guanacaste chain blocks the northeast trade winds, protecting the plain from heavy, constant Caribbean rains. The 1,000m coastal mountains of the Nicoya Peninsula also act as a watershed for the rainbearing south-west winds that blow from May through October. Thus, the lowlands of Guanacaste, lying in the lee of both mountain ranges, often suffer from drought even during the rainy season.

The mean climatic values at Liberia and the mean phenological stages of upland rice is shown in the figure below.



Mean decadal climatic values at Liberia and mean phenological stages of rice. Evaporation USWB Class A pan.