Fourth LACCEI International Latin American and Caribbean Conference for Engineering and Technology (LACCEI' 2006)
"Breaking Frontiers and Barriers in Engineering: Education, Research and Practice", 21-23 June 2006 Mayagüez, Puerto Rico

WATER CONSUMPTION BY SELECTED CROPS AND CLIMATOLOGY: CASE STUDY IN TRINIDAD

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Abstract
This paper discusses climatic data of five weather stations in Trinidad and potential evapotranspiration with Hargreaves-Samani and modified Blaney-Criddle methods, and presents seasonal estimates of net irrigation requirements and total water consumption by twenty vegetable crops. Potential evapotranspiration range (mm/day) was 3.60 to 4.6 at the University of West Indies, 3.6 to 4.8 at Piarco, 3.6 to 4.7 at Hollis, 3.6 to 4.8 at Navet, and 4.1 to 5.3 at Penal.

Key words
Trinidad, agroclimatology, evapotranspiration, net irrigation requirement, crop water consumption.

1. Introduction

Irrigation provides plants with sufficient water to prevent yield-reducing stress. The frequency of irrigation and quantity of water depend on local climatic conditions, crop species, stage of plant growth and soil-plant-moisture characteristics. The need for irrigation can be determined in several ways that do not require data on rate of evapotranspiration (ET). Visual indicators such as plant color or leaf wilting and an early drop can be used [Doorenbos and Pruitt, 1977]. However, this information appears too late to prevent reduction in crop yield or quality. Other methods of irrigation scheduling include determination of plant water stress, soil moisture status and soil water potential [Goyal, 1989]. Methods of estimating crop water requirements using ET in combination with soil characteristics are useful in determining not only when to irrigate but also the quantity of water needed [Doorenbos and Pruitt, 1977]. Estimates of ET have not been used in Trinidad even though necessary climatic data are available. Trinidad's water supply is dwindling because of luxury consumption of ground water resource (e.g. sprinkler irrigation of golf courses). There is an increasing demand of ground water for domestic, municipal and industrial uses. Water quality is declining as well. Thus, water is a limiting factor in Trinidad's goal for self- sufficiency in agriculture. Intelligent use of water will prevent sea water from entering into aquifers. Irrigation of crops in the tropics and on these soils requires appropriate working principles for the effective use of all resources peculiar to the local conditions. Adequate water supply for the entire growing season is essential for the optimum production of crops. The crop water requirements are often provided by both rainfall and irrigation. In places where sufficient rainfall is received throughout the growing period, irrigation is minimal. For good water management and irrigation planning, it is necessary to know the water consumption of crops grown in the project area. Hackbart [1987] has developed a computer program to estimate net irrigation requirements for various crops in which he has combined information from a modified Blaney-Criddle model [Doorenbos and Pruitt, 1977; Goyal et. al., 1988] together with the USDA-SCS Technical Release No. 21 of USDA-SCS. In Florida and Puerto Rico, irrigation water requirements for vegetables and other agronomic crops have been computed by Rogers et. al. [1977] and Goyal and González-Fuentes [1989]. They have estimated net irrigation requirements (NIR) with mean monthly rainfall data and with 20% rainfall probability (dry years) data. Methods presented in this paper to estimate PET and total water consumption can be employed in Colombia and other countries to develop local data bases. The objectives of this study were to: 1. Estimate potential evapotranspiration (PET) with Hargreaves-Samani and modified Blaney-Criddle methods; 2. Estimate total water consumption by twenty crops at five locations in Trinidad.

2. Methods and Materials

The five weather stations were the University of the West Indies, Piarco Airport, Hollis, Navet and Penal as identified in figure 1. The potential evapotranspiration (PET) was estimated with available climatic data and the following equations:

$$PETHS = 0.0023 \times Ra \times (T + 17.8) \times (Tmax - Tmin)^{0.5} \quad \text{-------/1/}$$

$$PETBC = Kt \times H \times P \times (0.46 \times T + 8.128) \quad \text{------/2/}$$

Where: PETHS = potential evapotranspiration with Hargreaves-Samani method, mm/day.
PETBC = PET with modified Blaney-Criddle model, mm/day
Ra = extraterrestrial radiation, mm/day
T = average temperature, ˚C
TMAX = maximum mean temperature, ˚C
Tmin = minimum mean temperature, ˚C
Kt = (0.03114 x T + 0.5222) = temperature coefficient.
H = humid area factor of 0.8 for Trinidad.
P = monthly percentage of total daylight hours.

With values of Kt and H for Trinidad, equation /2/ reduces to:

$$PETBC = (0.024912 \times T + 0.41776) \times (0.46 \times T + 8.128) \times P \quad \text{-------/3/}$$

$$= K1 \times K2 \times P \quad \text{-------/4/}$$

Where, $K1 = (0.41776 + 0.24912 \times T)$ -------/5/

$K2 = (8.128 + 0.46 \times T)$ -------/6/

K1 versus T and K2 versus T are shown in Figure 2. K1 and K2 are temperature dependent coefficients. For each monthly value of T, K1 and K2 were interpolated. With monthly K1, K2 and P in equation /4/, PETBC was determined. Monthly water consumption was estimated for banana, cabbage, cucumber, dry onion, egg plant, grain corn, honeydew, lettuce, plantain, potato, pumpkin, snap bean, wet and dry season rice, snap bean, sugarcane, sweet pepper, sweet potato, tomato and watermelon. Monthly water consumption values (Cum, inches per month) were estimated with climatic data from Trinidad, Hackbart's computer model, USDA-SCS Technical Release No. 21 and the following equations:

$$CUm = Kc \times Kt \times P \times TF \times H \quad \text{------/7/}$$

$$CU = CUml + CUm2 + \text{----} + CUmi \quad \text{------/8/}$$

$$NIR = CU - ER \quad \text{------/9/}$$

where: CUm = Monthly water consumption for the first, ----, last month (inches/month).
CU = Total water consumption during the season.
Kc = Crop growth coefficient.
TF = Mean air temperature, ˚F
ER = Effective rainfall, inches, (Calculated using Technical Release No. 21).
NIR = Net Irrigation for normal years, inches.

Monthly water consumption values (CUm) were summed to obtain seasonal water consumption (CU). A net irrigation requirement (NIR) was estimated with equation /9/.

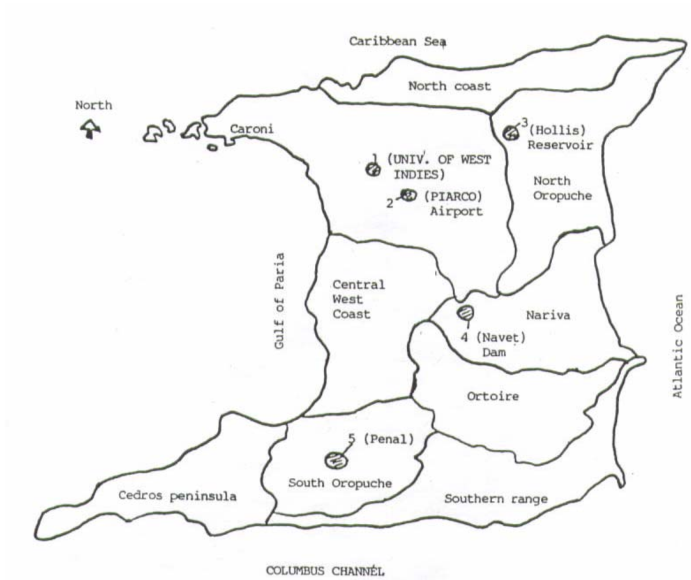

Figure 1: Location of hydrometric stations in Trinidad.

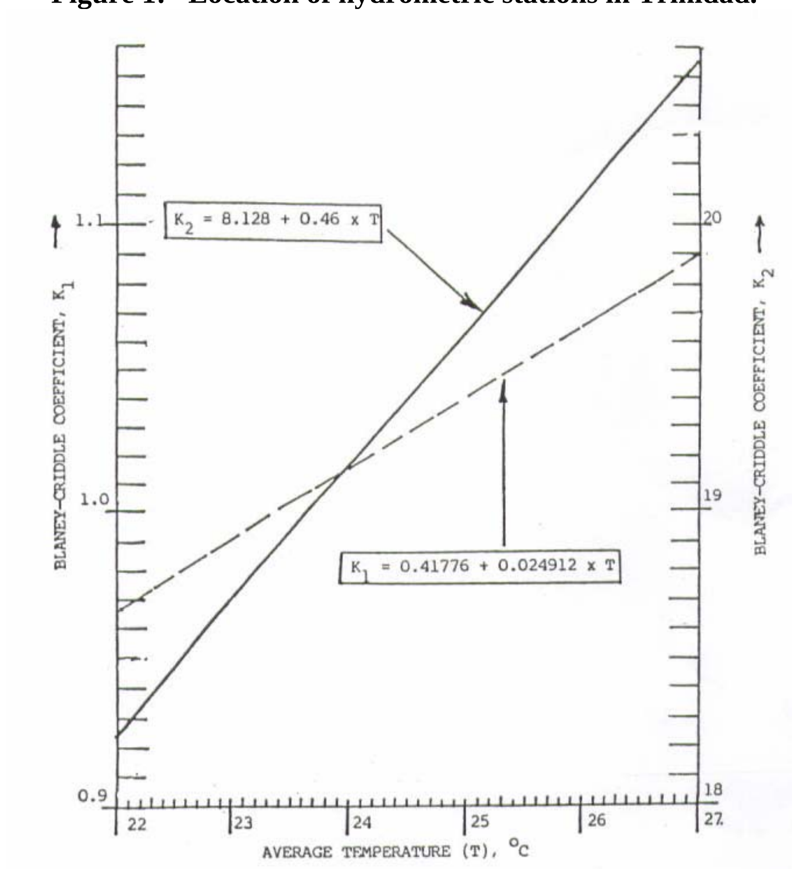

Figure 2: Blaney Criddle coefficients versus average temperature in Trinidad [USDA – SCS Technical Bulletin No. 21].

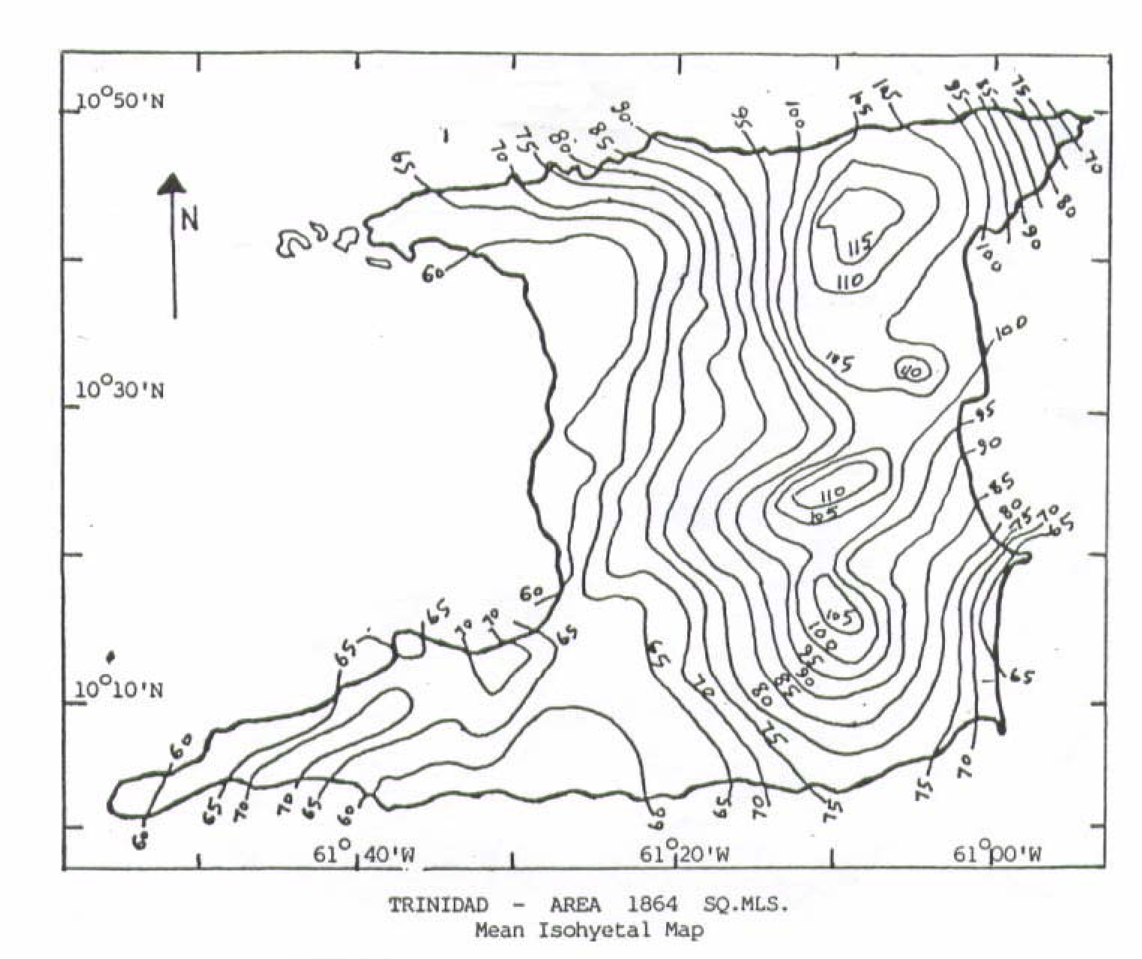

Figure 3: Mean annual distribution of rainfall (inches) in Trinidad.

3. Results and Discussions

3.1 Climatology

All results are shown in tables 1 to 4. Mean monthly temperature was highest in May at the University of the West Indies and Piarco Airport; and in August at Hollis, Navet and Penal. Mean monthly temperature was lowest in January at the University of the West Indies, Piarco, Navet and Penal; and in December at Hollis. Average monthly temperature range (˚C) was 24.8 to 26.9˚ at the University of the West Indies; 24.6 to 26.7˚ at Piarco Airport; 22.3 to 23.9˚ at Hollis; 24.3 to 25.9 at Navet; and 24.3 to 26.8˚ at Penal. Mean annual distribution of rainfall (inches/year) in Trinidad is shown in Figure 3. West and south coasts are driest, and central Trinidad is wettest. In Trinidad, January through April is dry season and May through December is wet season. March is the driest month. Wettest month is August at the University of the West Indies; July at Piarco and Hollis; June at Navet and Penal. Mean monthly rainfall range (mm/month) was 32.8 to 241.6 at the University of the West Indies; 35.8 to 263.8 at Piarco; 90 to 411 at Hollis; 56 to 343 at Navet; 35 to 228 at Penal. Mean monthly relative humidity (%) ranges from 71 to 87 during the year. The wind speed ranking was Piarco > Navet > Hollis > Penal. Mean monthly daylight hour percentage ranged between 7.39 to 9.95 at University of the West Indies, 7.15 to 9.55 at Piarco, 7.20 to 10.48 at Hollis, 7.56 to 9.36 at Navet, 6.68 to 9.74 at Penal (table 3).

3.2 Potential Evapotranspiration

Monthly PET (mm/day) with Blaney-Criddle (ETBC), Hargreaves and Samani (ETHS) methods and class A pan evaporation (Epan, mm/day) at five locations in Trinidad are shown in table 4. Epan is minimum in December at Piarco and Hollis; and in November at Navet and Penal. Epan (mm/day) ranged between 4.5 to 7.0 at Piarco, 2.9 to 4.8 at Hollis, 4.0 to 5.7 at Navet, 3.0 to 5.9 at Penal during the year. At all locations during the year, ETBC is greater than ETHS. At Hollis, Navet and Penal, monthly ETBC was always higher than Epan. At Piarco, monthly ETHS were lower than Epan. ETHS range (mm/day) was 3.60 to 4.58 at the University of the West Indies; 3.59 to 4.75 at Navet; 4.05 to 5.34 at Penal. ETBC range (mm/day) was 5.37 to 6.75 at the University of the West Indies; 5.14 to 6.61 at Piarco; 4.46 to 6.12 at Hollis; 5.16 to 6.50 at Navet; and 4.83 to 6.83 at Penal.

3.3 Seasonal Net Irrigation Requirements

Table 1 gives the total water consumption (CU) and seasonal net irrigation requirements for normal years (NIR) at five locations in Trinidad. Among these five locations, CU range (mm/season) was 1302 to 1527 for banana; 257 to 295 for cabbage; 156 to 180 for cucumber; 282 to 325 for dry onion; 295 to 416 for eggplant; 262 to 301 for grain corn; 218 to 250 for honeydew; 171 to 196 for lettuce; 1302 to 1527 for plantain; 403 to 483 for potato; 330 to 383 for pumpkin; 400 to 539 for dry season rice; 377 to 555 for wet season rice; 254 to 293 for snap bean; 1330 to 1559 for sugarcane; 476 to 586 for sweet potato; 380 to 441 for tomato; 364 to 422 for transplanted sweet pepper; and 246 to 386 for watermelon, respectively. Higher values belong to the University of the West Indies, and lower values belong to the Hollis location. Average daily CU range (mm/day) was 3.6 to 4.2 for banana; 2.9 to 3.3 for cabbage; 2.5 to 2.9 for cucumber; 3.1 to 3.6 for dry onion; 3.2 to 4.5 for eggplant; 2.9 to 3.4 for grain corn; 2.8 to 3.2 for honeydew; 2.8 to 3.2 for lettuce; 3.6 to 4.2 for plantain; 2.7 to 3.2 for potato; 5.3 to 6.2 for pumpkin; 3.0 to 4.2 for rice dry season; 3.6 to 4.5 for wet season rice; 2.8 to 3.3 for snap bean; 3.6 to 4.3 for sugarcane; 5.9 to 6.8 for sweet pepper; 3.1 to 3.9 for sweet potato; 3.1 to 3.6 for tomato; and 2.0 to 3.2 for watermelon. In Trinidad net irrigation requirement (NIR, mm/season) ranged between 321 and 935 for banana; 113 to 203 for cabbage; 45 to 102 for cucumber; 120 to 230 for dry onion; 185 to 311 for eggplant; 111 to 208 for grain corn; 70 to 159 for honeydew; 61 to 117 for lettuce; 320 to 936 for plantain; 165 to 319 for potato; 159 to 280 for pumpkin; 151 to 413 for dry season rice; 35 to 299 for wet season rice; 112 to 201 for snap bean; 385 to 974 for sugarcane; 282 to 450 for sweet potato; 198 to 334 for tomato; 189 to 317 for transplanted sweet pepper; and 151 to 282 for watermelon. _Average daily NIR (mm/day) range was 0.9 to 2.6 for banana; 1.3 to 2.3 for cabbage; 0.7 to 1.6 for cucumber; 1.3 to 2.6 for dry onion; 2.0 to 3.3 for eggplant; 1.2 to 2.3 for grain corn; 0.9 to 2.1 for honeydew; 1.0 to 1.9 for lettuce; 0.9 to 2.6 for plantain; 2.7 to 4.5 for pumpkin; 1.1 to 3.1 for dry season rice; 0.3 to 2.4 for wet season rice; 1.2 to 2.2 for snap bean; 1.1 to 2.7 for sugarcane; 3.0 to 5.1 for sweet pepper; 1.9 to 3.0 for sweet potato; 1.6 to 2.8 for tomato; 1.2 to 2.3 for watermelon. These CU, NIR values were estimated with Kc from climatic areas similar to those of Trinidad. Experimental work to determine Kc in Trinidad is lacking.

4. Recommendations and Applications to Local Agriculture

Evapotranspiration range (mm/day) was 3.6 to 4.6 at the University of West Indies, 3.6 to 4.8 at Piarco, 3.6 to 4.7 at Hollis, 3.6 to 4.8 at Navet, and 4.1 to 5.3 at Penal. For the island of Trinidad ET varies from 3.6 to 5.3 mm/day. Seasonal net irrigation requirements for various vegetable crops are useful in the design and management of irrigation systems in Trinidad. Based on net irrigation requirements, farmer/extensionist/investigator can determine gross irrigation requirement for micro-, sprinker - and gravity irrigation systems for each vegetable crop. This study provides basic ET information to the irrigator. Lysimeter studies should be conducted to determine crop coefficients in Trinidad, and to verify NIR values of this study. Blaney- Criddle coefficients for Trinidad are:

$$K_1 = 0.41776 + 0.024912 \times T$$

$$K_2 = 8.128 + 0.46 \times T$$

Where, T is average temperature in ˚C and K_1, K_2 are the coefficients. Using an isohyetal map of Trinidad, one can find mean annual distribution of rainfall (inches) for any location in Trinidad. Similar results and data bases can be developed for Colombia and other countries using methods presented in this paper.

5. References

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6. Authorization and Disclaimer

7. Acknowledgements

This paper #045 was prepared for presentation at The Fourth Latin American and Caribbean Conference [LACCEI] on June 21 - 23, 2006 at Mayagüez, Puerto Rico. Authors thank the editorial staff for suggestions. This paper summarizes the work done as part of a training program of Oscar Brathwaite by Tropical Agricultural Research Station of USDA-ARS, Mayagüez - Puerto Rico. Author thanks Piarco Meteorological Office and Prof. V.I. Lindsay, University of West Indies for providing the climatic data. Special thanks to Oscar Brathwaite, County Extension Agent, Government of West Indies, Trinidad-W.I. for helping to analyze the climatic data. For more details please send your comments at my email or visit my webpage: <http://www.ece.uprm.edu/~m_goyal/home.htm>

Table 1: Seasonal irrigation requirement and water consumption of selected crops in Trinidad, using Blaney – Criddle method.

Crop	Total CU and NIR, mm/season					
	Location					
	Parameter [1/]	Univ	Piarco	Hollis	Navet	Penal
Banana	CU ER NIR	1527 594 933	1505 611 894	1302 981 321	1468 808 660	1512 577 935
Cabbage	CU ER NIR	295 92 203	291 100 191	257 144 113	290 138 152	288 95 193
Cantaloupe	CU ER NIR	250 91 159	946 98 148	218 148 70	246 138 108	246 95 151
Cucumber	CU ER NIR	180 78 102	177 81 96	156 110 45	177 110 67	177 79 98
Eggplant	CU ER NIR	416 105 311	410 114 296	358 173 185	295 70 225	402 108 294
Lettuce	CU ER NIR	196 79 177	194 82 112	171 110 61	193 108 85	193 80 113
Onion (dry)	CU ER NIR	325 95 230	320 105 217	282 162 120	318 144 174	317 98 219
Pepper (transplanted)	CU ER NIR	422 105 317	417 114 303	364 175 189	412 159 253	409 109 300
Plantain	CU ER NIR	1527 594 933	1506 611 895	1302 982 320	1469 809 660	1513 577 936
Potato	CU ER NIR	483 164 319	474 169 305	416 251 165	474 241 233	475 169 306
Pumpkin	CU ER NIR	383 103 280	378 113 265	330 171 159	374 155 219	371 107 264

Table 1: Continued

Crop	Total CU and NIR, mm/season					
	Location					
	Parameter [1/]	Univ	Piarco	Hollis	Navet	Penal
Rice-dry IR8	CU ER NIR	539 126 413	532 135 397	464 229 235	526 189 337	522 131 391
Rice-wet IR8	CU ER NIR	550 263 287	537 262 275	464 411 53	532 353 179	555 256 299
Rice-dry IR747-B26	CU ER NIR	411 110 301	404 119 285	356 205 151	402 167 235	400 113 287
Rice-wet IR747-B26	CU ER NIR	440 240 200	435 250 185	377 342 35	418 309 109	438 223 215
Snap bean	CU ER NIR	293 92 201	289 100 189	254 142 112	287 137 150	286 95 191
Sugarcane	CU ER NIR	1559 585 974	1535 595 940	1330 945 385	1503 795 708	1541 568 973
Sweet corn	CU ER NIR	301 93 208	296 101 195	262 151 111	295 141 154	294 96 198
Sweet potato	CU ER NIR	467 107 360	586 136 450	507 225 282	575 188 385	572 132 440
Tomato	CU ER NIR	441 107 334	434 116 318	380 182 198	430 164 266	428 111 317
Watermelon	CU ER NIR	386 104 282	381 113 268	334 174 160	378 159 219	246 95 151

1/ mm/season CU = water consumption
ER = effective rainfall
NIR = net irrigation requirement = CU - ER
2/ Univ. of West Indies is located at St. Augustine (figure 1)

Table 2: Factors that affect irrigation at five locations in Trinidad.

Description	Location				
	Univ.W.I.	Piarco	Hollis	Navet	Penal
I. <u>Geographical Factors</u>					
Weather Station no.	NA	9:32	2:3	3:8	7:7
Latitude	10˚58' N	10˚35' N	10˚41' N	10˚24' N	10˚10' N
Longitude	61˚23' W	61˚21' W	61˚11' W	61˚15' W	61˚27' W
Elevation above sea level, m	15	11	150	122	12
II. <u>Soil Factors</u>					
Soil type	Clay loam	Fine sand	Clay loam	Clay loam	Clay loam
AWC depth, in	3.6	3.6	3.8	3.6	3.0
Allowable depletion	50%	50%	50%	50%	50%
III. <u>Crops</u>	**<u>Planting</u>**	**<u>Last Harvest</u>**	**<u>Crops</u>**	**<u>Planting</u>**	**<u>Last Harvest</u>**
Banana	Jan 01	Dec 31	Rice IR_8, dry	Dec 01	Apr 11
Cabbage	Dec 01	Feb 28	IR_8, wet	Sep 01	Jan 02
Cantaloupe	Dec 01	Feb 15			
Cucumber	Dec 01	Jan 31	IR 747B2-6 dry	Dec 01	Mar 08
Eggplant	Jan 01	Mar 31	IR 747B2-6 wet	Jun 01	Sep 04
Lettuce	Dec 01	Jan 31	Snap bean	Dec 01	Feb 28
Onion	Dec 01	Feb 28	Sugarcane	Jun 01	May 31
Pepper	Dec 01	Mar 31	Sweet corn	Dec 01	Feb 28
Plantain	Jan 01	Dec 31	Sweet potato	Dec 01	Apr 30
Potato	Nov 01	Mar 03	Tomato	Dec 01	Mar 31
Pumpkin	Dec 01	Mar 31	Watermelon	Dec 01	Mar 31

NA = Not Available

Table 3: Percentage day light hours at five locations in Trinidad and Tobago.

Location	Mean day light hours percentage [1/]											
	Month											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1. University of the West Indies	8.68	8.89	9.95	8.73	8.73	7.39	8.33	7.98	7.39	7.98	7.84	8.10
2. Piarco Airport	9.00	8.79	9.55	9.10	9.12	7.15	8.16	8.19	7.69	7.79	7.56	7.89
3. Hollis	7.95	7.96	10.48	7.64	8.82	7.20	8.99	9.81	8.52	7.67	7.24	7.72
4. Navet	9.36	8.96	8.76	8.98	8.39	8.31	8.22	8.33	7.73	7.56	7.66	7.75
5. Penal	8.20	9.46	8.57	9.74	9.28	7.53	8.12	8.66	7.52	7.09	6.68	8.29

Table 4: Potential evapotranspiration in mm/day with Blaney – Criddle [ETBC] modified and Hargreaves-Samani [ETHS] models at five locations in Trinidad. EPAN = Class A pan evaporation.

Locations	Potential evapotranspiration, mm/day												
	Month												
	Pet [1/]	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1. University of the West Indies	ETHS	3.82	4.15	4.58	4.52	4.52	3.73	4.30	4.01	4.56	4.33	3.92	3.60
	ETBC	5.67	6.55	6.75	6.19	6.28	5.37	5.83	5.61	5.47	5.69	5.67	5.46
	Epan	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2. Piarco Airport	ETHS	3.87	4.24	4.66	4.78	4.53	3.69	4.23	4.40	4.46	4.21	3.89	3.59
	ETBC	5.80	6.37	6.46	6.61	6.53	5.14	5.66	5.69	5.59	5.41	5.32	5.17
	Epan	5.00	6.00	6.80	7.00	6.70	5.30	5.50	5.40	5.40	5.00	4.60	4.50
3. Hollis	ETHS	3.55	3.91	4.32	4.49	4.43	3.92	4.54	4.68	4.72	4.44	4.09	3.67
	ETBC	4.71	5.14	6.11	4.77	5.43	4.51	5.48	6.12	5.50	4.65	4.49	4.46
	Epan	3.10	3.60	4.00	4.30	3.50	3.40	3.50	4.80	3.60	3.50	3.00	2.90
4. Navet	ETHS	4.26	4.21	4.41	4.53	4.47	3.99	4.43	4.49	4.75	4.15	3.97	3.60
	ETBC	5.96	6.50	5.74	6.29	5.77	5.82	5.57	5.57	5.42	5.17	5.37	5.16
	Epan	4.00	4.80	5.00	5.70	5.30	4.40	4.30	4.90	4.40	4.10	4.00	4.10
5. Penal	ETHS	4.26	4.75	5.19	5.34	5.13	4.29	4.39	4.56	4.69	4.43	4.05	3.82
	ETBC	5.25	6.72	5.61	6.83	6.45	5.41	5.64	6.22	5.58	5.09	4.83	5.45
	Epan	4.10	4.90	5.30	5.90	5.20	4.70	4.20	4.50	3.90	3.80	3.00	3.20