DEPENDABLE PRECIPITATION AND POTENTIAL YIELDS FOR SENEGAL

A Practical Guide for Rainfed Agriculture

George H. Hargreaves

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by

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INTRODUCTION

Agriculture in Senegal is principally rainfed or flood recession. Studies are now being undertaken for the development of large areas for irrigated agriculture. However, if found feasible, the planning, construction and project development will encompass many years. Feasibility studies for the irrigation projects should include realistic comparisons with potential benefits and costs associated with non-irrigated crop production.

This study is concerned principally with climate as a resource for agriculturel development. Some knowledge of soil conditions is also incorporated. The analyses presented assume that the soils are capable of storing enough readily available moisture to supply maximum requirements for good plant growth for a period of ten days. Some sandy soils may require replenishment of moisture after as little as five days and some of the better soils will store enough water for fiteeen or more days.

The procedures used are presented in Appendix B. Detailed climatic information for five typical locations is presented as Appendix C. The main portion of the report deals with those aspects of climate that relate to crop selection, water management for rainfed agriculture and the potential yields under good management.

DEPENDABLE PRECIPITATION

Dependable precipitation is defined as the amount that is normally equalled or exceeded three-fourths of the time. It is the 75 percent statistical probability of occurrence (or exceedence). Each month or each ten-day period was evaluated. The dependable growing season was determined as the total length in days during which the dependable precipitation for each successive ten day period exceeded 30 mm.

The monthly dependable rainfall was compared with potential evapotranspiration or reference crop evapotranspiration. If dependable precipitation was less than one-third of potential evapotranspiration, that month was considered to be too dry for rainfed agriculture. If the dependable precipitation for the month exceeded four-thirds of the potential evapotranspiration, rainfall for the month was considered excessive. Either natural or artificial surface drainage is required during months of excessive rainfall in order to maintain satisfactory levels of crop production.

Table 1 presents monthly dependable precipitation for the rainy season and mean annual rainfall in mm at 57 locations in Senegal.

TABLE 1. Dependable Precipitation and Mean Annual Rainfall (mm).

Station	N.Lat.	W.Long.	June	July	Aug.	Sept.	Oct	Annual
Bakel	14° 53'	12° 24'	7	70	135	60	0	498
Bambey	14° 42'	16° 27'	0	74	174	116	12	632
Bignona	12° 49'	16° 14'	79	199	405	259	93	1408
Boulel	14° 08'	15° 21'	24	108	146	117	25	671
Coki	15° 30'	16° 00'	0	48	146	83	1	488
Dagana	16° 30'	15° 30'	0	14	97	34	0	316
Dahra	15° 21'	15° 29'	0	61	134	72	4	511
Dakarville	14° 40'	17° 26'	0	104	178	78	6	540
Dakar-Yoff	14° 44'	17° 30'	2	40	150	120	11	599
Dara	15° 20'	15° 29'	0	48	152	82	0	517
Daroumousty	13° 53'	15° 48'	0	57	129	74	11	509
Dialacoto	14° 39'	13° 09'	98	175	235	204	31	1097
Didloulou	13° 02'	16° 35'	32	219	466	213	69	1081
Dioubel	14° 39'	16° 09'	5	78	173	116	17	650
Fatick	14° 20'	16° 20'	14	110	230	146	25	804
Foundidgne	14° 07'	16° 28'	7	122	272	169	30	890
Gassane	14° 49'	15° 18'	15	65	138	106	47	615
Gossas	14° 30'	16° 04'	19	102	167	130	73	725
Goudyry	14° 11'	12° 43'	42	117	203	134	31	833
Guento	13° 34'	13° 48'	80	129	206	176	13	912
Inor	13° 00'	15° 42'	74	227	334	194	70	1275

TABLE 1. (Continued)

Station	N.Lat.	W.Long.	June	July	Aug.	Sept.	Oct.	Annual
Joal	14° 10'	16° 51'	2	159	262	186	69	985
Kaffrine	14° 06'	15° 28'	14	90	205	123	15	716
Kaolack	14° 08'	16° 04'	21	110	229	156	20	823
Kebemer	15° 22'	16° 27'	0	37	164	86	23	543
Kedougou	12° 33'	12° 10'	136	182	251	255	72	1307
Khombole	14° 46'	16° 42'	0	70	196	110	10	620
Kidira	14° 28'	12° 13'	48	123	186	126	10	782
Kolda	12° 55'	14° 55'	88	180	291	221	73	1194
Koumpentoum	13° 59'	14° 33'	49	89	177	122	31	758
Koungheul	13° 58'	14° 49'	69	124	199	129	22	840
Linguere	15° 23'	15° 09'	7	74	142	88	9	531
Louga	15° 38'	16° 09'	0	43	107	77	0	422
Maka-Colibentan	13° 40'	14° 17'	56	94	173	139	24	765
Matam	15° 38'	13° 13'	16	68	151	63	0	527
M'Baba Garage	14° 59'	16° 44'	0	45	172	106	9	564
M'Bake	14° 44'	15° 55'	0	73	173	100	5	592
M'Bad	14° 45'	17° 19'	0	32	166	112	3	564
M'Bour	14° 25'	16° 55'	0	67	209	134	13	685
Mont Roland	14° 56'	16° 59'	0	69	195	133	35	696
Niord Rip	13° 44'	15° 49'	34	131	262	162	28	916
Oussouye	12° 30'	16° 30'	86	347	472	290	103	1722

TABLE 1. (Continued)

Station	N.Lat.	W.Long.	June	July	Aug.	Sept.	Oct.	Annual
Podor	16° 38'	14° 56'	0	18	82	33	0	311
Rufisque	14° 40'	17° 15'	0	40	206	119	0	604
Saint-Louis	16° 01'	16° 30'	0	16	96	52	.5	390
Saraya	12° 50'	11° 45'	139	199	269	184	107	1292
Sedhiou	12° 43'	15° 42'	78	210	355	270	194	1387
Tambacounda	13° 46'	13° 41'	82	147	215	178	37	886
Thiadiaye	14° 25'	16° 24'	0	117	200	211	41	862
Thiel	14° 56'	15° 04'	5	38	130	107	27	540
Thies	14° 48'	16° 56'	0	59	205	138	13	664
Thilmaka	15° 02'	16° 14'	0	43	152	94	2	512
Tivaduane	14° 57'	16° 45'	0	46	78	118	1	586
Toubacouta	14° 42'	15° 49'	37	96	346	235	50	1077
Velingara	13° 09'	14° 09'	98	146	236	204	43	1063
Yang-Yang	15° 40'	15° 18'	0	48	151	84	3	520
Ziguinchor	12° 35'	16° 16'	75	302	421	272	80	1559

the rainy season is normally June through October or somewhat shorter. The dependable precipitation shown for these months is the amount for which there is a 75 percent probability of receiving the value indicated in Table 1 or more. If the crop requirement is equal to the dependable precipitation, there is an approximate 25 percent probability of having some deficit in the total rainfall during the month and significantly greater probabilities of a deficit for the crop due to distribution during the month and to amounts of rain that run off and do not enter the soil or become available for crop use.

The mean annual precipitation is shown as there is a good correlation between annual totals and length of the dependable rainy season. The mean value will occur somewhat less than half of the time. Use of mean rainfall for agricultural planning will result in deficits in total amount in about 65 percent of the years.

GROWING SEASON ZONES

The length of the growing season for rainfed crops depends upon the length of the period of water adequacy for crop growth. If the crop fails to reach maturity or near maturity by the end of the rainy season, yields or production will be quite low. Doorenbos, et al. (1) used the Stewart model to predict yield reductions resulting from water deficits by using the relationship between relative yield decrease and relative evapotranspiration deficit.

The equation can be written:

$$\left(1 - \frac{Y_a}{Y_m}\right) = ky \left(1 - \frac{ET_a}{ET_m}\right) \qquad (1)$$

in which:

Y_a = actual harvested yield

Y_m = maximum harvested yield

ky = a yield response factor

ET_a = actual crop evapotranspiration

ET_m = maximum crop evapotranspiration

Values of ky, the yield response factor, are given in Table 2 for typical crops grown in Senegal. The average for the eight crops presented indicates that a given percentage water deficiency produces nearly a corresponding reduction in yield. In general, crops are less sensitive to soil moisture deficits during the ripening period, indicating that the growing seasoin can extend somewhat beyond the length of the rainy season in order to allow the crop to suffer some stress while exhausting the residual soil moisture.

Figure 1 gives six zones, each with a different length of the dependable rainy season. The rainy season increases in length from north to south. For maximum yields, crops must be selected that have length of growing season requirements corresponding with, or only a little longer than, the period of adequate water availability.

TABLE 2. Yield Response Factor (ky).

Crop	Vegetative Period			Flowering period	Yield formation	Ripening period	Total growing period
	Early	Late	Total				
Beans			0.2	1.1	0.75	0.2	1.15
Cotton			0.2	0.5		0.25	0.85
Groundnut			0.2	0.8	0.6	0.2	0.70
Maize			0.4	1.5	0.5	0.2	1.25
Sorghum			0.2	0.55	0.45	0.2	0.90
Soybean			0.2	0.8	1.0		0.85
Sunflower	0.25	0.5		1.0	0.8		0.95
Watermelon	0.45	0.7		0.8	0.8	0.3	1.10

Source: Doorenbos, et.al. (1)

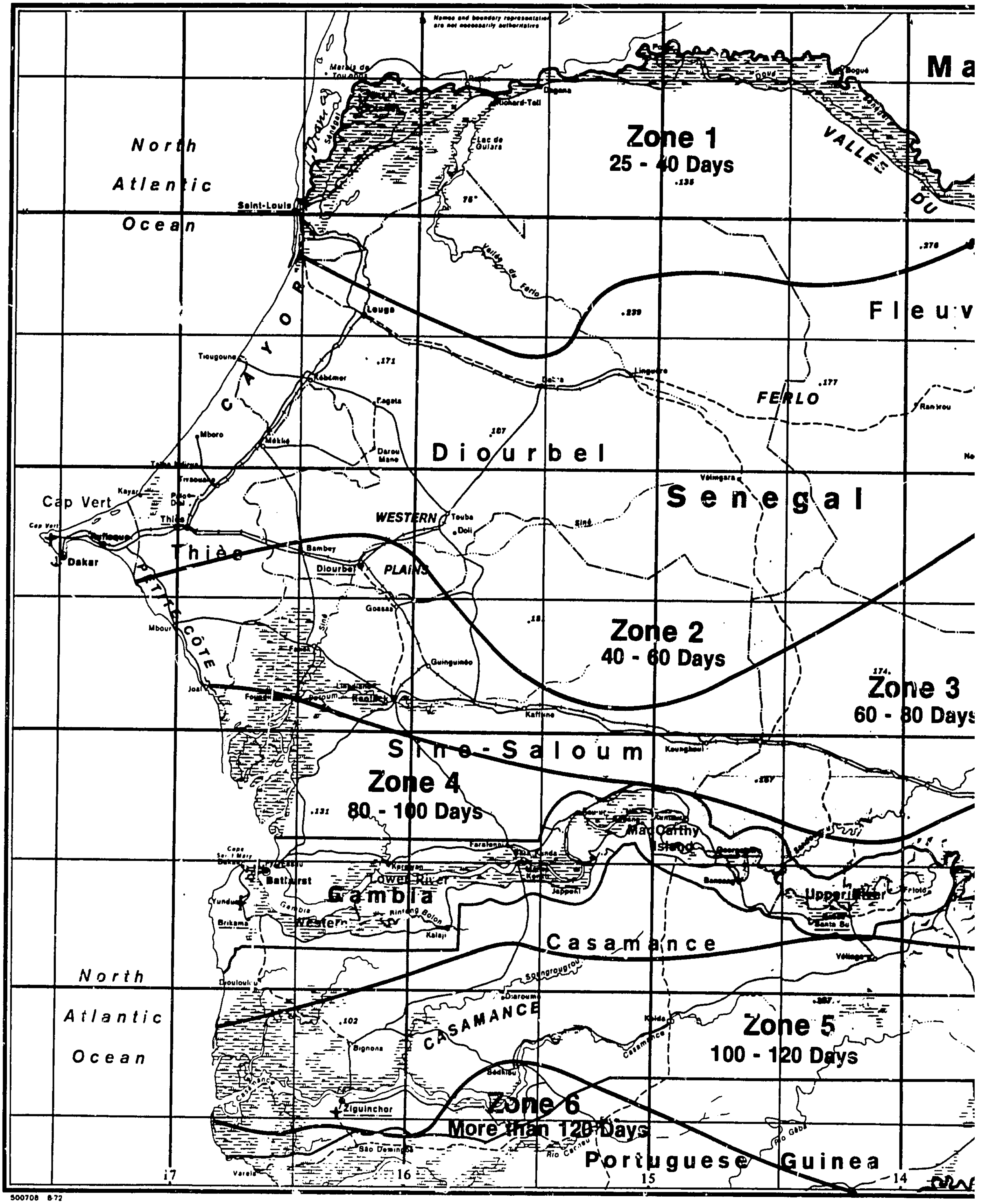
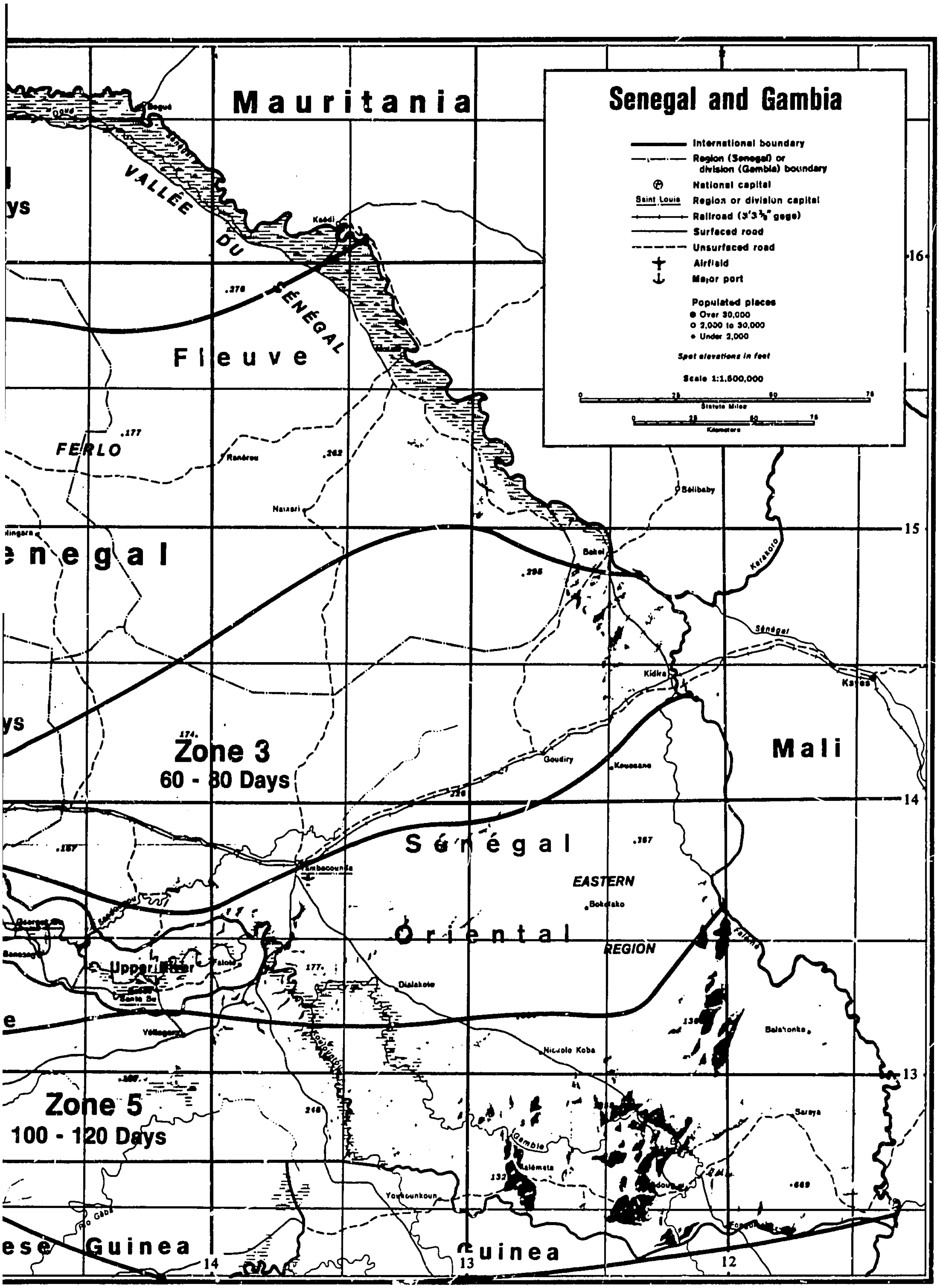


FIGURE 1 Zones Showing Length of Growing



Length of Growing Season for Rainfed Agriculture

CROP SELECTION

Millets, particularly the short growing season millets, are very drought resistant and will produce an economic yield with less water than other grains. Special consideration should also be given to the production of mung beans, as some varieties mature in as little as 45 days. Yields of this crop are sometimes satisfactory when planted on soils of good water holding capacity near the end of the rainy season.

Maize is the least drought resistant of the crops listed in Table 2. If water is sufficient, adequately fertilized maize grown on deep soils having good water holding capacity outproduces the other grains. Because of its potential for high yield and the demand as a food crop, maize should be given special consideration. In some countries maize is harvested as a vegetable during the ripening period, thereby reducing the length of time for which adequate soil moisture is required. Table 3 presents the number of days required from planting to maturity for various maize hybrids.

Table 4 shows 11 crops which are climatically suited to the area and can be considered for production in Senegal. There are many varieties of some of the crops suggested. Selection will be necessary because some varieties have specific requirements for length of daylight hours, length of growing season or other conditions. The fertilizer recommendations are from Doorenbos, et al. (1) and are general. Soils vary greatly in their needs for

TABLE 3. Time from Planting to Maturity for Hybrid Maize.

HYBRID CORN RELATIVE MATURITY CHART
I.M. DIVISION

Growing Degree Days*	1950 to 2050		2050 to 2150		2150 to 2300		2300 to 2400		2400 to 2500		2500 to 2650	2650 to 2900
NORTHRUP KING	PX403	PX414 PX11	PX419 PX7 PX14	PX443 -	PX449	PX15 PX20 PX24 PX485	PX32 KE497 PX529 PX37	PX46 PX49 PX39	PX585 PX610 PX59	PX606 PX603 KT626	PX74 PX72 PX75	PX788
CENEX			3010A	3059 2084	2004 3011	2093 2091 3015	3094 2111	3123 2098 3100 2119	3103 2106 2104 4106	2134 3139 2108 2110A	2110 2203 2114 2157A	3366 2371 2380 2124
PIONEER	3894 3992		3978 3872	3965A 3970	3906	3901	3747	3780 3732 3773	3541	3536	3369A 3360	3323 3183
FUNKS		G4082 G4055 G4065	G5048 G5150 G4040 G4042 G4081	G5190 G4085	G4141A G4195 G4180 G4143 G4171 G4256	G4252 G4224 Silomix 100	G4288 G4272 G4300 G4315 G4342 G4321a G4306	G4444A G4323 G4444 Silomix 110	G4408 G4426 G4430 G4435 G4438 Silomix 115	G4465 G4449 G4450	G4507 G4507A G4557	
P.A.G.	501	SX111 503	SX121 SX137	SX157	SX67 SX177 517	SX181	SX189 529 534	SX249 547	SX397 SX277 SX454	576	SX351 SX333 314 7476	SX373 SX98 584
TROJAN			TX85	TX880 TX891	T950 TX90 T910 T929 T930	TXS94 TXS99	T1000	T1050 T1058 T1069	T1100 TX111 TXS113	TXS115A TX115 T1189	TX119A TXS119	T1230 T1251
IDAHYBRID UTAHYBRID			216	SRX33		330 30-30	30-50 SRX336 SR4136	544A 45-70	SRX50	45-90 680 54-40		
CARGILL		805	810 404	822	830 832 834 426		836 434 863 838 862 430	449 872	890 892	921 924	949 967 934 1800W	979 SX70W 495
FERRY MORSE				GT1050	GT1064	GT1090 GT218A	GT2006 GT2015	GT770 GT9770	GT2080	GT3006 GT484	GT3020 GT3025 GT4025	GTA49 GT42W
Days to Maturity	75	80	85	90	95	100	105	110	115	120	125	130

Prepared by Jim L. Bushnell, Ph.D. in conjunction with the major seed companies.

TABLE 4. Suggested Crops for Senegal.

Crop	Days to Maturity	Potential yield	Fertilizer kg/ha N	P	K
Beans	90 - 120	1.5 - 2.5 T/ha	20-40	40 -60	50-120
Cotton	150 - 180	3-4 T/ha	100-180	20-60	50- 80
Groundnut	90 - 115	3-4 T/ha	10-20	15-40	25- 40
Kenaf	100 - 125	40-50 T/ha	175	30	85
Maize	80 - 140+	6-8 T/ha	100-200	50-80	60-100
Millet	60 - 90	2-4 T/ha	See Sorghum		
Mungbean	45 or more	2.5-2.8 T/ha	See Groundnut		
Sesame	85 - 150	1-2 T/ha	50	20	15
Sorghum	90 - 140	3.5-5 T/ha	100-180	20-45	35-80
Soybean	75 - 150	2.5-3/5 T/ha	10-20	15-30	25-60
Sunflower	90 - 130	2.5-3.5 T/ha	50-100	20-45	60-125

Sources: a) Samuel C. Litzenberger, editor, (4) 321 p.
b) Doorenbos, et.al. (1)
c) Miscellaneous

phosphate and potassium, and fertilizer applications must be adjusted in accordance with actual requirements. Response of most non-leguminous crops to nitrogen is quite outstanding, and it may often be desirable to exceed the recommendations given in Table 4. This is particularly true where soil conditions, climate and water adequacy are favorable for optimum production.

The yields shown in Table 4 are significantly above average for many areas. They are, however, conservative for conditions of good management. For example, high yielding, longer growing season maize hybrids fertilized with about 340 kg of nitrogen have yielded, under good management, 10 to 12 tons of corn grain per hectare on large commerial plantings. These yields are possible with irrigation and also with rainfed agriculture.

In general, the short growing season varieties of a given crop yield less than those that mature more slowly. Production of plant material requires energy from photosynthesis to produce carbohydrates from water and carbon dioxide. More total energy for plant growth is available for crops with longer growing seasons. Water, however, is also essential. The selection of crop variety should consider the total length of time during which there is a high probability of reasonably adequate water for crop growth. This will depend on the amount and distribution of rainfall and also on how much water enters the soil and is stored in the crop root zone as readily available soil moisture. Optimum crop selection requires experience and judgment in order to select varieties that take advantage of the full period of time for which water is adequate.

Figure 1 indicates the length of the dependable rainy season in days. For the periods indicated, rainfall is generally 85 percent to fully adequate for producing maximum yields. The dependable growing season based upon the criteria of the 75 percent probability of having one-third adequacy or more is generally at least one month longer than indicated in Figure 1. Selection of crops on the basis of this longer season will result in a higher probability of serious water deficits with corresponding reductions in yields. Response to fertilizer, other inputs and good management is greatly reduced unless water is nearly fully adequate.

Figure 2 indicates the approximate reduction in yields for the eight crops included in Table 2. These yield reductions are general. The seriousness or importance of the deficit depends also upon the timing of the water shortage with respect to the crop stage of growth. For most crops water adequacy is more important during the flowering stage. The relative importance of having adequate moisture during the various stages of growth is shown in Figure 3.

The yields presented in Table 4 are considered conservative if water is adequate and normal good farming practices are followed. However, as indicated in Table 2 and Figure 2, if water is only 85 percent adequate, then yields will be correspondingly reduced. The average for the crops shown will be close to a 15 percent yield

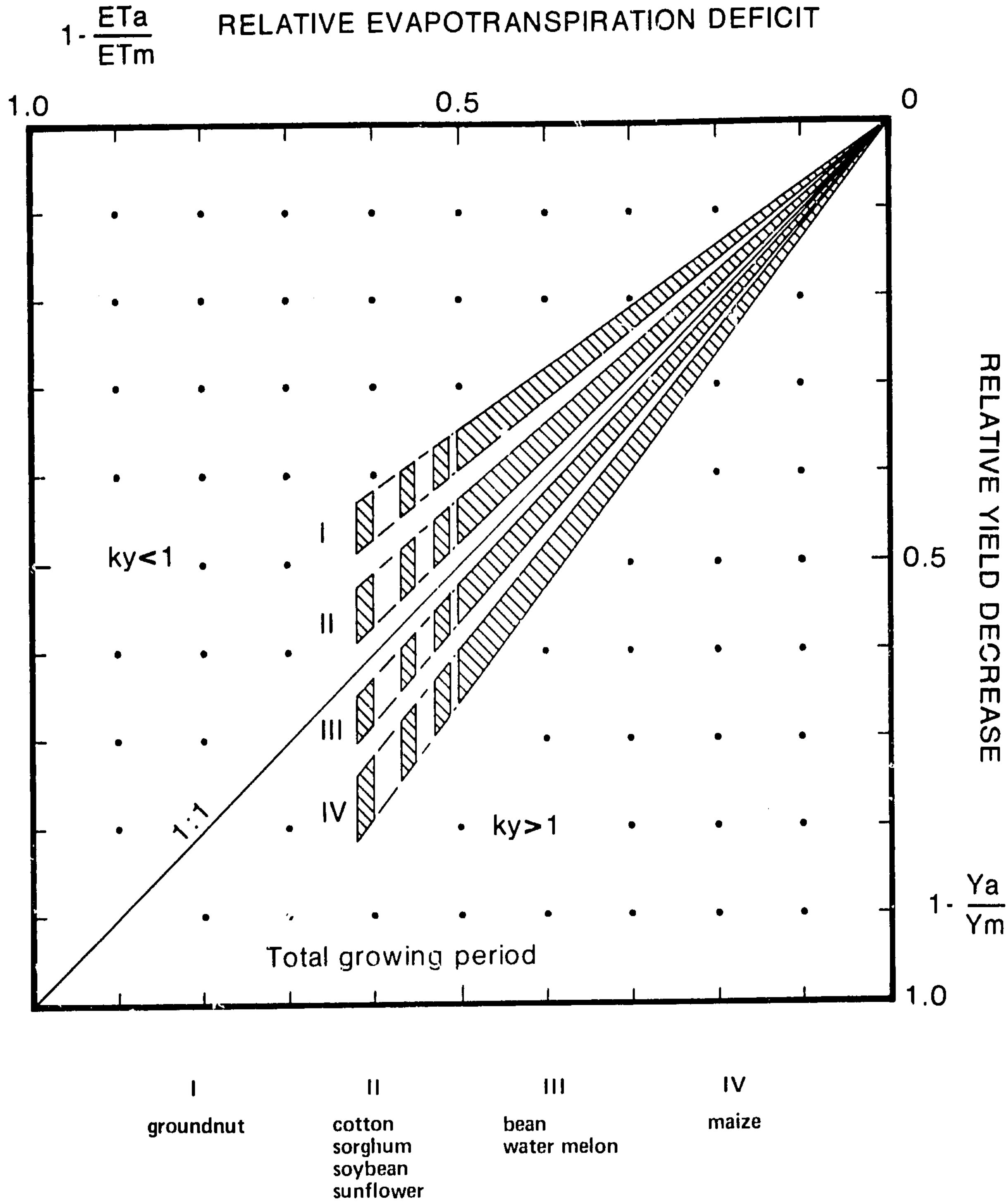


FIGURE 2. Generalized Yield Reduction from Water Deficits for Total Growing Period from Equation 1, Table 2. Source: Doorenbos, et al. (1).

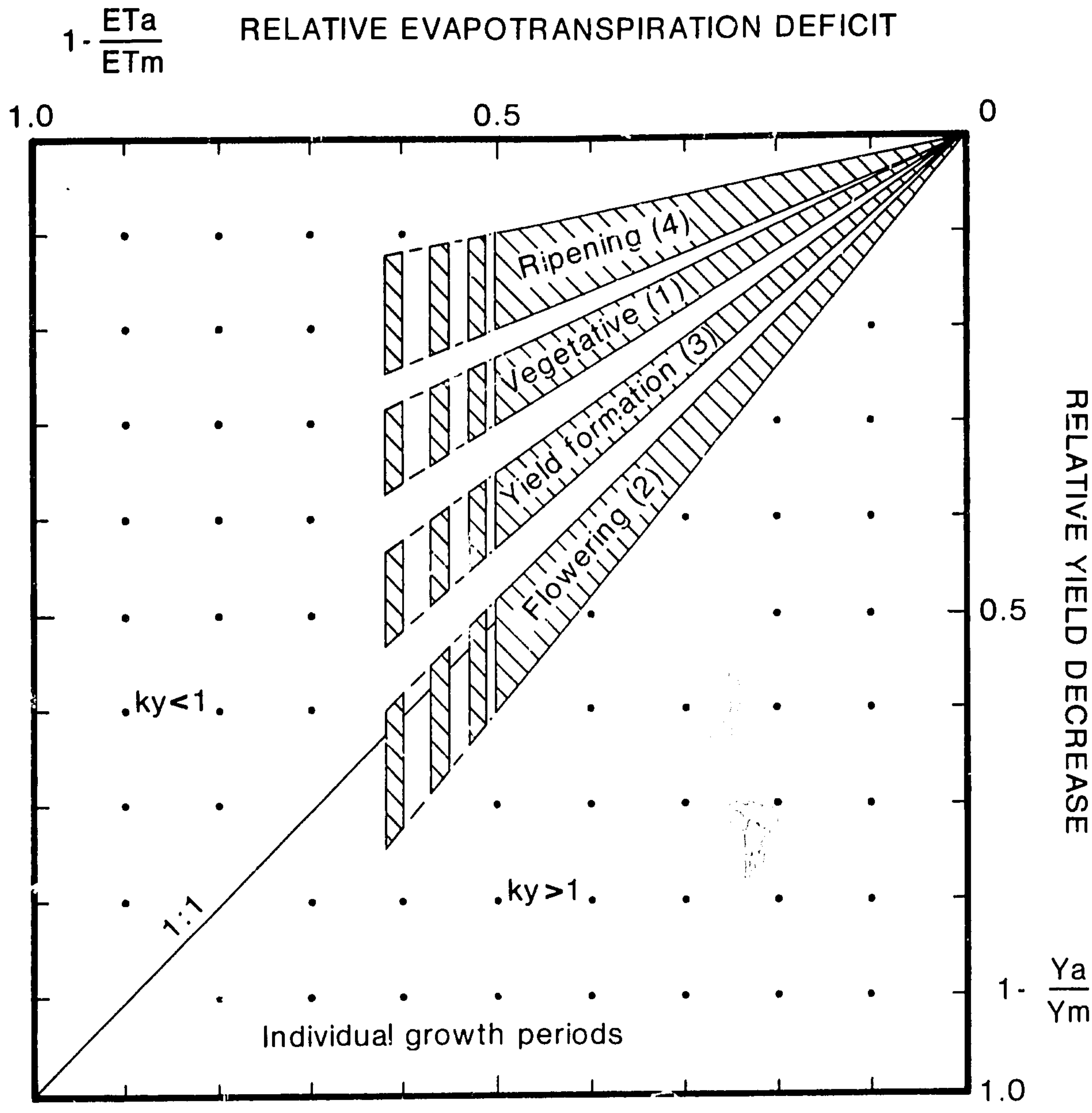


FIGURE 3. Generalized Relationship Between Relative Yield Decrease ($1-Y_a/Y_m$) and Relative Evapotranspiration ($1-ET_a/ET_m$) for Crop Stages. Source: Doorenbos, et al. (1).

reduction.

WATER MANAGEMENT

Attempts to transfer agricultural experience or technology from one location or region to another have sometimes been very productive and have on occasion resulted in disappointing failures. The failures usually resulted from significant differences in conditions that were overlooked. The six zones shown in Figure 1 are areas of fairly uniform climate and moisture regimes. Crops produced successfully and profitably under similar climatic regimes in other countries or regions can be expected to produce good results in corresponding conditions in Senegal. In some cases, however, soil conditions or local culture and customs may make technology transfer difficult.

Zone 1

In Zone 1 there is little rain to manage. The scarce rainfall amount comes in a few storms that are often intense enough to produce considerable runoff. The principal management practices should include measures to increase infiltration of water into the soil. If runoff occurs, concentration into large erosive streams must be prevented. Since the rainy season is very short, storage facilities, where feasible, to collect surface runoff for later use would greatly improve the agricultural potential.

Zone 2

The climate and the rainfall regime of Zone 2 are very similar to conditions at Hyderabad (Begampet) India, but soil conditions are somewhat different. However, it seems probable that most of the successful water management and cropping practices developed by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad can be applied with good results in Zone 2.

Monthly rainfall amounts at Hyderabad and in Zone 2 are generally not excessive when compared with crop requirements. Rainfall depth duration amounts are such that surface drainage usually needs to be improved. A system of graded beds and furrows can be used to provide the required surface drainage, to improve infiltration and water conservation and to reduce soil erosion. The optimum slope for the system depends upon the rainfall and soil conditions. ICRISAT has used slopes varying from 0.3 to 0.8 percent. In some southern states of the United States slopes in the range of 0.2 to 0.5 percent are preferred. The system of raised beds and furrows can be easily prepared with machinery or with animal-drawn implements. The "bedformer" used by ICRISAT has ridger units 150 cm apart with a leveling float in between the ridgers. Grassed drainage ways are used to remove the excess runoff.

Some of the advantages of the bed and furrow system are:

1. Only minor earth movement or smoothing is required.

2. The beds and furrows can be made by animal-drawn equipment or tractors.
3. While planting between early rains, the top of the bed dries more quickly than flat cultivated areas, thus facilitating earlier planting.
4. The beds are permanent features which can be easily maintained.

ICRISAT's research indicates that present farming practices in similar areas frequently use only 20 to 50 percent of seasonal rainfall. Through improved resource management with more productive cropping systems, the value of crop production at Hyderabad was consistently increased at rates exceeding 300 percent. Kampen and Krishna (2) have described the methods and benefits. Figure 4 indicates some of the cropping systems and row arrangements.

Experience in India would seem to indicate that crop combinations including maize, sorghum, pearl millet, setaria, soybean, groundnut, mung bean, chickpea, pigeon pea, safflower and tomato could be profitable in Zone 2 providing appropriate water management practices are adopted. The cropping systems used and the plant spacings are given in Figure 4.

Table 5 presents various treatments and cropping systems used by ICRISAT and the rainfall productiveness obtained as measured by the crop value in Rs per cm per ha (8.8 Rs = $1.0 U.S.). It should be noted that 5 cm of supplemental water was applied to some of the

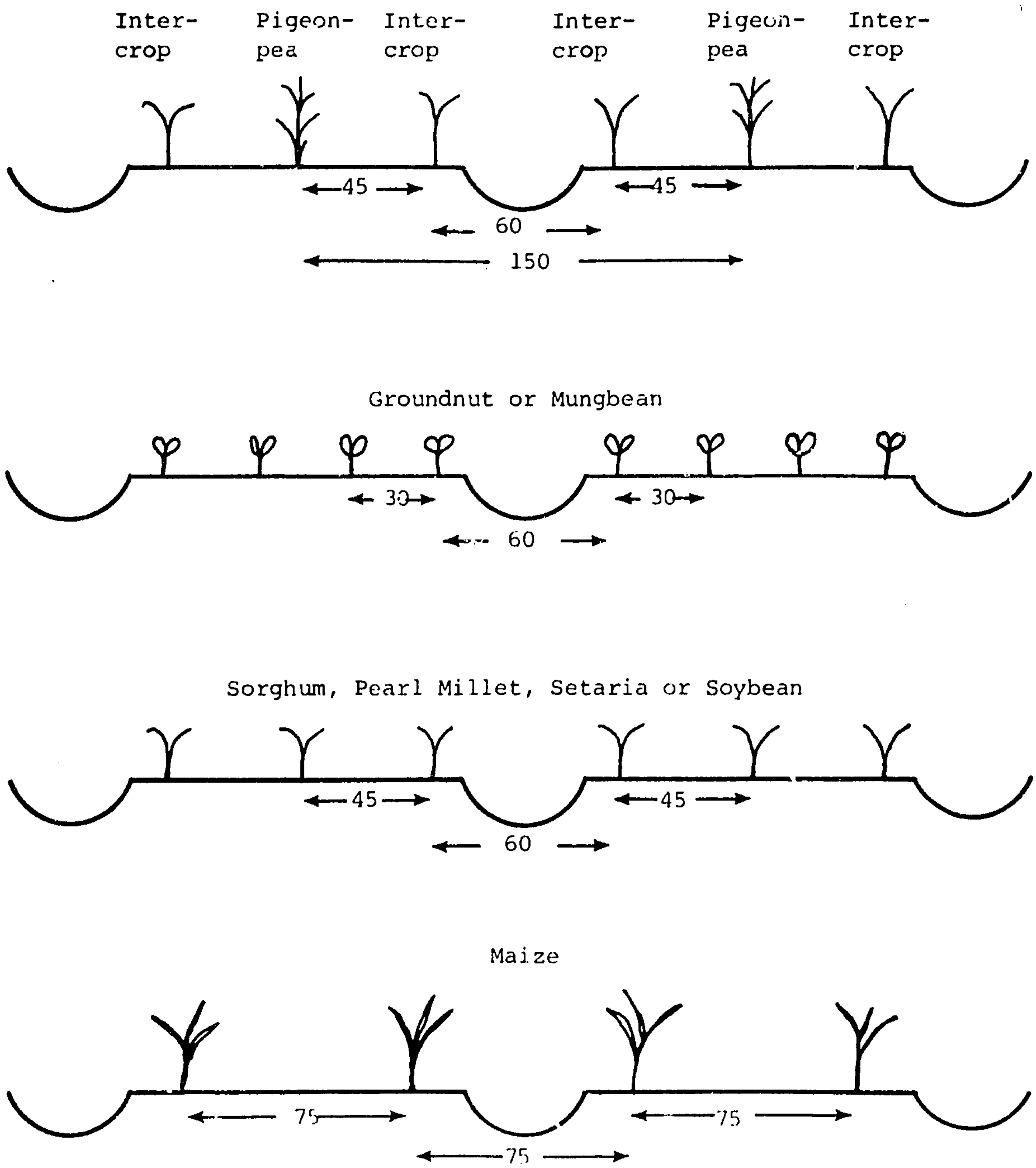


FIGURE 4. Alternative Cropping Systems and Row Arrangements on Broad (150 cm) Beds. (All Dimensions in cm.)

TABLE 5. Rainfall[1] Productiveness, RP, Obtained from Alternative Farming Systems by ICRISAT.

Watershed No.[2] and Treatment	Cropping System and Water Use[3]	RP[5] (Rs/cm/ha)
1975-76 Vertisols		
BW1, narrow (75 cm), graded (.6%) beds	Maize-Chickpea	58
	Pigeonpea-Setaria	34
BW3A, narrow (75 cm), graded (.4%) beds	Maize-Chickpea	52
	Pigeonpea-Setaria	39
	Maize-Sorghum S(5)	62
BW4C, flat, field bunded, traditional[4]	Fallow-Sorghum	12
BW6B, flat, contour bunded	Fallow-Sorghum	16
1976-77 Vertisols		
BW1, broad (150 cm), graded (.6%) beds	Maize-Chickpea	53
	Pigeonpea-Maize	68
BW3A, broad (150 cm), graded (.4%) beds	Maize-Chickpea	53
	Maize-Chickpea S(5)	63
	Pigeonpea-Maize	68
BW4C, flat, field bunded, traditional	Fallow-Sorghum	9
BW6B, flat, contour bunded	Fallow-Sorghum	17
1975-76 Alfisols		
RW1D, broad (150 cm), graded (.4%) beds	Pigeonpea-Sorghum	36
	Pearl Millet-Tomato	92
	Pearl Millet-Tomato S(5)	133
RW1E, flat, contour bunded	Pigeonpea-Sorghum	31
	Pearl Millet-Tomato	77
	Pearl Millet-Tomato S(5)	100
1976-77 Alfisols		
RW1D, broad (150 cm), graded (.4%) beds	Pigeonpea-Setaria	36
	Groundnut-Safflower	66
RW1E, flat, contour bunded	Pigeonpea-Setaria	30
	Groundnut-Safflower	43

[1]In 1975, the total seasonal rainfall in Vertisol watersheds was 1040 mm and in Alfisols 1100 mm; in 1976, the rainfall on Vertisols was 720 mm and on Alfisols 680 mm.

[2]BW refers to Vertisol watersheds, RW to Alfisol watersheds.

[3]The symbol "S" followed by a number indicates that supplemental water was provided at the given quantity in cm.

[4]Those systems defined as traditional simulate local farming practices in terms of seed, fertiliser, farm equipment, etc.; in all others, optimum technology in terms of land and crop management is maintained.

[5]One dollar U.S. = 8.8 Rs.

cropping systems used (see footnote 3 of Table 5).

Zone 3

Zone 3 has a longer growing season and there is usually one month of excessive rainfall. Unless this excess water is drained away the soils will become waterlogged and crop production will be low. A study made in Zone 3 by the Land Resources Division (3) indicated that infiltration rates of rain into groundnut fields ranged from 5 to 20 mm per hour. Although rainfall amounts may be continuously adequate during each ten day period for 60 to 80 days, the amount that enters the soil and becomes available for crop growth is frequently quite deficient. A system of raised beds and furrows on flat slopes is recommended. The water conservation practices and cropping systems will be similar to those in Zone 2. However, due to the higher rainfall it may be necessary in Zone 3 to use somewhat higher beds than in Zone 2.

Zones 4, 5 and 6

Zone 4 has two or three months of excessive rainfall. In Zones 5 and 6 rainfall is excessive during three or more months. In similar rainfall conditions in South and Central America yields have been increased through the use of broad raised beds. These are frequently 20 to 40 meters wide and raised in the center by 40 to 80 cm. Benefit cost ratios for these raised beds has in some areas consistently exceeded five to one. The broader beds are constructed with machinery. Similar results have been achieved using narrower beds (2 to 6 meters wide) constructed by hand.

In Central and South America where raised beds are used with very good results, the rainy season is somewhat longer than in Senegal. Some adaptation is suggested for the conditions prevailing in southern Senegal. It is evident, however, that maximum production of most crops can only be attained with good water control, including improved water infiltration and conservation as well as better surface drainage to improve aeration of the surface soil and of the crop root zone.

In these zones crops need to be selected that have a total growing season that does not exceed the period for which there will be a high probability of precipitation in reasonably adequate amounts.

OPTIMIZING PRODUCTION

A knowledge of water-fertility and other interactions is necessary for optimizing yields. If water availability to the plant is too low. fertilizer applications may actually depress yields while with adequate water, response to fertilizer may result in large increases in production. Optimum plant densities depend upon water availability as well as upon fertility, solar radiation and other climatic factors.

For non-leguminous crops response to nitrogen is usually outstanding providing water and other conditions are favorable. For example, at several locations high yielding maize hybrids have been found to demonstrate an optimum response to nitrogen application that is indicated by the equation:

$$N = 0.32 \times ET \tag{2}$$

in which N is nitrogen application in kg per ha and ET is seasonal evapotranspiration of the maize crop in mm. Equation 2 is applicable providing there is no serious water deicit during the critical polination period.

In summary, optimization of production for rainfed agriculture will require adequate use of fertilizers, improved methods of water conservation and of infiltration of rain, better surface drainage, new cropping systems and selection of varieties that are well adapted to the climate and of growing seasons as determined by the period of available water.

Additional effort is recommended in the collection and compilation of information on crops, yields and practices from research stations and other sources in locations having climatic conditions similar to those of Senegal. The potential for improving rainfed agriculture in Senegal is large. Studies leading to a good documentation of possible benefits and corresponding costs are strongly recommended.

APPENDICES

APPENDIX A - REFERENCES

1. Doorenbos, J., et al., editors, "Yield Response to Water," FAO Irrigation and Drainage Paper No. 33, Rome, 1979, 193 p.

2. Kampen, Jacob and J. Hari Krishna, "Resource Conservation Management and Use in the Semi-Arid Tropics," ASAE Technical Paper 78-2072 (paper presented at 1978 Summer Meeting of American Society of Agricultural Engineers), 13 p. plus tables and figures.

3. Land Resources Development Center, "Soil and Water Investigation in the Gambia," Technical Bulletin 3, Ministry of Overseas Development, 1979, 183 p.

4. Litzenberger, Samuel C., editor, "Guide for Field Crops in the Tropics and Subtropics," Office of Agriculture, Agency for International Development, 1974, 321 p.

APPENDIX B - PROCEDURES USED OR METHODOLOGY

The 75 percent probability of precipitation occurrence or exceedence (that amount equaled or exceeded 75 percent of the time) was selected as an index of water availability and defined as dependable precipitation, PD. Thirty year rainfall records from five locations were used to develop a relationship between mean monthly rainfall, PM, and dependable precipitation, PD. The equation found by regression can be written:

$$PD = -30 + 0.95 \times PM \qquad \text{(B-1)}$$

in which PD and PM are in mm per month. The coefficient of determination, R^2, was 98 percent indicating a good degree of reliability in the use of the equation. Equation B-1 was used to estimate the dependable monthly precipitation at 57 locations in Senegal.

The 75 percent probability of precipitation occurrence for 10 day periods was determined for 16 locations in and near Senegal. The effective length of the growing season was taken as the number of consecutive 10 day periods with 30 mm or more of dependable precipitation plus an assumed 10 day soil moisture carryover. The estimated length of growing season was then compared with long term mean annual precipitation resulting in the equation:

$$LS = 15 + 0.075 \times PMA \tag{B-2}$$

in which LS is length of the growing season in days and PMA is mean annual rainfall in mm. Equation B-2 indicates that for a mean annual precipitation of 1000 mm the effective growing season should average about 90 days.

Reference crop evapotranspiration or potential evapotranspiration, ETP, can be estimated from mean temperature in degrees Fahrenheit, TF, and incident solar radiation, RS. The equation can be written:

$$ETP = 0.0075 \times RS \times TF \tag{B-3}$$

in which ETP and RS are expressed in the same units. For this study RS was in equivalent mm of water evaporation. RS is usually reported in Langleys per day (cal. per cm^2). Langleys per day divided by 58.5 results in equivalent mm per day of water evaporation.

Meausured radiation is only available for a few locations. It is therefore necessary to estimate RS from other climatic measurements. RS can be determined from temperature difference, TD, or the range between maximum and minimum temperatures. The equation for Senegal can be written:

$$RS = 0.16 \times RA \times TD^{1/2} \qquad \text{(B-4)}$$

in which RA is extraterrestrial radiation in the same units as RS, and TD is the mean temperature difference or temperature range between mean maximum and mean minimum in degrees Celsius. The constant, or coefficient, 0.16, was evaluated from local data at five locations indicting a standard error of the estimate of in the range of five to ten percent, depending on location. Extraterrestrial radiation is presented by latitude and month in mm per day in Table B-1.

Potential evapotranspiration, ETP, or reference crop evapotranspiration, was estimated for each month of the rainy season for nine locations. Isolines of estimated ETP were then drawn for each month and ETP values were compared with the dependable precipitation PD for each month. These comparisons resulted in some revisions of the previously estimated length of the rainy season growing period.

Use was made of a moisture availability index, MAI, calculated from the equation:

$$MAI = PD/ETP \qquad \text{(B-5)}$$

A month with MAI of less than 0.33 is considered a dry month

TABLE B-1. Extraterrestrial Radiation, RA, Expressed in Equivalent Evaporation in mm/day.

Latitude	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
18	11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1
16	12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6
14	12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0
12	12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5

with little contribution of rainfall to agricultural production.

Those months of MAI of 1.33 or more were marked as having excessive rainfall with good artificial or natural drainage being required for a satisfactory level of crop production.

APPENDIX C - DETAILED CLIMATIC INFORMATION AT FIVE LOCATIONS

A study was made for five locations using the 30 year climatic records published by the World Meteorological Organization (WMO). The results of this study are given here in order to indicate typical conditions in various parts of Senegal. The column headings for the tabular presentation are as follows:

Heading	Description
PM	Mean monthly precipitation in mm
PMI	Minimum monthly recorded precipitation (30 years)
P79	The 79 percent probability of precipitation occurrence
P60	The 60 percent probability of precipitation occurrence
PMX	Maximum monthly recorded precipitation
TMC	Mean monthly temperature in degrees Celsius
HM	Mean monthly percent relative humidity
HMC	Percent relative humidity calculated from sunshine
S	Percentage of possible sunshine
SC	Percentage of sunshine calculated from HM
PD	Dependable precipitation - the 75 percent probability of precipitation occurrence (that amount equaled or exceeded 75 percent of the time)
ETP	Potential evapotranspiration
ETDF	Potential evapotranspiration deficit (ETP - PD)
MAI	Moisture availability index (PD/ETP)

DAKAR/YOFF SENEGAL   EL= 23 LAT= 14 44 N LONG= 17 30 W KS= 8.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	0.	2.	0.	0.	1.	15.	88.	249.	163.	49.	5.	6.	578.
PMI	0.	0.	0.	0.	0.	0.	23.	54.	55.	0.	0.	0.	
P79	0.	0.	0.	0.	0.	1.	34.	134.	114.	9.	0.	0.	
P60	0.	0.	0.	0.	0.	4.	61.	210.	142.	20.	0.	0.	
PMX	7.	20.	3.	7.	16.	94.	273.	493.	330.	250.	53.	112.	
TMC	21.1	20.4	20.9	21.7	23.0	26.0	27.3	27.3	27.5	27.5	26.0	23.2	24.3
HM	69.	75.	76.	77.	78.	76.	76.	78.	79.	79.	73.	64.	75.
SC	48.	43.	42.	41.	40.	42.	42.	40.	39.	39.	45.	52.	43.
PD	0.	0.	0.	0.	0.	2.	40.	150.	120.	11.	0.	0.	
ETP	104.	96.	118.	122.	130.	139.	143.	144.	133.	127.	114.	111.	1485.
ETDF	104.	96.	118.	122.	130.	137.	109.	-6.	14.	115.	114.	111.	1163.
MAI	.00	.00	.00	.00	.00	.01	.27	1.04	.90	.09	.0[illegible]	.00	

LINGUERE SENEGAL   EL= 21 LAT= 15 23 N LONG= 15 9 W KS= 8.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	0.	2.	2.	0.	4.	31.	101.	209.	136.	45.	4.	2.	535.
PMI	0.	0.	0.	0.	0.	0.	26.	47.	58.	0.	0.	0.	
P79	0.	0.	0.	0.	0.	4.	73.	134.	82.	6.	0.	0.	
P60	0.	0.	0.	0.	0.	16.	80.	172.	112.	22.	0.	0.	
PMX	1.	35.	44.	1.	40.	104.	159.	395.	279.	196.	33.	31.	
TMC	24.0	25.6	27.9	29.7	31.2	30.9	29.1	28.0	27.9	28.5	27.5	23.9	27.9
HM	28.	34.	29.	34.	41.	52.	63.	74.	77.	65.	45.	35.	48.
SC	73.	70.	72.	70.	66.	60.	52.	44.	41.	51.	64.	69.	61.
PD	0.	0.	0.	0.	0.	7.	74.	142.	88.	9.	0.	0.	
ETP	137.	139.	183.	192.	203.	185.	172.	153.	137.	146.	139.	129.	1916.
ETDF	137.	139.	183.	192.	203.	178.	98.	11.	49.	137.	139.	129.	1595.
MAI	.00	.00	.00	.00	.00	.04	.43	.93	.64	.06	.00	.00	

SAINT-LOUIS SENEGAL   EL= 4 LAT= 16 3 N LONG= 16 27 W KS= 8.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	1.	1.	0.	0.	1.	7.	44.	161.	97.	29.	2.	3.	347.
PMI	0.	0.	0.	0.	0.	0.	1.	5.	8.	0.	0.	0.	
P79	0.	0.	0.	0.	0.	0.	13.	86.	44.	4.	0.	0.	
P60	0.	0.	0.	0.	0.	1.	25.	133.	84.	8.	0.	0.	
PMX	10.	18.	3.	3.	15.	71.	113.	290.	235.	186.	24.	45.	
TMC	22.0	22.3	22.2	21.8	22.3	25.7	27.6	28.0	28.5	29.1	25.0	23.1	24.8
HM	57.	65.	70.	77.	83.	83.	82.	82.	81.	66.	57.	71.	73.
SC	56.	51.	47.	41.	35.	35.	36.	36.	37.	50.	56.	46.	44.
PD	0.	0.	0.	0.	0.	0.	16.	96.	52.	5.	0.	0.	
ETP	113.	108.	128.	122.	121.	127.	140.	140.	132.	143.	122.	102.	1498.
ETDF	113.	108.	128.	122.	121.	127.	124.	44.	80.	138.	122.	102.	1329.
MAI	.00	.00	.00	.00	.00	.00	.11	.69	.40	.03	.00	.00	

TAMBACOUNDA SENEGAL EL= 46 LAT= 13 46 N LONG= 13 41 W KS= 8.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	0.	1.	0.	2.	20.	131.	196.	289.	231.	70.	2.	0.	942.
PMI	0.	0.	0.	0.	0.	31.	102.	77.	64.	3.	0.	0.	
P79	0.	0.	0.	0.	0.	77.	140.	199.	173.	33.	0.	0.	
P60	0.	0.	0.	0.	8.	99.	173.	275.	196.	52.	0.	0.	
PMX	4.	7.	2.	29.	129.	338.	385.	495.	414.	186.	26.	2.	
TMC	24.9	27.1	29.8	31.8	32.[illegible]	30.0	27.2	26.5	26.9	27.7	27.8	24.4	28.0
HM	28.	26.	25.	29.	39.	59.	75.	82.	83.	70.	59.	37.	51.
SC	73.	74.	74.	72.	67.	55.	43.	36.	35.	42.	55.	68.	58.
PD	0.	0.	0.	0.	2.	82.	147.	215.	178.	37.	0.	0.	
ETP	144.	151.	195.	204.	209.	172.	148.	134.	125.	133.	134.	134.	1894.
ETDF	144.	151.	195.	204.	207.	91.	1.	-[illegible]1.	-53.	96.	134.	134.	1224.
MAI	.00	.00	.00	.00	.01	.47	.99	1.60	1.42	.28	.00	.00	

ZIGUINCHOR SENEGAL EL= 10 LAT= 12 35 N LONG= 16 16 W KS= 9.0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	0.	1.	0.	0.	10.	125.	363.	532.	361.	146.	8.	1.	1547.
PMI	0.	0.	0.	0.	0.	30.	147.	199.	191.	42.	0.	0.	
P79	0.	0.	0.	0.	0.	70.	293.	407.	259.	70.	0.	0.	
P60	0.	0.	0.	0.	2.	94.	334.	472.	323.	120.	2.	0.	
PMX	1.	12.	0.	1.	43.	307.	649.	904.	664.	275.	43.	20.	
TMC	24.0	25.7	27.3	28.0	28.5	28.4	27.0	26.4	27.0	27.8	27.0	24.5	26.8
HM	56.	56.	58.	63.	68.	75.	84.	88.	85.	81.	74.	62.	71.
SC	60.	60.	58.	55.	51.	45.	36.	31.	35.	39.	46.	55.	48.
PD	0.	0.	0.	0.	0.	75.	302.	421.	272.	80.	0.	0.	
ETP	130.	133.	164.	163.	165.	149.	134.	123.	125.	130.	122.	123.	1663.
ETDF	130.	133.	164.	163.	165.	74.	-168.	-297.	-148.	49.	121.	123.	512.
MAI	.00	.00	.00	.00	.00	.50	2.25	3.41	2.18	.62	.00	.00	