SORGHUM BREEDING - A PROJECTION

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INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID
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SUMMARY

I. Sorghum Breeding

The opportunity available to the sorghum program of ICRISAT has expanded substantially in the last year. Beside the station at Ouagadougou, Upper Volta, a sorghum breeder has been stationed at Wad Medani, Sudan, Ilonga, Tanzania, and it is anticipated that a sorghum breeder will be stationed within the ICRISAT program at Samaru, Nigeria. A program is also developing that will focus on the higher elevation situations primarily in Ethiopia and Kenya. ICRISAT has a sorghum breeder stationed at CIMMYT in Mexico; however this paper concentrates on India and Africa.

The Government of India has approved five locations as substations of ICRISAT: Bhavanisagar, Dharwar, Gwalior, Hissar, and a site yet to be selected in Jammu-Kashmir. How these locations might contribute to an ICRISAT cooperative network for sorghum breeding research is considered in this paper.

A second important development at ICRISAT is the increasing opportunities to screen sorghum for various traits of economic importance. Important criteria are:

1. Yield and stability
2. Quality
   a) Traditional concepts
   b) Food preparation and taste
   c) Nutrition high lysine low tannin.
3. Resistance
   a) Insects: stem borer, shootfly, Midge, possibly head bugs
   b) Diseases: Grain moulds, Charcoal rot, Downy mildew
   c) Drought
   d) *Striga*.

The increasing capability to screen for these traits provides an ever improving base for effective cross discipline cooperation. An effort has been made in this paper to indicate how this multidisciplined approach would interact with the sorghum breeding program.

Indication has been made as to how the regional stations both within and outside of India could contribute to support the multidisciplined approach.

The program base is expanding to include material adapted to an array of climatic situations, and to incorporate some photosensitivity across the range of maturities. Some photosensitivity for the drier zones protects the cultivator who must repeatedly sow to establish stand, that he will have moisture at the end to mature his crop. A late sown photo-insensitive type might run out of moisture at the end of the season because it could be maturing after the rains had stopped. Some photosensitivity in late maturing types might well contribute to adaptation.

It is anticipated that each of the regional stations of ICRISAT outside of India will have its own research program and undertake service functions such as regional trials and nurseries. Breeders at these locations are looking to the center at Hyderabad for ever improving source material for factors as mentioned above. It is anticipated that the ICRISAT stations will truly form an effective network for crop improvement.

The important aspect of collection has not been stressed in this paper. It is recognized that the collection is a source of variability for the traits of interest. It has, is, and will be screened and evaluated for traits of concern. The introgression project is an important step between many collections and their use in the crop improvement program. The collection is recognized as an important source material.

It is anticipated that proven agronomically elite lines, showing weakness for one trait, will, whenever possible, be improved by a type of backcrossing program. This breeding procedure has not been mentioned in detail as it is reasonably straight-forward and specific. The breeding schemes presented are generalized and simplified in most cases.

The ICRISAT Regional Stations have been associated, in this paper, with environmental zones. These zones are useful for the evaluation of adaptation; however, it is recognized that breeding materials are useful across different zones. The comments made herein are not meant to imply a restriction on this movement but to help focus a concentration of effort.

This paper has been developed primarily within the sorghum breeding group at the Center (Hyderabad). It has been organized to serve as a base paper to generate interaction and comments. It is not considered a finished proposal. Your comments are most welcome.

February 1978. L.R. House

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SORGHUM IMPROVEMENT

APPROACH WITHIN SORGHUM BREEDING

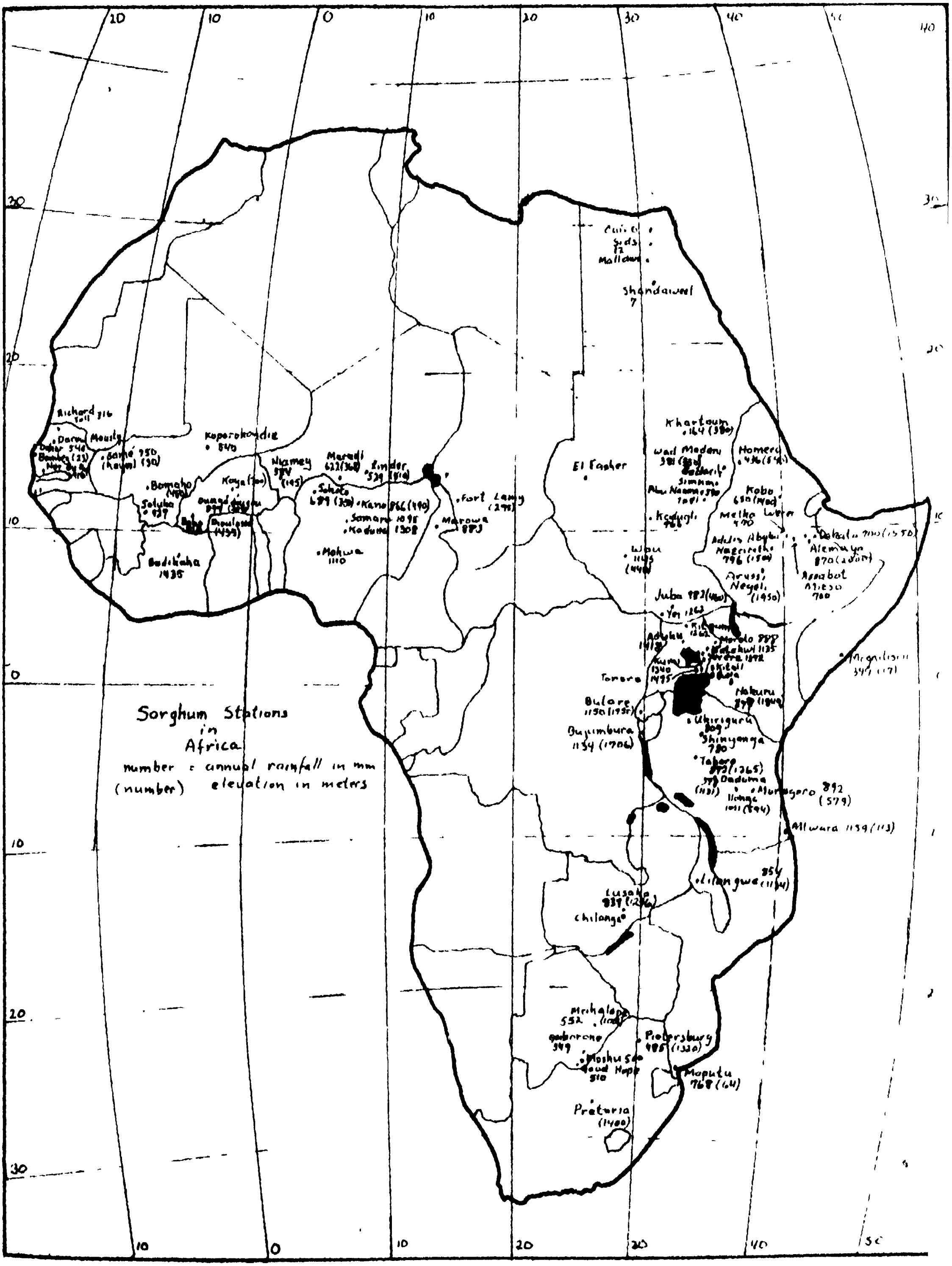
I. Introduction

The improvement of sorghum rests on across discipline approach. The problem is how to most effectively integrate the contributions from the disciplines. It is possible to improve several varieties for one or two particular traits and once these have been stabilized, cross with varieties stabilized for other traits. This building block approach is slow. Part of this paper presents an attempt to describe an approach to sorghum improvement in which promising breeding material is strengthened for all important traits during its development. Over time continually better varietal material should be forthcoming in terms of yield, resistance and quality traits. It should also be possible to more clearly focus on the problems of screening and to point to areas where greater effort and expanded facilities are required. This approach is also in keeping with the philosophy at ICRISAT; and, the desires of our cooperators, that we provide better and better source material.

This past year ICRISAT has had the opportunity to expand within and outside of India. The Government of India approved outreach locations at Bhavanisagar, Dharwar, Gwalior, Hissar, and a site in Jammu or Kashmir. Overseas, beside the program in Ouagadougou and Sotuba, programs began in the Sudan and Tanzania. Soon programs may open with likely centers at Samaru, Nigeria, and in the Ethiopia, Kenya area. ICRISAT has also taken responsibility for the cold tolerance program centered in Mexico. This represents a tremendous expansion of opportunity for ICRISAT's sorghum program. Each of the overseas regional stations has or will have its own program. It is expected that all centers will form a network of cooperating stations. As the stations are able, it is expected that they will be responsible for regional nurseries and trials as well as other activities such as collecting and germplasm maintenance, for their regions. Climatic differences exist and an attempt has been made in this paper to begin to describe these differences in terms of station relationships. There is particular interest in the relationship between the ICRISAT centers within India and those in Africa. This exercise should subsequently be expended for other locations of concern in the world. A map of Africa is presented showing the location of many sorghum stations there (Fig. 1).

II. Geographical and climatological relationships of ICRISAT stations in India and Africa

The network of ICRISAT stations has and is expanding considerably. It is important to attempt to analyze relationships between these locations for soil, climate, other environmental factors and the crop, and also, to consider the unique traits of each location with reference to contribution to the whole system. Cooperation between several interest areas at ICRISAT is obviously valuable.


Sorghum Stations
in
Africa
number = annual rainfall in mm
(number) elevation in meters
Richard Toll 316
Kaporokoudie 840
Niamey
Maradi 622 (368)
Zinder
Sokoto 689
Kano 866 (470)
Samaru 1095
Kaduna 1308
Mokwa 1110
Fort Lamy
Marowa 883
Badikaha 1435
Bamako
El Fasher
Shandaweel 7
Khartoum 164 (380)
Wad Medani
Homera
Kobo 650
Melka Werer 470
Kadugli
Wau
Juba 983
Dakata
Alemaya 870
Assabot
Addis Abeba
Nazareth 796
Arussi
Neyei (1950)
Mogadishu
Tororo 1495
Bulore
Bujumbura 1134 (1706)
Nakuru
Ukiriguru 809
Shinyanga 780
Tabora
Dodoma
Morogoro 892 (579)
Mlwara 1139 (113)
Lilongwe 854 (1134)
Lusaka 837
Chilanga
Mahalapye 552
Gaborone 549
Pietersburg 485 (1320)
Moshuse
Good Hope 510
Maputu 768 (64)
Pretoria (1400)
10
0
10
20
30
40
50

i) The relationship between stations in India and Africa:

Geographical information about stations in India and in Africa with which they are climatologically most closely related is presented in Table 1. (It is assumed that Srinagar represents a climatological situation for the ICRISAT site in Jammu-Kashmir). Climatological information is presented in Table 2. Geographical information is presented for a number of stations in Africa in Table 3. It appears, for working purposes, that the climatic situation can be divided into eight categories:

1. The low rainfall zone
2. The intermediate rainfall zone
3. The high rainfall zone
4. The equatorial zone
5. The high elevation intermediate rainfall zone
6. The temperate zone
7. The East African zone
8. The Rabi Season, India.

An indication is made in Table 3 how each station might fit into this climatic division.

Weather records were used for the regional stations in India and for locations in Africa chosen to indicate broad climatological differences. These locations are not necessarily sorghum stations but are in areas where sorghum is an important crop. This information is presented in Figures 2 through 35. Graphical comparisons are made in

Tables 2 through 7 and climatological information on a station by station basis made in Tables 8 through 35; in fact, Tables 2 through 7 were made from the others.

The station at Hissar is most representative in India of the low rainfall zone (Figs. 2, 8, 10, 11, 12, 13). The rainfall is similar to that in the Sudan from Kassala south to Abu Naama. The rainfall at Hissar and Kassala is lower than at the West African locations. However, rainfed sorghum is taken on the road between Wad Medani and Gedariff (Figs. 2 and 11). With a station at Wad Medani, this would seem to be a good location in Africa to work on sorghums for the low rainfall zone. The temperatures at Hissar are definitely colder during the winter months, but during the growing season are hotter than at the African locations. The opportunity for supplemental irrigation at Hissar might help approximate the dry African situation. Hissar, then, would be a useful location for the sorghum program.

The climatic situation at Hyderabad is similar to that at Ouagadougou; Figs. 3, 16, 18, 20, 21, 22, 23, 33. The climatic situation across Africa from Roseires in the Sudan to Kano and Kayes is very similar to that at Ouagadougou. The dip in expeceted rainfall in August at Hyderabad is not expected at the other locations but the overall pattern is similar. Temperatures during the rainy season are very similar.

The rainfall and temperature patterns at Llongwe, Malawi, and Lusaka, Zambia, are cooler but close to those of the other stations in this zone. It would seem useful that regional activities from both Hyderabad, and Ouagadougou, as well as other stations in the zone, exchange seeds with these stations in the Southern Latitude.

The rainfall at Gwalior is higher than at Hyderabad (Figures 18 and 19) indicating that Gwalior might counterpart for a somewhat higher rainfall situation in Africa. However, the duration of rainfall is less (the season shorter), also, Gwalior is fairly far north (26° 14') which would present problems working with the photosensitive sorghums of the higher rainfall zones of Africa.

None of the regional stations in India have a climate similar to the high rainfall zones of Africa (Figs. 4, 26, 27, 28). This climatic zone will be best represented by the ICRISAT regional center developing at Samaru (Fig. 4). Breeding for this zone might also be undertaken at Sotuba in Mali. The total rainfall pattern in high elevation, high rainfall Ethiopia (Fig. 24) is similar to stations at lower elevation but the temperatures are very different. The need to service such areas needs to be considered in developing a program expected to center in Ethiopia and Kenya (Figs. 24 and 25 - note the similarity in rainfall pattern between Jimma and Kitali).

The rainfall pattern in the equatorial zone is best represented in India by the station at Bhavanisagar (Figs. 5, 32, 34, 35). The similarity in rainfall and temperature between Bhavanisagar and the ICRISAT regional center at Ilonga (near Morogoro) is good. Temperatures drop at higher elevations (particularly Butare) but still it seems reasonable to service this higher elevation area from the ICRISAT centers at Bhavanisagar and Ilonga. The rainfall pattern in this zone is different from those in the low, intermediate, and high rainfall zones in that the rain starts early in May and keeps increasing until October. Bhavanisagar is an important location to the sorghum program.

The climate of the high elevation intermediate rainfall zone of Ethiopia appears to be relatively similar to that of Dharwar (Figs. 6, 29, 31). The rainfall pattern at Nazareth is between that of Dharwar and Hyderabad (Figs. 6 and 18). Night temperatures at Harar are cooler (5^{o}C) and Dharwar is some 6^{o} of latitude further north. However, we should try and evaluate sorghums from the Ethiopian highlands at Dharwar in the Kharif to see if they give a near normal expression. If so, this would be useful to the sorghum program.

Srinagar is in a temperate climate with colder temperatures and low rainfall (Figs. 7, 15, 17) during the growing season. It is the only station in India which approximates many of the growing conditions of Southern Africa. Supplementary irrigation would be required, but with this we could evaluate materials of potential value for temperate

Southern Africa. Although not represented here, this location might relate well to growing conditions in the Near East. This station could counterpart with ICARDA should this become a regional station for the ICRISAT sorghum program. This station has potential value for the sorghum program.

The climate in East Africa is different from those so far described; there can be a distinctly bimodal rainfall pattern (Fig. 14), generally rather high rainfall (Figs. 24 and 25), and generally relatively high and cool. The program now proposed for Ethiopia and Kenya should be able to identify locations for appropriate testing. The idea of a center at Kitali is not bad, the rainfall is high and it is cool. The development of strong links to the Ethiopian Sorghum Improvement Program should also make possible useful sites for development and evaluation. The program now under consideration for Ethiopia and Kenya is for the high elevation cool situation. There are dry warmer, even hot, situations at lower elevations that may in time be reached (Fig. 14).

In summary, it is interesting and fortunate that there are such similarities in climate between the sites now available to ICRISAT in India and the regional station in Africa. These can be summarized as follows:

Low rainfall zone - Hissar, Wad Medani

Intermediate rainfall zone- Hyderabad, Ouagadougou

High rainfall zone	-	Samaru
Equatorial	-	Bhavanisagar, Ilonga
High elevation intermediate rainfall	-	Dharwar, Nazareth
Temperate	-	Srinagar
East African	-	Kitali and other locations in Kenya and in Ethiopia (in cooperation with the Ethiopian Sorghum Improvement Program)
Rabi	-	Hyderabad, Dharwar

This array of stations appears to provide working access to most of the climatic situations of interest. A high rainfall site in India, a temperate site in Africa, and opportunity for work for the hotter drier conditions of East Africa could be beneficial.

A better physical description of the environment in which sorghum grows would do much to help delineate zones and to relate these to the ICRISAT stations. It should also be possible to gain a better predictive base for the movement of varietal material from one location regionally. The possibility of cooperation of agroclimatology, soil physics and cereal physiology to describe in detail the environments and relate these to the growth of a standard set of lines including entries from all zones appears to be a reasonable approach.

Table 1: Geographic Information for ICRISAT Stations.

Station	Country	Zone	Elev.(M)	Latitude	Longitude
Hyderabad	India	Intermediate Rainfall, Rabi	545	17° 27'N	78° 28'E
Ouagadougou	Upper Volta	Intermediate Rainfall	308	12° 22'N	1° 31'W
Hissar	India	Low Rainfall	221	29° 10'N	75° 40'E
Wad Medani	Sudan	Low Rainfall	405	14° 23'N	33° 29'E
Bhavanisagar	India	Equatorial	278	11° 27'N	77° 30'E
Ilonga	Tanzania	Equatorial	594	6° 50'S	37° 00'E
Samaru	Nigeria	High Rainfall	686	11° 11'N	7° 38'E
Sotuba	Mali	High Rainfall		11° 12'N	8° 27'E
Dharwar	India	High Elevation Inter. Rainfall, Rabi	727	15° 27'N	75° 00'E
Nazareth	Ethiopia	High Elevation Inter. Rainfall	1500	8° 33'N	39° 17'E
Srinagar	India	Temperate	1586	34° 05'N	74° 50'E
Kitali	Kenya	East African	1895	1° N	35° E

Table 2: Rainfall Data (mm) for ICRISAT stations.

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Hyderabad	1.7	11.4	13.4	24.1	30.0	107.4	165.0	146.9	163.3	70.8	24.9	5.5	764.0
Ouagadougou	0.0	2.0	13.0	16.0	83.0	122.0	203.0	280.0	144.0	33.0	1.0	0.0	897.0
Hissar	19.1	14.7	17.0	6.2	11.0	34.2	122.1	113.9	81.2	14.6	7.5	4.5	446.0
Wad Medani	0	0	0	3.0	15.0	33.0	130.0	129.0	55.1	15.0	1.0	0	381.2
Samaru	3	1.5	7.1	38.1	124.5	165.1	221.5	281.4	230.4	36.1	1.3	0	1117.3
Sotuba	0	0	0	5.1	48.0	180.0	333.0	253.0	213.1	51.1	6.1	0	1089.0
Bhavanisagar	11.3 (Jul)	12.2 (Aug)	21.8 (Sep)	50.8 (Oct)	94.0 (Nov)	41.7 (Dec)	52.0 (Jan)	90.8 (Feb)	108.1 (Mar)	171.9 (Apr)	116.9 (May)	35.1 (Jun)	806.7
Ilonga	6.1	13.0	15.0	32.0	89.9	132.1	122.9	124.0	176.0	209.0	78.0	13.0	1010.9
Dharwar	2.0	1.6	8.9	47.7	74.5	95.3	173.9	121.3	102.3	125.1	48.1	12.01	812.7
Nazareth	8.9	21.1	47.0	67.1	35.1	95.0	178.1	202.0	110.0	17.0	10.9	6.1	796.0
Srinagar	72.8	72.3	104.1	78.1	63.4	35.6	61.0	62.8	31.8	28.7	17.5	35.9	564.0
Kitali	20.1	38.1	71.1	147.3	165.1	132.1	160.0	170.2	106.7	73.7	58.4	40.6	1181.1

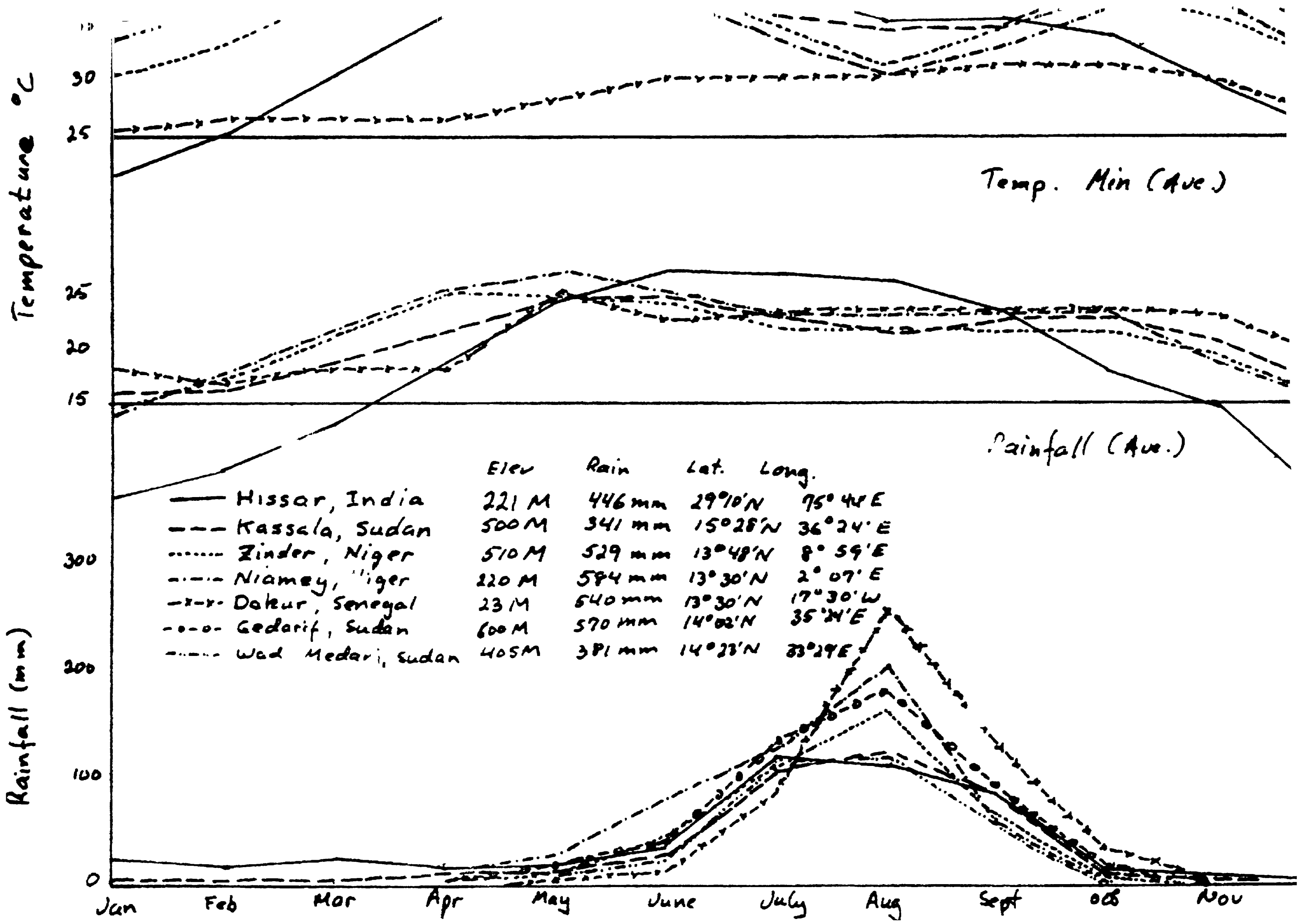
Table 3: Climatological and geographical information for some sorghum stations in Africa

Station	Country	Latitude	Longitude	Rainfall mm	Elevation meters	Climate (1)
Ab[illegible]aama	Sudan	13.09 N	33.57 E	590	430	LR
Aduku	Uganda	2.17 N	32.56 E	1418	1095	EA
Agadi	Sudan					
Alemaya	Ethiopia	12.25 N	35.34 E	870		HEIR
Arus Negele	Ethiopia	5.05 N	39 E			HLIR
Badikaha	Ivory Coast	9.27 N	5.38 E	1435	300	HR
Bambey	Senegal	14.42 N	16.27 W	632	20	LR
Bobo Dioulasso	Upper Volta	11.12 N	4.18 W	1181	432	HR
Bujumbura	Burundi	3.23 S	29.21 E	1139	1706	Trop, EA, HR
Butare	Rwanda	2.36 S	29.44 E	1150	1754	Trop, EA, HR
Chilanga	Zambia	15.5 S	29.1 E	775	1200	IR
Dodoma	Tanzania	6.10 S	35.46 E	578	1131	Trop, LR
Darou	Senegal	15.00 N	16.00 E	517	40	LR
Fanaye	Senegal					Temp, LR
Gaboronne	Botswana	24.40 S	25.55 E	540	983	Temp, LR
Good Hope	Botswana	25.28 S	25.26 E	510	1283	LR
Humera	Ethiopia	15.07 N	36.04 E	436	590	Trop.
Ilonga	Tanzania	6.50 S	37.00 E	1011	594	HR, Trop
Juba	Sudan	4.52 N	31.36 E	982	460	HR
Kaduna	Nigeria	10.36 N	7.27 E	1308	645	IR
Kadugli	Sudan	11.00 N	29.43 E	765	450	IR
Kamboinse	Upper Volta	12.22 N	1.31 W	852	308	IR
Kano	Nigeria	12.03 N	8.32 E	866	490	IR
Katakwi	Uganda	1.54 N	33.59 E	1135	1158	EA
Khartoum	Sudan	15.37 N	32.32 E	64	380	LR
Kitgum	Uganda	3.17 N	32.53 E	1262	914	EA, HR
Kobo	Ethiopia	11.49 N	39.36 E	650	1400	HEIR, LR
Koporo	Mali	14.30 N	4.12 W	540		LR

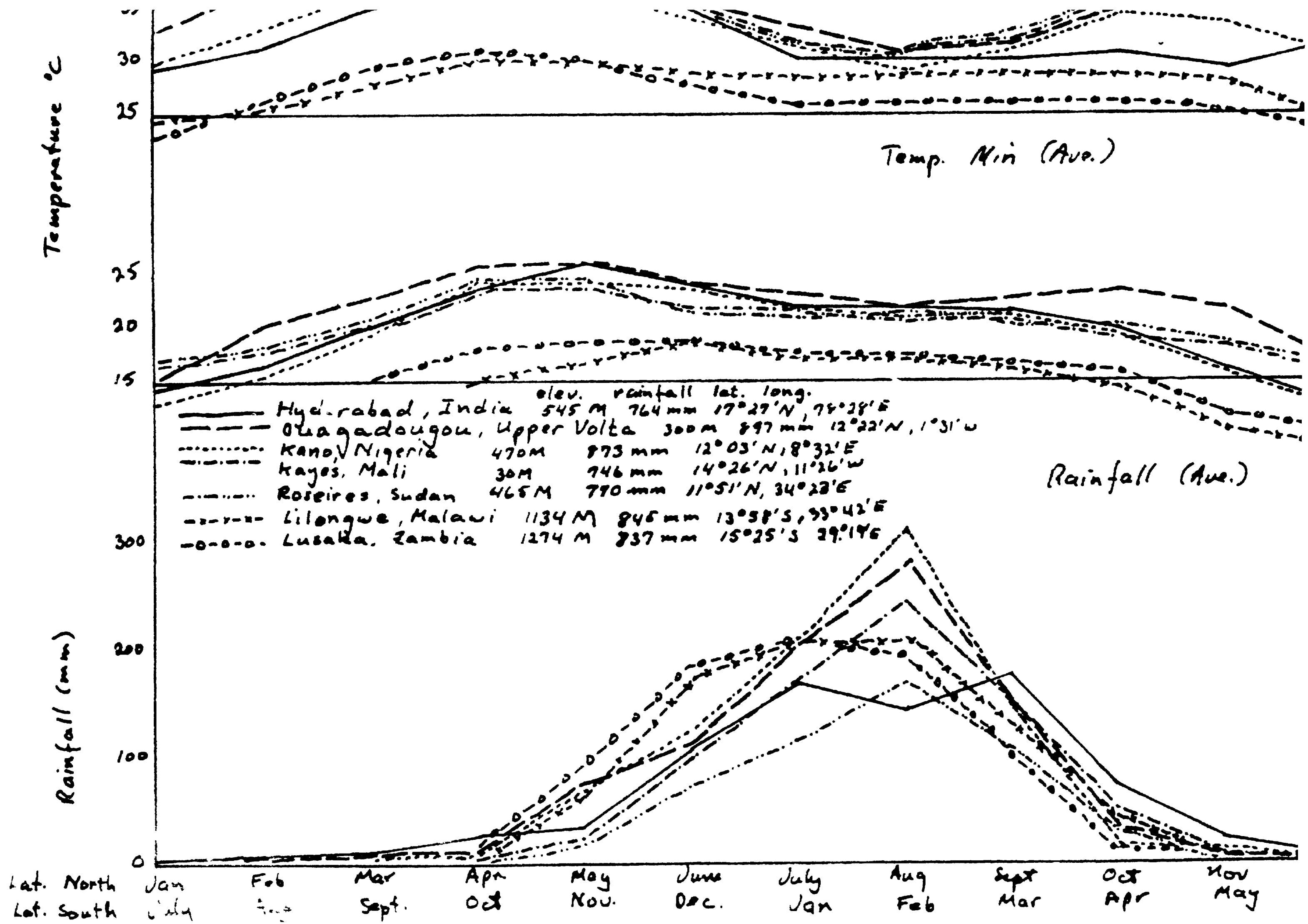
tation	Country	Latitude	Longitude	Rainfall mm	Elevation meters	Climate (1)
ml	Uganda	1.27 N	33.46 E	1340	1128	EA
saka	Zambia	15.25 S	29.19 E	837	1277	IR
halape	Botswana	23.05 S	26.48 E	552	1006	Temp, LR
radi	Niger	13.28 N	7.06 E	622	269	LR
rowa	Cameroon	10.26 N	14.19 E	883	404	IR
lka Werer	Ethiopia	8.59 N	40.10 E	570	916	LR
kwa	Nigeria	9.04 N	5.59 E	1110	184	HR
rogoro	Tanzania	6.51 S	37.40 E	892	520	Trop
roto	Uganda	2.33 N	34.36 E	888	1524	EA
shu	Botswana	24.26 S	26.09 E	500	945	Temo, LR
nza	Tanzania	2.28 S	32.55 E	1002	1140	Trop
zareth	Ethiopia	8.33 N	39.17 E	796	1500	HEIR
kuru	Kenya	0.17 S	36.04 E	877	1849	EA, HEIR
ioro du Rip	Senegal	13.44 N	15.49 W	916	18	HR, IR
ichard Toll	Senegal	16.5 N	15.5 W	316	7	LR
aria	Upper Volta	12.5 N	2.5 W	837		IR
ame	Mali	14.26 N	11.26 W	750	46	IR
amaru	Nigeria	11.11 N	7.38 E	1095	686	HR
hinyanga	Tanzania	3.33 S	33.24 E	780	1219	Trop
imsim	Sudan	13 N	35.4 E			LR
inthion Mdeme	Senegal	12.43 N	15.42 W	1387	15	HR
utuba	Mali	11.12 N	8.27 W	927		HR, IR
'oboro	Tanzania	5.02 S	32.49 E	892	1265	Trop
'ororo	Uganda	0.42 N	34.10 E	1475	1233	EA
'ozi	Sudan	12.5 N	34. E			LR
kiriguru	Tanzania	2.42 S	33.01 E	809	1199	Trop
'ad Medani	Sudan	14.23 N	33.29 E	381	405	LR
'au	Sudan	7.42 N	28.01 E	1128	435	HR
ei	Sudan	4.01 N	31 E			HR

(1) See next page.

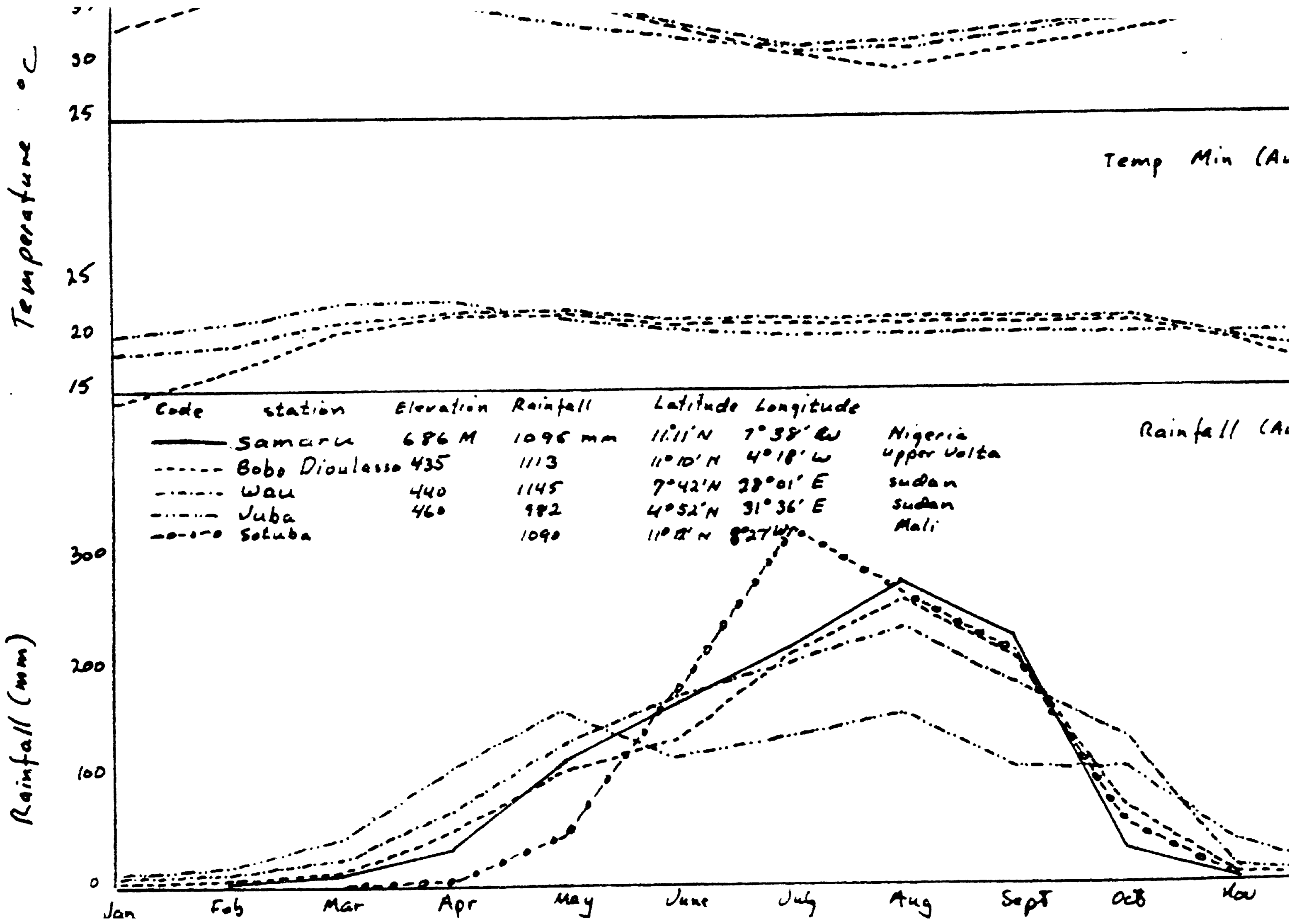
(1) Approximate climatic classification	ICRISAT Main Locations
The Low Rainfall Zone = LR	(Hissar)
The Intermediate Rainfall Zone = IT	(Hyderabad, Ouagadougou)
The High Rainfall Zone = HR	(Samaru)
The Equatorial Zone = Trop.	(Bhavanisagar, Ilonga)
The High Elevation Inter. Rainfall Zone = HEIR	(Dharwar, Nazareth)
The Temperate Zone = Temp.	(Srinagar)
The East African Zone = EA	(Kitali, Ethiopia ?)



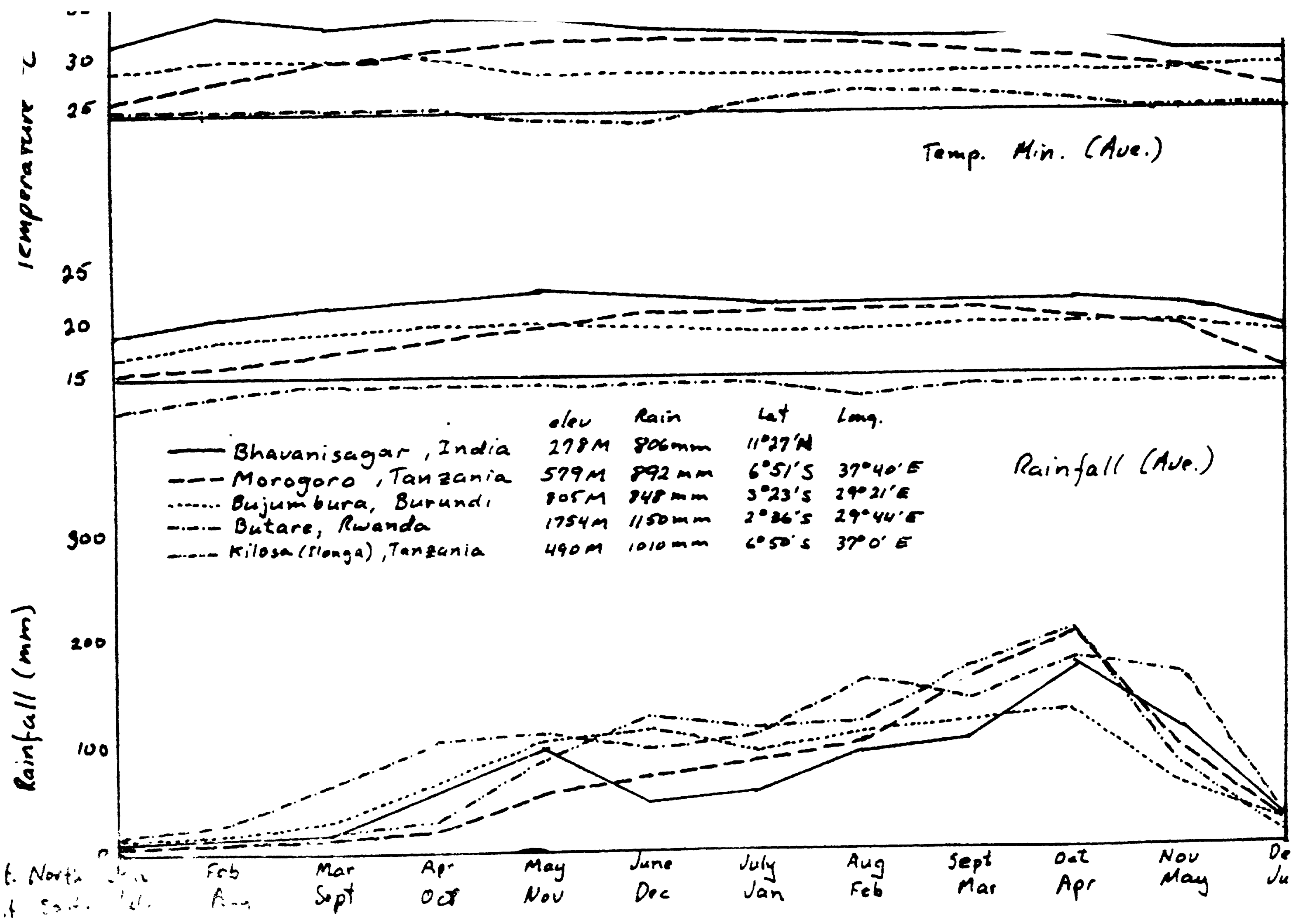
Temperature °C
30
25
Temp. Min (Ave.)
25
20
15
Rainfall (Ave.)
Elev Rain Lat. Long.
Hissar, India 221 M 446 mm 29°10'N 75°48'E
Kassala, Sudan 500 M 341 mm 15°28'N 36°24'E
Zinder, Niger 510 M 529 mm 13°48'N 8°59'E
Niamey, Niger 220 M 594 mm 13°30'N 2°07'E
Dakar, Senegal 23 M 540 mm 13°30'N 17°30'W
Gedarif, Sudan 600 M 570 mm 14°02'N 35°24'E
Wad Medani, Sudan 405 M 381 mm 14°23'N 33°29'E
Rainfall (mm)
300
200
100
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov



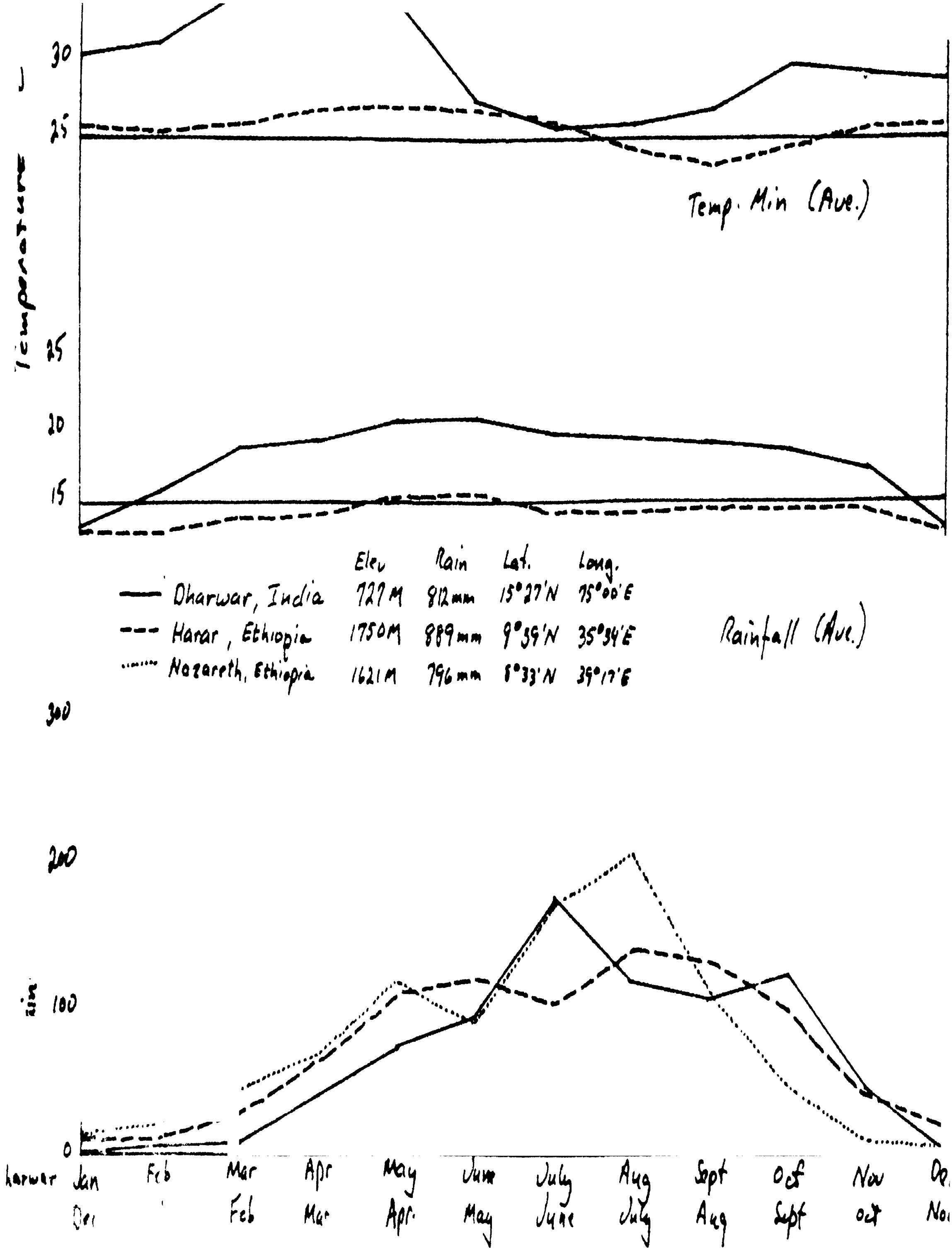
Temperature °C
30
25
Temp. Min (Ave.)
25
20
15
elev. rainfall lat. long.
Hyderabad, India 545 M 764 mm 17°27'N, 78°28'E
Ouagadougou, Upper Volta 300 m 897 mm 12°22'N, 1°31'W
Kano, Nigeria 470M 873 mm 12°03'N, 8°32'E
Kayes, Mali 30M 746 mm 14°26'N, 11°26'W
Roseires, Sudan 465M 770 mm 11°51'N, 34°23'E
Lilongwe, Malawi 1134 M 846 mm 13°58'S, 33°42'E
Lusaka, Zambia 1274 M 837 mm 15°25'S 28°19'E
Rainfall (Ave.)
Rainfall (mm)
300
200
100
0
Lat. North Jan Feb Mar Apr May June July Aug Sept Oct Nov
Lat. South July Sept. Oct Nov. Dec. Jan Feb Mar Apr May



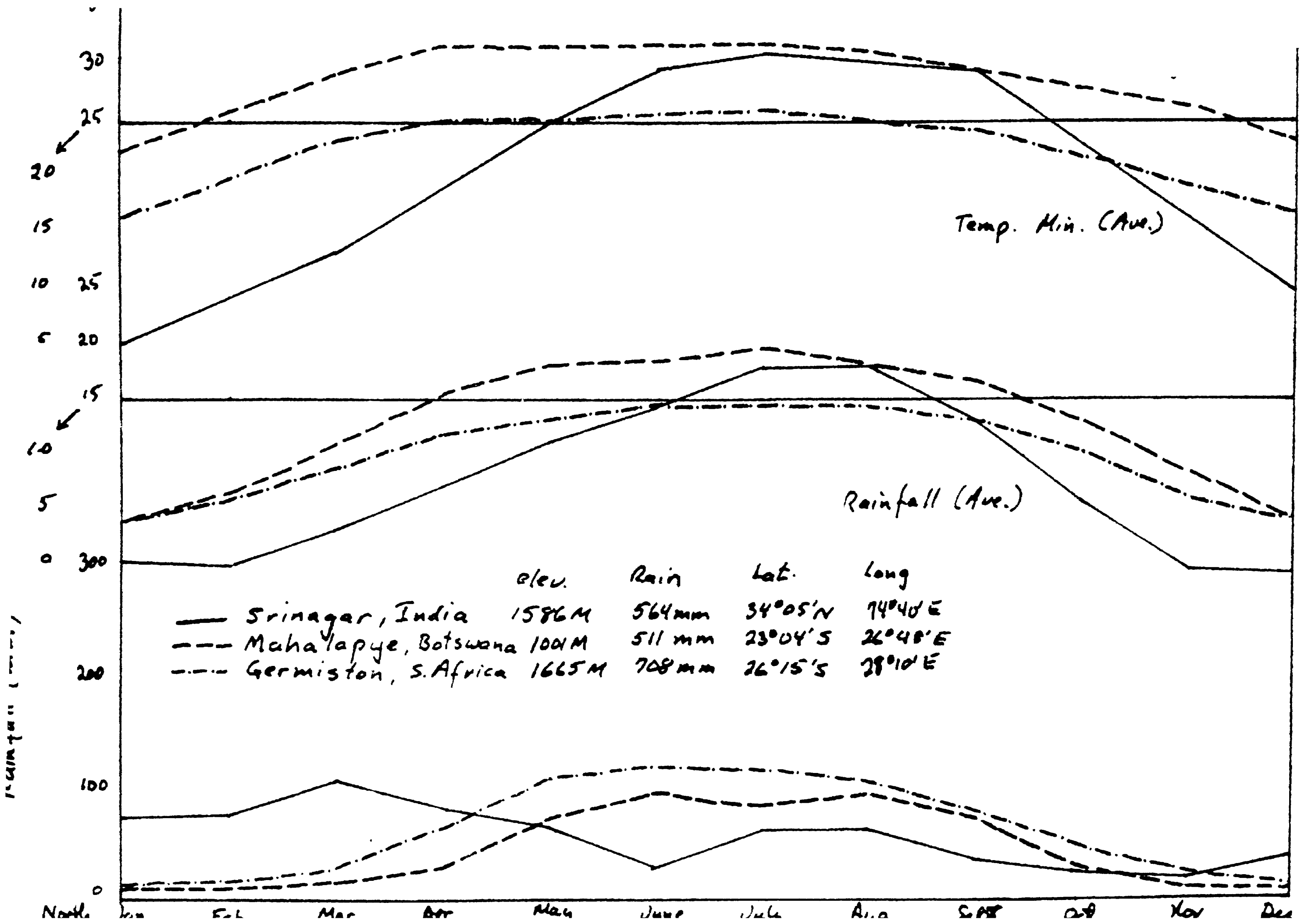
Temperature °C
30
25
Temp Min (A
25
20
15
Code station Elevation Rainfall Latitude Longitude
Samaru 686 M 1096 mm 11°11'N 7°38'W Nigeria
Bobo Dioulasso 435 1113 11°10'N 4°18'W upper Volta
Wau 440 1145 7°42'N 28°01'E sudan
Juba 460 982 4°52'N 31°36'E sudan
Sotuba 1090 Mali
Rainfall (A
Rainfall (mm)
300
200
100
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov



Temperature °C
30
25
25
20
15
Temp. Min. (Ave.)
elev Rain Lat Long.
Bhavanisagar, India 278M 806mm 11°27'N
Morogoro, Tanzania 579M 892 mm 6°51'S 37°40'E
Bujumbura, Burundi 805M 848 mm 3°23'S 29°21'E
Butare, Rwanda 1754M 1150mm 2°36'S 29°44'E
Kilosa (Ilonga), Tanzania 490M 1010mm 6°50'S 37°0'E
Rainfall (Ave.)
Rainfall (mm)
300
200
100
0
Feb Mar Apr May June July Aug Sept Oct Nov
Sept Oct Nov Dec Jan Feb Mar Apr May



Temperature
30
25
Temp. Min (Ave.)
25
20
15
Elev Rain Lat. Long.
Dharwar, India 727M 812mm 15°27'N 75°00'E
Harar, Ethiopia 1750M 889mm 9°39'N 35°34'E
Nazareth, Ethiopia 1621M 796mm 8°33'N 39°17'E
Rainfall (Ave.)
300
200
100
0
Jan Feb Mar Apr May June July Aug Sept Oct Nov
Feb Mar Apr. May June July Aug Sept oct



Temp. Min. (Ave.)
Rainfall (Ave.)
elev. Rain Lat. Long
Srinagar, India 1586M 564mm 34°05'N 74°40'E
Mahalapye, Botswana 1001M 511 mm 23°04'S 26°48'E
Germiston, S. Africa 1665M 708mm 26°15'S 28°10'E
30
25
20
15
10
5
0
300
200
100
Mar
May
June
Aug
Nov

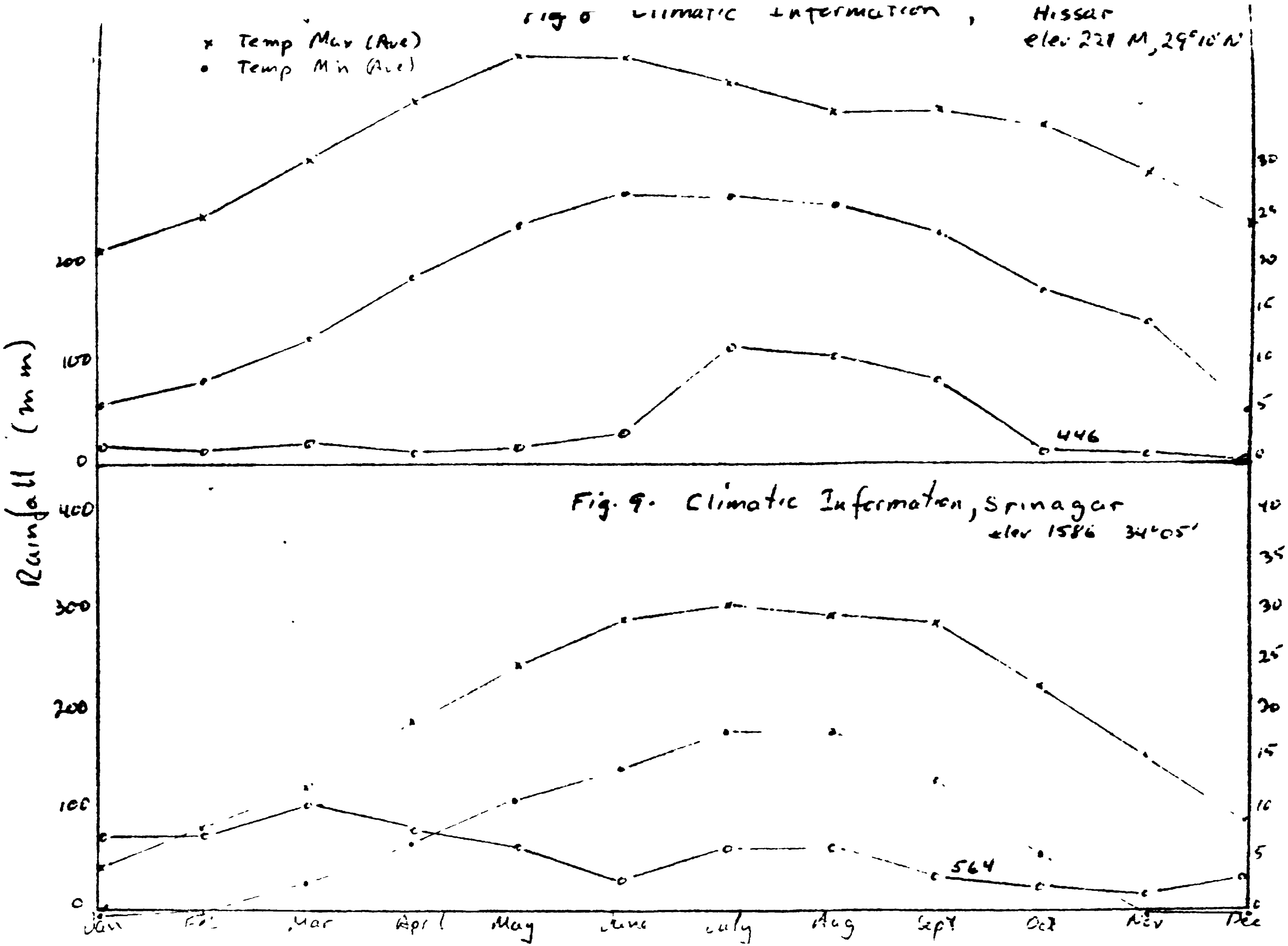
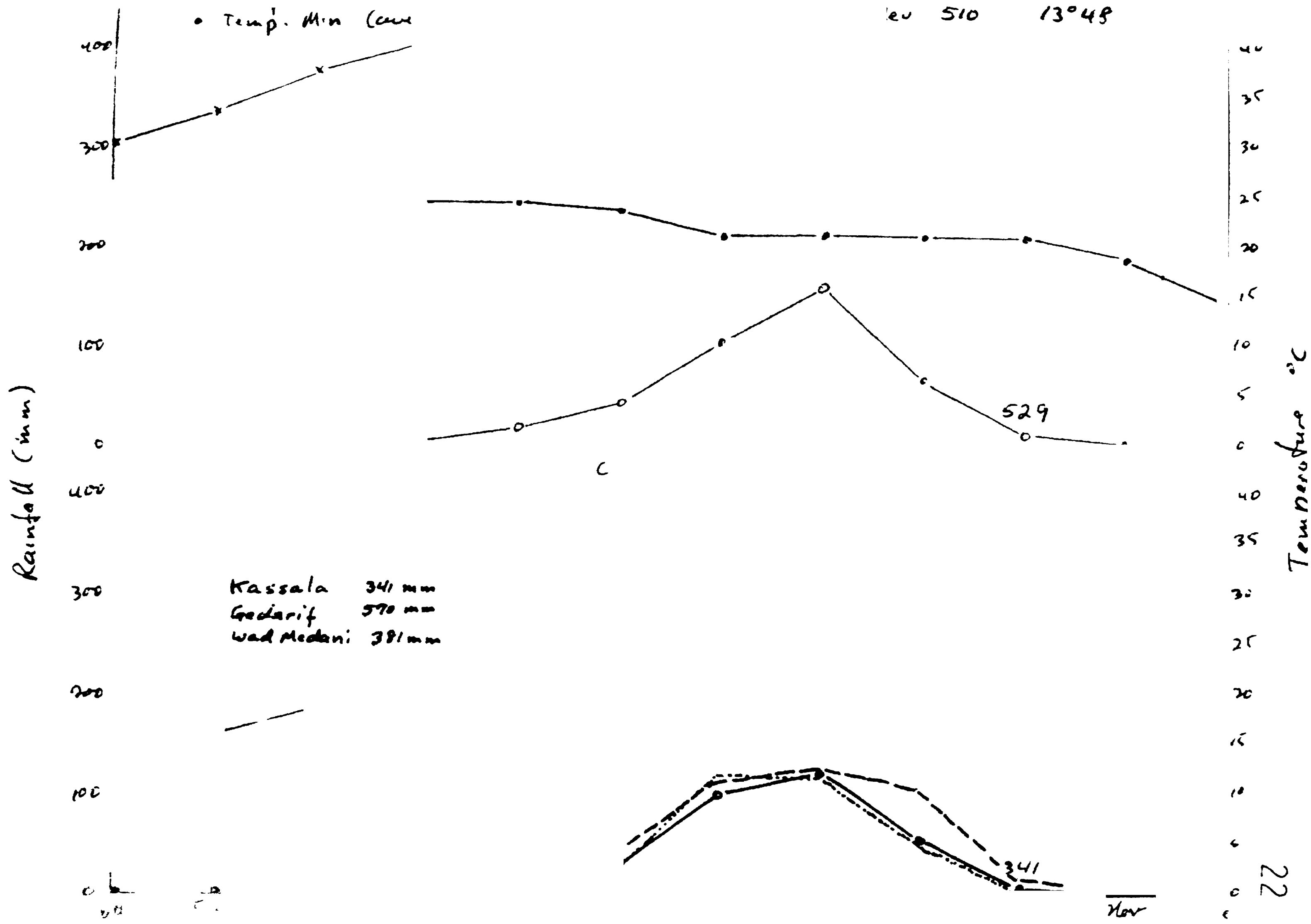
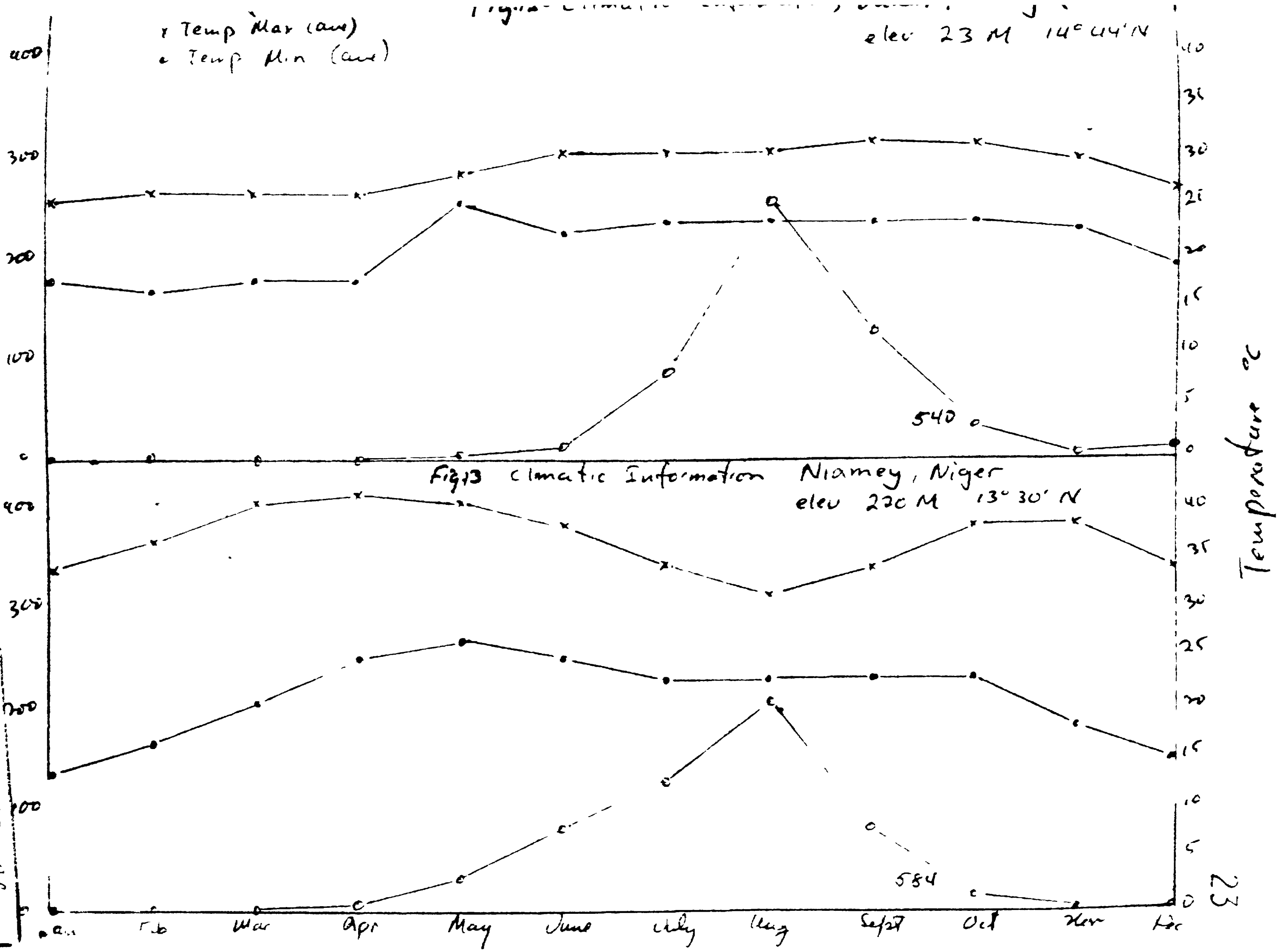


Fig 8 Climatic Information, Hissar
elev 221 M, 29°10'N

Fig. 9. Climatic Information, Srinagar
elev 1586 34°05'


• Temp. Min (curve
lev 510
13°48
529
Kassala 341 mm
Gedarif 590 mm
Wad Medani 381 mm
341
Nov
Rainfall (mm)
Temperature °C
0
100
200
300
400
5
10
15
20
25
30
35
40


x Temp Max (ave)
• Temp Min (ave)
elev 23 M 14°44'N
Fig 13 Climatic Information Niamey, Niger
elev 220 M 13°30' N
540
584
Rainfall (mm)
Temperature °C
400
300
200
100
0
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

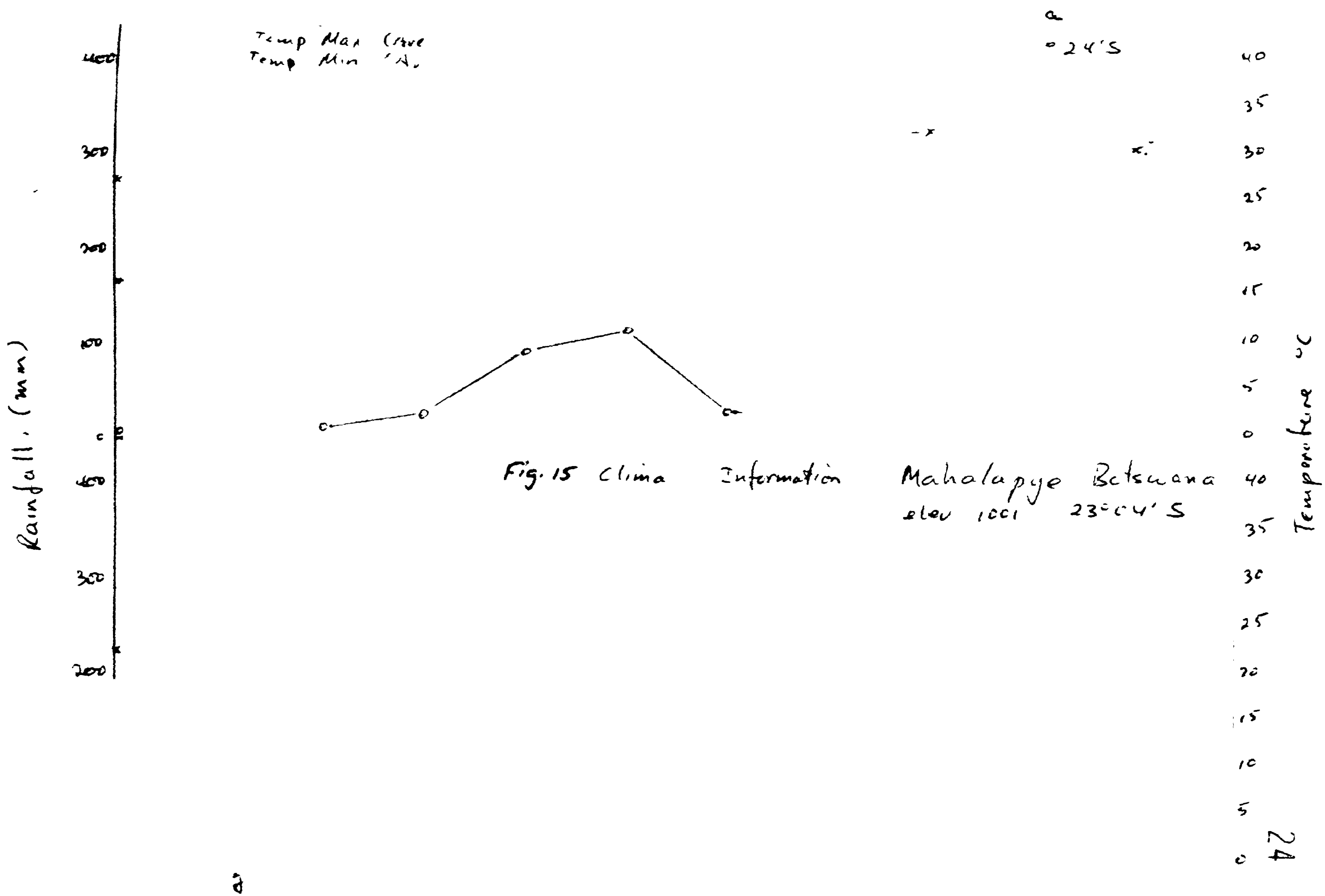


Fig. 15 Clima Information Mahalapye Botswana
elev 1001 23°04'S

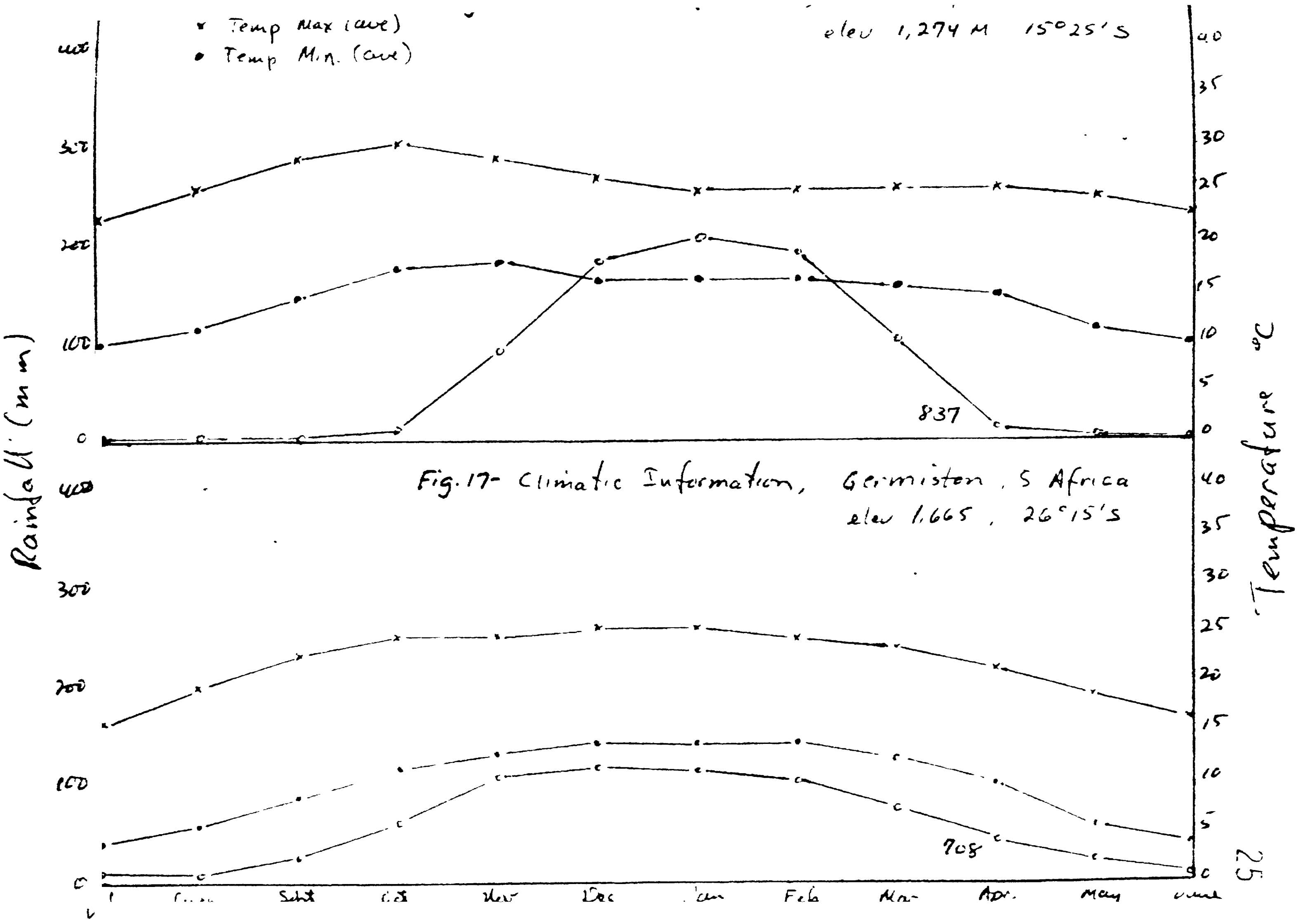


Fig. 17- Climatic Information, Germiston, S Africa elev 1,665, 26°15'S

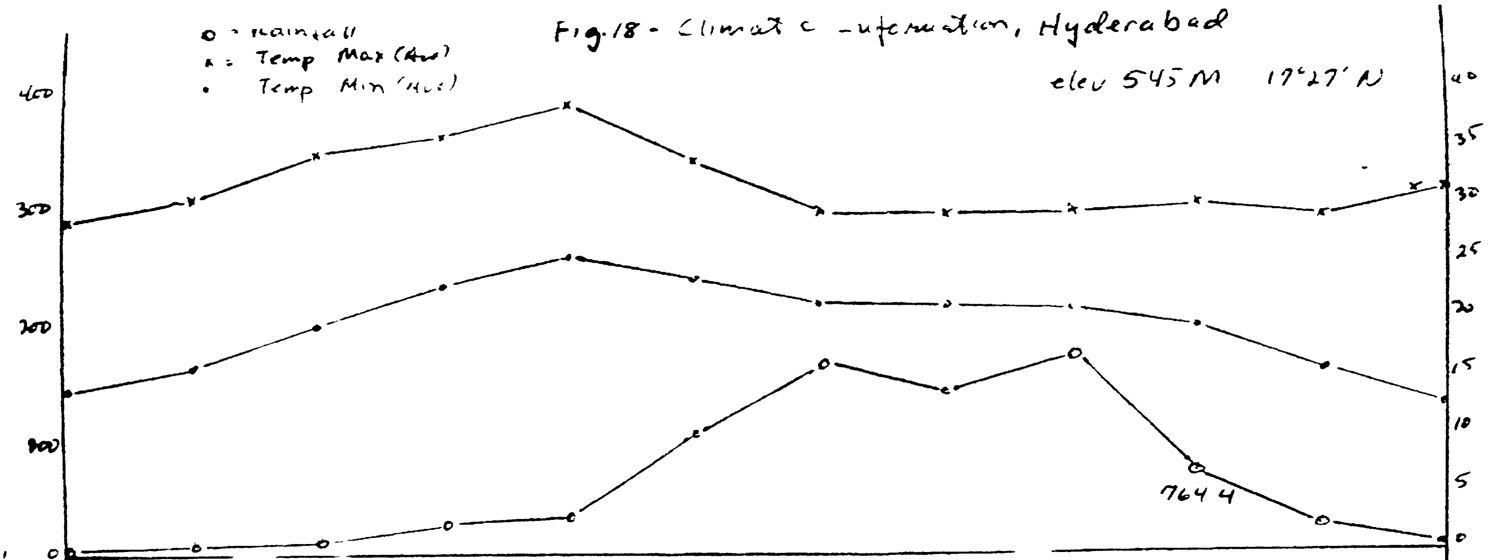


Fig. 18 - Climatic Information, Hyderabad
elev 545 M 17°27' N

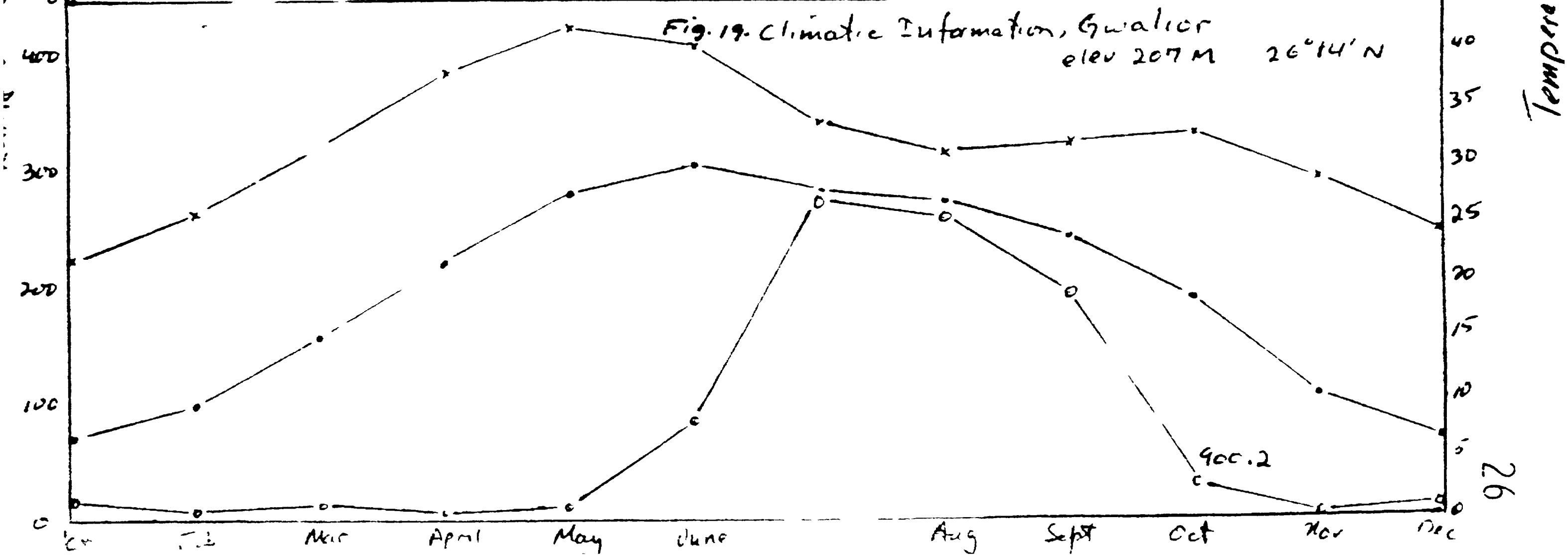
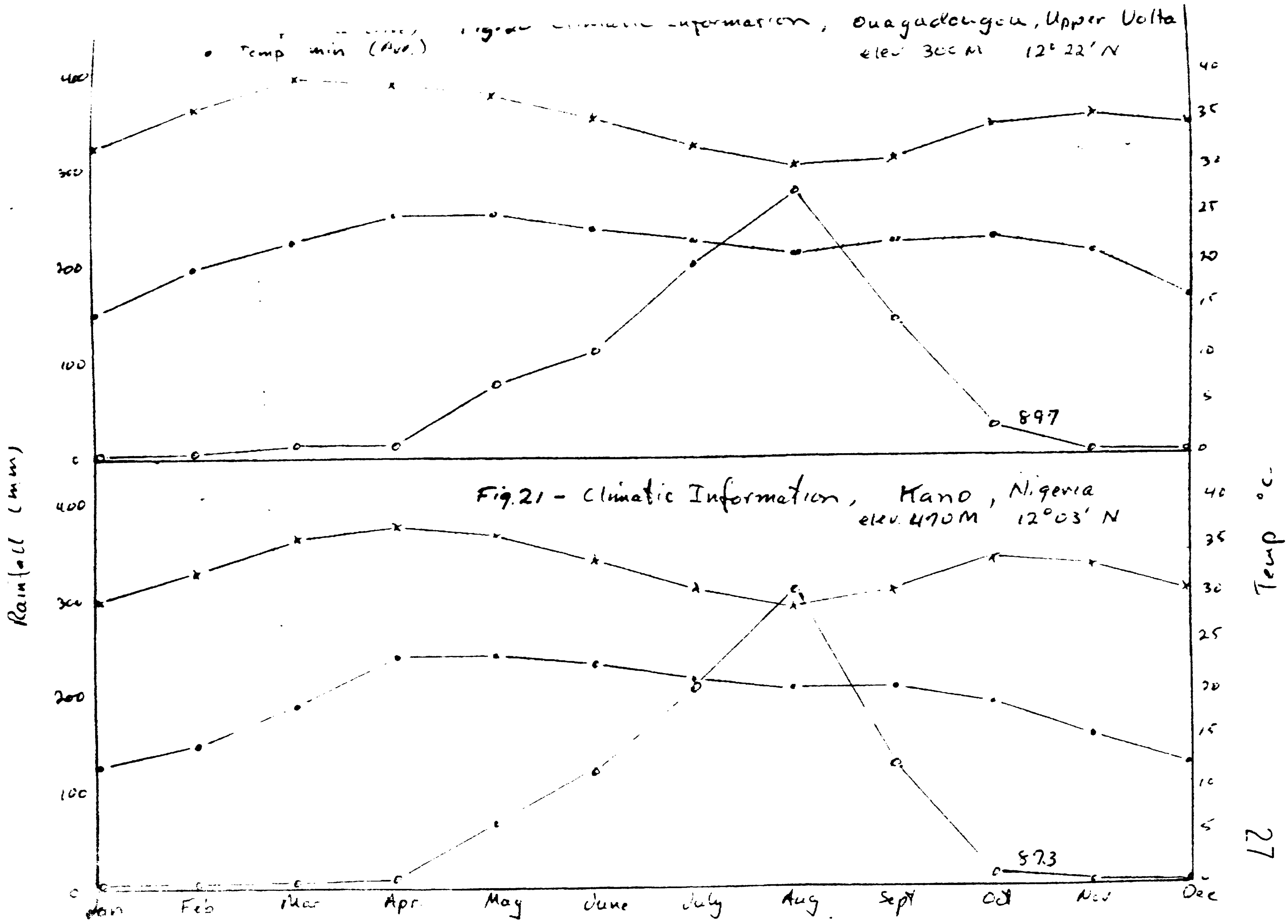


Fig. 19. Climatic Information, Gwalior
elev 207 M 26°14' N



Climatic Information, Ouagadougou, Upper Volta elev 300 M 12° 22' N

Fig.21 - Climatic Information, Kano, Nigeria elev. 470M 12°03' N

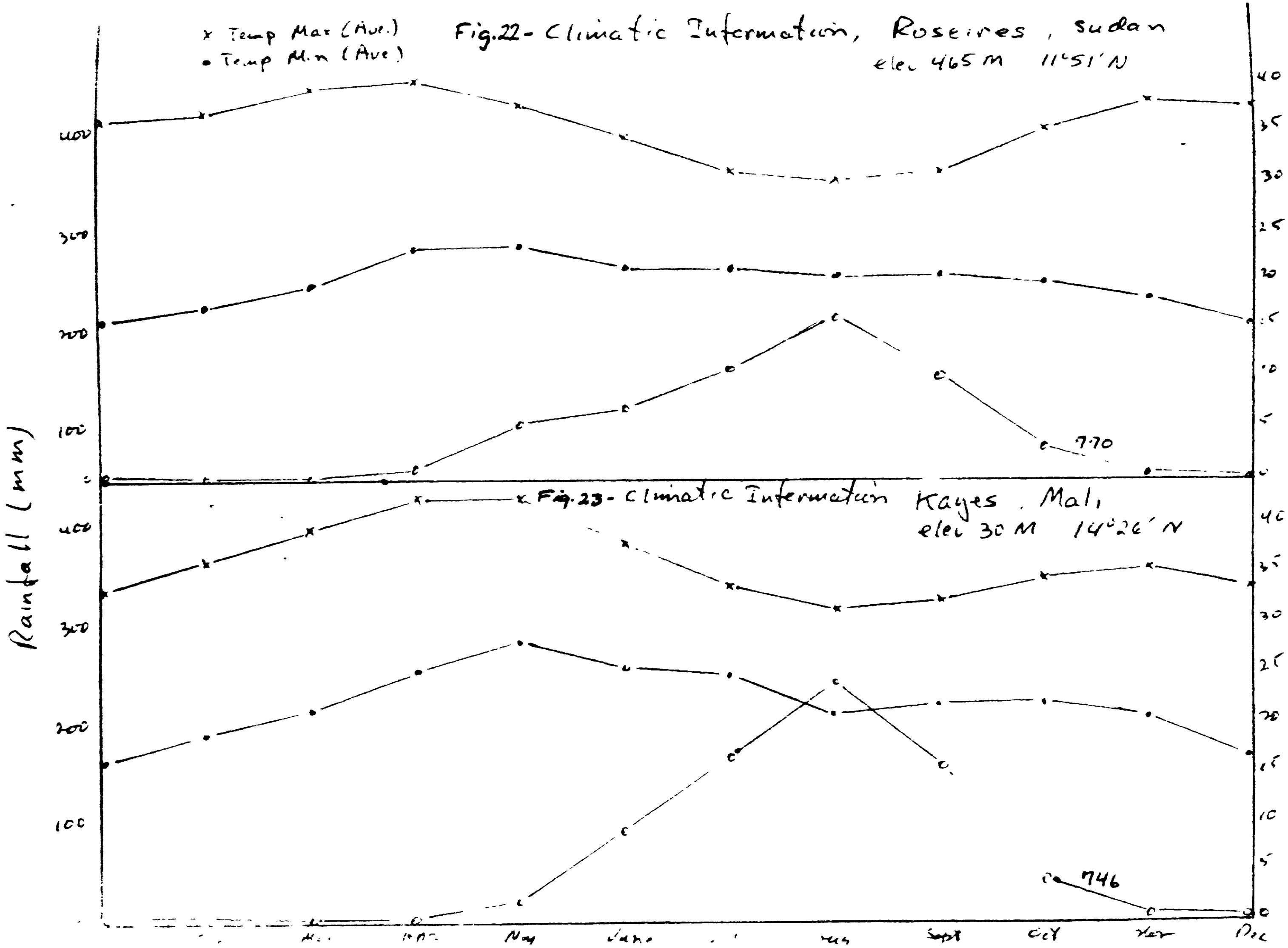


Fig.22 - Climatic Information, Roseires, Sudan
elev 465 M 11°51'N

Fig.23 - Climatic Information Kayes, Mali,
elev 30 M 14°26'N

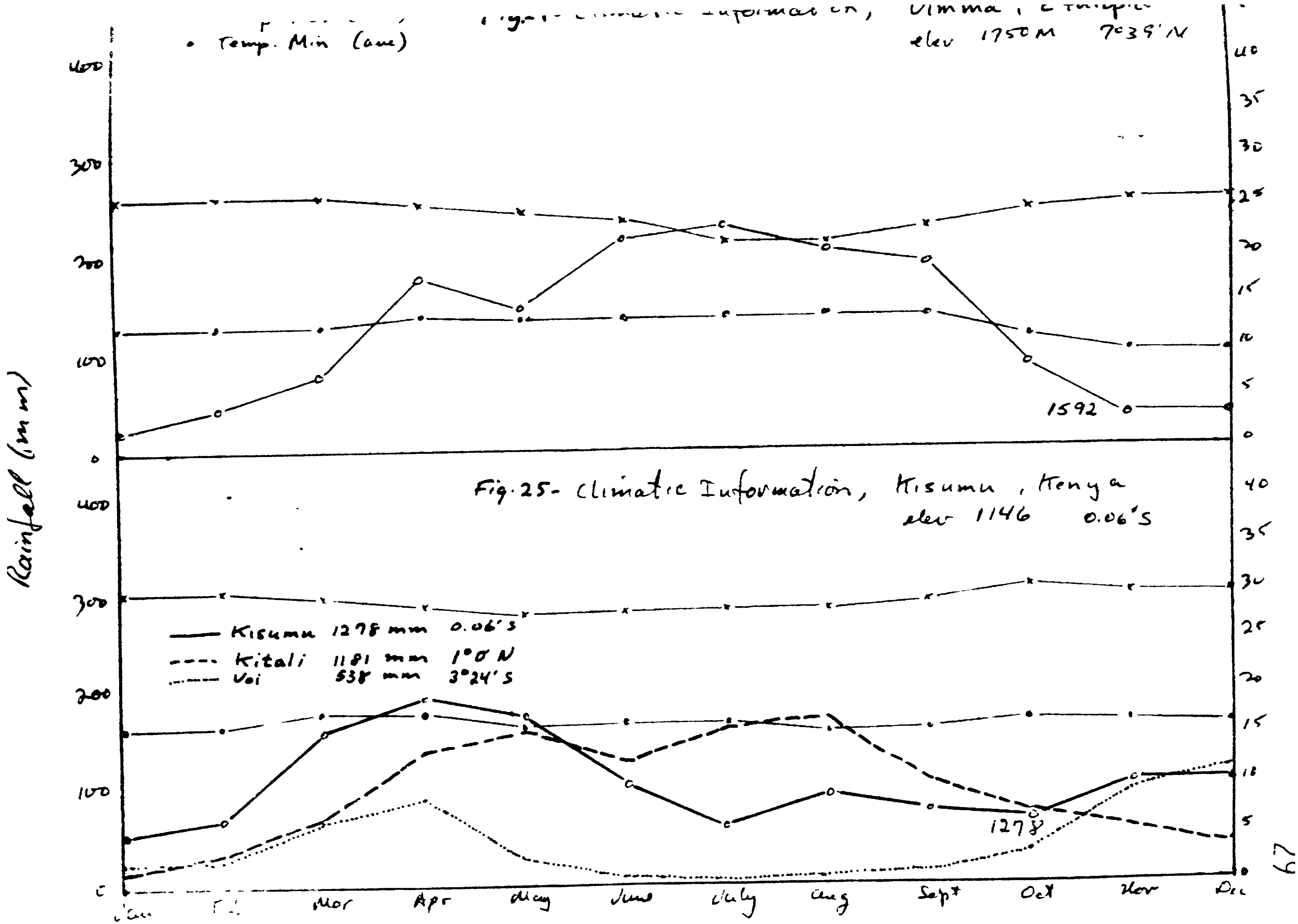


Fig. 25- Climatic Information, Kisumu, Kenya
elev 1146 0.06'S

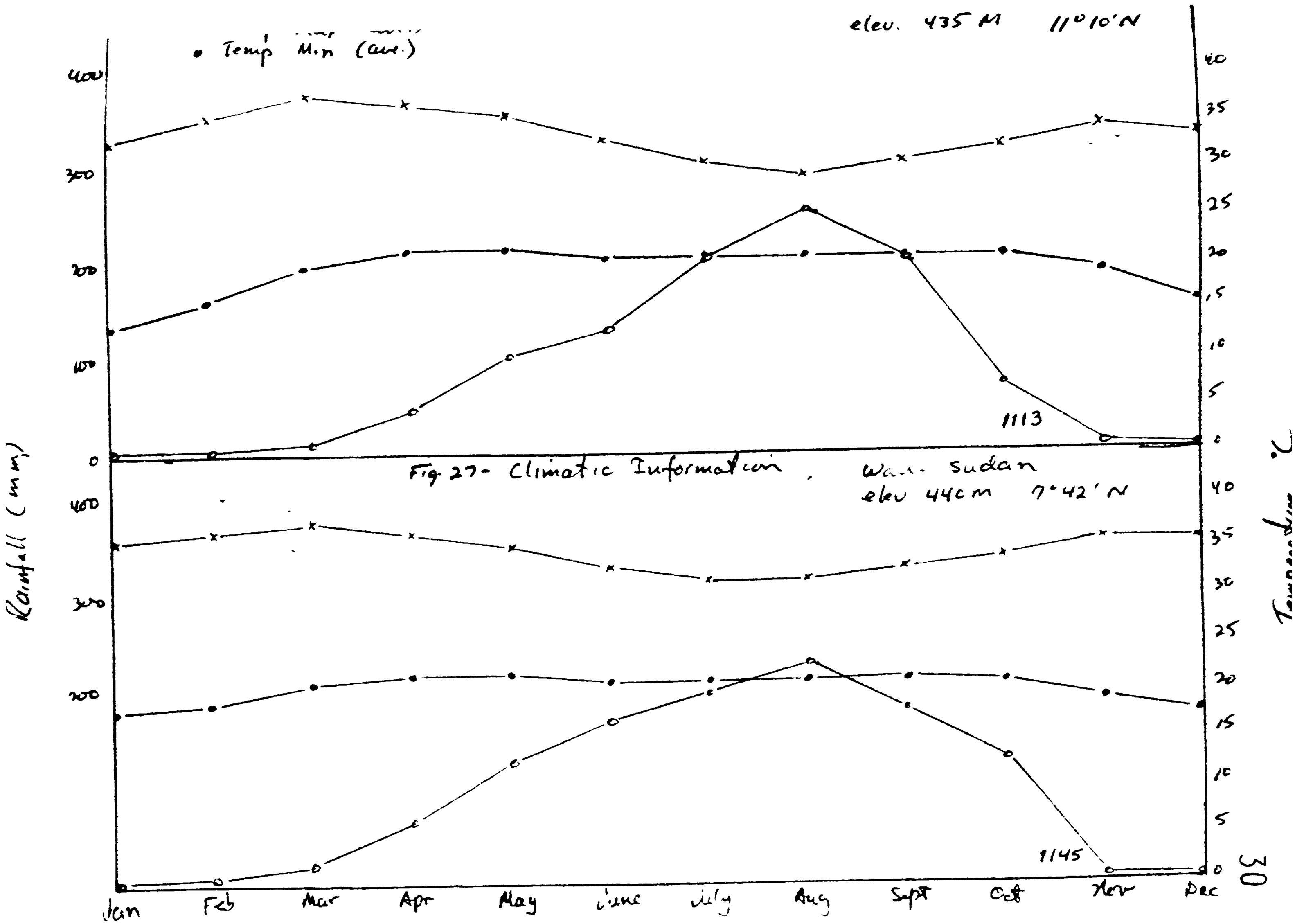


Fig 27- Climatic Information, Wau- sudan

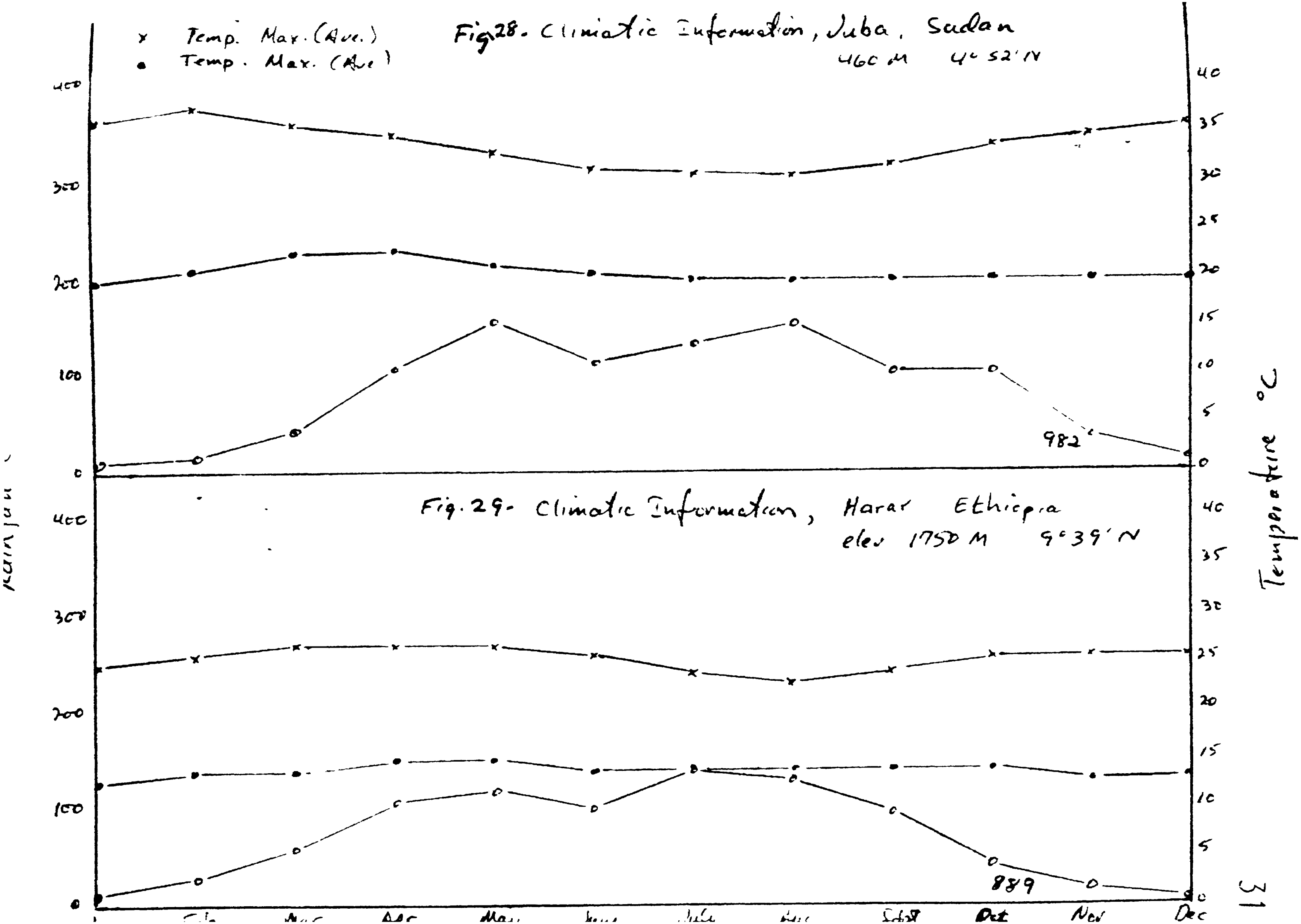


Fig 28. Climatic Information, Juba, Sudan 460 M 4° 52′ N

Fig. 29. Climatic Information, Harar Ethiopia elev 1750 M 9° 39′ N

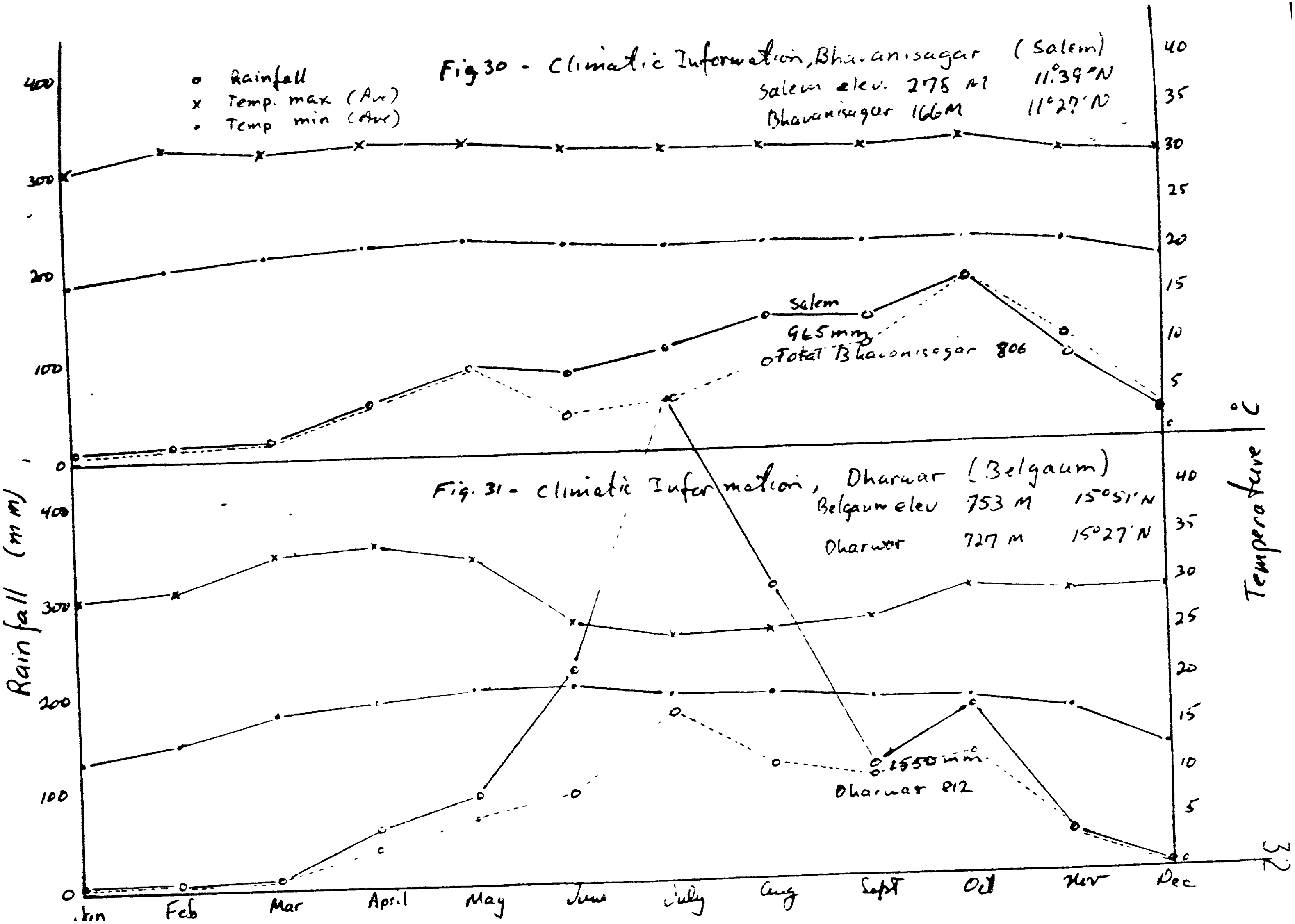


Fig 30 - Climatic Information, Bhavanisagar (Salem)

Fig. 31 - Climatic Information, Dharwar (Belgaum)

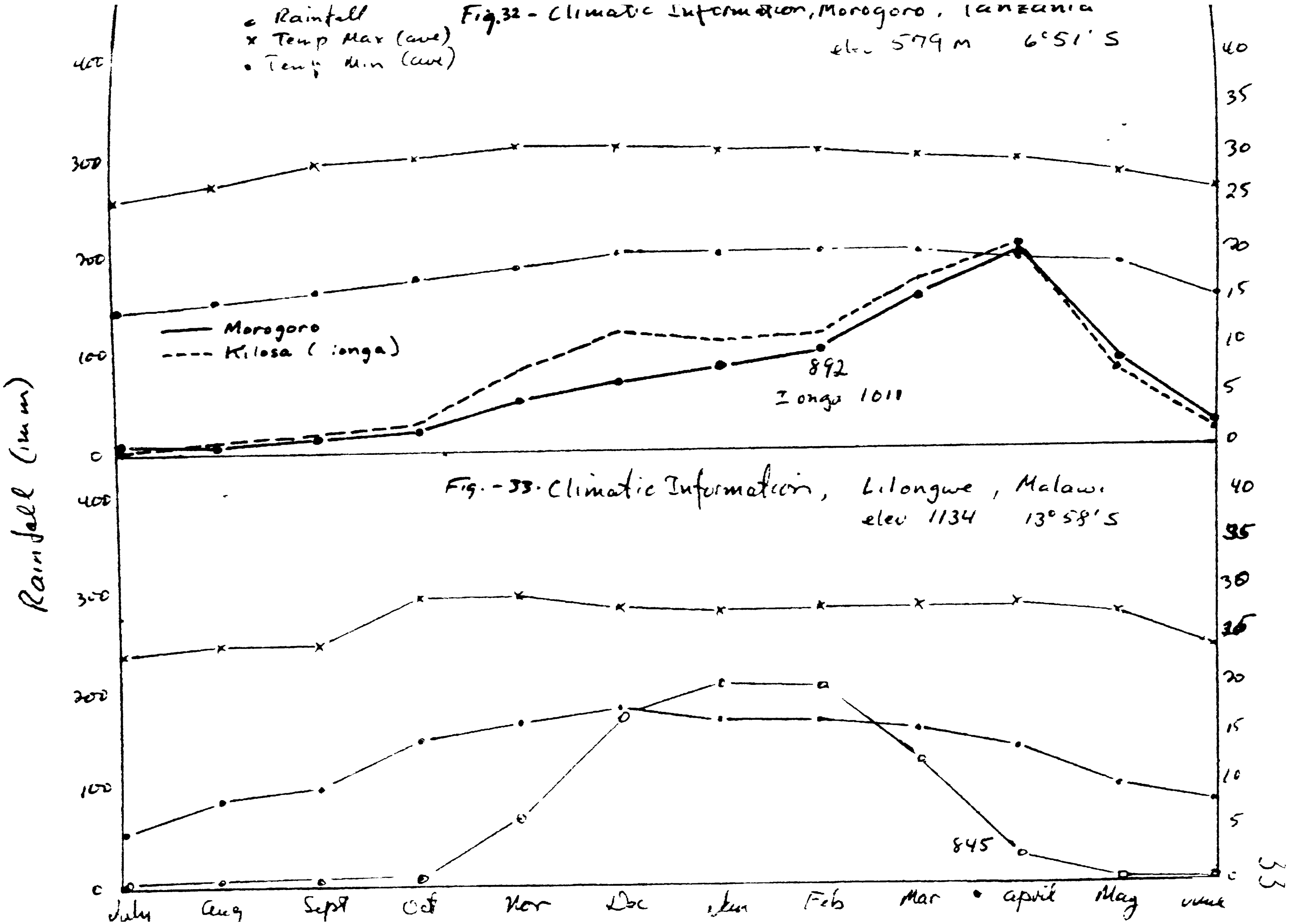


Fig.32 - Climatic Information, Morogoro, Tanzania
elev 579 M 6°51'S

Fig.-33. Climatic Information, Lilongwe, Malawi
elev 1134 13°58'S

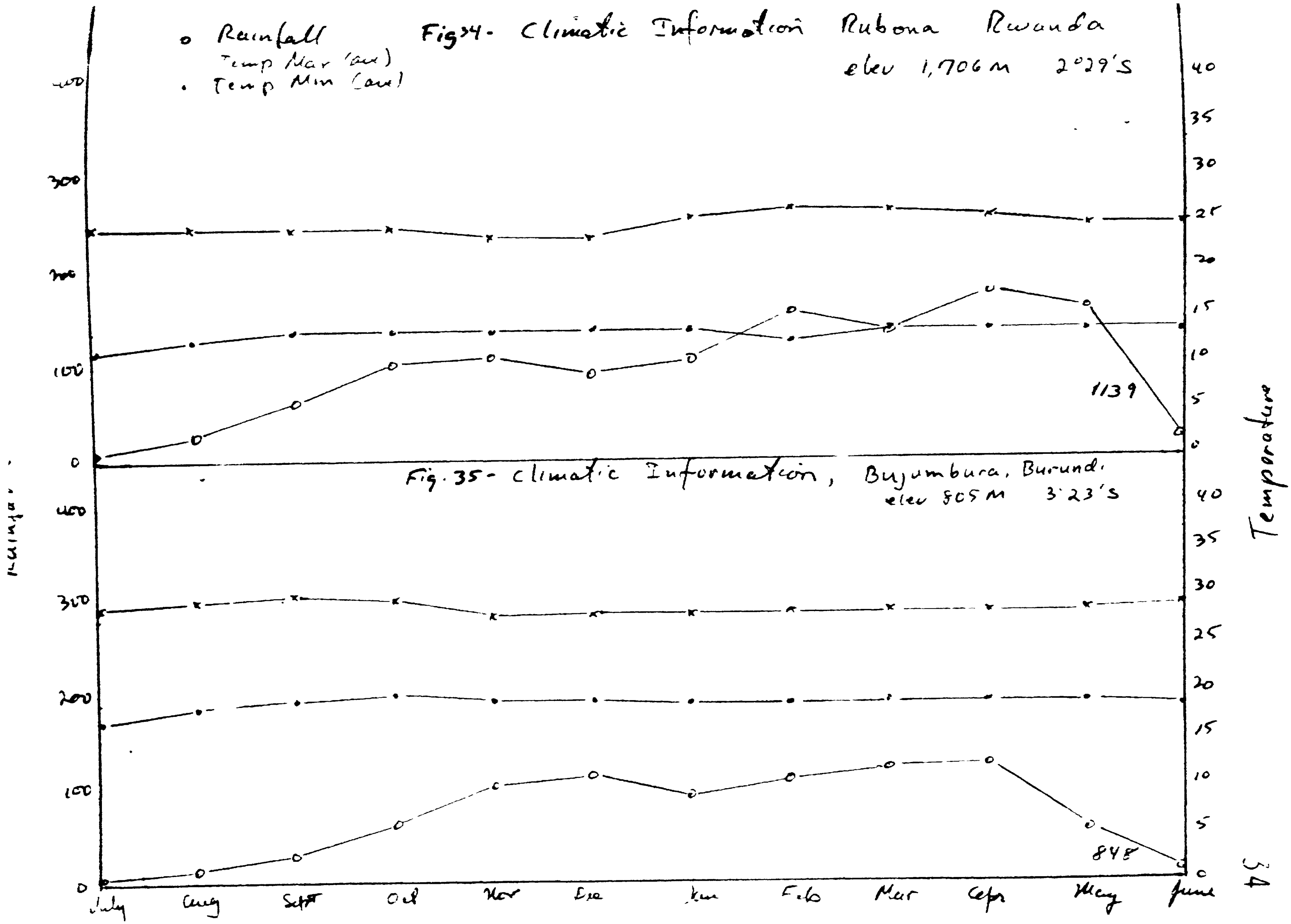


Fig 34 - Climatic Information Rubona Rwanda

Fig. 35 - Climatic Information, Bujumbura, Burundi

III. The Experimental Program, Organization and Approach

The sorghum breeding program has been divided more or less into program units with an S1 scientist incharge of one or more units. As the program has developed changes have been made, and now, with an expanded opportunity within India and overseas, following the increase in locations available, there is need to redefine the program again.

Other opportunities are facilitating the opportunity to modify the program. Screening techniques are constantly improving, and a reasonable level of agronomic eliteness has been achieved. Probably the biggest change that we anticipate in the future is a closer interdisciplinary working relationship.

It is important that the regional centers in India are research centers (as opposed to off-season and testing centers) and that the research at these stations will be largely determined from the center. Overseas, the programs at the regional centers will be largely determined by a staff there. It is already fairly clear that scientists in these regional centers, as well as in country programs, are looking to headquarters for constantly improved source material; material combining better levels of yield, stability, quality and resistance traits.

It is important that these centers develop as a network of cooperating stations, headquarters included. This cooperation is being strengthened via a coordinating function serviced by staff from the center. It is also anticipated that staff at the overseas regional stations will help, even assume, a coordinating function among country programs in their regions. They will receive material from anywhere, evaluate its potential, and organize only the most promising material for their region into regional trials; Wad Medani for the dry zone, Ouagadou for the intermediate rainfall zone, Samaru for the high rainfall zone, etc. This appears to be an adequate base to encourage intercooperation and the opportunity for all involved to contribute their skills.

These comments can to some extent be represented diagramatically as follows:

1. Development of source material (yield limiters and quality traits) Intense screening for trait and protection from other limiters. Source material from Center and Regional Stations	2. Development and identification of elite agronomic stock (Protection against yield limiters). Cooperation between Center and Regional Stations. Final selection at Regional Stations
Grain mould and weathering	Introduction
Food quality	Population
High lysine	Pedigree
Tannins	Hybrid
Striga	A-lines
Shoot fly	
Stem borer	
Midge	
Head bugs	
Downy mildew	
Charcoal rot	
Drought	

3.
Interaction (1 x 2)

Development of varieties and hybrids; multidisciplinary screening at selection pressures suitable for the material at center and select regional stations. Feed back into units 1 and 2. Specific improvement of otherwise elite material.

In the breeding program todate there has been intercrossing between source material and between source material and agronomically elite lines. These crosses have been made by the various scientists and the progeny incorporated back into their specific interest areas. Broadly, the proposal now made indicates that the development of source materials (units 1 and 2) would be more or less as in the past but with likely greater cooperation with Regional Stations. The progeny from crosses between (unit 3) would become less specifically assigned, protection against yield limiting traits would be dropped or reduced and all disciplines would be involved in screening and evaluating the material. Quality traits would also be evaluated. Different seasons, screening techniques, and locations can be used. Coordination and responsibility for this phase could be ensured by international scientist(s) in sorghum breeding.

The strengthening of source material (unit 1) is also important. This implies the strengthening of the source for the particular trait of interest; for example, strengthening resistance to shoot fly within the program for the development of shoot fly resistant types. Improvement of source also includes crossing between different source materials, for example, shoot fly and *Striga* resistance, or high yielding types with sources of grain quality. Interaction of disciplines is important; cooperation between breeding and pathology for grain mould resistance, between breeding and physiology for drought tolerance, and between breeding and food technology for food quality evaluation. It is proposed that early generation progeny, following many of these crosses be included in unit 3 for across the board screening and then at an appropriate stage backcrossed into units 1 or 2. Evaluation in areas of adaptation is relev

Obviously, when a number of individuals are using the same source material there is a real possibility that different individuals are attempting the same crosses. The same would be true of evaluation of progeny from the crosses. The best solution to this problem appears to group planning and partitioning of the work load in an equitable fashion.

It is also suggested that entries being advanced are subjected to across the board evaluation. This is in contrast to dividing seeds of a progeny and sowing into different tests and then recombining selected entries. The program should permit a rapid enough flow through that the same progeny can be advanced through all tests included as part of the evaluation. It is suggested that moderate to high levels of fertility be included for materials in units 1 and 2, and high and low levels of fertility for items in unit 3.

The population breeding approach more clearly and easily provides a mechanism for the incorporation of many traits, and as can be seen in the statement for population breeding, plans are to modify the breeding approach to do this. Populations will be developed for the various climatological zones. Leadership for some of these populations should be undertaken at regional stations.

Breeding is a progression or process of improvement. The best materials at any point in time may be contributing inspite of some weaknesses. Useful material generally can be generated more rapidly by the pedigree breeding approach. Both approaches have a place.

We are also interested in the improvement of proven or elite agronomic material for specific traits by backcrossing or a modification of this procedure. Today, for example, there is an array of agronomically elite material undesirably susceptible to charcoal rot. An attempt will be made to recover the lite type with charcoal rot resistance.

Steps are being taken at ICRISAT and at the regional centers to include the development and evaluation of hybrids. It is nearly a universal experience that hybrids outyield varieties and that this difference becomes greater as the growing conditions become more harsh. Some countries are in a better situation than others to develop a seed industry, but none of them can even try without good hybrid material to produce.

Confounding the number of traits that require evaluation is the number of climatic situations for which varietal material is required. The array of regional stations in India is a big advantage; equitorial types can be evaluated at Bhavanisagar (more photosensitive types); drought tolerant types can be evaluated at Hissar (kharif) and Dharwar (summer); and cold tolerant types in Kashmir. Dharwar can be used to evaluate charcoal rot, downy mildew and possibly resistance to midge in addition to drought. Shoot-fly has a bimodal peak in population in the north which may be an advantage to hasten screening. It may be necessary to undertake screening at a regional center requiring inoculation or infestation; for example, the evaluation of charcoal rot in photosensitive material at Bhavanisagar. It may be necessary to create new facilities at the regional center, or expand facilities at the main center; for example, we currently are in great need to increase facilities to rear stem borer. We need to establish a reliable screen for midge.

More detailed statements about projects in sorghum breeding are made below.

A. Screening

i) Source material: The development of source material (units 1 and 2) are expected to remain in objective essentially as they are. A severe situation is created for the trait(s) of interest with protection from other limiting factors. Special laboratory and field techniques may be involved. Procedures used are not indicated in detail on the diagrams for breeding schemes. Concentration is on unit 3.

It is suggested for unit 1 material that severe tests are alternated with the opportunity for selection when plants are grown under good conditions of management. This will permit an opportunity to select for agronomic eliteness.

ii) Breeding material (unit 3): Screening will be across traits of concern. Field tests will be used enhancing the expression of a number of factors using early and late sowing dates and different locations. Dharwar, for example, is valuable because of the expected severity of downy mildew, charcoal rot, and midge. Field screening should be undertaken at various locations representing different moisture and temperature situations to enable field screening for prevailing problems. There is a need to balance the use of stations providing exceptional screening opportunities and the need for zonal adaptation.

Problems considered to require screening in most of the climatic situations are:

Grain mould and weathering	Head bugs
Food quality	*Striga*
Shoot fly	Downy mildew
Stem borer	Charcoal rot
Midge	High and low fertility
	Drought

Lab tests are available or being developed for *Striga*, food quality, grain mould and weathering, and possibly seedling reaction to drought stress will be found helpful.

Some tests are incompatible; for example, grain mould with midge, head bugs, and probably charcoal rot; also, evaluation for damage by midge and head bugs on the same crop is difficult.

Replication of the screening tests is worth evaluation and Dharwar is an obvious choice because of the regular occurrence of dwony mildew, charcoal rot, and midge. Replication would also offer protection against failure of a test(s) at one location.

It is desirable that screening be undertaken on plants in the breeding program so that all entries are screened for all traits. In some instances screening will be on a plant basis and in others on a family basis.

The following is suggested.

Grain mould and weathering	Family - F_3
Food quality	Family - F_4 or F_5
Striga	Family - F_3
Shoot-fly	Individual - F_2; Family - F_3
Stem borer	Individual - F_2; Family - F_3
Midge	Individual - F_2; Family - F_3
Head bugs	Individual - F_2, Family - F_4
Downy mildew	Individual - F_4
Charcoal rot	Individual - F_3
Drought	Individual - F_2; Family - F_4 (no irrigation)
Low fertility	Family - F_4

(note that the S_1 is like an F_2 and the S_2 is like F_3)

The screening procedure is shown diagramatically in Fig. 36. The word "Screening" on the diagrams for the various breeding programs refers to some aspect of this procedure. It is assumed that many of the screening and breeding procedures will be modified with experience.

Not all of these factors are important in all zonal areas. The experimental approach can be set in accordance with the priorities.

iq. 36 - Suggested Procedure for Screening

Unit 1 Source
Resistance, Quality

x

Unit 2 Source
Yield Stability

Unit 3

F_1

↓

F_2 (Main Season)

Late Sowing (primarily for insects)
Individual Plant Selection
Stemborer, Shootfly, Midge, Mild Drought,
Charcoal Rot

F_3 (Off-season)

Individual
Plant Selection
Charcoal Rot

Family
Evaluation

Drought
Hyd.

Shootfly
Hissar

Bhavanisagar
Lab

Mould

Midge

F_4 (Main Season)
Seed from Selected Plants (Charcoal Rot) from
Selected Families

I. Y.T.

Individual Plant
Selection
Downy Mildew

ity

Low
Fertility

Grain
Mould
Early
Sowing

Drought
(Hissar)

Head
Bug

Midge
(Dharwar)

Food
Quality Lab

↓

F_5

Seed from Selected Plants (Downy Mildew) from Selected
families

B. Population Breeding

The population breeding program is being modified with time. Initially there were aspects including source, backup and advanced populations. The backup populations were intended towards retaining large variability through low selection intensity accompanied by frequent intercrossing. A corresponding population for each backup population was also running simultaneously in advanced unit with higher selection pressure to achieve quick results. Under the source group, development of new populations for specific regions or requirements was being undertaken. Two scientists were engaged in this whole area of population breeding work. Currently one scientist is taking care of this program. The major emphasis is on six of the 10 advanced populations which are listed in Table 1. US/R and US/B populations have high yield potential and good variability for many desired traits. We have been very successful in extracting promising lines from these populations. There are indications that US/B population will produce a range of good B lines which could easily be converted into A lines to support and strengthen the hybrid program. Rs/R and Rs/B populations have tropically adapted material. Rs/R has performed well in Thailand and Brazil. Rs/B is being considered for extracting good B lines with equatorial adaptation. Early population is being taken up for low rainfall zone and medium-late population will meet the requirements of intermediate rainfall zone.

The performance of tropical conversion and Serere elite populations has not been found satisfactory and therefore they are being discontinued. The two fast lane populations will soon phase out and the derivatives from these will suitably be merged into other populations or will be utilized in other programs.

Out of the source and backup populations, Indian diallel and West African Early, are found to be most productive. These populations have been put on regular selection scheme. The other populations have gone into cold store to meet specific seed requests.

An attempt is being made to have one population for each geographic region. With the availability of increased locations for testing the material, the testing of the populations will be confined only to the locations of its adaptation. With the addition of work on the development of hybrids, the emphasis on B composites is being increased. The preliminary test on possibility of getting good B lines from populations has given good results. Of the 141 lines tested for their reaction to A lines, 80 have been found as good B lines.

The major emphasis in the area of population breeding in future, will be on strengthening the populations for quality and resistance traits, the details of which are given in the following note.

Table 4. Breeding Populations at ICRISAT.

Name of the Populations	Components
US/R	3 Nebraska and 2 Purdue restorer populations
US/B	2 Nebraska and 2 purdue maintainer populations
Rs/R	Population developed at Serere using tropically adapted restorer lines
Rs/B	Population developed at Serere using tropically adapted maintainer lines
Early Pop.	Developed by intercrossing 45-60 days flowering material
Mid late Pop.	Developed by intercrossing 60-70 days flowering material
Indian diallel	Indian adapted material
West African Early	WABC + Bulk Y

i) Diversification and strengthening sorghum populations for different resistances

We have spent a little over four years of working on sorghum populations at ICRISAT and I think this is the time to analyse, evaluate and, if necessary, modify the plan and reset our goals and objectives.

We completed nearly 2 cycles of selection in most of our populations, the priority of selection being on grain yield and agronomic eliteness. Of these two cycles, the first was based on eye evaluation of S_1 lines in order to eliminate a lot of poor, brown and red grains and late, tall and photosensitive material to bring poorly accepted, mostly feed grain but reasonably good yielding populations to a stage where systematic selection could be practiced. The second cycle of selection was primarily directed towards improving grain yield and stability over environments. In spite of the fact that the test was not as extensive as planned because of limitations on number of diverse sites/ countries and facilities at cooperating centres, very encouraging results have been obtained. The populations and several of their derivatives have shown distinct superiority in grain yield over other materials. In fact, some of the lines are fairly close to the yield levels of the best available hybrids and are equally consistant over locations and seasons.

Another character where tremendous shift has been made is the grain colour and quality. The frequency of brown and high tannin grains is reduced to zero. The proportion of vitreous, lustrous bold white grains has increased considerably and further rate of progress should be much faster. The height of tropical tall populations has been reduced by about 25% and phenotypic uniformity is increased.

With regards to acceptability of population breeding materials in our cooperative programs, there are contradictory reports. Early generation (population progeny S_2) tests have, by and large, not been appreciated at most of the centres, Ethiopia being the exception but the advanced generation derivatives, which are the ultimate products, looked promising in most countries except Upper Volta. The general observation is that the proportion of useful material in S_2 trials is low. This is, however, not surprising in early stage of the program. This is quite true at Patancheru also. Only about 50-60 plants have been selected from each of the 200 entry trials and these have been advanced to further generations through head rowing. These plants have been producing very diverse and attractive lines. Similar results were expected from other centres as well. In fact when similar selections were made in Ethiopia, they produced good lines. These observations indicate that though early generation trials do not appear very attractive, they can produce useful material provided careful plant selections are made. As the selection under diverse conditions proceeds, the proportion of material with wider acceptability and stability should increase steadily.

The success of deriving high yielding lines, however, should not detract us from the weaknesses of the material which are responsible for their poor acceptability in several regions. The desired grain quality in a tan plant colour and good levels of resistances to prevailing pests and diseases, *Striga*, drought etc., are very important for any material to be accepted in a region. Good levels of resistances are also necessary for stable performance of a genotype over locations and years. But very little has so far been done in improving the populations for these characteristics. The reasons for postponing work in this vital area are two fold. 1. Screening facilities for several traits were not developed and sources of resistances were not identified. 2. Since most of our populations were obtained from the centres where problems of pests and diseases are different from those of the semi-arid tropics, there is lack of sufficient variability in the populations for many such traits.

Now that a good deal of information on sources of resistances for shoot-fly, *Striga*, grain mould and to certain extent on borer, midge, downy mildew is available, we have to evolve an appropriate system to utilize them in our populations. Sufficient care should be taken not to off-set the gains of early selection. As most of the resistances exist in tall, photosensitive, poor yielding local types, it will be hazardous to put them directly into the populations. This is bound to bring the populations back to their original shape which would need another 4 years to bring them to the present level of eliteness.

The side car approach is considered to be an ideal system to deal with such a situation. In this system each population is crossed to a resistant source and screened in segregating generation and then back crossed to the improved version of the population each cycle. These side cars thus remain only one generation behind the improved population. The system allows recovery of resistances in elite background without hindering improvement of the population for other traits. The side cars for different traits can be intercrossed at an appropriate stage to form the population with several added characters which will eventually replace the main population. This approach was proposed in the beginning but is more resource consuming and requires more than one person for population breeding work. In the absence of such a large scale integrated population breeding program, due to lack of facilities and personnel engaged in this area, an alternative system has to be worked out. I propose the system which is diagramatically illustrated in Figure 37.

The system is not very different from that of the side car approach. It is based on the assumption that it would be possible to recover a number of resistant lines from crosses between populations and resistant sources having eliteness similar to that of population S_2 entries. These lines will be intercrossed along with population S_2's at recombination stage only when they have satisfactory level of agronomic eliteness. However, if recovered lines were not found worth intercrossing in the populations, they could be backcrossed to population and the process repeated.

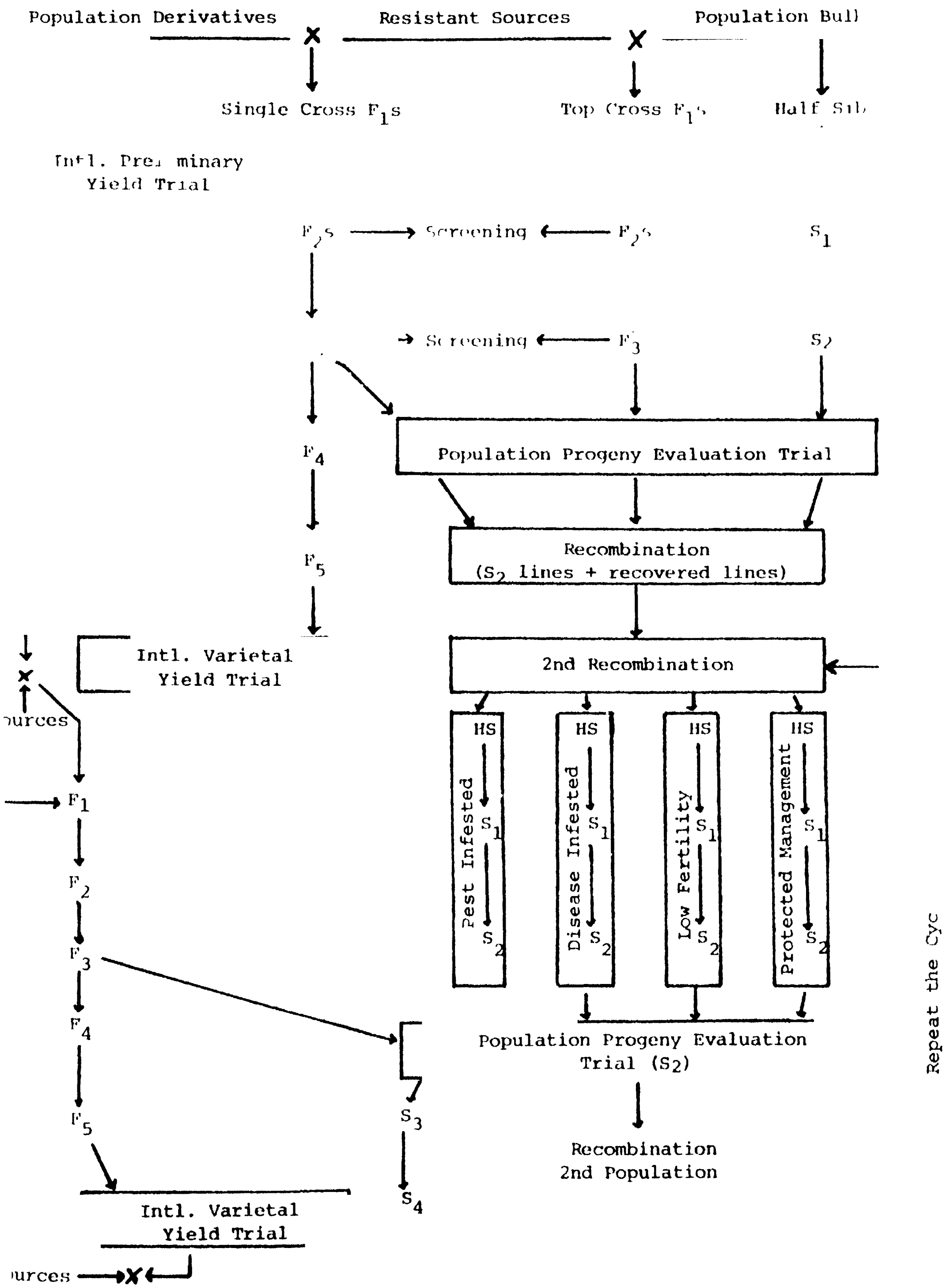
The system involves crossing improved populations and promising population derivatives to 4-5 best resistant sources for each disease or pest as and when identified. It has been observed that many population derivatives have specific weaknesses for one or the other trait. Many of these derivatives keep segregating for male sterility upto S_4 generation. Therefore, it is easy to treat them as female and cross them to required resistant sources. However, population bulks should be used as male for making crosses to resistant sources. The F_2's of both single crosses (population derivatives and resistant parents) and top crosses (resistant parents x populations) will be screened under appropriate selection pressure. Sibbing can be done between resistant sterile and fertile plants in order to make use of sterile segregates. The best S_3 lines or S_2 sibs from each cross will be included along with S_2 lines derived from population in a trial. The trial will be conducted at different sites to evaluate lines for yield, stability and other agronomic characters. The F_3 and F_2 sibbed lines from resistant top crosses and single crossed will simultaneously be evaluated under appropriate selection pressure for resistances in question. At recombination stage, the best lines from each group of resistance and high yielding S_2 lines will be intercrossed together. Such a population will have to be recombined atleast twice before starting next cycle of selection. The number of lines from each group of resistance being tested and selected will be determined by the nature of inheritance of the character. Hopefully, 20-25 lines selected from each group of F_2 would give 2-3 or more lines for recombination.

The promising lines from all crosses could be handled in pedgiree method. The lines in F_4 or F_5 generation could be tested as potential improved varieties. The selected varieties from such crosses can be recycled in the population at any recombination stage. This will save the population from possible genetic drift for good genes as well as increase level of resistances.

Once we have resynthesized the population, we expect enough variability for improving the population against these traits. For this it is proposed that after every recombination the half sibs or bulk populations should be grown under different conditions within the zone of adaptation, namely, good protected management, pest and disease infected conditions, to extract S_2 progenies. These S_2 progenies should then be field tested in a common test under varying, locations and environments. On the basis of indications available on inheritance of *Striga* resistance, it appears that it is a simply inherited character. For such a trait it may be possible to screen S_2 lines in the laboratory for strigol production and strigol negative lines could then be tested for mechanical type of resistance and also field tested, if necessary.

Such a cyclic selection would bring simultaneous improvement over all characters and slowly we should be able to recombine different kinds of resistances into one material for stable production.

Fig. 37 - Flow Chart for Population Breeding Program



C. Improvement of Grain quality and Mould resistance

One of the constant problems in the breeding program is to outcross for any number of reasons but still produce, in the end, a variety or hybrid with acceptable grain quality.

Universally, whether for low or high rainfall situations, all breeders want earlier material. This is important in obtaining yield when the rains stop early. When the rains continue beyond expectation these earlier types weather and mould. It is important to couple resistance to grain mould and weathering with earliness.

Source material is developed by subjecting selected plants to high moisture conditions (rain and sprinkler and inoculation. It is anticipated that screening for unit 3 material will be regulated by sowing date so that grain is developing during periods of expected rains.

Grain quality is first visual; pearly white round bold seeds on tan plants. Subsequently seed of selected grain will be evaluated for chapatti making traits. This evaluation is included in the flow pattern of screening.

A suggested breeding pattern is presented in Figures 39 and 40.

There is already an ongoing program for the development of materials for the early and mid-season situations. There is now interest in including the development of materials for the late season. This effort must be initiated and because of photosensitivity in the material will be best undertaken at Bhavanisagar (Fig. 40).

The development of high lysine varieties constitutes part of the program for quality grain. The program began by crossing the two Ethiopian sources of high lysine (IS 11758 and IS 11167) to agronomic elite types. Selection for plump grain with high lysine was practiced but in advanced generations there frequently was a reversion to normal lysine levels. Agronomic eliteness was lost and this particular aspect of the program was discontinued.

The drop in lysine content in the soft start P721 grain has not been a problem, generally seed size has been small and the germplasm base narrow. There are indications that progenies from crosses between P721 and the Ethiopian sources have better seed size. Recent availability of two vitreous sources of high lysine (Purdue and Texas A&M), while in a very small seeded background, and, a diverse array of recovered types from crosses with P721 offer new hope for progress. Efforts will now be made to use these sources, to increase seed size in a high lysine background, and to expand the diversity available. The breeding program is presented schematically in Fig. 41.

1 8 - Improvement for Grain Quality and Mould Resistance Early, Medium, and Medium Late Maturity Types (Preliminary Stations Hyderabad, Bhavanisagar).

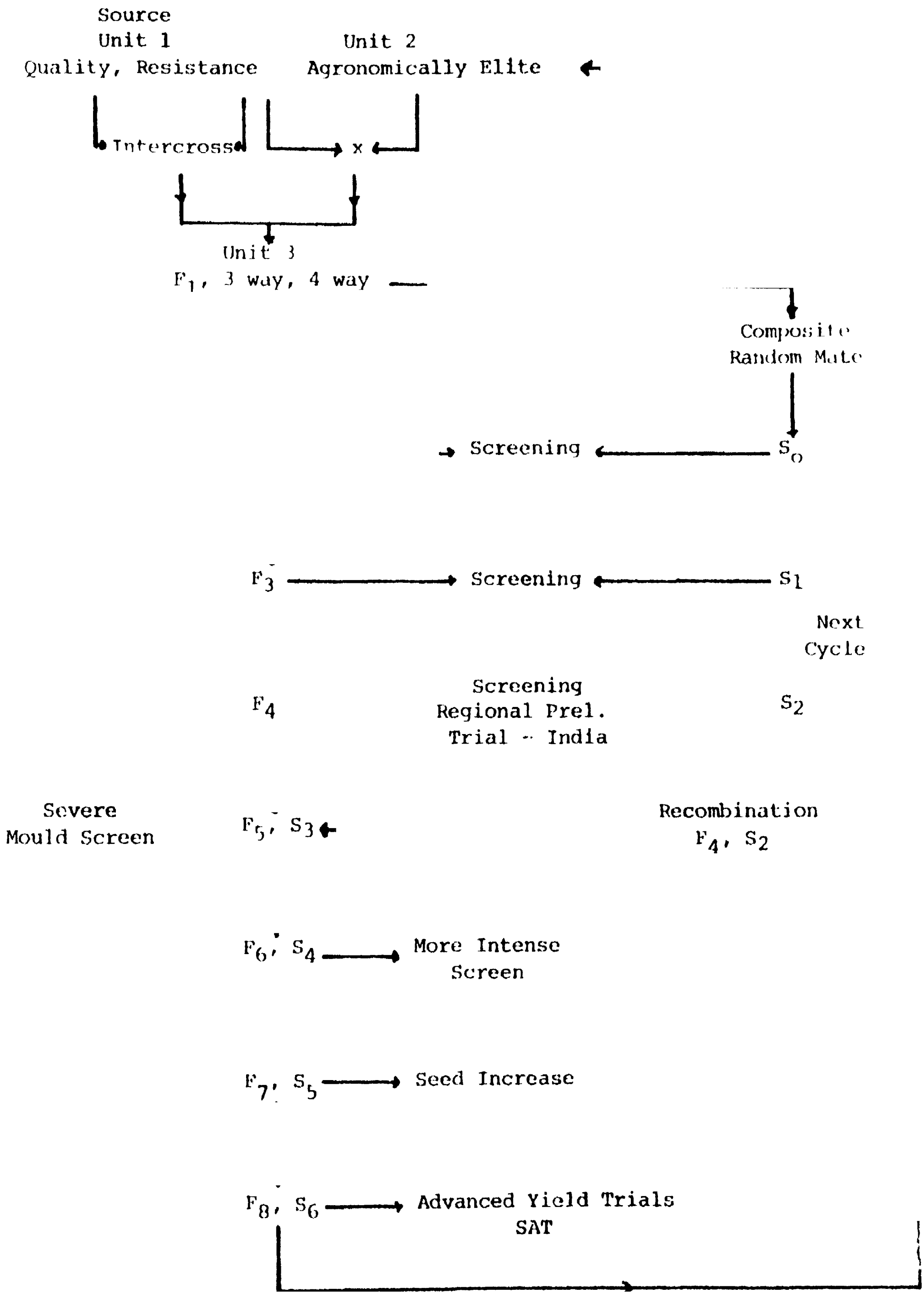


Fig. 39 - Improvement For Grain Quality and Mould Resistance Photosensitive and Late Types (Work to Be Undertaken Primarily at Bhavanisagar)

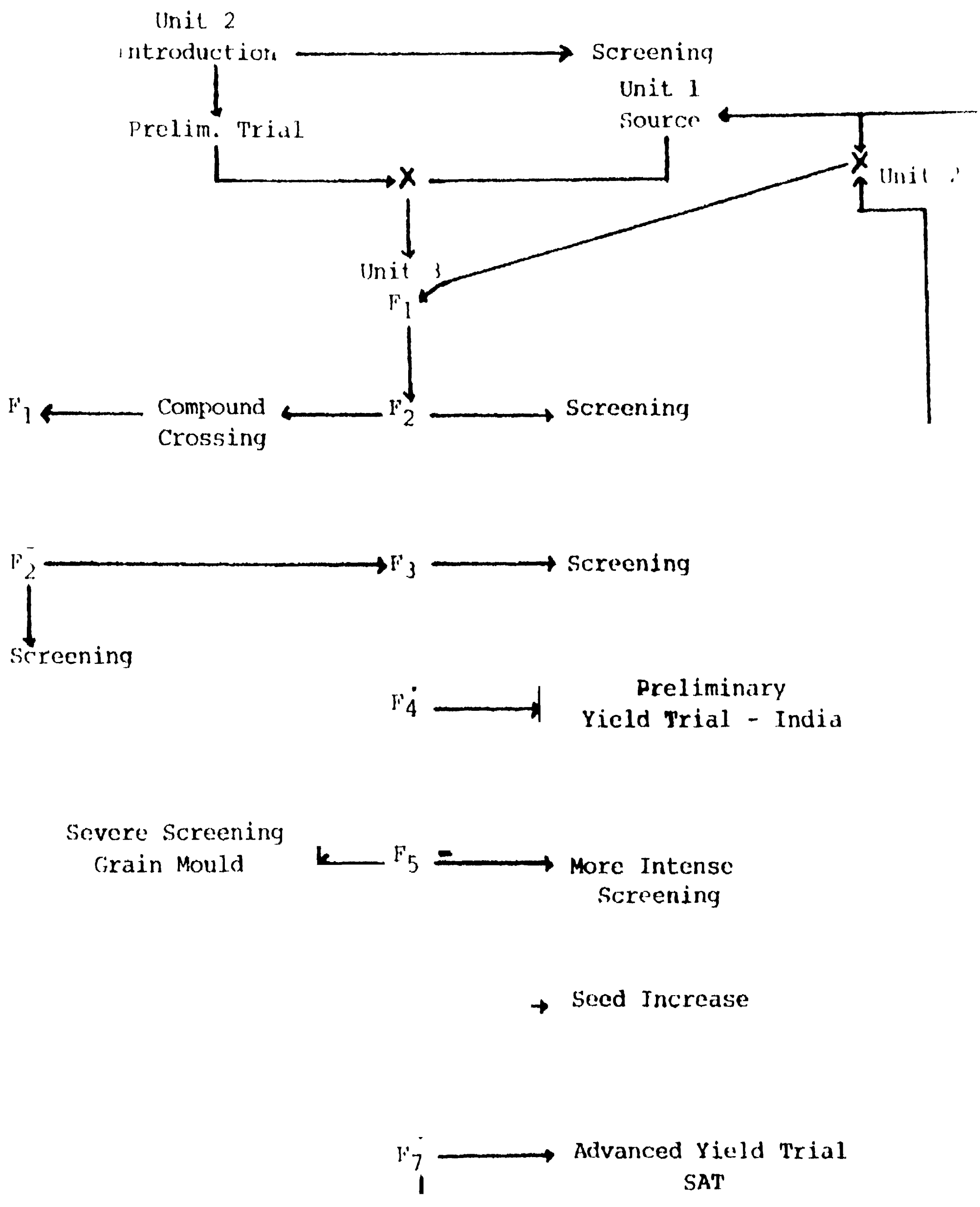
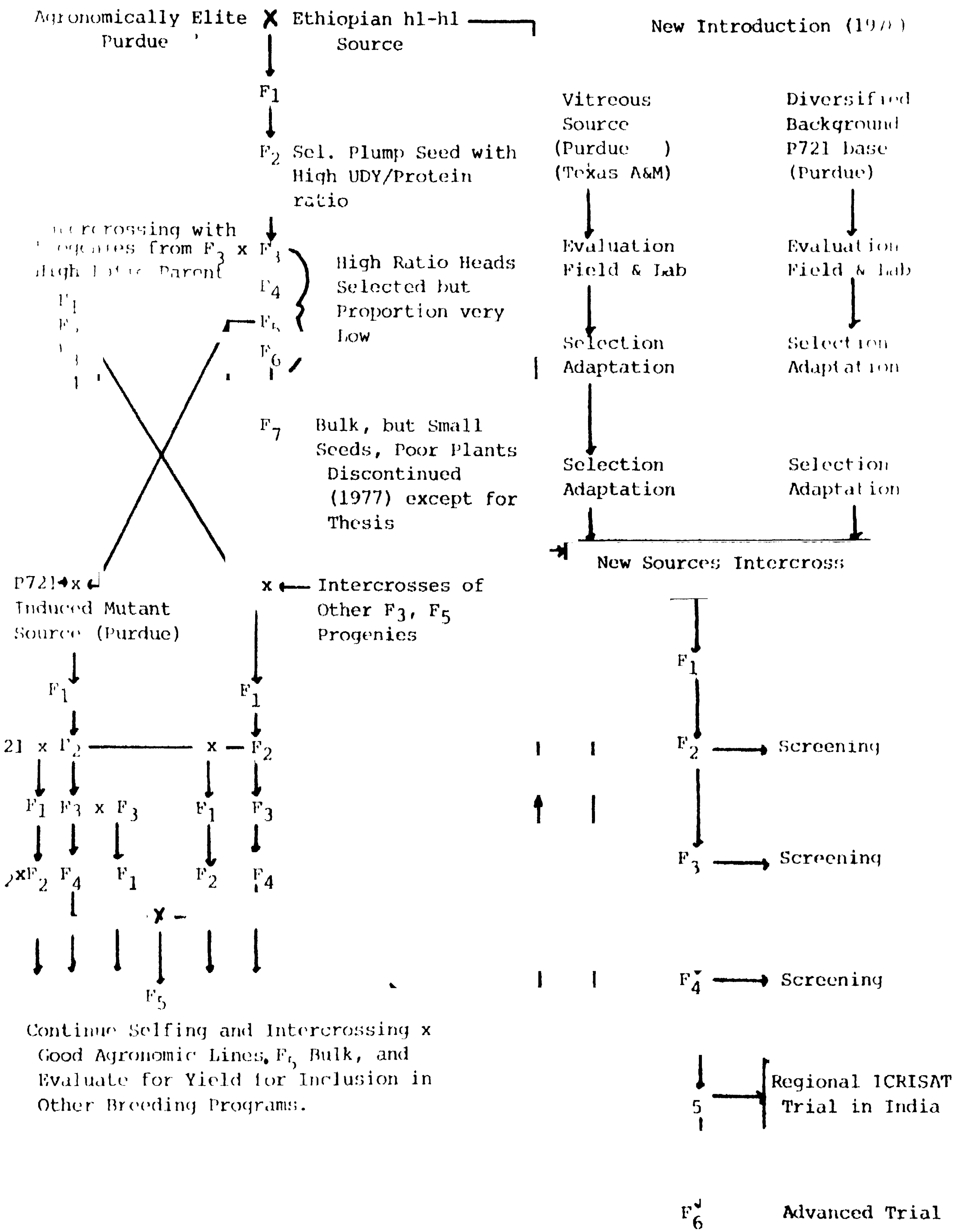


Fig. 40 - Breeding Scheme For Development of High Lysine Lines.



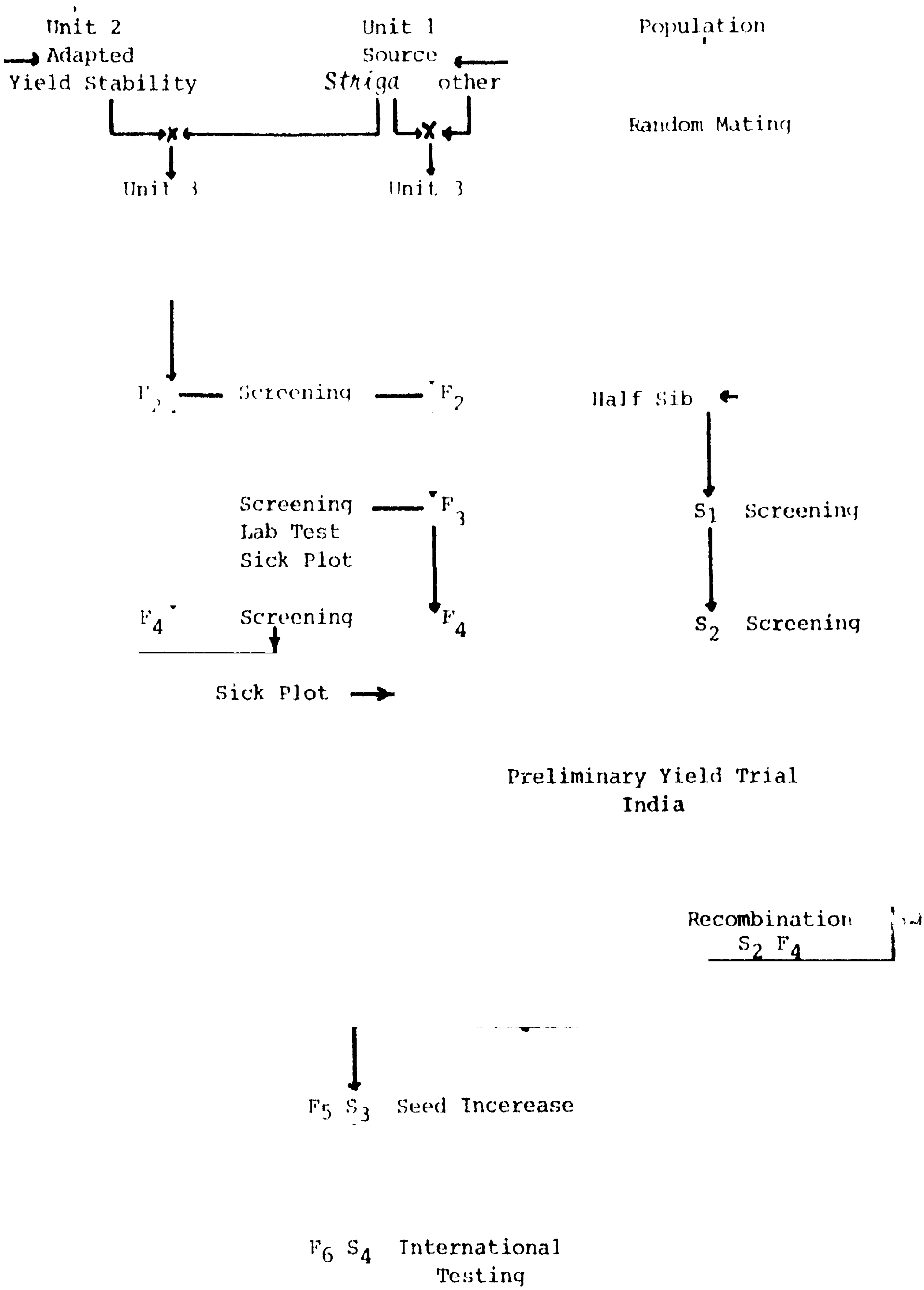
3. *Striga* project and its integration with other projects

i) Pedigree approach - main *Striga* program

The laboratory screening techniques for both resistances - low stimulant (LS) and anti-haustorial factors (AHF) - have been worked out. Both are seedling techniques and can safely be used to screen F_3 or S_2 seedling progenies in the *Striga* laboratory. We have identified several lines which have one type of resistance or the other. The scheme to make use of these lines to develop (i) lines with increased level of *Striga* resistance by intercrossing different types of resistant lines and (ii) *Striga* resistant lines with good agronomic background by crossing with high yielding adapted parents is presented in Fig. 41. This scheme integrates laboratory and field testings with the breeding program. Though the inheritance of AHF is not yet known the procedure outlined assumes simpler inheritance for both the types of resistances. The work is in progress to determine the inheritance of AHF and if it happens to be polygenic the F_3 seedlings identified as having AHF will be propagated in *Striga* sick plots and the F_4 seed obtained would be field tested along with the material coming from the mainstream. The term 'anti-haustorial factors' (AHF) is preferred in place of mechanical barriers to include the possible involvement of chemicals in interfering with successful haustorial penetration through the host root tissue. However, this excludes the resistance mechanism which is due to antibiosis which operates after haustorial establishment.

As more information is available about mechanisms of resistance and screening opportunities the breeding procedure will be modified.

41 Flow Pattern for the *Striga* Breeding Program and its Integration with other Projects.



E. Breeding for Pest Resistance

Breeding for pest resistance was begun during the rabi season of 1974. The three insects of concern are shoot-fly, stem borer and midge. There is currently concern about head bugs and this pest may be added to the list. The breeding technique included both population and pedgiree methods.

The pedigree approach began by crossing 26 varieties from India, West Africa and East Africa to resistant sources. The population method was begun by using resistant sources as the female and advanced lines from populations as male; this introduced the genetic male-sterility factors ms_3 and ms_7. Results have indicated that screening in the S_1 and S_2 is more effective than in the half sib.

The program developed so that in 1976, 287 F_2's were screened for shoot-fly during the kahrif and 142 selections were made. During the rabi 286 F_2's were screened and 198 selections were made. The screening techniques for stem borer has been developed but a good screening opportunity for midge is still required. It will be important to be able to separate the effects of midge and headbug.

Resistance to these insect pests is quantitative in inheritance and in the case of shoot-fly and stem borer recessive. The population approach, though requiring time, is apt to be the best. The program is now being structured to have one population for each of the three main pests and one population for all three of them combined.

These populations will be primarily for the improvement of source material. Three additional populations, one for the low, one for the high

Fig. 42 - Strengthening of Sources of Resistance

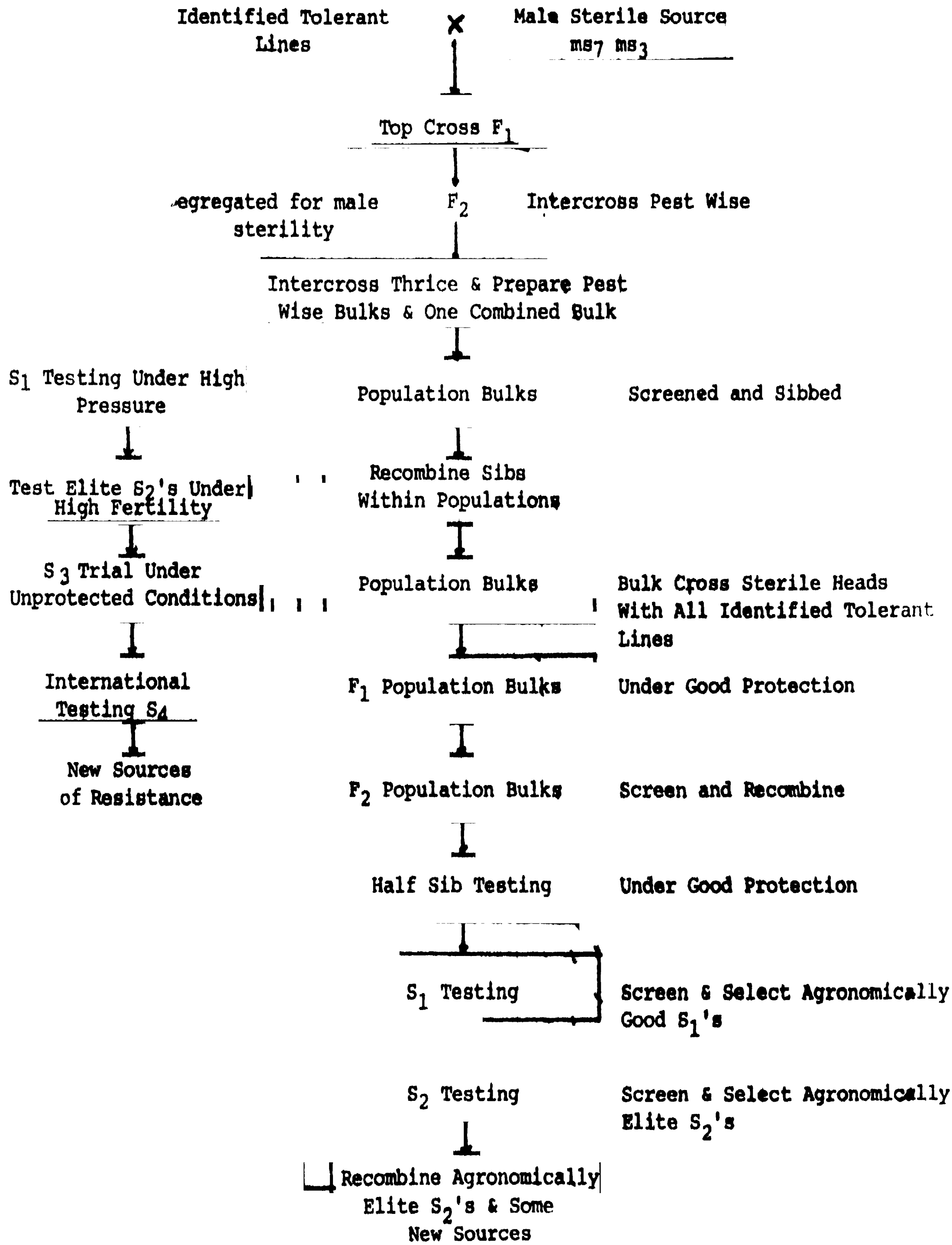
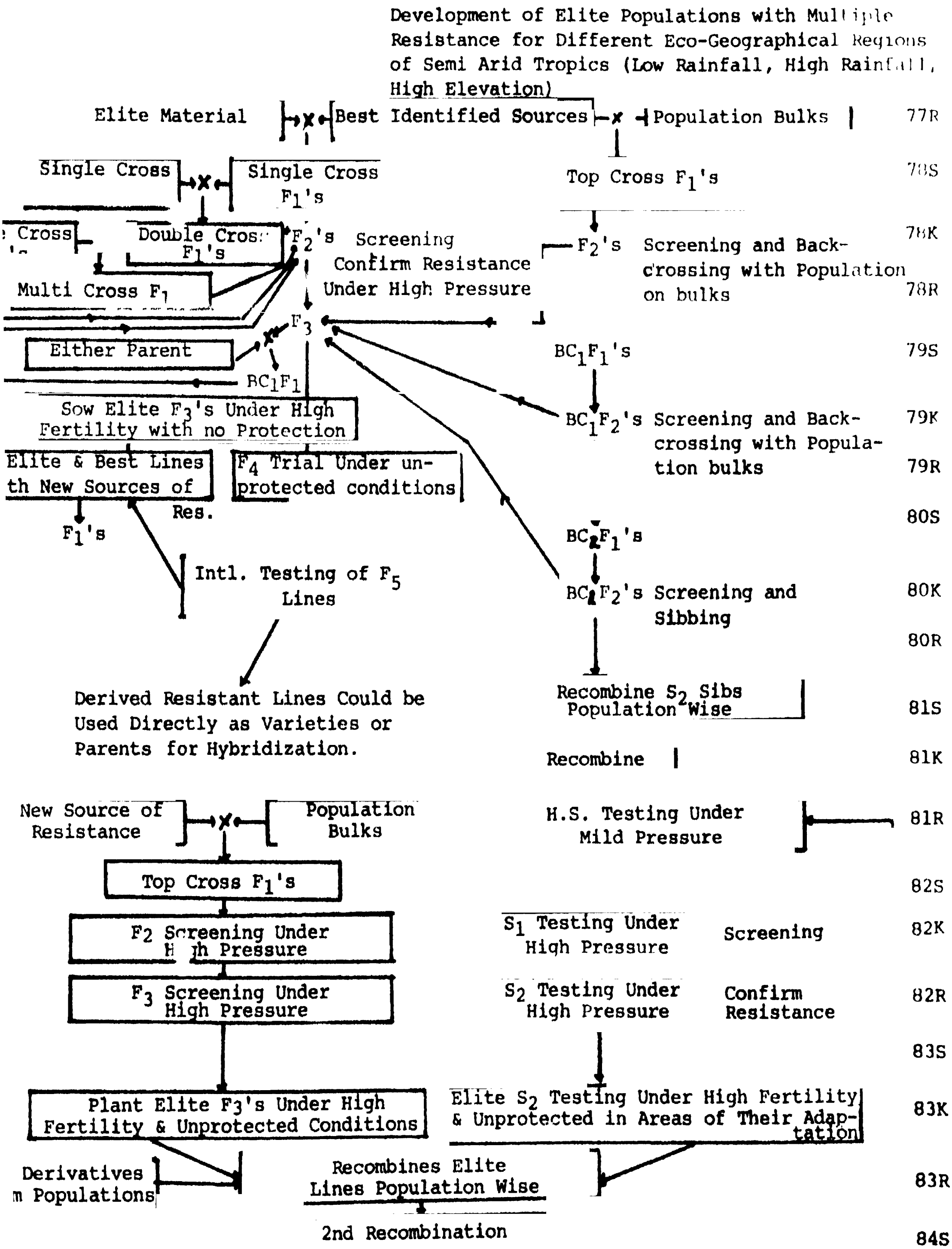


Fig. 43 - Incorporation of Resistance into Elite Backgrounds



rainfall situations, and one for high elevation areas, is being developed to bring together agronomically elite lines sources of resistance to other traits, quality, and resistance to insects. The decision to have these populations was made in 1977.

Genetic male-sterility has been introduced into all of these populations but there has been no backcrossing so the contribution from the sterility sources is high. Therefore, before beginning recurrent selection it is desirable to bulk cross the populations onto resistant sources. The F_2 populations would be screened and bulk crossed. Development of these populations will require time but good material can be derived from almost anywhere in the breeding program. The breeding programs are shown schematically in Figures 42 and 43.

Currently, enhanced efforts are being made to partition resistance to shoot-fly into component parts; antibiosis, recovery resistance, and oviposition preference. As more is learned about these individual effects, the screening and breeding procedure could be modified.

F. Breeding for Drought Resistance

The problems associated with the breeding for "drought resistance are now receiving increased attention by the sorghum breeding group in cooperation with the physiologist. This is a new area of research in sorghum breeding and in the next four or five years is expected to be an important part of the research effort.

The concerned is primarily about rainfall behaviour leading to drought stress; i.e., a limited supply (650 mm. of rainfall or less), intermittent

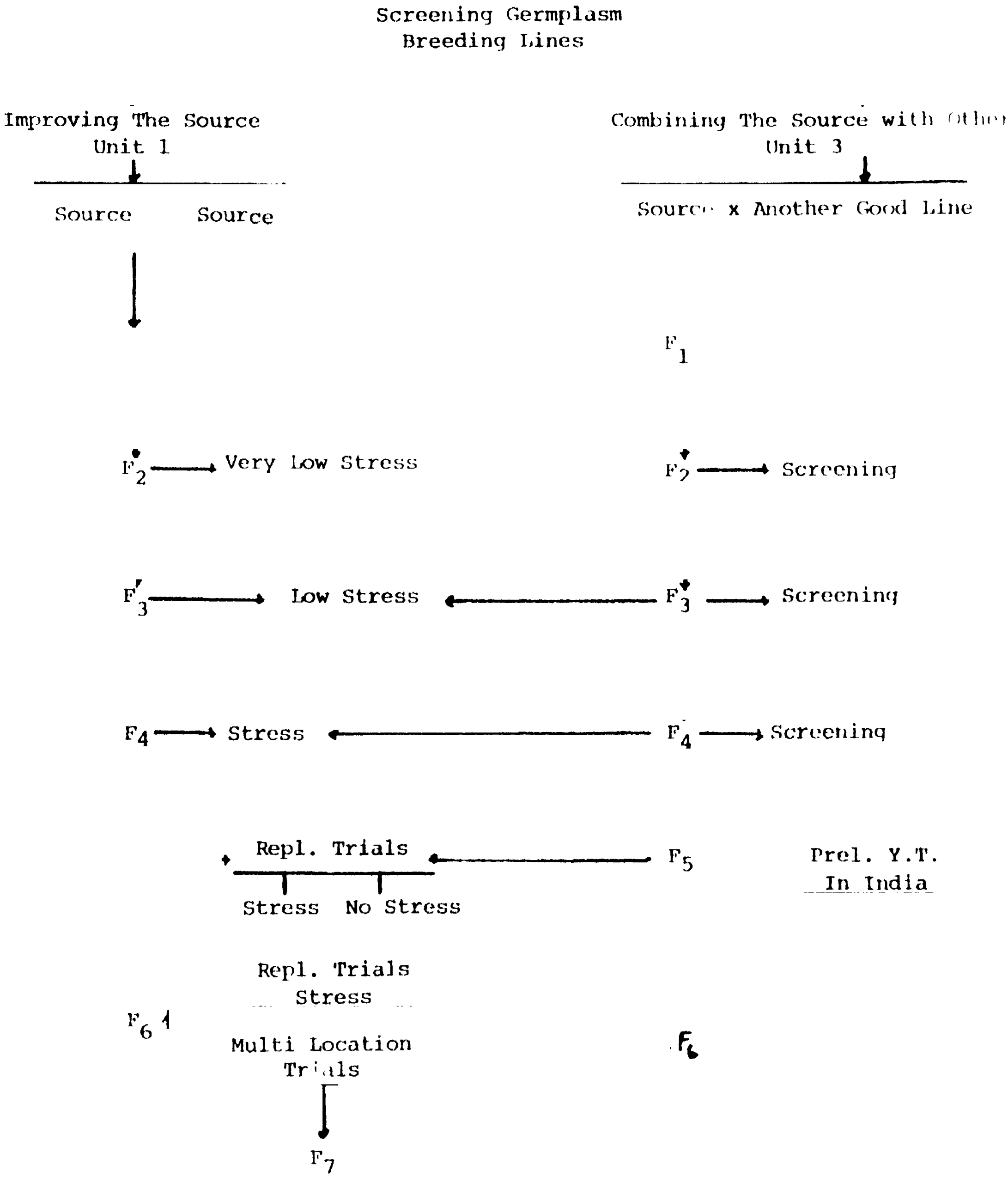


Fig. 44 - Breeding for Drought Resistance

drought at any time in the plants life, and the rabi season in India when plants grow essentially on residual moisture. Generally, the drier areas also the hotter areas so evaluation in the natural situation may be relevant for both moisture and temperature stress. ICRISAT stations are located in natural rainfall situations that can be used to suitably evaluate plant material. However, it would also be useful to have seed and/or seedlin tests that correlate well enough with resistance to drought in the field that more susceptible material can be screened out.

The opportunity for the evaluation of drought resistance at Hyderabad, Hissar, and Hyderabad in India is relevant. The opportunity to develop drought resistant types for the low rainfall situation at and around Wad Medani appears promising in Africa. This would also be an important part of the program in Tanzania.

The current breeding plants are for selection in advanced generations from single crosses, three-way, and double crosses. Once suitable parental material has been identified, the population breeding approach may be appended. The pedigree breeding program proposed is outlined in schematic form in Figure 44.

G. Breeding for Charcoal Rot Resistance - A Proposal

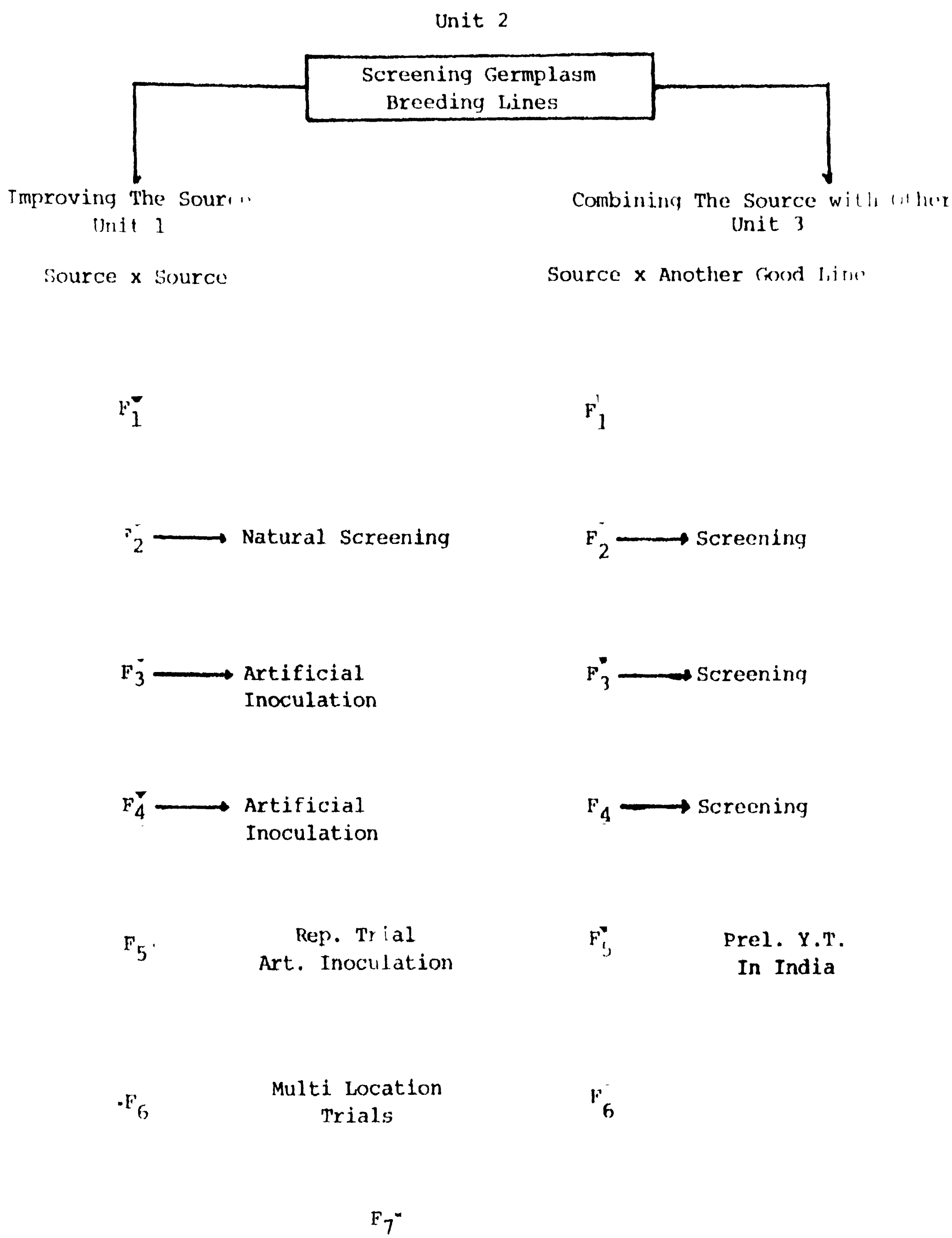
Charcoal rot caused by the sclerotial stage of *Macrophomina phaseolia* is a serious disease of dryland sorghums. Disease development is influenced by many factors including soil moisture, tillage method, crop sequences, plant spacing, soil fertility, etc. The pathogen probably enters the stalk through the roots and advances within the stalk from the crown upward. It is typified by three successive stages: 1) General water soaking of pith tissues, 2) Intense pigmentation (red to black) of affected tissues and 3) fading of colour, drying of affected tissues and formation of sclerotia on the vascular remnants. In infected seedlings the symptoms are seen as seedling blights and in adult plants as stalk rots. In adult plants external symptoms are not visible until near maturity. Just before maturity, the affected plants may lodge, and grain development can be poor. Drought and high temperatures are known to precondition the plant for charcoal rot infection.

The extent of yield losses and the areas affected in the SAT region are not known. A survey in this regard would be of help. There is also a need to study the inheritance of resistance and relative influences of various environmental factors.

The objectives of this project are therefore, 1) to determine the areas and extent of yield losses (pathologists); 2) to understand the factors influencing the development of the diseases (pathologists, breeders and others); 3) to standardise screening techniques (pathologists); 4) to screen the germplasm and other breeding lines to identify sources of resistance (pathologists); 5) to study the inheritance of resistance (breeders and pathologists); 6) if necessary to improve the sources of resistance and 7) to put together the favourable alleles of resistance and other stability traits including yield, pest, *Striga*, etc. (breeders and pathologists and others).

Clearly, good cooperation between the breeders and pathologists is essential for the success of the project.

Fig. 45 - Breeding for Charcoal Rot Resistance



The breeding program in general includes:

1. Identification and development of source material:

   a) Screening of germplasm and other breeding lines (pathologists)

   b) Upgrading the source by crossing among the types (breeders and pathologists).

This would be carried out under protection for other yield limiting factors such as shoot-fly and stem borer.

2. Bringing together the favourable alleles for resistance, yield and other stability traits.

The breeding method is largely pedigree selection in the populations obtained by single, three-way or double crosses.

Later on, as more information is available (for example, if the resistance is found to be a polygenic system) composites will be developed to take up the population breeding approach, if the inheritance is simple a backcrossing approach will be used.

A suggested breeding approach is represented schematically in Figure 45. A similar type of program is expected to develop for resistance to downy mildew.

H. Rabi Sorghums - A Breeding Project Proposal

Approximately 40% of the sorghum area in India is sown in the rabi season. Rabi sorghums are traditionally sown in September-October though there are some indications that earlier sowing is beneficial. The rabi crop generally grows and matures on a receding moisture supply.

Experience of the All India Coordinated program is that it has been more difficult, and continues to be more difficult, to develop improved sorghum for the rabi season as comapred to the kharif. India is the only country of the SAT where winter sorghum is an important crop. The germplasm base is narrow and presents a problem for the development of superior rabi sorghum types. The reason why it is difficult goes beyond the more obvious factors of increased incidence of shoot-fly and drought. Possibly temperature and even day length may be relevant.

The rabi area may conveniently be grouped into three zones. The objectives of the breeding program for each zone are outlined below:

(i) Arid Zone:

The expected rainfall is approximately 45 cm, most of it is in September and October. The following will be taken into consideration:

1. Shoot-fly is not a problem since there is no previous sorghum crop in such areas.
2. Sugary disease may be severe.
3. Farmers want both fodder and grain.
4. Farmers generally take up late sowings in October.

Accordingly the breeding objective is to produce a variety that matures in about 100-110 days so that it escapes moisture stress and is tall enough to give fodder. The plant type should be such that yield compensation is good under low population density. The evident quality characters - plumpy round grain, straw coloured glume, etc. need to be considered.

(ii) Assured Moisture Zone:

In this zone, both kharif and rabi crops overlap. Shoot-fly, stem borer, downy mildew, and leaf diseases are problems.

The breeding objective is therefore, to evolve lines of 120 to 125 days duration and medium tall with resistance to diseases and pests. They should also be responsive to fertilizers.

(iii) Assured Water Supply Zone:

Farmers more and more in irrigated areas are sowing sorghum as one of the crops in a multiple cropping system.

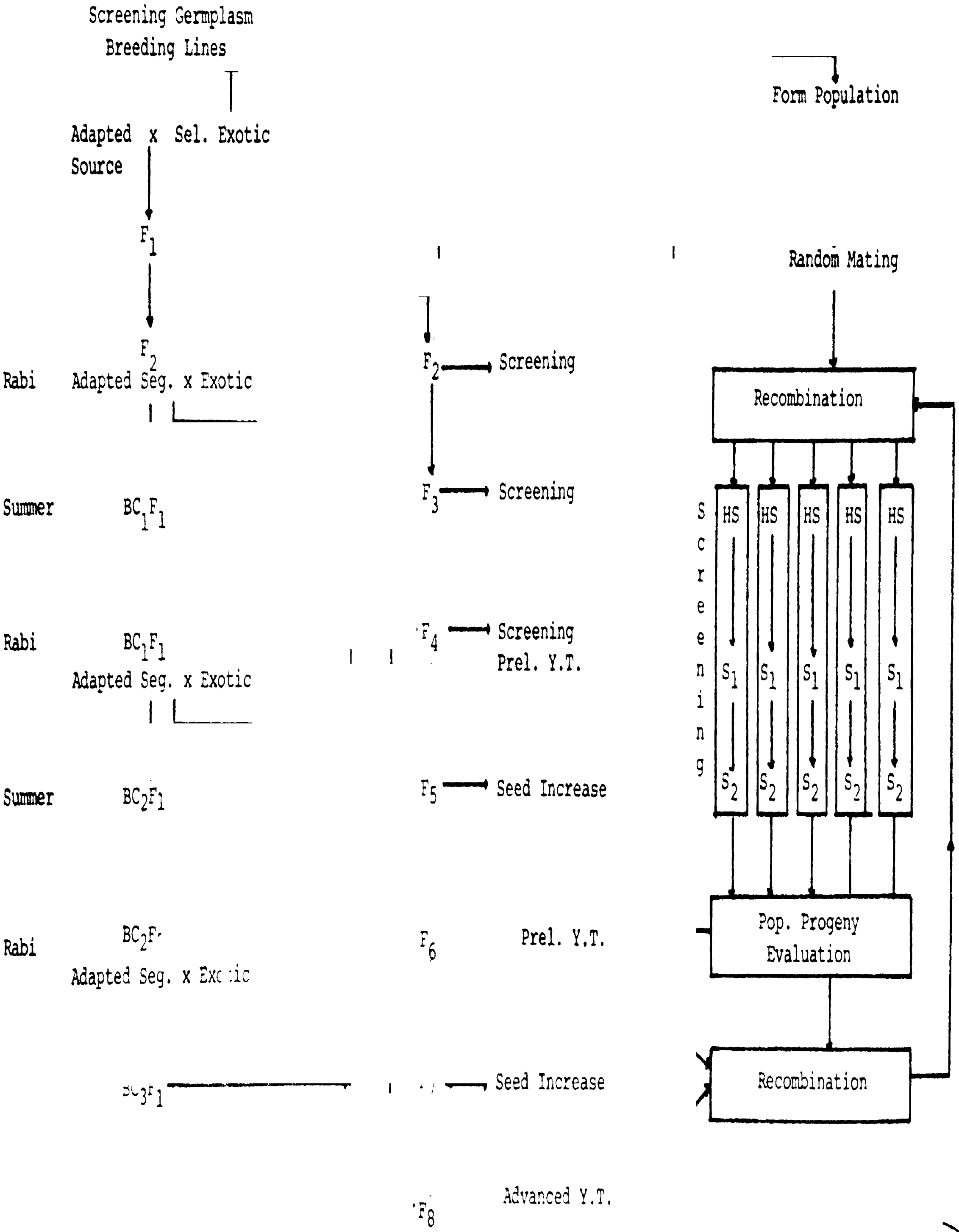
For such areas, breeding early and dwarf types with resistance to diseases and pests and fertilizer responsiveness become the objective.

(iv) The Rabi Breeding Program:

The breeding program in general includes:

1. Development of source material:
    a. Screening of germplasm and other breeding lines.
    b. Upgrading the source by crossing among the types. This would be carried out under complete protection for other yield limiting factors such as pests, diseases, *Striga* etc.
2. Putting together the favourable alleles for rabi adaptation yield and other stability traits.

The breeding method is largely pedigree selection in the populations obtained by single, three-way or double crosses.


Screening Germplasm
Breeding Lines
Adapted Source
x
Sel. Exotic
F1
F2
Rabi
Adapted Seg. x Exotic
Summer
BC1F1
Rabi
BC1F1
Adapted Seg. x Exotic
Summer
BC2F1
Rabi
BC2F·
Adapted Seg. x Exc·ic
F1
F2
Screening
F3
Screening
F4
Screening
Prel. Y.T.
F5
Seed Increase
F6
Prel. Y.T.
Seed Increase
F8
Advanced Y.T.
Form Population
Random Mating
Recombination
Screening
HS
S1
S2
Pop. Progeny Evaluation
Recombination

Later on, as more diverse useful material and information is available on the mechanism(s) of response to the rabi environment, composites will be developed for a population breeding approach. As with the drought resistance breeding, active cooperation of physiologists is essential for the success of the project.

An outline of suggested breeding plans is presented schematically in Figure 46.

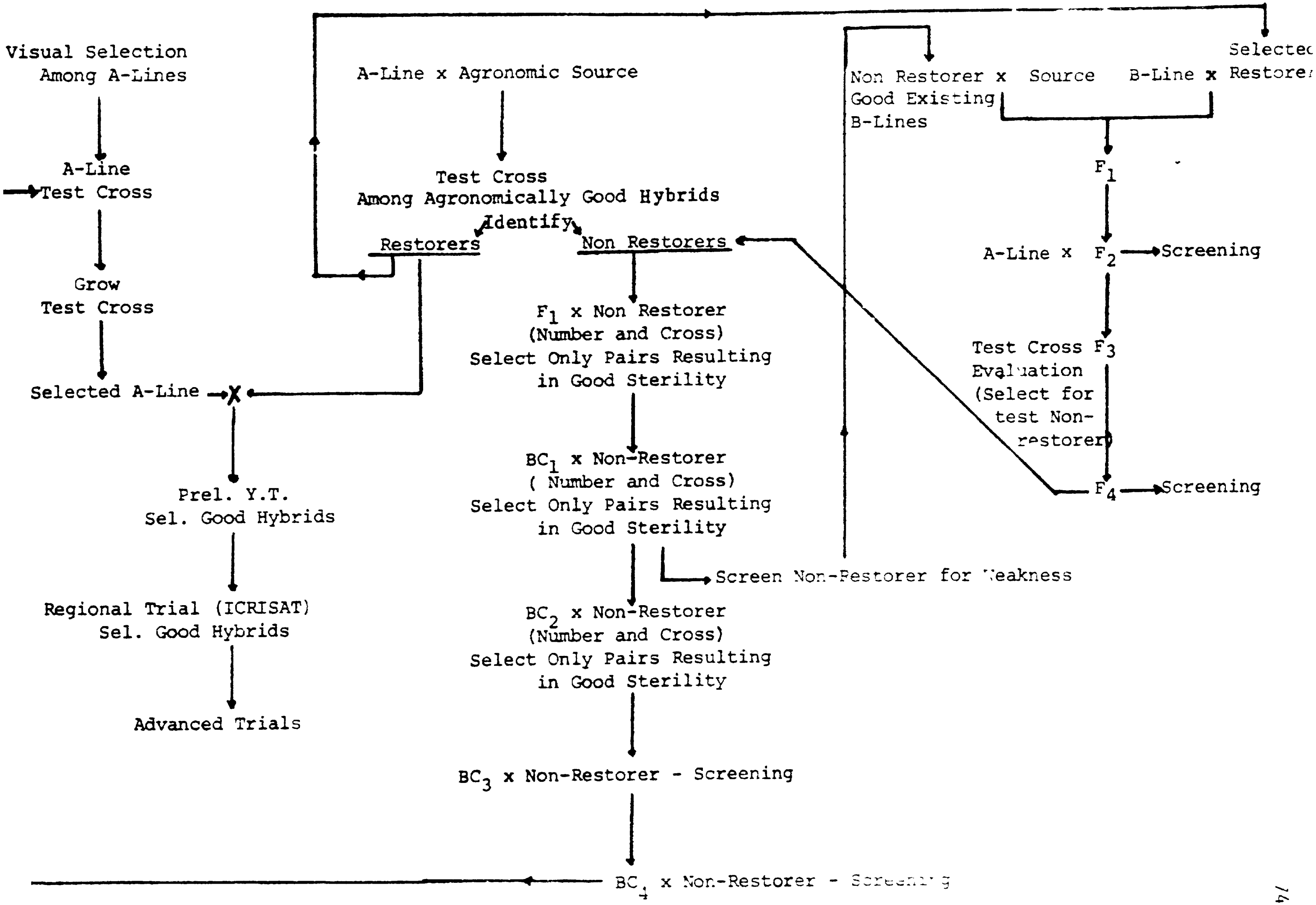
Development and Evaluation of Hybrids

The development of hybrids is an extension of a varietal improvement program. To support the hybrid program it is important that fertility restoring and non-restoring lines are kept separate during the development phase (across projects) i.e., care is required to insure that B-lines do not lose their non-restoring trait as they are outcrossed with other source material.

One of the major problems, particularly in the tropics, is the availability of good A-lines. Generally, diversification of the phenotype of A-lines would be beneficial. It is anticipated that there will be a substantial effort in the program to help with these problems.

It is also planned to improve good A and B lines for specific weakness by a backcrossing program suitably modified for the nature of inheritance of the trait.

The diagram in Figure 47 outlines a breeding procedure to develop A and B lines from good pollinator parents that are either restoring or non-restoring.


Visual Selection Among A-Lines
A-Line Test Cross
Grow Test Cross
Selected A-Line
X
Prel. Y.T. Sel. Good Hybrids
Regional Trial (ICRISAT) Sel. Good Hybrids
Advanced Trials
A-Line x Agronomic Source
Test Cross Among Agronomically Good Hybrids
Identify
Restorers
Non Restorers
F1 x Non Restorer (Number and Cross) Select Only Pairs Resulting in Good Sterility
BC1 x Non-Restorer (Number and Cross) Select Only Pairs Resulting in Good Sterility
BC2 x Non-Restorer (Number and Cross) Select Only Pairs Resulting in Good Sterility
BC3 x Non-Restorer - Screening
BC4 x Non-Restorer - Screening
Screen Non-Restorer for Weakness
Non Restorer x Good Existing B-Lines
Source
B-Line x Selected Restorer
F1
A-Line x F2
Screening
Test Cross F3
Evaluation (Select for test Non-restorer)
F4
Screening

Salinity Tolerance in Pigeonpea [*Cajanus cajan* (L.) Millsp] and its Wild Relatives

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