Costa Rica: Instituto Meteorologico Nacional

Roberto Villalobos and José Retana

Introduction

Agriculture constitutes 19% of the annual GDP in Costa Rica, making it the second most important activity of the GDP. The number of people working in this sector shows its importance; it constitutes 24% of the economically active population.

Costa Rica shows a strong ENSO influence on climate variability. Since agriculture is highly important in Costa Rica, weather variability may have major economic and social impacts. In Costa Rica, we will characterize the ENSO impacts on climate and bean crop in the Northern Caribbean area (Los Chiles), and on rice crop in the Northwestern Pacific area (Liberia).

I. Characterization of study region

1.1. Northern Caribbean area: Los Chiles

1.1.2. Geographical position

Los Chiles is located at latitude 10°51' north and longitude 84°40' west, and at 43m above sea level (Figure 1). The maximum width is around 50 km, northeast-southwest, from the Hito No 6 in the frontier with the Republic of Nicaragua, on the east river bank of Poco Sol through the Rito River flow (Chinchilla, 1987).

1.1.3. Cartographic location and geographical situation

The study region is located in the cartographic sheet: "Los Chiles, Medio Queso, Zapote"; scale 1:50.000. This area belongs to the XIV region, Los Chiles, Alajuela. Elevations above sea level are: Los Chiles city (43), Villa Caño Negro (33), Villa El Amparo (44), Villa Porvenir (70) (Chinchilla, 1987).

1.1.4. Relief

The region is characterized by its undulating-flat relief with slopes of 5-15% and an average height of 43m above sea level. Northeastern slopes, though a few, are very rugged, averaging 15-30% (Ginneken and Calderón, 1978).

1.1.5. Hydrography

The fluvial system in Los Chiles corresponds to the North sub-slope of the Caribbean Slope, which belongs to the basins of the Poco Sol, Frío and Zapote rivers. Important rivers are: Hernández, Isla Chica, Sabogal, Purgatorio, Rito, Chambacu, and the Zapote river, which separates Los Chiles from Upala (Chinchilla, 1987).

Figure 1. Costa Rica, Northern Caribbean area (Los Chiles), and Northwestern Pacific area (Liberia).

1.1.6. Vegetation and soil

According to the map of vegetation types of Costa Rica (Gómez, 1986), the prevailing vegetation is Lowland Tropical Rainy Forest. Soils are hydromorphic (Turbas, Gley, and Humics, with little humus). A small region north and east of Los Chiles presents Latosol soil (Pérez, 1978). Traditionally, soils are dedicated to extensive use, with permanent crops, livestock and forest in latosoles soils. According to the *Ecology Map of Costa Rica* (Tosi, 1969), Los Chiles presents bioclimatic conditions, which situate it within the "Tropical Humid Forest" life zone.

1.1.7. Climate

Los Chiles weather is highly influenced by the Caribbean, with a rather dry spell that lasts around the months of February, March, April (IMN, 1991). The map on the Costa Rica weather types (Herrera, 1985) shows the classification of the weather in Los Chiles as "humid very hot," with a slight water deficit (Climate Group D3, Table 1).

Annual Mean Precipitation (mm)	2200-2740
Annual Mean Temperature (°c)	25-27
Annual Potential Evapotranspiration (mm)	1710-1950
Aridity Index (%)	40-60
Hydric Index (%)	10
Dry Season	January, March, April

Table 1. Some characteristics of D3 Climatic Group

1.1.7-1. Precipitation

The mean annual precipitation is 2223.1 mm. March has the smallest mean precipitation with 25.0 mm, followed by April with 33.7 mm. On average, the rainiest months are July, with 333.4 mm, followed by August with 337.7 mm. Some important details about monthly rainfall are in Table 2.

Month	Max.	Year	Min.	Year
Jan	221.7	1989	18.0	1980
Feb	164.2	1997	8.9	1987
Mar	73.8	1986	1.1	1987
Apr	199.2	1981	0.7	1983
May	356.2	1996	10.5	1995
Jun	478.2	1986	101.4	1983
Jul	518.2	1992	204.7	1983
Aug	554.9	1994	66.7	1980
Sep	402.0	1983	123.7	1982
Oct	412.2	1993	96.4	1995
Nov	286.0	1994	101.5	1982
Dec	797.4	1985	71.0	1989

Table 2. Maximum and minimum values of monthly precipitation (mm) in Los Chiles, Costa Rica (1980-1997).
Maximum precipitation in a year: 1985 with 2887.0 mm.
Minimum precipitation in a year: 1982 with 1046.4 mm

1.1.7-2. Temperature

The annual mean temperature shows little variation from one month to another, the annual mean maximum is 30.6°C, and the annual mean minimum is 22.0°C, while the mean is 26.2°C. Figure 2 details the mean monthly behavior of the climate variables under study. At Los Chiles, the lowest mean precipitation is found in March, followed by April. The highest maximum temperature is found in April, while the lowest minimum mean monthly temperature occurs in March. Solar radiation is highest in March and April.

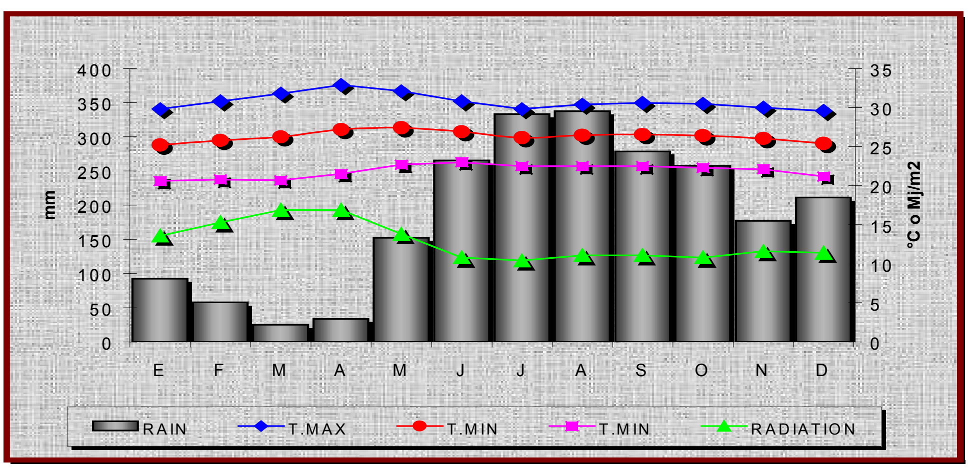


Figure 2. Mean Monthly Precipitation, Temperatures and Radiation, Los Chiles.

1.2. Northwestern Pacific area: Liberia

1.2.1. Geographical position

Liberia is located at latitude 10°41' degrees north and longitude 85°29' degrees west. The maximum width is around 70 km, north-south, from the mountain slope of Orosilito to the Tempisque river, north of La Guinea town, part of Carrillo (Chinchilla, 1987).

1.2.2. Cartographic location and geographical situation

The study region is located in the cartographic sheet: Murciélago, Cacao, Ahogados, Monte Verde, North Carrillo, Belén and Tempisque. This area belongs to canton 1 of Guanacaste. It is situated 144 m above sea level. Its districts and their elevations are: Liberia City (144), Villa Cañas Dulces (105), Villa García Flamenco (366), Villa Guardia (29) and Villa Cerededa (130) (Chinchilla, 1987).

1.2.3. Relief

There are different kinds of relief, but this region is characterized by its undulating-flat relief with some slopes of 5-15%. Specifically, the first district, Liberia, fed by the Tempisque, Ahogados and Hacienda Tempisque rivers, shows a flat-concave relief with slopes of 0-5%. To the northeast of Liberia and near Bahia Culebra, one can see rugged relief with slopes of 15-30%. Mountainous areas, like Santa Marta volcano and the coastal areas of Cero Carbonal and Punta Culebra, have very rugged slopes (30-45%) (Ginneken and Calderón, 1978).

1.2.4. Hydrography

The fluvial system in Liberia is part of the Pacific Slope, and is in the basin of the Tempisque River. This basin has important rivers such as the Colorado, Liberia, Salto, and Tempisquito Rivers, all of which flow from northeast to southeast.

1.2.5. Vegetation and soil

According to the map of vegetation types of Costa Rica (Gómez, 1986), the prevailing vegetation is deciduous and semi-deciduous lowland forest. Soils are Inceptisoles, deep and well-drained Latosoles as well as brownish-red Latosoles planosoles. According to the *Ecology Map of Costa Rica* (Tosi, 1969), Liberia presents bioclimatic conditions that correspond to the tropical dry forest transition.

1.2.6. Hydrometeorological threats

The region near the banks of the Liberia and Tempisque Rivers is threatened by floods. Moreover, the remaining areas of the region are affected by storms, heavy rains and minor droughts (Vahrson and Hernández, 1991).

1.2.7. Climate

The weather in Liberia is influenced by the Pacific, where dry conditions last for approximately six months, from December to May, while the rainy season is from June to November. The map on the climate types in Costa Rica (Herrera, 1985) categorizes the weather in Liberia as: "A1: Sub-moist dry very hot (Table 3)," and "A2: Sub-moist dry, very hot with a moderate surplus of water" (Table 4).

Annual Mean Precipitation (mm)	1300-1700
Annual Mean Temperature (°C)	>27
Annual Potential Evapotranspiration (mm)	<1710
Aridity Index (%)	>20
Hydric Index (%)	-33.3 – 0
Humidity Index (%)	0 –16.7

Table 3. Some characteristics of A1 Climatic Group

Annual Mean Precipitation (mm)	1300-1700
Annual Mean Temperature (°C)	>27
Annual Potential Evapotranspiration (mm)	<1710
Aridity Index (%)	>20
Hydric Index (%)	-33.3 – 0
Humidity Index (%)	16.7 – 33.3

Table 4. Some characteristics of A2 Climatic Group

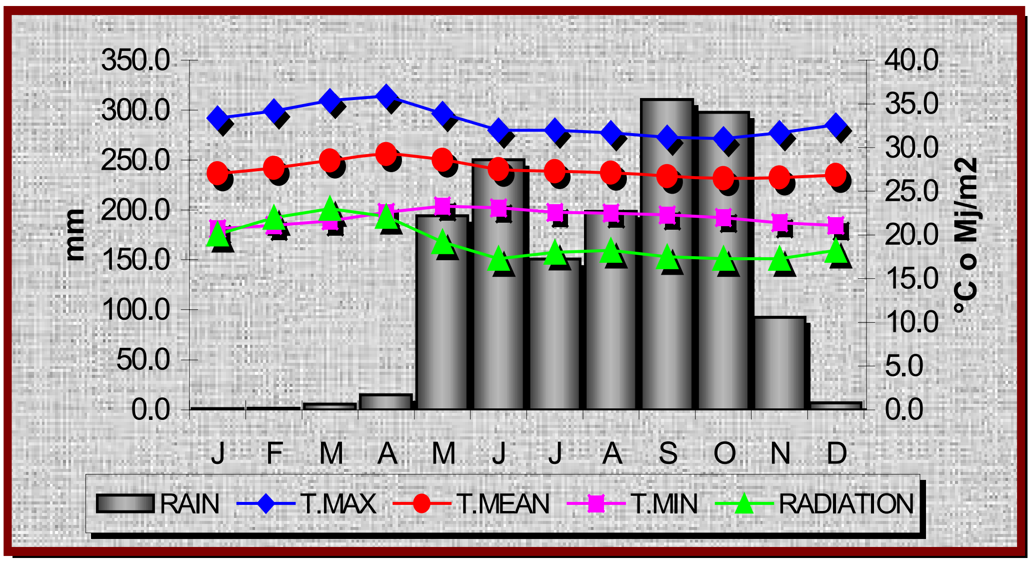


Figure 3. Mean Monthly Precipitation, Temperatures and Radiation, Liberia.

1.2.7-1. Precipitation

The mean annual precipitation at the Liberia station averages 1652.7 mm. The driest months are January with 3.9 mm, February with 12.0 mm, and March with 5.2 mm. September and October are the wettest months, averaging 343.7 mm and 312.0 mm, respectively (IMN, 1986).

Month	Max.	Year	Min./1	Year
J	16.4	1996	0.0	1957
F	24.7	1992	0.0	1957
M	69.5	1980	0.0	1959
A	122.3	1979	0.0	1957
M	629.7	1982	7.5	1967
J	761.4	1979	21.0	1997
J	370.8	1966	10.0	1986
A	527.7	1981	14.6	1982
S	640.4	1979	68.5	1976
O	874.3	1969	0.0	1997
N	509.2	1961	0.0	1972
D	61.4	1978	0.0	1959

Table 5. Maximum and minimum values of precipitation (mm) in Liberia, Costa Rica (1957-1997)

Maximum precipitation in a year: 1996 with 2490.7mm.
Minimum precipitation in a year: 1997 with 552.6mm

1.2.7-2. Temperature

The maximum mean annual temperature is 33.0°C. The minimum mean annual temperature is 22.0°C, and the annual average is 27.5°C.

Months →	J	F	M	A	M	J	J	A	S	O	N	D
Max. T.	33.4	34.2	35.4	35.9	33.9	32.0	32.0	31.7	31.2	31.0	31.7	32.6
Min. T.	20.7	21.1	21.6	22.6	23.3	23.1	22.6	22.5	22.3	22.0	21.4	21.1

Table 6. Mean monthly maximum and minimum historical temperatures in Liberia, Costa Rica (°C).

Historical extremes of maximum annual temperatures:
1987: 34.1°C; 1981: 32.0°C

Historical extremes of maximum monthly temperatures:
April, 1986: 36.8°C
September, 1979: 29.4°C

Historical extremes of minimum annual temperatures:
1997: 22.6°C; 1986: 21.4°C

Historical extremes of minimum monthly temperatures:
July, 1997: 24.7°C
February, 1986: 18.0°C

1.3. Agriculture

1.3.1. Crops

Our purpose is to study bean crops (*Phaseolus vulgaris* L.) in Los Chiles. This legume grows very quickly and is consumed heavily in Costa Rica, constituting the main source of protein (18-25%) for populations with very low income. Rice (*Oriza sativa* L.) production in the Northwestern Pacific area constitutes a major agricultural activity from a socioeconomic perspective. Because rice is a basic commodity, rice production receives preferential treatment from the State.

1.3.2. Importance of production

Agriculture has recently accounted for nearly 20% of the Gross Domestic Product (GDP) in Costa Rica. It is the second largest contributor to the GDP. Since 24% of the economically active population is dedicated to agricultural activites the labor generated from this sector shows agriculture's economic importance (SEPSA 1992, 1997).

Year	Total Exports	Agricultural Exports	% of total
1983	872.6	563.6	64.6
1984	1005.9	666.1	66.2
1985	927.5	661.0	71.3
1986	1071.0	809.7	75.6
1987	1105.4	786.9	71.2
1988	1167.2	825.1	70.7
1989	1338.1	893.8	66.8
1990	1353.6	904.1	66.8
1991	1480.5	1077.1	72.8
1992	1707.7	1196.0	70.0
1993	1979.2	1346.4	68.0
1994	2141.6	1463.3	68.3
1995	2497.6	1722.0	68.9

Table 7. Proportion of agriculture products, in Free on Board (FOB) value (millons of dollars)

Beans are grown in several types of weather, each corresponding to different altitudes. During the late 80s, the economic opening of Los Chiles increased the production potential. The region topography, the agroclimatic conditions of the area, and the response of farmers to bean crop activities have fostered the technological implementation of this crop, as shown by the contribution of this area to the national production of seed during the last ten years (52%). Still, the negative effects of ENSO-related climate variability have severely affected bean production in the area for the last four years (SEPSA 1997).

The Northwestern Pacific, once considered the granary of Costa Rica, shows an significant decrease in rice production due to the frequent dry spells affecting the region. This region, characterized by predominant dry land production, is vulnerable to climate variability because harvests are highly dependent on the quality and distribution of rain. Regions dedicated to agriculture in the Pacific and Caribbean areas of Costa Rica, which suffered the ENSO phenomenon in 1982-1983, reported damages estimated to be $100 million (OMM, 1983). The grain production of the region was especially hard-hit.

1.3.3 Crop calendars

The sowing time of basic grains for all agricultural regions in Costa Rica is established according to the recommendations issued by the Agricultural Department of the National Insurance Institute (INS). These suggestions are designed in conjunction with the Executive Secretariat of Regional Agricultural Planning (SEPSA) and the Economic Studies Department of the National Production Board (CNP). According to Hernández 1997, the adequate sowing time for rice is established on the basis of rainfall, wind and night temperature.

Table 8 shows rice and bean sowing and harvest time during the agricultural calendar in each of the areas under study.

AGRICULTURAL REGIONS	Months																							
	M		J		J		A		S		O		N		D		J		F		M		A	
Rice (Chorotega region)				SOWING TIME	SOWING TIME	SOWING TIME	SOWING TIME						HARVEST TIME	HARVEST TIME	HARVEST TIME	HARVEST TIME								
Bean (Northern region)														SOWING TIME	SOWING TIME	SOWING TIME				HARVEST TIME	HARVEST TIME			

SOWING TIME HARVEST TIME

Sowing time period for rice in the Chorotega region and for beans in the northern region:

Rice (Chorotega region):	June 15 through July 20 (Alfaro 1983) June 15 through July 31 (MAG 1983) Between July and August (ONS 1996)
Beans (Northern region):	End of November and all December (Alfaro 1983) December 01 through December 30 (CNP 1990) November 15 through early January (MAG 1983)

Table 8. Sowing and harvest time for rice in the Chorotega Region and beans in the Northern region of Costa Rica

1.3.4 Crop production and yield

From 1980 to 1990, national rice production decreased 14.8%. According to SEPSA (1992), this behavior (observed in the entire sown land) is attributable to the elimination of crop surplus, new restricted loans granted by the bank, the reduction of insurable land, and the elimination of the buying power of the National Production Board as well as the rigid nominal price on the product. Nonetheless, national rice production recovered after 1990. Indeed, production increased 31.9% from 1990 to 1998. From 1990 to 1997, rice was the displayed a positive increase rate of 0.6%. However, the recent increase production has not fufilled domestic demand; it is necessary to import rice. The overall decrease in production for domestic consumption is caused by the fact that rice has an established price by law since it is a staple food (SEPSA 1998).

Between 1980 and 1990, rice yields increased 29.4% as a result from the implementation of new technologies and the expansion of irrigated sown land. Between 1990 and 1998, yields augmented 24.4%. Table 9 shows production and yields for the entire nation and for the Chorotega Region since 1980.

The introduction of new bean sowing lands in the northern region resulted in area and production growth during the 80s. Production increased at a mean annual rate of 9.3% while yields reached 0.51 ton/ha. Yields do not seem to be modified by the different sowing varieties applied (SEPSA 1992). During the 90s, total production dropped to 29.1%. Sowing lands were also diminished and production decreased 48% as an average of the previous four years. Yields were surprisingly better than those displayed during the 80s. According to SEPSA (1997), bean production diminished as a consequence of the different adverse weather phenomena, particularly Hurricane Caesar and the last ENSO event. This also explains the severe drop in yields during the last four years.

	Rice						Beans					
	National			Chorotega Region			National			Northern Region		
	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield
1980	84.629	243.590	2,88	37.635	118.871	3,16	23.681	12.289	0,52	4.109	2.257	0,55
1981	72.294	202.028	2,79	32.795	86.732	2,64	35.507	16.312	0,46	5.975	3.326	0,46
1982	76.598	148.372	1,94	36.573	28.457	0,78	39.120	14.362	0,37	6.357	2.948	0,37
1983	88.351	281.388	3,18	42.472	138.409	3,26	41.631	20.584	0,49	5.769	4.237	0,50
1984	72.335	222.740	3,08	32.043	82.919	2,59	43.279	22.893	0,53	6.220	4.440	0,53
1985	72.319	244.050	3,37	32.924	106.436	3,23	48.271	28.992	0,60	7.050	5.448	0,60
1986	60.323	184.811	3,06	31.015	86.134	2,78	56.489	32.186	0,57	12.450	7.852	0,57
1987	50.770	153.737	3,03	23.248	66.241	2,85	48.478	22.803	0,47	11.970	8.658	0,47
1988	58.352	205.500	3,52	25.861	102.730	3,97	48.701	22.456	0,46	10.531	5.780	0,46
1989	67.848	238.026	3,51	34.433	133.987	3,89	63.664	34.257	0,54	16.764	12.564	0,57
1990	61.084	209.912	3,44	28.906	101.945	3,53	69.580	34.267	0,49	22.625	16.687	0,49
1991	55.700	207.513	3,73	26.061	100.994	3,88	63.160	35.569	0,56	22.940	16.310	0,56
1992	62.217	230.152	3,74	25.448	97.064	3,81	59.030	33.359	0,57	21.300	15.165	0,56
1993	46.899	173.506	3,70	20.917	81.800	3,91	56.856	35.337	0,62	21.900	19.145	0,62
1994	51.867	194.694	3,75	21.239	87.035	4,10	57.477	35.707	0,62	28.431	21.920	0,62
1995	49.934	199.247	3,99	22.272	95.296	4,28	19.584	21.535	0,65	15.830	13.898	0,88
1996	73.446	295.999	4,20	29.691	129.080	4,35	43.336	13.258	0,50	20.169	8.801	0,34
1997	69.920	246.875	3,59	27.842	112.053	4,11	38.006	13.404	0,40	16.840	5.759	0,40
1998	64.710	276.897	4,28	25.086	112.827	4,50	39.513	25.218	0,64	19.000	16.900	0,89

Area (sown land): hectares Prod (Production): tons Yield: t/ha

Table 9. Rice and beans sowing area, production, and yields in Costa Rica
Source: National Production Board

1.3.5 Management of crops

Management policies vary according to the crop type, area, soil and weather. Dry-land rice in Guanacaste usually uses the CR1113 variety. This variety has been widely used since 1975 because of its high production potential and its resistance to *Pyricularia*. Generally, the following recommendations should be observed: the land should be brought under the plow twice and raked once. The land must be raked again after 15 to 20 days before sowing. The land plane should be then used, and insecticides and fertilizers should be also applied. Nitrogen fertilization should be applied in three parts: 30 kg to the sown land (with 40 kg of phosphate and 20 kg of potassium), 30 kg during cluster (30 days after seedling) accompanied by 20 kg of potassium, and finally, 30 kg of nitrogen at pre-flowering (60 days after seedling). Ammonium nitrate (NH_3NO_4) or urea is normally employed. 75 kg of N/ha, 40 kg of P_2O_5/ha and 40 kg K_2O/ha, divided in three applications during the cycle, may also be used.

The National Seeds Office (ONS) recommends a sowing density of 400 plants per square meter, with 90% emergence (360pl/m2 emerge). Sowing may be mechanical, aerial or manual scattering. Weeds are eliminated with herbicides before and after emergence.

The Brunca variety of beans is mostly used in the Northern region. This black bean is rapidly grown and may be sown leaving a protective covering "mulch" (with little plowing), with a plantling stick, or with maize to help the crop extend. This variety was introduced in Costa Rica in 1979 and released in 1982. Usually, it has been used as a monoculture with 60 cm between each hollow and 13 seeds per linear meter; representing a density of 217,000 plants per hectare. Beans are handled in a semi-mechanized manner in the Northern region.

Fertilization will work efficiently if the formula is rich in phosphate. Suggested applications are 160-200 kg of nitrogen per hectare and 100-140 kg of P_2O_5/ha. Weeds and plagues are eliminated manually or with the help of agrochemical products.

1.3.6 Agricultural systems

Rice production is in the hands of medium and large growers; large growers exploit regions above 200 ha, and small farmers produce only for their own consumption. The average size of land exploited by medium farmers is 100 ha, while large growers may have 770 ha to grow rice using a totally mechanized system. Since the beginning of the 80s, the number of people growing rice diminished by 92.4%, from 15,200 growers to 1,100 in 1992. At the beginning of the 90s, small growers (below 10 ha) were only 600 people. Estimates from the National Production Board indicate that there are 380 registered growers (medium and large) representing a total of 59,000 ha cultivated (Murillo 2000, Murillo and Rivera 2000).

According to the National Rice Office, by the mid 90s, 41% of rice growers were located in the Chorotega Region. Only 1% of these growers exploited 23% of the total cultivated land with plots of over 500 hectares. During 1994-1995, 88% of the cultivated land was in the hands of 34% of the total growers. After that time, small and medium growers have shifted their activity to sugar cane, melon, reforestation, or they have rented or sold their lands.

Serious problems have contributed to the reduction of exploited land. Some of these problems are related to organization (lack of aggressive and stable production policies). The reduction of loans granted, the reduction of insurable land, the deficient technical support, the lack of agricultural and territorial organization, low profitability, losses caused by adverse weather conditions and the political current to open the market are also influential. These difficulties have eliminated most small and medium rice growers.

However, bean production remains in the hands of small and medium growers, with most plots between 20 and 200 ha. Since bean production in the northern region has been growing for over a decade, the activity has gained technical support, and has become a semi-mechanized activity. Despite this major boost, the number of growers dropped 18% as a result of discouraging policies during the mid 80s. The lack of incentives has also been observed in basic grains since the first Structural Adjustment Program (PAE) was approved in 1982. The problem has also worsened because of the lack of integrated policies for agricultural activities (SEPSA 1992). In the 90s, bean production decreased because of adverse weather conditions (hurricanes, ENSO) and the increase in interest rates, provoking a decrease in technological levels.

Table 10 compares some attributes of the exploitation types that characterize rice and bean production in the regions under study.

Characteristics of the Activity		Rice Activity	Bean Activity
Exploitation size in hectares	Small	Less than 10	Less than 20
	Medium	Between 11 and 100	Up to 250
	Large	More than 100	-
Exploitation type		Extensive, mechanized	Semi-mechanized
Production System		More than 80% dry-land	Dry-land
Market		Unable to satisfy local demand. The product must be imported	
Number of growers (1999)		380 people registered at CNP*	No data available
Production (tons in 1999)		276897	25218
Cultivated area (hectares in 1999)		64710	39513
Productivity (ton/ha)		4.28	0.64
Harvest insurance		By 2000, 90% of crops are not insured because bank loans were reduced and demanded several requisites to insure crops; besides that, insurance cost is elevated (¢14000 per rice hectare)	
Financing		By mid 90s, only 20% of the total cultivated land were financed. Finaning has been decreasing ever since.	In the northern region, only the Project for Small Growers (PPZN) finances and helps growers with soft loans and technical support
Defined promotion policies		Agreement to increase import duties to 35% and a safeguard of 8%	Agreement to increase import duties to 30% and a safeguard clause
		Law of the National Rice Office establishing imports only during shortage periods (pending)	Law of the Institute of Technological Innovation to generate applied research (pending)

*CNP: National Production Board

Table 10. Characteristics of rice and bean production in Costa Rica.
Source:Barquero 2000, SEPSA 1992, 1997, Murillo, 2000,
Datos del Consejo Nacional de Producción

1.3.7 Agricultural decision makers

Academic groups supervising growers make technical and scientific decisions on production management and strategies (scheduling) for the different agricultural activities. In regard to rice and bean production, the Ministry of Agriculture (MAG), through the National Insurance Institute (INS) and the agricultural department of the National Production Board (CNP), are responsible for these decisions. These institutions provide advice on the variety recommended, management, sowing time, sowing land and marketing. The National Seeds Office also intervenes because it takes care of production and distribution of certified seeds, thus providing technical support to buyers. The utilization of certified seeds is a requisite to insure the cultivated land. The National Rice Office defends the interests of the rice sector and participates in the administrative area, although its role is not always noticed.

The Agricultural Research and Technological Transfer for Bean Program (PITTA-Bean) gathers a number of experts from MAG, CNP, ONS and different universities in an effort to promote the application of research to the national bean producing community. This group plays a major role in decision-making in technical and managerial aspects of this activity.

Political decisions are made by important government officials, particularly those from the Ministry of Agriculture, the Ministry of Environment and Energy, and the Ministry of Economy and Commerce. They are responsible for the organization of national production, the protection of both growers and consumers and the promotion of agriculture through adequate policies and laws, which may empower this activity and pursue self-sufficiency. However, during the last several decades, agricultural policies have not been coordinated with technical and scientific efforts to preserve the national production of basic grains.

1.3.8 Climate requirements: problems

Rice and bean production is located in specific geographic areas mainly because of the existing soil and weather conditions favor those activities. Rain distribution is critical to these crops. These grains need a dry period coinciding with the maturity and harvest phases. Similarly, water availability is fundamental during development and reproduction. Tables 11 and 12 present weather conditions during the field tests carried out to validate rice and bean crop models in Liberia and Los Chiles, respectively.

Phenological phase (stage)	Duration (dds)	Maximum (°C)	Minimum (°C)	Rainfall (mm)	Transpiration (mm)
Germination	5	31.5	22.4	107	22
Cluster	46	31.5	22.4	414	177
Panicle formation	63	29.5	22.3	639	261
Flowering	96	31.0	23.1	888	398
Beginning of grain fill	110	31.0	23.1	894	498
Harvest	125	32.0	21.5	896	504
TOTAL	125			896	504

Table 11. Weather conditions during the field test carried out to calibrate the CERES-Rice Model. Liberia, Guanacaste. CR1113 Variety. 1997

Phenological phase (Stage)	Duration (dds)	Maximum (°C)	Minimum (°C)	Rainfall (mm)	Transpiration (mm)
Germination (V0)	5	29.2	19.8	0	0
Emergence (VI)	7	29.0	19.8	3	1
Primary leaves (V2)	9	29.0	19.8	4	2
1° primary leaf (V3)	16	29.0	21.6	7	8
1° trifoliate leaf (V4)	30	29.5	21.6	86	37
Flowering (R6)	38	29.9	21.6	136	62
Pod formation (R7)	43	30.1	20.3	175	77
First seed (R8)	58	30.1	20.3	250	105
Harvest	78	30.1	20.4	286	147
TOTAL	**78**			**286**	**147**

Table 12. Weather conditions during the field test carried out to calibrate the CROPGRO Dry Beans Model. Los Chiles, Alajuela. Brunca Variety. 1997

Research indicates that dry-land rice needs from 300 to 900 mm of rain per cycle, depending on the variety. On the other hand, beans require from 200 to 400 mm of rain. Even though these minimum water requirements were satisfied according to tables 11 and 12, the principal climate problem that this activity faces is related to rain distribution.

Rice in the Chorotega Region has been affected by water deficits during the dry spell months (July and August), when sowing occurs. The problem worsens when an extended dry spell occurs and that affects even September or October (as in 1982). Figure 4 displays the behavior of the elements affecting water balance for rice in Liberia 1982. The graph shows that an extended dry spell covering the first 70 days after sowing (August and September) resulted in very low yields (0.93 t/ha).

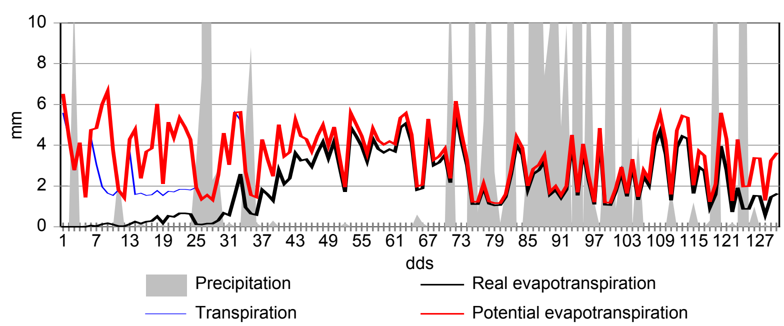


Figure 4. Water balance for rice. Liberia, 1982.

Since this cereal is produced between July and August, panicle formation, flowering and sometimes the beginning of grain fill occurs in September and October (when precipitation is higher). Accordingly, extended water deficits may affect final yields. Figure 4 displays how atmospheric water vapor demand is not satisfied by soil evaporation. Correspondingly, all plants diminish their water level during their development. On the other hand, extreme rainfall conditions during September, October and November have also affected sown fields (1998 and 1999).

In the last four years beans in the Northern region have been deeply affected by extreme weather conditions. In 1996 and 1997, yields decreased 40% as compared to the figures obtained during the beginning of the 90s. Heavy rains during December and January of 1996, 1998 and 1999 affected land preparation and consequently the grain itself during germination and emergence. Moisture provoked the emergence of several fungi problems, among other diseases. Rainfall occurring at the end of the period caused harvest losses because the grain did not reach maturity in the pod.

In 1997, the effects of an uncommon dry spell damaged most sown land. As shown in figure 5, although rain distribution was regular, it did not satisfy the water demand of each crop phase. This took more energy from the plant and causds low yields. The northern region underwent a similar situation in 1982 when precipitation during the first part of the year was considerably below the historical average. In that year, bean production in that region was not as important as today, but still yields were extremely low.

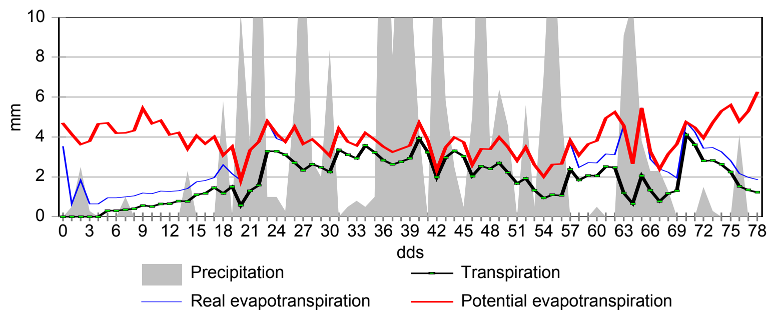


Figure 5. Water balance for beans. Los Chiles, 1997

Given the geographical location of Costa Rica, the magnitude and distribution of temperature and solar radiation do not vary as significantly as with precipitation. The seasonal character affects monthly behavior, but generally it does not constitute a major physiological assimilation problem. Variations to these elements may be related to the appearance of pathogen populations.

1.3.9 Other Factors

Bean production in the northern region occurs only under dry land conditions. There are no irrigation programs because the region's weather conditions are adequate. Normal rain conditions guarantee rainfall throughout the year though rainfall diminishes a little during March and April.

Rice production in the Chorotega region benefited from the implementation of the Arenal-Tempisque irrigation project. This project, designed and executed by the National Electricity Institute (ICE), consists of the utilization of the natural lake of the Arenal Volcano as a multiple purpose seasonal dam. The project's first objective is to generate hydroelectric power; the dam is also used also as an irrigation source for the province of Guanacaste.

The second objective was achieved through the Arenal-Tempisque irrigation project designed by the Ministry of Agriculture. This project takes part of the Arenal damming waters and, through a channel system with a constant level of $14.3m^3$/sec, irrigates 60,000 hectares (IFAM, 1974). Even though this project has expanded, Cañas obtains most benefits in rice, sugar cane, fruit trees and livestock activities. After the last episode of El Niño in 1997-1998, local residents have been trying to obtain international support to widen the irrigation perimeter.

II. ENSO effects on agricultural production

2.1. ENSO and production of rice and bean in two agricultural regions from Costa Rica

Agriculture in Costa Rica is very sensitive to climate variability (Sandoval, 1996; Vega and Stolz, 1997). The ENSO phenomenon is one of the most important phenomena affecting climate conditions (UCAR, 1994); its changes in the sea surface temperature (SST) across the eastern equatorial Pacific, are associated with changes in the barometric pressure ratio and wind patterns across the Tropical Pacific (Glantz, 1998). Variations resulting from ENSO, (El Niño: positive anomalies in SST; La Niña: negative anomalies in SST) are related to unusual changes in global climate patterns (IRI, 1996). There are some investigations of ENSO and agricultural activities (Hansen et al., 1998; Magrin et al., 1998; Hansen et al., 1999). In this manner, this study aims to present some interesting results derived from the relationship between ENSO phases and agriculture in Costa Rica.

2.1.1. Methods

We are using the SST anomalies during the growing season (El Niño: the warm phase; La Niña: the cold one and Neutral: the intermediate phase) related to a region, on the eastern equatorial Pacific, known as Niño3 (Trenbert, 1997) (latitude 5° north 5° south, longitude 90-150° west). The specific crops analyzed were non-irrigated rice in Liberia, Guanacaste (Northern Pacific), and beans in Los Chiles, San Carlos (Northern region).

2.1.2. Results

Case 1: Non irrigated rice in Liberia.

Figure 6 displays annual precipitation (1957-1998) in Liberia (Llano Grande, Meteorological Station) and ENSO phases. During cold phases (La Niña) rainfall figures are obviously above the annual average (1,551.4 mm), while they are below the average during warm phases (El Niño).

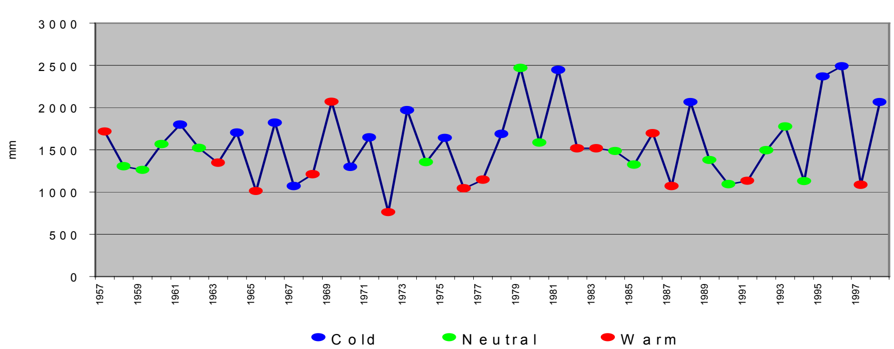


Figure 6. ENSO Phases and Annual rainfall, Liberia, Costa Rica.

Figure 7 and table 13 display statistical differences (∝≤0.05) in mean annual precipitation for each ENSO phase. According to this information, there is a significant statistical difference between the cold phase (-1) and the corresponding neutral (0) and warm (+1) ones. These results show that during cold ENSO phases (La Niña), precipitation increases in Liberia compared to the neutral and warm phases.

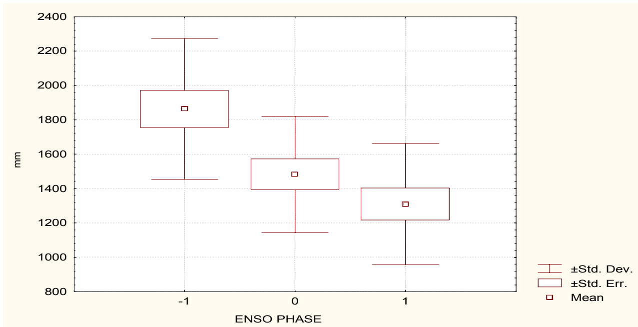


Figure 7. Categorized box plot for ENSO phases (Cold -1, Neutral 0, Warm 1) and annual rainfall,Liberia, Costa Rica (1957-1998).

Rainfall Phase	-1 1862.9	0 1482.0	1 1309.3
-1		0.009410	0.000470
0	0.009410		0.221836
1	0.000470	0.221836	

Table 13. Duncan's multiple range test for ENSO phases and annual rainfall. Liberia, Costa Rica. Results displayed in red are significant.

According to figure 8, there is a similar tendency in the behavior of rainfall per ENSO phase even when only the seasonal rainfall of the growing season of non-irrigated rice (generally grown between July and November) is taken into consideration.

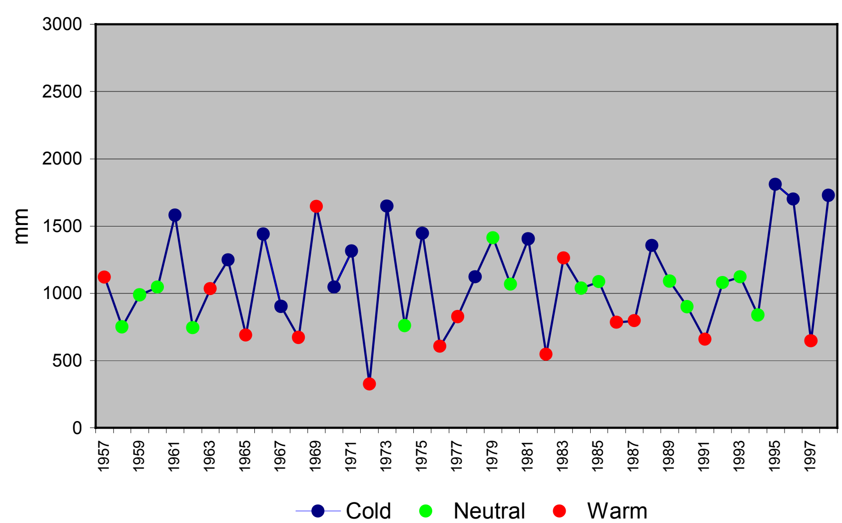


Figure 8. ENSO Phases and Seasonal rainfall, Liberia, Costa Rica.

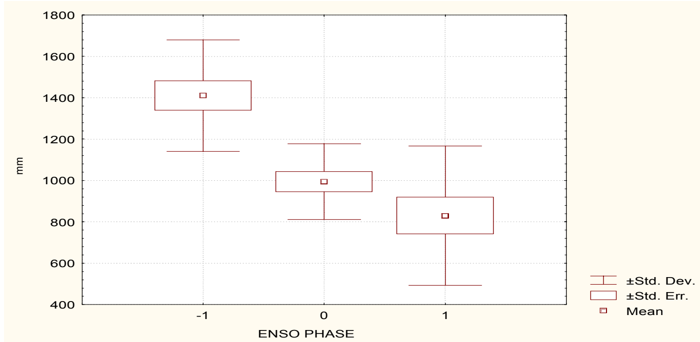


Figure 9. Categorized box plot for ENSO phases and seasonal rainfall, Liberia, Costa Rica (1957-1998).

Figure 9 and table 14 display the results which display the difference in seasonal rainfall (July-November) during a cold ENSO phase. Both annual and seasonal results determine that during cold ENSO phases, rainfall in Liberia is over the annual and seasonal mean (1078,1 mm), respectively.

Rainfall Phase	-1 1410.6	0 994.4	1 829.4
-1		**0.000329**	**0.000063**
0	**0.000329**		0.114731
1	**0.000063**	0.114731	

Table 14. Duncan's multiple range test for ENSO phases and seasonal rainfall Liberia, Costa Rica. Results displayed in red are significant

Air temperature constitutes another important meteorological parameter to grow rice. Maximum, minimum and mean temperatures were differentiated. Figures 10 & 11 refer to the categorization of maximum temperatures during ENSO phases. In accordance with this analysis during warm ENSO phases, maximum temperatures increase.

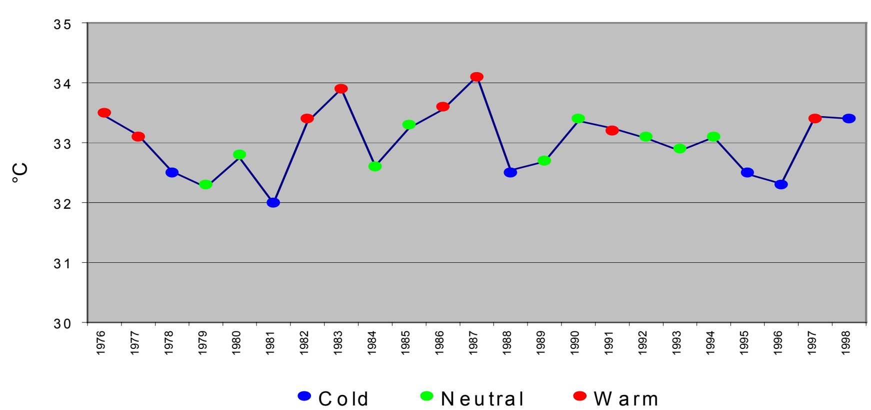


Figure 10. ENSO Phases and Annual Maximum Temperature, Liberia, Costa Rica.

According to table 15, maximum temperatures during a warm ENSO phase are statistically different from the ones registered during the neutral and cold phases, which, on the contrary, show similar values. For this reason, these results mark warmer periods during warm ENSO phases.

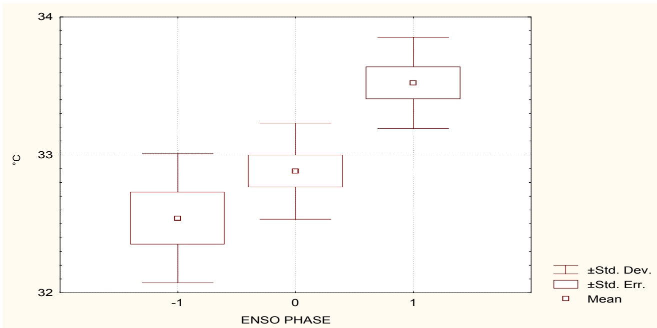


Figure 11. Categorized box plot for ENSO phases and annual maximum temperature, Liberia, Costa Rica (1976-1998).

Temperature Phase	**-1 32.5**	**0 32.9**	**1 33.5**
-1		0.094000	**0.000152**
0	0.094000		**0.003944**
1	**0.000152**	**0.003944**	

Table 15. Duncan's multiple range test for ENSO phases and annual maximum temperature, Liberia, Costa Rica. Results in red are statistically significant.

A similar test for mean annual minimum temperature (figures 12, 13 & table 16) shows that these temperatures do not differ statistically during ENSO phases. In other words, even though temperature could increase at daytime during warm phases, minimum temperatures are not consistently different from the ones observed in other ENSO phases.

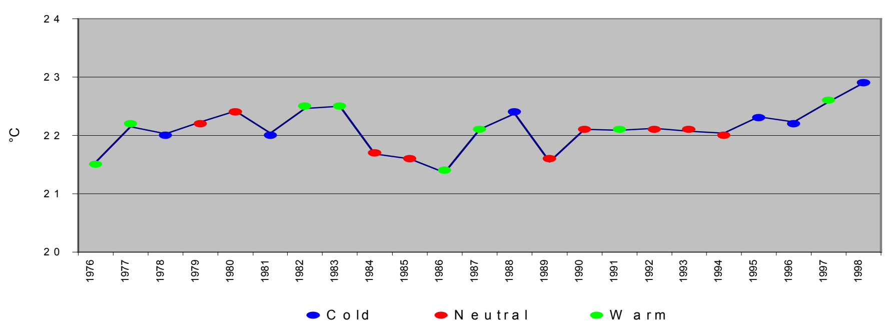


Figure 12. ENSO Phases and Annual Minimum Temperature, Liberia, Costa Rica.

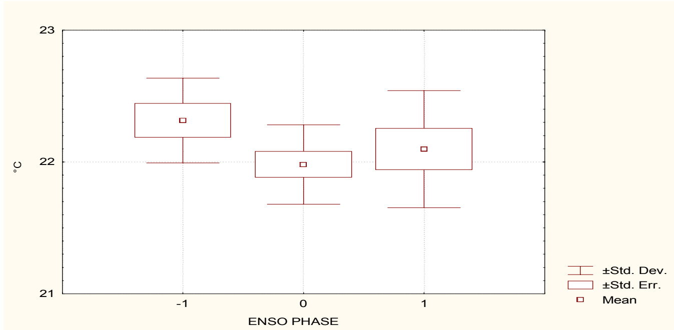


Figure 13. Categorized box plot for ENSO phases and annual minimum temperature, Liberia, Costa Rica (1976-1998).

Temperature Phase	-1 22.3	0 22.0	1 22.1
-1		0.106825	0.262866
0	0.106825		0.538379
1	0.262866	0.538379	

Table 16. Duncan's multiple range test for ENSO phases and annual minimum temperature, Liberia, Costa Rica.

Once annual mean temperatures were analyzed, the statistical study determined that they behaved just like maximum annual temperatures (figures 14, 15 & table 17); accordingly, this behavior on maximum temperatures during El Niño phases is strong enough to be observed in annual mean temperatures. The historical series on non irrigated rice yields in Liberia (1980-1998), taken from the official statistics of the National Production Center (CNP) was corrected using smoothing in order to segregate technological modifications from yields.

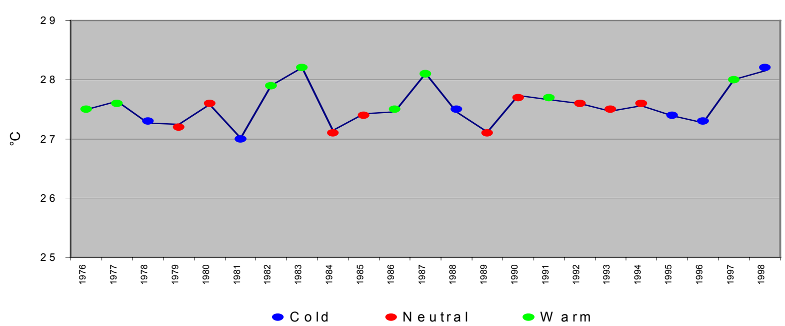


Figure 14. ENSO Phases and Annual Mean Temperature, Liberia, Costa Rica.

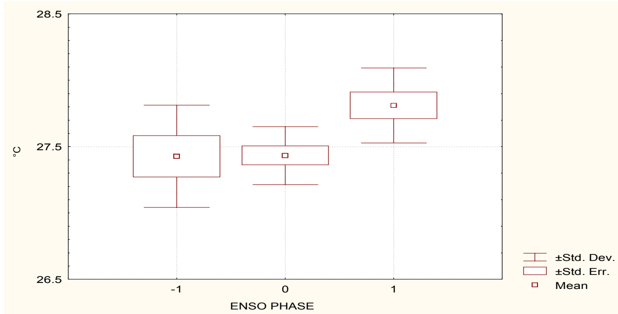


Figure 15. Categorized box plot for ENSO phases and annual mean temperature, Liberia, Costa Rica (1976-1998).

Temperature Phase	-1 27.4	0 27.4	1 27.8
-1		0.974666	**0.024600**
0	0.974666		**0.020801**
1	**0.024600**	**0.020801**	

Table 17. Duncan's multiple range test for ENSO phases and annual mean temperature, Liberia, Costa Rica. Results displayed in red are statistically significant.

Then anomalies for each annual yield were estimated in relation to the trend, and finally, the impact of each ENSO phase on yields was determined (figure 16).

Although the regional yield series is short, results are interesting. For example, all La Niña phases (cold ENSO phase) surpassed the mean, but during El Niño phases (warm ENSO phase), three out of five (60%) were below the average. During neutral phases, four out of eight (50%) surpassed the average.

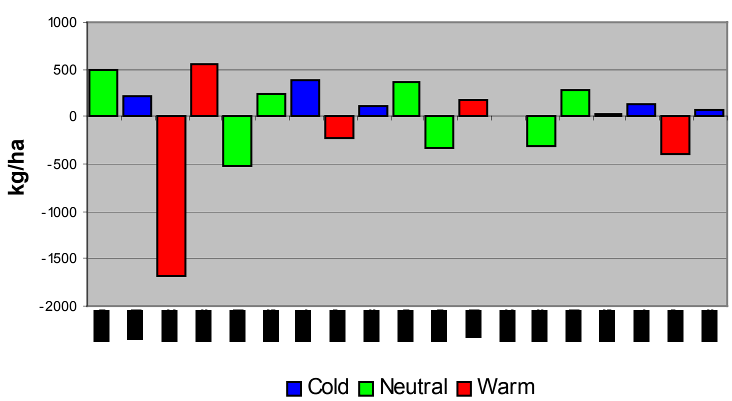


Figure 16. Rice yield anomalies and ENSO phases, Liberia.

Comparing figures 16 with seasonal precipitation anomalies (figure 17), shows that yields are most likely to be above average during La Niña and below the average during El Niño. This tendency is associated with rainfall occurrence during the growing season, which are modified in the same way during El Niño (decrease) and La Niña (increase).

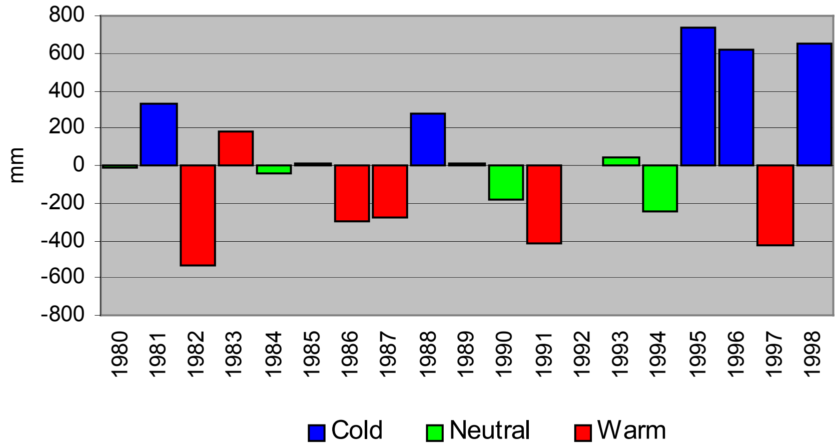


Figure 17. Rainfall anomalies in rice growing seasons and ENSO phases, Liberia.

However, rain distribution during the growing season is still the major issue. During flowering, water availability is critical to success in grain development. Availability is closely related to high yields at that point in the process, but a high amount of water diminishes yields and the quality of the grain.

Case 2: Beans in Los Chiles, San Carlos.

Figure 16 displays annual precipitation (1961-1998) in Los Chiles, San Carlos (Comandancia-Los Chiles meteorological station) per ENSO phase. The trend is not as obvious as in Liberia since this region shows a more balanced behavior in those cases (above or below the precipitation average of 2,238.8 mm).

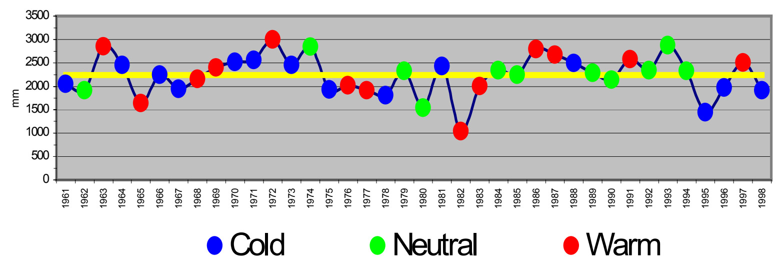


Figure 18. ENSO Phases and Annual rainfall, Los Chiles, Costa Rica.

Figure 19 and table 18 show that there is not an actual statistical difference ($\alpha \leq 0.05$) between annual precipitation and ENSO phases. This is probably due to the influence of the Caribbean Systems. This region does not have a defined dry season, as opposed to the northern Pacific region of Costa Rica.

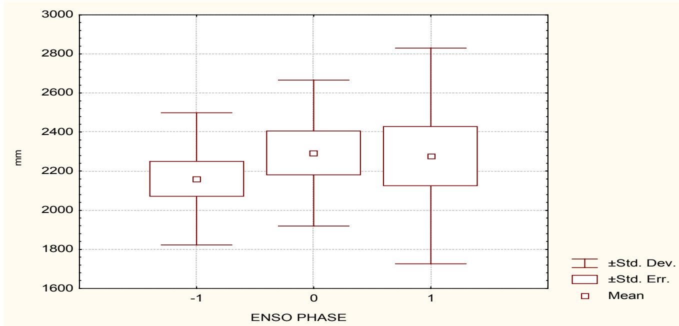


Figure 19. Categorized box plot for ENSO phases and annual rainfall, Los Chiles, Costa Rica (1961-1998).

Rainfall Phase	-1 2160.4	0 2292.5	1 2277.7
-1		0.476912	0.501238
0	0.476912		0.932254
1	0.501238	0.932254	

Table 18. Duncan's multiple range test for ENSO phases and annual rainfall Los Chiles, Costa Rica.

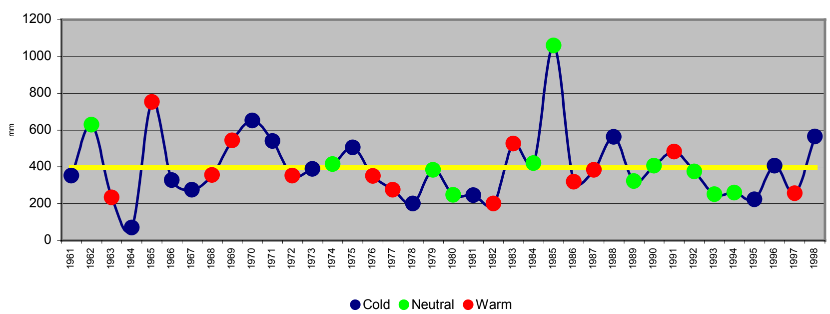


Figure 20. ENSO Phases and Seasonal rainfall, Los Chiles, Costa Rica.

The analysis of seasonal precipitation (December-March) for beans–identifying the ENSO phase according to the general trend of SST anomalies in El Niño 3 throughout the year, which does necessarily comply with the anomalies during the growing season–shows that as in figure 20, seasonal precipitation scatters, similar to annual precipitation. Accordingly, there is no statistical difference within seasonal precipitation (figure 21 and table 19).

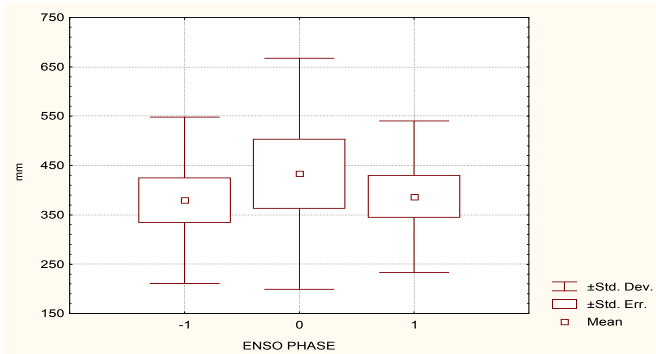


Figure 21. Categorized box plot for ENSO phases and seasonal rainfall, Los Chiles, Costa Rica (1961-1998).

Rainfall Phase	**-1 379.5**	**0 433.3**	**1 386.6**
-1		0.499186	0.924602
0	0.499186		0531739
1	0.924602	0531739	

Table 19. Duncan's multiple range test for ENSO phases and seasonal rainfall in Los Chiles, Costa Rica. Statistically significant results are shown in red.

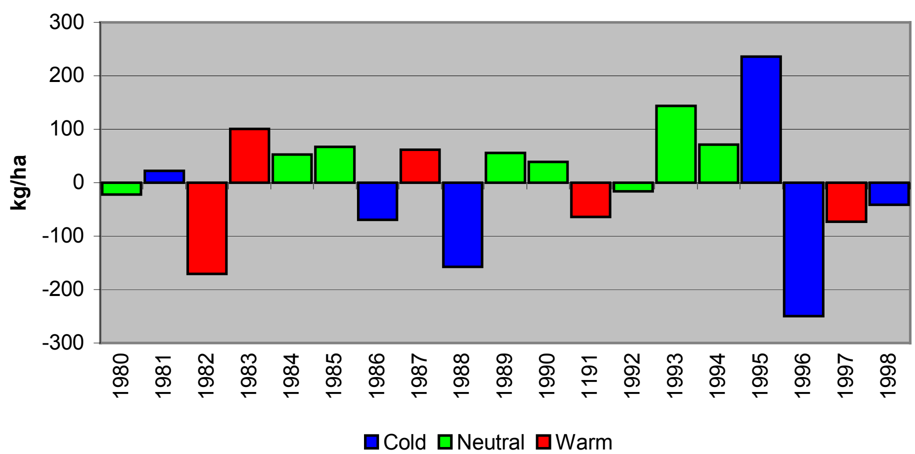


Figure 22. Bean yield anomalies and ENSO phases, Los Chiles

The statistical analysis of mean temperature displayed the same result. There was no statistical difference between maximum and minimum mean annual temperatures per ENSO phase, respectively. Bean yield anomalies were analyzed per ENSO phase (figure 22).

During cold phases, 66.6% of the cases display below average yields. During warm phases, 60% of the cases are below average yield. However, during neutral phases, yields are usually above average. Comparing figures 22 and 23 reveals that some years with negative rainfall anomalies (1980, 82, 86, 92, 97) coincide with negative yield anomalies. Some years, like 1993, 1994 and 1995 have negative rainfall anomalies but positive yield anomalies. 1983, 1984 and 1985 all had above average rainfall and positive yield anomalies, regardless of ENSO phase. Figure 24 and table 20 show that there is no statistical difference in yield anomalies per ENSO phase.

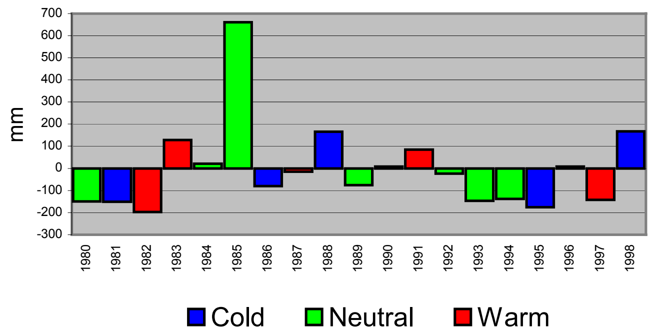


Figure 23. Rainfall anomalies in the growing season of beans and ENSO phases.

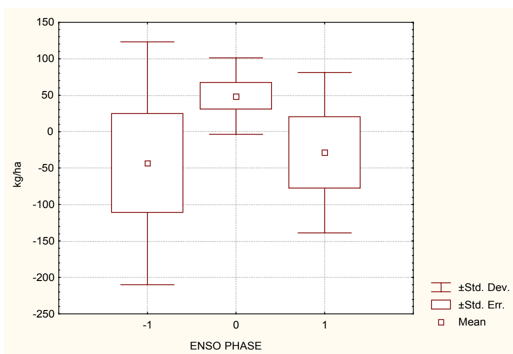


Figure 24. Categorization of bean yield anomalies and ENSO phases.

Yield Phase	-1 -43.25	0 48.80	1 -29.02
-1		0197834	0.829570
0	0.499186		0.248810
1	0.899570	0.248810	

Table 20. Duncan´s multiple range test for bean yield anomalies and ENSO phases.

These behavior patterns seem to indicate that ENSO phases have less influence over this region and that other climate variations related to the northern region (cyclonic activity and northeastern wind) may affect the behavior and distribution of the parameters analyzed in this research.

During strong warm ENSO phases (like 1982 and 1997), yield and precipitation anomalies are negative. However, in strong cold phases, when grain production depends on rainfall distribution, yield and rainfall anomalies are not coincident.

Accordingly, the effects of ENSO phases on these two regions (and even the entire country) differ; therefore, yield variations will depend mainly on rainfall distribution, moisture availability during the vegetative cycle of crops and on the intensity of the ENSO phase.

III. Agricultural decision makers

3.1 Current sources, uses of climate and weather Information

As a result of the impact of dry spells on agriculture, such as the El Niño events of 1982, 1986 and 1997, and because of the floods related to La Niña event in 1998 and 1999, decision-makers are concerned about climate variability and seasonal nature. During the last two decades, action plans for handling emergencies related to extreme weather events have been implemented. To this end, the National Technical ENSO Phenomenon Committee (COENOS) was created in 1997, and the National Meteorological Institute (IMN) was appointed the official source of information of the National Emergency Committee (CNE), the coordinator of all aspects of emergencies which occur throughout Costa Rica. During the 1997 and 1998 ENSO episodes, the National Meteorological Institute designed a plan for improving the relationships among production sectors such as agribusiness, fishing, and hydrology, as well as decision-makers and those related to mitigation and preparedness in case of emergency (Stolz and Sanchez, 1998).

The actions which should be applied during climate-related emergencies (and other mitigation operations usually put into practice during dry spells) are simply old methodologies redesigned and systematized to fit current needs. For instance, since 1972, agriculture has implemented action plans in order to fight dry spells (especially in the northern Pacific region). The main difference between old and new plans is the availability of climate information. Now documents do not refer to “plans to fight dry spells in Guanacaste” (1992); instead, they address specific issues like “plans to mitigate the ENSO effects on agriculture” (1997). The IMN has become a valued information source thanks to recently acquired knowledge of evolving climate phenomena. Actions implemented to mitigate dry spells and floods are now based on timely ENSO forecasts, their development and effects on the climate of Costa Rica.

As a result of agrometeorological studies, it has been possible to issue timely warnings of the appearance of plagues (locust and rodents), as reported in *La República* (1997) and *Barquero* (1998). But other problems arose due to weather uncertainty and production hazards. Based on ENSO forecasts, the national banking system stopped giving loans to all tobacco activities in one of the main producing regions. The Ministry of Agriculture (MAG) then asked the IMN to carry out a study on the expected weather conditions in the tobacco producing area. The study (Villalobos et al 1997) concluded that rainfall during the growing season would be sufficient to satisfy the water demand of tobacco, so farmers regained access to loans. A similar event occurred with bean producers in the northern region. In 1997, decision-makers from MAG requested some research in regard to bean cultivation in the northern region (Retana et al 1997, Villalobos et al 1998, Villalobos and Retana 1999). The decisions based on that research (principally regarding sowing time) have minimized the risks and losses provoked by climate variability resulting from the cold and warm ENSO episodes (Rojas 1999, Corrales 1999).

3.2 Previous knowledge of ENSO activity, climate Prediction

Climate variability resulting from the ENSO phenomena has been related to important losses in agriculture since 1982 (see table 1). Before that time, El Niño was not a subject of discussion nationally or internationally, and agricultural losses were related to extended dry spells or floods. Some studies carried out after 1982 mention the relationship between ENSO episodes and low yields in agriculture, particularly in grain production (Fernández and Ramírez 1991, Arroyo and Patterson 1988) and fishing (Vega and Stolz 1997, Retana 1999).

Most studies of the ENSO effects on agriculture in Costa Rica refer to the ENSO warm episode and extended dry spells in the Pacific watershed (Ramírez 1990, Fernández and Ramírez 1991, Vega and Stolz 1997). A report presented to the International Forum on El Niño Forecasting by the Ministry of Planning (Solís 1996) states that ENSO affects the country unevenly, with a strong impact on grain production in the northern region. Unfortunately, most reports of ENSO effects are based on information submitted by cooperatives and farmers, and lack scientific analysis to support observed behavior (Barquero 1998). Few studies relate ENSO episodes to national agricultural activities. The lack of reliable information limits preventive actions, and the role of the State usually centers on the mitigation and control of the effects of climate-related emergencies.

Unfortunately, many decision-makers have implemented policies designed to mitigate the negative effects of extreme weather events regardless of their awareness of the problem. The scientific community first encouraged study of the ENSO phenomenon in 1982. Since that time, Costa Rica has suffered the consequences of the ENSO phenomenon three times (in 1986-1987, 1992-1994, and 1997-1998). The improvements in the spread of information and access to data have contributed to the current capacity for monitoring the evolution of ocean-atmosphere phenomena in real time. Besides that, technological enhancements in both equipment and personnel of the IMN have resulted in better forecasting, preparedness, and strategy design. For instance, the information on the evolution of the 1994 ENSO phenomenon and its precipitation impact across the country promoted the creation of a commission among institutions and ministries that would generate mitigation mechanisms to face the forecasted dry season (*La Nacion,* 1994).

Prediction of the development of the 1997 ENSO warm episode, as well as the spread of information and special bulletins, helped the CNE to coordinate all actions aimed at diminishing the problems provoked by this phenomenon in various sectors. The plan was designed to aid agricultural activities and provided timely assistance to cattle in vulnerable regions. Recommendations on the adequate sowing time and resource exploitation helped maintain yields of rice, maize, citrus, melon, beef cattle and sugar cane, among other products (García, 2000) within the average registered in recent years. For agriculture, it has been considered a great success—doubtless because of experience and the value which the government and private institutions give to forecasting and climate data. Concern about the effects of these weather events facilitated media reports and access to information for both the public and the authorities—the IMN has transferred information directly to the Ministries, Government and the CNE. However, despite the above-mentioned efforts, important economic losses were registered, as shown in table 21 and 22.

3.3 Limitations, risk attitudes

As shown in table 21, dry spells related to ENSO have usually affected the northern Pacific, central Pacific and central regions. The negative effects registered in agriculture for the southern Pacific region are a consequence of heavy rains and dry spells. There is not enough information for the Caribbean watershed and the northern region. Rice and maize are the crops most vulnerable to heavy rains or dry spells, while sugar cane, melon (northern pacific), beans (northern region and southern pacific), vegetables (central region) and cocoa and banana (southern and Caribbean region).

Despite the emergency actions carried out during climate events, losses are considerable. In 1997-1998, losses in agriculture and livestock reached $33.2 million and $16 million respectively (Jovel 2000). Table 22 displays the reported damages in detail.

ENSO	Effect	Región	Crop	Losses	Reference
1957	Rainfall	Limón	Cacao	75% of the harvest	Diario de CR, 1957
1958	Rainfall	Southern Region	Banana	300,000 hands that were going to be exported	Diario de CR, 1958
	Dry spell	Cartago	Potatoes	¢ 16 million in agriculture. Low yields in potatoes	Ultima Hora, 1959
1969	Rainfall	Southern Region	Rice	¢ 5 million	La Nación, 1969
1973	Dry spell	National	Rice	3.6800 tons	La Nación, 1973
			Maize	4.600 tons	
1976	Dry spell	Guanacaste	Rice	75% of the total sown area	Arroyo and Patterson, 1988
1977	Dry spell	Guanacaste	Rice	7.000 ha	Arroyo and Paterson, 1998
			Maize	Losses in Carrillo and Santa Cruz	
1982	Dry spell	National	Agriculture	$100 million	LeComte, 1982
	Dry spell	Guanacaste	Rice, Maize	¢500 million	La Nación, 1982
1983	Dry spell	Guanacaste	Maize, Sorghum	Sowing stopped in 10.000 ha. ¢1.500 million in agriculture	Vega, 1983
1986	Dry spell	Guanacaste	Rice, Maize	$6 million. Low national production	OMM, 1987
1991	Dry spell	Guanacaste	Rice	2,000 ha were lost	Leitón, 1991
	Rainfall	Southern Pacific	Beans	¢187 million in the entire country	
1994	Dry spell	National	Rice, Maize and Beans	¢160 million. 4 to 6% in the total national grain production	Fuentes, 1994
1994	Dry spell	Guanacaste Northern region	Rice, Maize and Beans	¢290 million in staple food	La Nación, 1994

Table 21. Effects of extreme weather conditions during ENSO years on agriculture in Costa Rica (continued on next page).

ENSO	Effect	Región	Crop	Losses	Reference
1997	Dry spell	National	Agriculture	¢600 million in agriculture until September	La República, 1997a
		Central	Vegetables	Low yields due to high temperature	Barquero, 1998
		Northern region	Grains	Water deficit	
		Southern Region	Palmito Banana	Low yields due to high temperatures. Low production	
		Caribbean	Banana	Water deficit	
		Guanacaste	Melon	Harvest loss. Low quality.	
		Guanacaste	Rice	80% of production was affected.	Agüero, 1998
		San Carlos	Beans	20% of production was affected.	
		Parrita	Rice	5% of production was affected.	
1998	Dry spell	National	Grains, Plantain, Coffee, Sugar cane, melon	¢40,500 million in damages	Calderón and Cantero, 1999

Table 21 (continued). Effects of extreme weather conditions during ENSO years on agriculture in Costa Rica.

PRODUCT	LOSSES	COST (million $)
Rice	40,425 tons	11.4
Maize	8,083 tons	1.7
Bean	13,598 tons	10.9
Sugar cane	200,000 tons	3.0
Others*		6.2
Beef cattle	2,000 head	7.2
Poultry		1.4

Table 22. Losses in agriculture caused by droughts in 1997-1998
*"Others" includes orange, melon, palmetto, tuber, mango, papaya and plantain.
Source: Jovel 2000.

Damages are usually caused by limited implementation of the weather event contingency plan. Having decision-makers execute plans is not sufficient; many other problems obstruct the implementation of migitating measures.

3.3.1. Limitations of the weather forecast

As mentioned by Stolz (2000), forecasting is hindered by the lack of mesoscale numeric models because it is difficult to obtain specific results. Maintenance and expansion of the national meteorological network are crucial for adequate forecasts, but resources are scarce. Private institutions are not aware of their role and governmental economic policies cannot support the network.

3.3.2. Lack of credibility

Credibility is essential for effective weather forecasting (Stolz 2000). Recently public opinion about the quality and usefulness of weather forecasts has improved. However, when forecasts demand the adoption of measures requiring resource facility and work, credibility drops. For instance, according to Jovel (2000), agricultural damages during ENSO 1997-1998 could have been reduced for basic grains if some sectors had not ignored the dry spell warning forecasters issues based on meteorological data.

3.3.3. Bureaucratic procedures

The administrative and legal mechanism to declare a region under emergency became a problem during the last ENSO episode (1997-1998) when it delayed the assignment of funds to mitigate the situation in agriculture (Obando, 2000). At that time, there were also problems with the publication of a decree that authorized the reduction in interest rates. This measure was aimed at promoting livestock activities, but problems provoked a delay in assigning one billion colones (Barquero 1998).

3.3.4 Lack of constant action plans

Even though attempts to design effective plans to face disasters were made in 1976 and 1985, it was not until 1993 that a National Emergency Plan was created by decree. This plan enables consultation and inter-institutional participation. Though it is still in force, cooperation from the Foreign Office for Disaster Assistance (OFDA) of the United States of America (CNE 1997) was received only for two years. At this time, Costa Rica does not have any national programs to address emergencies caused by adverse weather events. There are only a few regional plans, coordinated by the CNE. The government has not designed an organized operational program which could be applied to the entire country. Initiatives to create a national plan are thwarted every four years (the length of time between elections) as new government employees take office and policies are modified. Additionally, access to foreign support is limited because other Central American economies are unstable. In other words, Costa Rica's vulnerability to weather phenomena is not as important as its need for financial support.

3.3.5 Disaster preparedness

The CNE was not allowed to take disaster prevention actions until 1999. Even now, due to absence of national policy, regional institutions or committees handle these actions. Indeed, zoning and land use regulations, which are critical to prevent disasters, are absent; on the contrary, construction and resource exploitation are neither controlled nore organized by the State.

3.3.6 Harvest insurance

The National Insurance Institute (INS) administers harvest insurance in Costa Rica. The ENSO episode in 1982 provoked severe losses in rice and maize, and the National Insurance Institute covered all losses. After that event, the INS adopted new policies to "insure" agriculture in the event of another emergency (Adamson 2000). These policies reduced the number of affiliates, leaving most producers without any protection. The Ministry of Agriculture has not addressed this problem through its action plans since production risks and threatening events are not considered in these plans.

3.3.7 Research

There are few studies about the ENSO effects on agriculture. New studies to develop prevention and mitigation plans are necessary. The Ministry of Agriculture has initiated research on some crops.

3.3.8 Attitude toward risk

During emergencies, two groups are responsible for agricultural decision-making. Professionals from different fields coordinate and execute contingency plans, basing their strategies on hydrometeorological information. During the last ENSO episode (1997-1998), this group designed plans to face the worst consequences. Their attitude assumed two possible results: if meteorological forecasts were right, they would be ready to face problems; but if they were wrong, credibility would fall and resources would be wasted. In the end, the plan had both failures and successes. Mango producers were affected because they modified flowering induction and their yields decreased; on the other hand, livestock maintained average yields because measures were taken to survive an extended dry season.

Politicians are the second group responsible for decision-making. Their information comes from the group of professionals. Their attitude towards adverse weather conditions and their consequences is unclear. For instance, before 1999, the CNE was not allowed to put prevention measures into practice. Even though this committee was created in 1969, it was not until 1974 (after ENSO 1972-1973) that an office was established. The CNE’s actions are often frustrated despite the seriousness of emergencies. For example, the Regional Commission appointed to take care of the ENSO phenomenon in 1997 had to persuade the State Council to declare emergency in some regions of the country.

Furthermore, government officials seldom attend seminars, workshops or conferences where scientific information on the effects of weather phenomena is discussed and decision-makers are encouraged to share their opinions.

4 Potential for flexible management

Weather variations during crop growth may affect production and yields, but weather is not the only influential agent. If forecasts provide alerts of production risks, flexible management mechanisms should be implemented to avoid damages.

However, many factors stand in the way of flexible management. Insurance policies are rigid and restrictive, making it difficult to modify sowing times and crop variations (among other variables) to compensate for expected weather conditions. Though market fluctuations can make alternative crops very expensive, there are no programs which promote alternative crops or help introduce crops like rice and sugarcane to national and international markets. Since bean and maize are staple foods they are grown regardless of weather conditions. The role of the agro-industrial sector in grain imports is also problematic. Negative weather forecasts can promote grain imports before harvest, causing a severe impact on producers (even though national production usually covers demand during emergency).

These problems make the potential for implementing flexible management mechanisms for risky crops during adverse weather conditions rather small. The government should establish permanent policies to organize agriculture in Costa Rica. But limited access to loans and the lack of incentives are making things worse. Globalization and open markets are leaving small farmers aside since they cannot adjust to adverse weather conditions effectively.

IV. Analysis of decision options

4.1 Other crops

Rice plantations in the Chorotega region are tilled by medium and large farmers. About 600 small farmers grow rice to survive. Bean plantations in the Huetar Norte region have expanded rapidly since the 90s, bringing important changes to the region (and the entire country). These plantations are currently in the hands of medium and large farmers. Since rice and beans are staple food in Costa Rica, incentives for growing these products should be designed and implemented. However, restrictive loans from the National Bank System, diminished insurance coverage, the elimination of the National Production Board which guaranteed buying power, the rigid nominal price to the farmer (SEPSA, 1992) and climate variability have threatened these crops.

Aside from the governmental initiative, one option for ensuring production (not necessarily the main crop) is crop rotation during adverse weather conditions. This demands a timely analysis of crop yields and weather during ENSO episodes.

4.1.1 Influence of the cold phase (La Niña)

Villalobos (1999) has shown the significant differences in mean annual temperature and maximum annual temperature, as well as in annual and seasonal rainfall, during the cold and warm phases of El Niño in the rice producing fields of Liberia. 60% of El Niño episodes coincide with low rice yields and 100% of La Niña episodes coincide with above-average yields. Accordingly, above-average yields are expected during La Niña episodes while below-average yields are expected during El Niño episodes. This corresponds to above or below-average rainfall during the growing season. Similarly, Adamson, et. al. (2000) found that rice yields in the Chorotega region increase during cold ENSO episodes.

Since statistical evidence supports the relation between cold phases and high rice yields, rice cultivation during La Niña should be motivated, not dissuaded. The hydrophilic capability of rice crops allows good yields in the region, despite increased precipitation. Indeed, according to SEPSA (1998), national rice yields have been sustained and in 1990-98 rice was the only grain that showed a positive increase (0.6%). Three cold episodes occurred during that period (1995, 1996, 1998).

The annual precipitation recorded between the 1988 cold phase and the most recent event (1998-1999) showed a rather rainy pattern in the lowest part of the Tempisque basin (the main rice producing area). This behavior is shown in table 23.

Year	Liberia	Cañas	Filadelfia	Santa Cruz	Stations (Tempisque Basin Lowlands)
70	ND	N	NR	R	
71	N	NR	NR	R	
73	NR	R	R	R	
74	N	N	ND	N	
75	N	N	N	N	
85	ND	D	N	ND	
88	R	NR	R	R	
95	R	R	R	R	
96	R	R	R	R	
98	R	R	R	R	
99	R	R	R	R	

Table 23. Annual rainfall during cold ENSO phases in four stations located in the Chorotega Region where rice is grown. N: normal; NR: slightly rainy; R: rainy; ND: slightly dry; D: dry.

Rainfall during cold ENSO phases usually provokes flooding in this region. A study of the Chorotega region revealed that since 1949, 71% of floods in this area are related to La Niña. If the Trenberth classification (1997) is used, 80% of floods occur during La Niña years. Using Japan Meteorological Agency metrics (JMA 1997) the match diminishes to 72%. In any case, the relationship is evident.

Statistics reveal that the most affected population resides in the low part of the Tempisque Basin, in Filadelfia, Bolsón, Bebedero, La Guinea and Cañas, where extensible agriculture is practiced (sugar cane and rice). In this region, 50% of floods are likely to occur in October, especially during the second decade of the month. Since there is a relationship between La Niña and above-average yields, and floods usually occur during ocean-atmosphere phenomena, one can conclude that floods have not affected yields severely. In October (when floods occur), rice crops are between flowering and grain filling, when excess water is not harmful. Indeed, in flooded rice fields these stages occur in deep-water plots (Parsons, 1987). On the other hand, regional orographic traits diminish the impact of floods because little sediment is swept away. Floods in this region last approximately 2.6 days. However, in 1999 a storm affected the region for sixteen days.

4.1.1 Influence of the warm phase (El Niño) in the Chorotega region

During the warm ENSO episode the maximum annual temperature increases and monthly rainfall patterns are modified (Villalobos 1999, Retana 1999). 93% of dry spells correspond to El Niño years (Retana 1999) as shown in table 24.

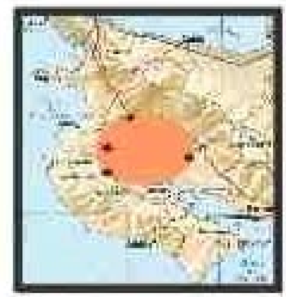
Year	Liberia	Cañas	Filadelfia	Santa Cruz	Stations (Tempisque Basin Lowlands)
72	D	ND	D	D	
76	D	D	D	D	
77	D	D	D	D	
82	N	N	N	ND	
83	N	ND	N	N	
86	N	N	ND	D	
87	D	D	D	ND	
91	D	ND	D	N	
92	N	D	ND	N	
94	D	N	ND	N	
97	D	D	D	D	

Table 24. Annual precipitation during years influenced by the ENSO warm phase in four stations of the rice producing area of the Chorotega Region. N: normal; NR: slightly rainy; R: rainy; ND: slightly dry; D: dry

Losses in rice activities (yields and production) have recently been registered (see table 1). Crop rotation for these years is justified, but crops like maize and sugar cane, which are adapted to the regional conditions and market, are also affected by extended dry spells, though sugar cane seems more resistant to these weather conditions. Melon, mango and other fruit trees mandate a large investment because they are annual crops which require technology for development. Cotton and sorghum have already disappeared. Timber is profitable, but only in the long term.

Gramineae and forage legumes (soybean, maize, sugar cane, sorghum and peanuts) would be useful for cattle during dry spells. It is estimated that 30% of beef cattle are located in the Chorotega region. Currently, double purpose cattle (beef & dairy) are becoming a better option; growth of forage crops would certainly help preserve this activity. Forage-like crops have lower production risk since they are harvested more rapidly. Furthermore, their yields are not proportional to the grain or sugar obtained.

4.1.2 Influence of the cold and warm phases in the northern region

Apparently, there is no relationship between the occurrence of ENSO episodes and bean yields in the northern region (Villalobos 1999; Adamson et al 2000). Despite this, bean crops in this region have been severely affected by weather events. Since 1996 (SEPSA 1992, Corrales 1999, Rojas 1999) dry spells and heavy rains have damaged cultivation either during the soil preparation and sowing time or during harvest or grain drying (as a result of moisture stress). The extended dry spell in 1997 and 1998 damaged almost the entire sown area. A relationship between ENSO episodes and precipitation seems possible, as shown in table 25 and 26.

Year	Chiles	Upala	Guatuso	Fortuna	Stations (Guatuso Plains)
70	-	NR	-	-	
71	-	NR	-	ND	
73	-	N	N	D	
74	-	R	R	N	
75	-	D	ND	N	
85	R	N	D	N	
88	N	NR	N	ND	
95	D	D	-	D	
96	D	D	-	-	
98	N	NR	-	-	
99	R	R	-	-	

Table 25. Annual precipitation during cold ENSO episodes in four stations located in a bean producing area in the Northern region. N: normal; NR: slightly rainy; R: rainy; ND: slightly dry; D: dry

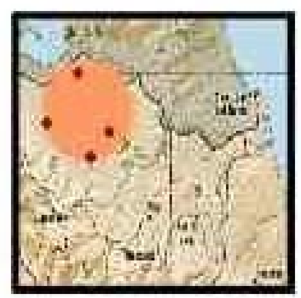
Year	Chiles	Upala	Guatuso	Fortuna	Stations (Guatuso Plains)
72	-	R	R	NR	
76	-	ND	R	N	
77	-	D	D	N	
82	D	D	N	NR	
83	N	N	ND	N	
86	R	R	D	N	
87	ND	ND	N	N	
91	NR	R	-	NR	
92	N	N	-	N	
94	N	N	-	D	
97	D	D	-	-	

Table 26. Annual precipitation during warm ENSO episodes in four stations located in a bean producing area in the northern region. N: normal; NR: slightly rainy; R: rainy; ND: slightly dry; D: dry

Since the late 1980s, the northern region of Costa Rica has been the country's main bean producing area. However, the vulnerability of this crop to climate variability resulting from ENSO (cold episode 1997-98 and warm episode 1998-2000) has caused some alarm in this sector. Due to the economic conditions of the region, crop rotation is not an option. Unfortunately, access to soft loans is limited and inflexible, and small farmers (the most vulnerable) depend upon the commercialization of their product to survive. Since beans are no longer profitable, some farmers have sold their lands to multinational companies like Hortifruit, a commercial citrus producer).

Maize and bean crops with shorter growing cycles (to diminish risk from having the crop on the soil), as well as melons (which are dispersely sown) may be feasible options.

4.2 Other factors, such as irrigation

Irrigation is the best option for preventing damages to rice cultivation during adverse weather conditions which provoke dry spells. Presently, water is supplied by the Arenal-Tempisque irrigating district, which can irrigate 60,000 hectares. This project will increase its coverage thanks to foreign support obtained by the National Irrigation and Irrigation Channels Service (SENARA) during the dry spell of 1997-1998. The district extension would favor rice and sugar cane production and the implementation of other crops like beans, melon, and fruit trees.

Dry-land rice is produced in this region. The weather conditions of the region satisfy the water needs of rice. Beans are grown in the northern region during the rainy season, under dry conditions. Since the Pacific and Caribbean influence this region, the dry season lasts only three months as compared to the Chorotega region, which is affected by a five-month dry season. Land preparation for bean cultivation in the northern region is critical because high precipitation occurs in December. Farmers in the Chorotega region usually prepare land for bean cultivation during the *veranillo* (dry conditions) in July or August.

Rice and bean production can be improved by using varieties with a shorter growing cycle and modifying sowing time according to annual rainfall. Actually, the main problem for these crops is temporary rain distribution; both crops demand adequate rain distribution during their establishment and development. On the other hand, dry conditions are needed during grain filling and drying, prior to harvest. Based on these characteristics, sowing time is usually scheduled for the end of the rainy season, but can be modified according to annual rainfall conditions (see section 4.3).

The Decision Support System for Agrotechnology Transfer (DSSAT) CERES-Rice computer model was used to study other alternatives for these crops. Results can be optimized with algorithms like “Adaptive Simulated Annealing,” developed for complex problems with multiple optimum results (Ingber 1993, 1997; quoted in Royce, 1998). The ASA-DSSAT module combines model results and optimization functions. The combination of management variables depends on profitability. Sowing time, nitrogen fertilization and population density are the management variables combined. Weather conditions are determined by the variability resulting from the cold and warm ENSO episodes. Table 27 shows the best combinations of the analyzed variables.

Management variable	Min	Max	Cold phase	Warm phase
Sowing time (day)	182	224	224	220
1st N_2 application (kg/Ha)	0	100	0	0
1st application time (dds)	1	1	0	0
2nd N_2 application (kg/Ha)	0	150	115	85
2nd application time (dds)	10	45	20	10
3rd N_2 application (kg/Ha)	0	150	90	85
3rd application time (dds)	50	90	50	60
Application density	100	750	475	500
Crop	CR1113	CR1113	CR1113	CR1113

Table 27. Best options for dry-land rice management in Guanacaste during ENSO phases according to ASA_DSSAT

With this type of management, model results indicate that during ENSO cold phases, yields could reach 3.5 ton/Ha with a growing cycle of 119 days. Warm phases displayed yields of 2.8 ton/Ha with a growing cycle of 112 days. Both results are based on the CR1113 variety.

4.3 Decision-makers' attitude toward suggested options, and future use of climate forecasting

Decision-makers have expressed different opinions regarding alternatives suggested by climate forecasting. Governmental authorities at middle-management levels seem to be receptive to this agrometeorological information. Similarly, institutions linked to the Ministry of Agriculture (MAG) have worked well together. MAG employees have solicited help from the National Meteorological Institute (IMN) in responding to weather conditions. IMN bean production studies in the northern region show that climate variability resulting from ENSO cold and warm phases in 1997-1999 has significantly modified rainfall distribution during the growing cycle of this crop (November-March). Given the above-mentioned conditions, it was recommended that sowing time be adjusted to the annual conditions (dry, normal, or rainy). Since 1998, decision-makers have adopted these recommendations, minimizing risks and damages caused by climate (Corrales 1999, Rojas 1999). Before that time, forecasts of probable dry conditions in the region in 1997-1998 (Villalobos et al 1997) reduced losses to the Insurance Company even though these forecasts were not taken into consideration by decision-makers (Madriz 1997).

The results of rice studies cannot yet be implemented. However, MAG employees are willing to work with the IMN to develop agricultural forecasting and recommendations. Indeed, one of the suggestions for mitigating loss and aiding agriculture during an emergency is to work in coordination with the IMN.

Top-level governmental decision-makers (mostly politicians) are not as receptive as the others—they base their decisions on short-term priorities. Their actions follow governmental ideology and focus on the most urgent and tangible problems with little regard for future planning. Correspondingly, medium-term climate issues seldom appear in the political agenda because the sectors involved do not demand immediate aid. Frequently, the public sector leaves inter-institutional cooperation aside, following political priorities instead.

Montero and Vanegas (1999) suggest that other factors can stop decision-makers and community leaders from pursuing viable alternative crops, management practices, or other solutions to adverse weather conditions. A lack of education, poor resource availability, the lack of organizations promoting the development of initiatives, the mitigation of negative effects as a result of climate variability, and the passive, resigned attitudes of some farmers all reduce the effectiveness of these alternatives.

4.3.1 Future Use of climate forecasts

Unfortunately, Costa Rica does not have agricultural forecasts. The agro-industrial sector which uses information from the IMN needs forecasts to schedule short-term activities and to have an idea of general weather conditions. Some people need specific information from the IMN to face particular situations.

The experience obtained through these studies, the spread of information of the negative effects of climate events, and the interest of some sectors in recurrent atmospheric phenomena confirms the importance of forecasts for agriculture.

Example of the utilization of medium-term forecasts in agriculture

After the study on the evolution of the 1999 La Niña event and its impact on rainfall in the northern region of Costa Rica concluded, MAG authorities recommended that the sowing time be delayed. Usually, sowing takes place from November to December in this region; however, the MAG recommended sowing in January since December was going to be rather rainy due to La Niña. Consequently, sowing took place in January, and the resulting yields will be evaluated in March 2000. Field information from Upala shows that this crop is developing normally.

Studies recommend sowing times based on three scenarios: dry, normal and rainy. These options are related to early ENSO forecasts and rainfall data on the evolution of the event. In this manner, early ENSO forecasts will inform the possibilities of having dry, normal or rainy conditions. Periodical monitoring of rainfall allows a real follow-up of the scenario. Final sowing time is determined by combining the scenario with forecasts of the evolution of the phenomenon.

To determine the exact sowing time the driest month of the scenario applied must be identified. Using this information, the best harvest time can be determined. The crop is situated in time taking this date into consideration, and according to its growing cycle. Once the first sowing date is determined, the expected precipitation during the growing cycle is analyzed (according to the scenario applied). If water conditions do not satisfy the needs of the crop in any of its stages, the initial sowing time is modified to avoid moisture stress. To optimize the range, the BEANGRO-dry bean model is run using a probability of 75% rainfall using a rainy scenario as the climate file. The program compares various sowing dates until the best yield is obtained.

V. Infrastructure and cooperation

5.1 Do people exist to do this?

Weather forecasting in Costa Rica is the responsibility of the National Meteorological Institute (IMN). This service has been especially important during the last three decades. The World Meteorological Organization has contributed to the strengthening of the meteorological network and personnel training since 1970. This effort has translated into more accurate research, analyses and forecasting. However, meteorological research aimed at the implementation of actions related to weather forecasting is also in the hands of the University of Costa Rica (UCR), Universidad Nacional (UNA), the National Electricity Institute (ICE), the Institute for Aqueduct and Sewage (AyA) and other institutions or private organizations such as research departments from banana or coffee companies as well as the Tropical Agricultural Research and Training Centre (CATIE). Meteorological applications for agricultural disease forecasting has been studied through different essays and research (Jiménez 1994, Retana and Herrera 1994). Despite this considerable work, there is little effort to establish a permanent, consistent system of meteorological alert. According to Jiménez (1994), young apple and grape plantations in the country have promoted the introduction of timely alerts which can be successfully applied in other countries. Retana and Herrera (1994) mention that some banana companies in the Caribbean (Costa Rica) have used local short-term rainfall forecasts to schedule the aerial application of agrochemical products.

In 1973, the IMN became, by law, the coordinator of all national meteorological activities. Over time the capacity and skills of the IMN have grown to favor end-users. Currently, the IMN does not issue a weather forecast which helps follow the evolution of the ENSO phases. Instead, the IMN takes the results of the different numerical models from ocean and weather services such as the National Oceanic and Atmospheric Administration (NOAA), the National Centers for Environmental Prediction (NCEP), and the long lead forecast issued by the Center for Ocean Land Atmosphere Studies (COLA). This information is used to predict rainfall behavior during the rainy season. The forecast is based on statistical evidence and constitutes the most important long-term prediction of the IMN (Stolz 2000). The rainfall forecast is utilized in tourism, agriculture, by the general public, and by national institutions such as the National Emergency Committee (CNE) and the Ministry of Agriculture (MAG).

Agriculture has widely benefited from the weather service. Weather forecasts in the media have allowed farmers and managers to plan their tasks on a better basis. Nonetheless, agricultural forecasting is not yet a reality in Costa Rica. Currently, the only rain season forecast available lacks an agricultural focus regarding crop types, soil preparation, sowing, harvest, cultural activities, or other variables. However, in general, growers still use this weather forecast for management purposes.

Most forecasting advances have occurred since 1997. The early forecast of the IMN on the expected effects of the warm ENSO episode was noticed by agricultural institutions and organizations, especially those depending on rain quantity and distribution for planning. Several agricultural groups asked the IMN for specific studies assessing each crop’s water demand for that year. These studies (Villalobos and Retana 1997a,b; Villalobos et al 1997, Retana et al 1997, Ramírez et al 1997) allowed financial support from the national bank system, the restriction of insured areas and drought hazard reduction in some areas of the country. This effort was intensified by technical conferences hosted by the IMN which strived to spread information about ENSO phenomena. Most conferences addressed petitions from agricultural organizations and the Ministry of Agriculture.

In this way, tobacco producers in Puriscal, coffee growers in Naranjo, bean producers in Los Chiles, Upala and La Cruz, banana producers in the Caribbean watershed, and rice producers in Liberia, Santa Cruz and Nicoya were all informed and alerted (Villalobos and Retana 1997).

Even though most bean producers in the northern region did not observe the IMN forecasts about the coming dry spell in the region (Villalobos et al 1997), losses provoked farmers to request agricultural forecasts of weather variability since 1998 and 1999 (Villalobos and Retana 1998, Retana and Villalobos 1999).

These studies have three elements: the rain season forecast emitted by the IMN, the monthly follow up of this forecast according to three scenarios (dry, normal, rainy), and agricultural models. In like manner, this forecast is validated and updated through the scenarios. The estimated rainfall according to the scenario average (or its occurrence probability at 75%) becomes a weather platform from which to run several models, modifying the sowing time in each. In the end, sowing time is estimated according to the best yields obtained.

For the 1999-2000 bean cycle, growers in the northern region were told to change the sowing time from mid-November and mid-December to the first half of January. This recommendation turned to be the best option given the rainfall conditions of December, January and February. According to the conversations held with some growers, those who followed the suggestions given by the IMN were able to harvest in the driest part of the cycle, which is ideal for maturing and drying the grain. Losses caused by rainfall for those bean crops which were sown at the usual time have not yet been estimated. Based on the information supplied by the Agricultural Center of Los Chiles (where 8,000 to 10,000 hectares are cultivated), farmers who sowed in December 1999 have suffered great losses (Barquero 2000).

The extreme effects from climate variability during the last decade in Costa Rica, show the vulnerability of economically and socially important sectors. Agriculture may be the most severely affected sector, suffering losses reaching US$33.2 million (36% of total nationwide losses) during the 1997 El Niño episode (Jovel 2000). Growers must obtain access to a weather forecast oriented to agriculture in order to plan their future activities, or such losses will likely occur again.

5.2 Could application of climate forecasts be sustainable?

Even though the need for weather forecasts oriented to agriculture is evident, demand is not as clear. To understand the cause of this problem, IMN deficiencies must be discussed.

Stolz (2000) states that forecast credibility depends on effectiveness over time—if forecasts are ineffective, credibility drops. IMN forecasts are not designed to prediction the evolution of ENSO phases, but instead focus on the behavior of the rainy season. The lack of adequate maintenance, slow modernization, slow expansion of the meteorological network, and gradually decreasing budgets all hinder this task. The international support available for these projects has allowed an acceptable operability. However, weak budgets definitely affects the forecasting accuracy and credibility.

The lack of mesoscale numerical models also limits the availability of results for Costa Rica. Current models cover large scales and the projection to local latitude sacrifices accuracy.

Considerably more research of ENSO effects on specific agricultural activities is needed. The ENSO phenomenon affects different regions of Costa Rica in different ways. It is difficult to translate this information to agriculture. A complex analysis is required for each crop, sowing time and affected region. No studies of this kind covering the all of Costa Rica or the country's most important crops.

The Conference on Climate Variability Impact Reduction, held in San José, Costa Rica, areas included discussion of areas related to weather forecast during ENSO events which need reinforcement in Central American weather services, particularly in Costa Rica. Conference participants concluded that foreign support is necessary since the government of Costa Rica cannot provide enough funds to guarantee an efficient service. Investment should cover three aspects: personnel training, acquisition of adequate technology and financial sustainability. In analyses and forecasting, models need to be validated and resolution in the region needs to be improved. For this purpose, the academic and research efforts of different universities should work with the IMN.

With its existing capacity, the IMN should the most important administrative organism of the national meteorological network. The database of the IMN comes from automatic and mechanical stations located throughout Costa Rica. There is currently a telemetric network which provides timely information about the most representative climate zones, with aid from satellite imagery on cloud cover and sea surface temperature. Institutions such as ICE and AyA administer some networks, but focus on hydrology. Private groups own some local pluviometric networks.

The IMN is in constant communication with other institutions like the National Emergency Committee (CNE) and the Ministry of Agriculture (MAG). It transmits information to the media and issues official information on the evolution of ocean and atmospheric phenomena such as the ENSO event.

The IMN has simulation models for agriculture. These models are calibrated and validated to fit national conditions as part of the Decision Support System for Agrotechnology Transfer (DSSAT). This system needs climate, soil and crop databases. The database of the IMN covers information from the country agricultural regions. The information comes in magnetic format and programs have been designed to restructure data for entry into DSSAT. MAG, through its Land Use and Planning Department, provided the IMN with a Natural Resource System of Costa Rica (RNCR), which compiles national soil information. With this system, it is possible to locate any site of interest and obtain data to design the corresponding soil file for DSSAT. Personnel trained in the management and use of data, computing systems and interpretation and analysis of results oversee this work.

Overall, despite the weaknesses of the IMN, the Institute is effective enough that national producers are able to access valuable information from the weather forecast. This undoubtedly helps diminish the hazards of extreme weather for agriculture. No other institution in Costa Rica handles a database like the one of the National Meteorological Institute. It is a reliable tool which provides dependable statistics. The IMN works with the basic human and material resources to generate studies and derive specific information for some agricultural sectors. The Institute is gaining experience and its efforts need to be reinforced.

VI. Conclusions

During ENSO phases normal annual and seasonal rainfall behavior, and minimum and maximum annual temperature all change in the Chorotega region. Despite the evidenced relationship between the ENSO phenomenon and weather in the Chorotega region, the effects of the phenomenon differ in time and space. Droughts or excessive rains are not explained by the occurance of ENSO in the region.

There are no significant changes to these parameters in any of the ENSO phases in the northern region.

Climate variability has affected basic grain production in Costa Rica, though its effect varies over time and in different locations. In the Chorotega region, the main rice producer of the country, production and yields of dry-land rice diminished in comparison with the average during the occurrence of most warm ENSO phases (between 1980 and 1998). Probably, the decrease in annual rainfall associated with this type of years affects production. Important drops in precipitation are observed in July and August, during the dry spell. In extreme cases, water deficits occur even in September and October, when rice enters flowering, formation and grain filling, and water availability is critical.

There is enough statistical evidence to indicate that during the cold ENSO phase, rice yields increase significantly over those of the warm and neutral phases. This behavior may be associated with rainfall conditions during La Niña years, over 70% of which coincide with floods in rice areas, especially in October. Since flowering and grain filling occurs in this month, flooding (high water quantity and runoff) have benefited this cereal instead of damaging it.

There is no statistical evidence demonstrating that ENSO phases severely influence bean production and yields in the northern region. No production behavior or climate condition associated with the ENSO phases was observed between 1980 and 1998. Though recent evidence suggests that abnormal rainfall distributions in November, December, January and February for the last four years (ENSO phases) have affected this activity, yields do not reflect the occurrence of each phenomenon. Due to excessive rains in 1996 and severe water deficits in 1997 (associated with ENSO), yields dropped 40% in the area.

ENSO effects in Liberia and Los Chiles vary. Yield variations depend on rainfall distribution, soil moisture during each crop cycle, and the intensity of the ENSO phase.

The information available to date has been well received by decision-makers at the technical and professional level. The response to the agricultural emergency of the 1997 El Niño was based on information about expected weather conditions disseminated by the IMN. Action plans and measures taken by the different sectors helped avoid agricultural losses like those reported by other countries of the region, which were affected similarly and with the same vulnerability level.

Since 1997, agrometeorological suggestions for bean producers in the northern region have helped diminish agricultural losses as a consequence of adverse atmospheric phenomena. Yields went from 0.3 and 0.4 t/ha in 1996 and 1997 (La Niña and El Niño years) to 0.8 and 1.0 in 1998 and 1999 (La Niña years). This should be recognized by the IMN.

However, a lot of work will still be needed to get political decision-makers to develop real, sustainable, multi-sector plans for the medium and long term. Producers can hardly promote planned adaptation processes because they are limited by the low academic capacity of community leaders, lack of information managing tools, unfamiliarity with the existing situations and resources, inefficient use of resources, excessive reliance on political production, and commercial and industrial policies.

Furthermore, all mitigation and adaptation plans will face problems such as lack of credibility towards forecasts, lack of research in agrometeorology, lack of defined policies for facing climate variability, excessive bureaucracy, minimal participation of insurance companies, restrictive financial policies, lack of incentives and fear of taking chances by political decision-makers.

No defined agricultural planning policies offer options to rice and bean producers during climate emergencies. Moreover, some foreign commerce policies endanger national production of basic grains since the import of grains is uncontrolled. Many producers have sold or rented their lands due to losses. In the Chorotega region many small rice producers have disappeared and others have switched to sugar cane because it is more profitable. The producers of the northern region seem more vulnerable because they cultivate beans as a monoculture and depend exclusively on this product for socio-economical status. Irrigation is only feasible in rice crops, and the current irrigation project can cover only a small area.

A real agricultural forecast is not yet possible in Costa Rica. However, the demand for the general weather forecast has grown and agriculture has become a major user of this service. This increase in the demand, combined with the increase in credibility due to increasing accuracy in forecasts and better information management, may generate the basis for a future agricultural forecast in Costa Rica. The IMN has proven that it has the basic platform to offer this product, but additional foreign financial support and policies for maintaining this activity are needed.

Recommendations

More studies of the actual ENSO influence over crops and agricultural regions in Costa Rica are needed. Actions for preventing or attending to agricultural emergencies related to climate variability should be designed based on these studies.

Results must reach decision-makers through an effective channel, not through workshops and seminars because few people attend these activities. Given the fact that the United States of America has a well-defined and settled environmental policy, particularly in regard to climate variability research, it is recommended that the IAI foster the communication of the results obtained in these studies to the national political community. This may work better than internal communication.

Timely alerts between the technical and scientific community and the public should be improved. In this way, without intermediaries, information will be more reliable. The media and other groups have manipulated some meteorological information during the most recent ENSO events, spreading erroneous information and creating misguided ideas.

The project should consider the creation, maintenance and update of an Internet node which may gather experiences and encourage the participation of scientists from other parts of the world who may be willing to share results in similar studies.

The countries affected by the ENSO phenomenon should be persuaded to propose, develop and promote methodologies which confront the problem of climate variability from different perspectives. In that way, more information about cause and effect would be available. The ENSO phenomenon should be considered as a separate climate variability event and not as "climate variability" because it is not possible to explain extreme weather conditions and work with the scenarios generated from the same database. Accordingly, the ENSO event should considered a scenario which may occur and must be updated every year.

Given the need to gather information in Costa Rica, these sort of projects should include activities which collect meteorological and agricultural data.

References

Adamson, M.; Hall, L.; Chavarría, H.; Robalino, J. 2000. Impacto económico del ENOS sobre los granos básicos en Costa Rica. Instituto de Investigaciones en Ciencias Económicas. Instituto Meteorológico Nacional. San José, Costa Rica. 127pp.

Alfaro, R. 1983. El cultivo del frijol. CAFESA. San José, Costa Rica. 108p.

Barquero, M. 2000. La Niña acecha. La República. 17 03 2000. http://www.nacion.co.cr/ln_ee/2000/marzo/13/economia1.html

CNP 1990. Recomendaciones técnicas del cultivo de frijol. Consejo Nacional de Producción, Departamento Agrotécnico. División de Fomento. 27p.

CNE 1997. Lista básica de comunidades nacionales prioritarias según región bajo la influencia de amenazas naturales o tecnológicas. Comisión Nacional de Emergencias. Sistema de Información para Emergencias. San José. C.R. 9p

Corrales, J. 1999. Solicitud para realizar un estudio sobre la climatología de la región de Los Chiles y Upala y su relación con el cultivo del frijol. Gerencia General del Consejo Nacional de Producción. San José, C.R. (correspondencia personal).

Chinchilla, E. 1987. Atlas Cantonal de Costa Rica, Instituto de Fomento y Asesoría Municipal (IFAN). San José, Costa Rica.

García, E. 2000. Plan para mitigar los efectos del fenómeno de El Niño en el sector agropecuario. Resultados del plan. Congreso: Reducción de Impactos de Variabilidad Climática: El caso de ENOS 1997-1998 en Costa Rica. CATIE-PNUMA-NCAR-WMO-IDNDR. IICA. Coronado, C.R. (Correspondencia personal).

Ginneken,V. y Calderón, J. 1978, Mapa de Categorías de Pendientes, escala, 1:200.000. Oficina de Planificación Agropecuaria, San José, Costa Rica.

Glantz, M. 1998. Corrientes de Cambio: El Impacto de "El Niño" sobre el Clima y la Sociedad. Cambridge University Press. 141p.

Gómez, L. D. 1996. Vegetación de Costa Rica.Editorial Universidad Estatal a Distancia, San José, Costa Rica. 385p.

Hansen, J. W.; Hodges, A. W.; Jones, J.W. 1998. ENSO Influences on Agriculture in the Southeastern United States. Journal of Climate 11:404-411.

Hansen, J. W.; Jones, J.W.; Kiker, C.F.; Hodges, A. W. 1999. El Niño-Southern Oscillation Impacts on Winter Vegetable Production in Florida Journal of Climate 12:92-102.

Hernández, C. 1997. Rice sowing time. National Rice Office. Interview.

IMN (Instituto Meteorológico Nacional de Costa Rica). 1986. Catastro de las Series de Precipitación Medias en Costa Rica, San José, Costa Rica.

IFAM 1974. Estudio para el desarrollo regional de la provincia de Guanacaste y tres distritos de la provincia de Puntarenas. Instituto de Fomento y Asesoría Municipal (IFAM). Departamento de Investigación y Evaluación. Volúmen I. Diagnóstico de la región. San José, Costa Rica. 184p.

IRI (International Research Institute). 1996. International Forum on Forecasting El Niño: Launching an International Research Institute, 6-8 November, 1995. Executive Summary. Washington, USA.

Jiménez, F. 1994. Uso de la meteorología en el combate de enfermedades fitopatogenas. En: García, J., Fuentes, G., Monge, J. 1995. Opciones al uso unilateral de plaguicidas sintéticos en Costa Rica: pasado, presente, futuro. Editorial Universidad Estatal a Distancia. Vol II: 101-125

JMA. 1997. Enso index according to JMA SSTA (1868-present). http:/www. coaps. fsu. edu/~legler/ jma_index1.shtml.

Jovel, R. 2000. El Impacto socio-económico de El Niño en Costa Rica durante 1997-1998. Congreso sobre la Reducción de Impactos de Variabilidad Climática: El Casode ENOS 1997-1998. CATIE-PNUMA-NCAR-WMO-IDNDR. IICA. Coronado, C.R. 18pp.

MAG 1983. Manual de recomendaciones. Boletín Técnico No 62. Ministerio de Agricultura y Ganadería. San José, Costa Rica. 234p.

Magrin, G. O.; Grondona, M. O.; Travasso, M. I.; Boullón, D. R.; Rodríguez, G. R.; Messina, C. D. 1998. Impacto del Fenómeno “El Niño” sobre la producción de cultivos en la Región Pampeana. Instituto Nacional de Tecnología Agropecuaria (INTA), Instituto de Clima y Agua. Castelar, Argentina. 16p.

Madriz, R. 1997. Comments on bean production during 1997-1998. National Meteorological Institute. Agriculture Dept. San José, Costa Rica (Interview).

Montero, V.; Vanegas, J. 1999. Factibilidad y viabilidad de adaptación local a los efectos del cambio y la variabilidad climática. Universidad de Costa Rica. Facultad de Medicina. Escuela de Salud Pública. Instituto Meteorológico Nacional. Maestría en Salud Pública con énfasis en Ambiente y Desarrollo Humano. Proyecto de Investigación. San José, C.R.

Murillo, K. 2000. País sin censo agrícola: ausencia de registro de tierras inactivas. La República, San José (C.R); feb.29: 4A

Murillo, K.; Rivera, E. 2000. Arroz encarece por importadores. La República San José (C.R); mar.16: 4A

ONS 1996. Epocas de siembra y densidades recomendadas. Oficina Nacional de Semillas. Calendario Anual. San José, Costa Rica.

Pérez, S. 1978. Manual Descriptivo del Mapa de Asociaciones de Subgrupos de Suelos en Costa Rica, escala 1:200.000. Oficina de Planificación Sectorial agropecuaria, San José, Costa Rica.

Ramírez, P.; Retana, J.; Zúñiga, B. 1997. Comportamiento de la precipitación durante 1997 en la Región Huetar Norte y la Huetar Atlántica y su relación con el evento ENOS. Instituto Meteorológico Nacional. Boletín informativo. Noviembre 1997.

Retana, J., Herrera, H. 1994. La agrometeorología en la protección agropecuaria. En: García, J., Fuentes, G., Monge, J. 1995. Opciones al uso unilateral de plaguicidas sintéticos en Costa Rica: pasado, presente, futuro. Editorial Universidad Estatal a Distancia. Vol II: 169-186.

Retana, J.; Villalobos, R. 1999. Climatologia y variabilidad climatica interanual de la región de los Chiles - Upala y su relacion con el cultivo de frijol. Informe Técnico Nº1-99. Instituto Meteorológico Nacional. Gestión de Desarrollo. San José, Costa Rica. 8p

Retana, J., Villalobos, R., Solano, J. 1997. Climatología de la Región de Los Chiles-Upala y su relación con el cultivo del frijol. Informe Técnico Nº2-97. Instituto Meteorológico Nacional. Gestión de Desarrollo. San José, Costa Rica. 13p

Retana, J. 1999. Efecto de las condiciones climáticas en la Región Chorotega provocadas por el fenómeno ENOS, sobre la producción bovina de carne en Costa Rica. Tesis de grado para optar por el título de Licenciatura en Ingeniería Agronómica con énfasis en Zootecnia. Universidad de Costa Rica. San Pedro, Costa Rica. 80p.

Rojas, G. 1999. Solicitud para realizar un estudio sobre la climatología de la región de Los Chiles y Upala y su relación con el cultivo del frijol. Gerencia Regional Sector Agropecuario. Región Huetar Norte. Ciudad Quesada, C.R. (correspondencia personal).

Royce, F. 1998. ASA-DSSAT Guide.30p. (correspondencia personal)

Sandoval, J. F. 1996. Variabilidad climática y rendimientos agrícolas: Una evaluación para el cultivo de frijol en la región sur de Costa Rica. En: Impacto del Fenómeno El Niño sobre los Recursos Hídricos y la Agricultura en Mesoamérica y el Caribe y nuevas Metodologías para la Aplicación práctica del Pronóstico Climático Estacional e Interanual. Instituto Internacional de Investigación sobre Cambio Climático (IRI). 31-34p.

Stolz, W. 2000. Capacidades para pronóstico climático con que cuenta Costa Rica. Instituto Meteorológico Nacional. Congreso sobre la Reducción de Impactos de Variabilidad Climática, El Caso del Niño 1997-1998 en Costa Rica. PNUMA-CATIE-NCAR. San José, febrero 2000.6p.

Tosi, J. 1969. Costa Rica, Mapa Ecológico, según la Clasificación de Zonas de Vida del Mundo de L.R. Holdrige. Escala 1: 750.000, San José, Costa Rica.

Trenberth, K. 1997. The definition of El Niño. Bulletin of the American Meteorological Society.78(12):2771-2777.

UCAR (University Corporation for Atmospheric Research). 1994. El Niño and Climate Prediction. Reports to the Nation: on our Changing Planet. Spring N°3.

Vahrson, W. y Hernández, G. 1991. Mapa de Amenazas Hidrometeorológicas de Costa Rica. Escuela de Geografía , Universidad Nacional, San José, Costa Rica.

Vega, G. y Stolz, W. 1997. El fenómeno de "El Niño", su impacto en la economía de Costa Rica. Instituto Meteorológico Nacional. San José, Costa Rica. 9p.

Villalobos, R.; Retana, J. 1997a. Climatología de la Región de Liberia y su relación con el cultivo de arroz. Informe Técnico Nº4-97. Instituto Meteorológico Nacional. San José, Costa Rica. 10p.

Villalobos, R.; Retana, J. 1997b. Comportamiento de la precipitación en diferentes zonas del país en relación al evento ENOS de 1997. Instituto Meteorológico Nacional. Gestión de Desarrollo. San José, Costa Rica. 3p

Villalobos, R.; Retana, J.; Solano, J. 1997. Climatología de la Región de Limón y su relación con el cultivo de banano. Informe Técnico Nº3-97. Instituto Meteorológico Nacional. Gestión de Desarrollo. San José, Costa Rica. 12p

Villalobos, R.; Retana, J.; Solano, J.; Solera, M. 1998. Climatología de la Región de Los Chiles-Upala y su relación con el cultivo del frijol. Informe Técnico Nº1-98. Instituto Meteorológico Nacional. Gestión de Desarrollo. San José, Costa Rica. 18p

Villalobos, R.; Retana, J.; Zúñiga, B.; Ríos, A. 1997a. Climatología de la Región de Puriscal y su relación con el cultivo del Tabaco. Informe Técnico Nº1-97. Instituto Meteorológico Nacional. Gestión de Desarrollo. San José, Costa Rica. 12p.

Villalobos, R.; Retana, J.; Zúñiga, B.; Ríos, A. 1997b. Pronóstico de la precipitación total anual para la Región Chorotega mediante un método de asociación de grupos de años. Informe Técnico Nº5. Instituto Meteorológico Nacional. San José, Costa Rica. 9p San José, Costa Rica. 2p

Waylen, P. R.; Quesada, M. E.; Caviedes, C. N. 1995. Temporal and Spatial Variability of annual precipitation in Costa Rica and the Southern Oscillation. International Journal of Climatology 16: 173-193.