Improvement of wheat in Zambia using incomplete resistance against rusts.

Aan mijn ouders
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IMPROVEMENT OF WHEAT IN ZAMBIA USING INCOMPLETE RESISTANCE AGAINST RUSTS

Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
in het openbaar te verdedigen
op woensdag 7 december 1983
des namiddags te vier uur in de aula
van de Landbouwhogeschool te Wageningen

STELLINGEN

1.
Nu het ekonomisch belang van onvolledige resistentie in academia ingezien wordt, dient onvolledige resistentie in praktijk gebracht te worden.

'Symposium on durable resistance in crops', Martina Franca, Italië, 1981.

2.
In Afrika wordt het belang van resistentie van tarwe tegen insekten onderschat. Dit komt mede door geringe interesse voor de plantenveredeling bij entomologen, en door een geringe bekendheid van veredelaars met de entomologie.

'Proceedings of Wheat Workshop', Mount Makulu Research Station, Chilanga, Zambia, 1981.

3.
De rassenbeproeving en de rassenregistratie van tarwe houden te weinig rekening met de duurzaamheid van resistentie en de stabiliteit van opbrengst.

Dit proefschrift.

4.
Een groot tarweareaal in Zambia kan ongunstig zijn voor de tarweproduktie in naburige landen.

5.
De vooronderstelling van gewasfysiologen, dat ziektes en plagen afwezig zijn, is niet realistisch.

Austin, R.B. 1982. J. agr. Sci., Cam. 98: 447.

6.
Skorda besluit uit haar proefresultaten ten onrechte dat zwarte roest in Griekenland relatief hoge verliezen veroorzaakt in laat gezaaide tarwe.

Skorda, E.A. 1972. 'Proc. European and Mediterranean Cereal Rust Conference I'. Praag, Tsjecho-Slovakije: 277-282.

7.
Deskundigen, uitgezonden naar ontwikkelingslanden op kosten van het Ministerie van Ontwikkelingssamenwerking, zouden zowel voor als na hun uitzending enige tijd moeten werken op kantoren van dit Ministerie.

8.
Het systeem van interne vacatures is op sociale gronden te verwerpen.

9.
De norm van foudloos spellen is in weze een statussimbool en wort gebruikt om sosjale ongeleikhijt aan te geven en in stant te houden.

10.
De term dierveredeling, als gebruikt in 'Opleidingscentrum voor de dierveredeling', doet ten onrechte vermoeden dat het hier om veredeling van dieren gaat en dient te worden vervangen.

Voorbeeld: Praktijkschool Barneveld. Opleidingscentrum voor de dierveredeling, dierverzorging en mengvoederindustrie.

11.
De term boerinnekaas zou vermeden moeten worden in reklameteksten.

Vink, I. 1983. Boerderij 68 (50): 90.

12.
Reizigers bij het openbaar vervoer dienen zich bij het instappen te realizeren dat er ook uitgestapt dient te worden.

Proefschrift van W.A.J. de Milliano
'Improvement of wheat in Zambia using incomplete resistance against rusts'.

Wageningen, 7 december 1983.

ABSTRACT

De Milliano, W.A.J. 1983. Improvement of wheat in Zambia using incomplete resistance against rusts. PhD thesis, The Netherlands. (xi) + 156 p, 55 tbs, 29 figs, 220 refs, English and Dutch summaries.

The programme of wheat improvement developed in Zambia used local facilities (finance, personnel, infrastructure), low budget, and few personnel. Incomplete resistance against rusts was used to obtain durable resistance.

The abiotic conditions, socio-economic status of the farmers, cropping methods, economic aims of wheat production and the status of research are described. Pests and diseases are discussed including some which are yet of minor importance. Possible grain yield losses are estimated.

Recent literature on stem and leaf rusts in southern Africa is reviewed; epidemiology of both rusts, race shifts, seasonal variations in development, yield losses, and possible effects of an increase in wheat area are considered. Selections exhibiting stable incomplete resistance may have differential resistance.

Qualitative and quantitative plant characteristics are described and results of trials from various irrigation seasons, are discussed. Selection criteria are given.

Avoidance of differential resistance, selection of parent genotypes, multiple crosses using Ethrel, breeding scenarios, implementation of selection and management of trials are described.

Suitable lines for irrigated, dambo and seepage wheat production were produced within 5 years by means of different scenarios. Resistance to helminthosporium and tolerance to low pH needed improvement, resistance to various pests and diseases was incomplete but adequate.

Opportunities for increasing wheat production in Zambia are discussed, and possible uses of the new lines indicated.

Keywords. Breeding, epidemiology, Ethrel, Helminthosporium sativum, incomplete resistance, Puccinia graminis, Puccinia recondita, rust races, stable resistance, temperature, wheat, yield components, yield loss, Zambia.

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CONTENTS

LIST OF ABBREVIATIONS AND SYMBOLS

Countries, organizations and institutes

CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico
FAO	Food and Agricultural Organization of the United Nations, Rome
GV	Golden Valley farm, Zambia
HRBP	Horizontal Resistance Breeding Programme for wheat, Zambia
IPHR	International Programme for Horizontal Resistance
MB	Zam-Can farm near Mbala, Zambia
MM	Mount Makulu Central Research Station, Zambia
NIRS	National Irrigation Research Station, Zambia
RDTN	Regional Disease Trap Nursery organized by CIMMYT
SA	South Africa
USA	United States of America
Zam-Can	Zambia-Canada Wheat Development Project

Cultivars and lines

The number between brackets indicates the Group number of parent genotypes.

AFR	Africa Mayo	(1)
BOB	Bobito'S'	(1)
BUB	Bubye	(1)
7CE	7 Cerros T66	(2)
CE2	unknowns selection	(1)
CER	Cerros 7 = Mexipak	(1)
CHE	Chenab 70	(1)
CN2	unknown selection	(1)
CN8	CNO'S'-8156BxCC-Inia	(2)
CNF	CNOxFury	(2)
CNO	CNO'S'-GalloxBB4a/K4496	(1)
CON	Condor	(1)
EMU	Emu'S'	(1)
FA	Florence Aurore	(2)
FAL	Falchetto	(2)
GIZ	Giza 156xPi62xLR64xKnott	(1)
HIN	Hindi	(2)
JUP	Jupateco 73	(REFCV)
KAL	KalxSon64 Jit16-2L	(2)
KIT	Kite	(2)
MXP	Mxp65-15Kr-20	(2)
PAK	Pakistani	(1)
PEN	Penjamo 62	(1)
SA4	SA42	(1)
SHA	Shashi	(1)
SOH	Sonora 64/C271	(1)
SON	Sonora 64	(2)
SOP	Son64-Pj62	(2)
SUP	Super X	(1)
TAN	Tanori 71	(RDTN)
TOK	Tokwe	(1, REFCV)
TUR	Turpin 7	(1)
TZP	TZPP-PLx7C	(1)
UMN	Umniati	(1, REFCV)

X1	unknown selection	(2)
ZAM	Zambesi I	(1, REFCV)

Measures

C	degree centigrade
cm	centimetre
g	gramme
h	hour
ha	hectare
hp	horse power
kg	kilogramme
km	kilometre
l	litre
m	metre
mm	millimetre
mt	metric ton
s	second

Statistics

***	very highly significant	($p < .001$)
**	highly significant	($p < .01$)
*	significant	($p < .05$)
arcsin x	arcsine transformation (arc in radians) of fraction x	
CV	coefficient of variation	
df	number of degrees of freedom	
F	variance ratio after Fischer and Yates (1938)	
LSD	least significant difference	
MS	mean square	
N	number of cases	
ns	not significant	($p > .05$)
p	probability level	
r	correlation coefficient (Pearson)	
r2	squared multiple correlation coefficient (proportion of variation explained by variables in regression equation (Nie et al., 1975)	
s2	pooled estimate of within-sample variance for independent samples (Snedecor and Cochran, 1967)	
SD	standard deviation	
SE	standard error	
SS	sum of squares	

Technical terms

-	not applicable, missing value
0	reaction type immune
a.i.	active ingredients of pesticide
ANOH2	average number of heads towards harvesting per m2
ANOKn	average number of kernels per n heads
ANOP	average number of plants 10 days after emergence per m2
ANOS	average number of spikelets
ANOVA	analysis of variance
APHT	average plant height in cm
asl	above sea level
GR5	grain weight of 5 heads in grammes

DAY	Julian day
DAYPSS	Julian day of observation of percentage stem rust on stems (PSS)
DC	Decimal Code (Zadoks et al., 1974)
DS	dry season
DVS	development stage in days or according to Decimal Code
EA	stem rust races determined with East African differential set
GEN	genotype
HAI	harvest index
IS	irrigation season in Zambia
ITCZ	Inter-Tropical Convergence Zone
K	Kwatcha, local currency (1 K is approximately 1 US dollar)
K2O	potassium oxide
KWLOS	kernel weight loss
LIR	logistic infection rate
MDI	mean daily increment
MSMV	symptoms similar to maize streak mosaic virus
N	nitrogen
NDH	number of dead heads
NOM	number of plants with MSMV symptoms
P2O5	phosphorus pentoxide
PHF	percentage helminthosporium on flag leaves
PHH	percentage helminthosporium on heads
PHL	percentage helminthosporium on lower leaves
PLF	percentage leaf rust on flag leaves
PLL	percentage leaf rust on lower leaves
PMF	percentage mildew on flag leaves
PML	percentage mildew on lower leaves
PREM	percentage realized emergence
PSF	percentage stem rust on flag leaves
PSL	percentage stem rust on lower leaves
PSS	percentage stem rust on stems
R	reaction type resistant, replicate
REFCV	reference cultivar
RRES	relative resistance
RS	rainy season in Zambia
S	reaction type susceptible, stem rust, stem
SHW	shoot weight in mt per ha, or in g per plot
sp.	species (singular)
spp.	species (plural)
SPSS	Statistical Package for Social Sciences (Nie et al., 1975)
TD(t)	terminal disease severity of entry
TD(s)	terminal disease severity of most susceptible genotype
TKWh	thousand kernel weight at harvesting in grammes
TKWp	thousand kernel weight at sowing in grammes
TL	terminal leaf rust severity (scale 0 - 9) of entire plant
TLF	terminal percentage leaf rust on flag leaves
TLL	terminal percentage leaf rust on lower leaves
TNDP	third national development plan for Zambia
TSF	terminal percentage stem rust on flag leaves
TSL	terminal percentage stem rust on lower leaves
TS(s)	terminal stem rust severity of most susceptible genotype
TSS	terminal percentage stem rust on stem
TS(t)	terminal stem rust severity of entry
WP	wettable powder
Y	grain yield in mt per ha

1. INTRODUCTION

1.1. The programme

1.1.1. Background and purpose

In 1975, the Zambian Government requested assistence from the Food and Agricultural Organization of the United Nations (FAO) to implement a Horizontal Resistance Breeding Programme for wheat (Triticum aestivum L. em. Thell.). At that time, Zambia had just begun increasing wheat production. Other motives were the discussions and conclusions of the 1974 World Food Conference (FAO, 1975) and new information available on horizontal resistance and its advantages (Vanderplank, 1963, 1968; Robinson, 1973). In January 1976, the author, appointed by FAO as an Associate Expert (Horizontal Resistance), became an Agricultural Officer in Zambia. The terms of reference given by FAO were: "to initiate and conduct a new programme of wheat improvement aimed at comprehensive horizontal resistance to all locally important pests and pathogens in accordance with new concepts and techniques being promoted by FAO". New good yielding lines were required with (long lasting) horizontal resistance to all locally important pests and diseases. These new lines were to be developed for various areas in Zambia, for both the rainy season (November to March) and the irrigation season (April to October).

1.1.2. Organization and financing

The Horizontal Resistance Breeding Programme for wheat (HRBP) in Zambia was part of the International Programme on Horizontal Resistance (IPHR), which also implemented similar programmes for wheat, maize, tomato and coffee, in Brazil, Morocco, Tunesia and Ethiopia (Robinson and Chiarappa, 1977). HRBP was a national programme of the Research Branch of the Department of Agriculture, and was stationed at the National Irrigation Research Station (NIRS). It was introduced to farmers by means of field days, at agricultural shows and through 2 local farming magazines (De Milliano, 1977 a, b). One foreign staff member was working in the programme. From 1980 to 1981 there were 2. There were 2 local workers in 1976 to 1978, 3 in 1978, and since 1979 4 to 5 workers have been active in the programme. In 1979, a graduate of Monze College joined HRBP as an Agricultural Assistant. He was promoted to Senior Agricultural Assistant in 1980. In 1980, a graduate of the Natural Resources Development College joined as a Technical Officer. Dr. L. Chiarappa, Mr. R.A. Robinson, Dr. W.C. James and Mr. C. Keller were FAO advisors to HRBP between 1976 and 1978. In 1979, the programme became part of the Netherlands Development Co-operation with Zambia, and Dr. J.C. Zadoks, Dr. J.E. Parlevliet and Dr. A. Darwinkel became advisors to the programme. Apart from the salaries of the 2 foreign staff members, the programme has been financed largely by the Research Branch of the Zambian Ministry of Agriculture and Rural Development. Between 1979 and 1980, FAO donated 2500 US dollars for running costs of the programme and the Netherlands Development Co-operation donated 2 vehicles, and goods to the value of 20,000 Dutch guilders.

1.2. Resistance

After studying the critical comments on the 'horizontal' resistance concept and the various terminologies used to indicate resistance which is expected to be long lasting, the term horizontal resistance was replaced by the term incomplete resistance. The term incomplete resistance was suggested by Parlevliet (1976 a) and put forward by Eskes at a symposium on durable resistance in crops in Martina Franca (Italy), 1981, as well as in publications (Eskes, 1983). Incomplete resistance is the type of resistance which does not completely inhibit reproduction of the parasite. A parasite is defined in accordance with terminology by Robinson (1976) and includes pathogens (fungi, bacteria, viruses, etc.) and pests. The breeding scenario advised by the 'horizontal' resistance concept, to obtain resistance which is expected to be long lasting (Dutlu and Prescott, 1976; Lamberti et al., 1983), is subject to more complications than initially suggested, and is subject to discussion (for example Nelson, 1978; Parlevliet, 1979; Eskes, 1983). The scenarios used in this programme are described in Chapters 7 and 8.

2. WHEAT IN ZAMBIA

Wheat is of considerable importance to Zambia (Section 2.3); the government has expressed a great interest in the development of wheat with resistance to locally important pests and diseases (Chapter 1). Before embarking on such a programme, a number of factors of importance to wheat production must be considered: the abiotic conditions (Section 2.1), the socio-economic status of the farmers (Section 2.2), methods and economic aims of wheat production (Section 2.3), the status of research (Section 2.4) and the selection of research stations (Section 2.5).

2.1. Zambia

2.1.1. Location and area

The Republic of Zambia, known as Northern Rhodesia before becoming independent in 1964, is tropical and being located between latitudes 8 and 18 degrees S and longitudes 22 and 33 degrees E (Figure 2.1). Its area is approximately 752,600 km2 in area (FAO, 1980). It has an irregular shape, vast distances and a diversity of physical features such as lakes, swamps and escarpments. Zambia's landlocked location limits its potentials for prosperity and stability (Davies, 1971 a). Zambia is surrounded by eight countries. The economy is heavily dependent on copper exports and imports of capital and consumer goods. Transport of goods through some of these countries may be delayed or is impossible if routes are closed. Distinct regional differences exist between the zone where the railway was first introduced, including the Copperbelt, Central and Southern Provinces and outlying regions. These differences are shown clearly by indicators such as urbanization, number of industrial establishments, banking services and population density. Since independence, some regional differences have been successfully reduced, for example in health and educational services (Davies, 1971 b; TNDP, 1979). The major part of the agricultural production takes place in the central regions where some 30% of the rural population lives, producing some 60% of the total agricultural output (including subsistence production). This has resulted in disparities in the level of living, which is a major concern of the government. The Third National Development Plan (TNDP) includes a provincial development strategy diverting investments to rural areas, and programmes to enable all categories of farmers to obtain maximum crop production.

2.1.2. Relief

Zambia consists mainly of a series of gently undulating to flat plateaux, with isolated hills and low ranges of resistant rocks. The slopes of the plateaux vary from gradual to very steep escarpments. The escarpment zones may be very long (up to 550 km). The highest of these plateaux is located in the east and north-east and reaches a maximum height of 2164 m above sea level (asl). The plateaux decrease in height towards the south and south-west, the lowest point being 325 m asl (Archer, 1971 a). Most of Zambia is between 900 and 1500 m asl. Although Zambia is a tropical country, the altitude permits production of a number of temperate crops which supplement tropical crops.

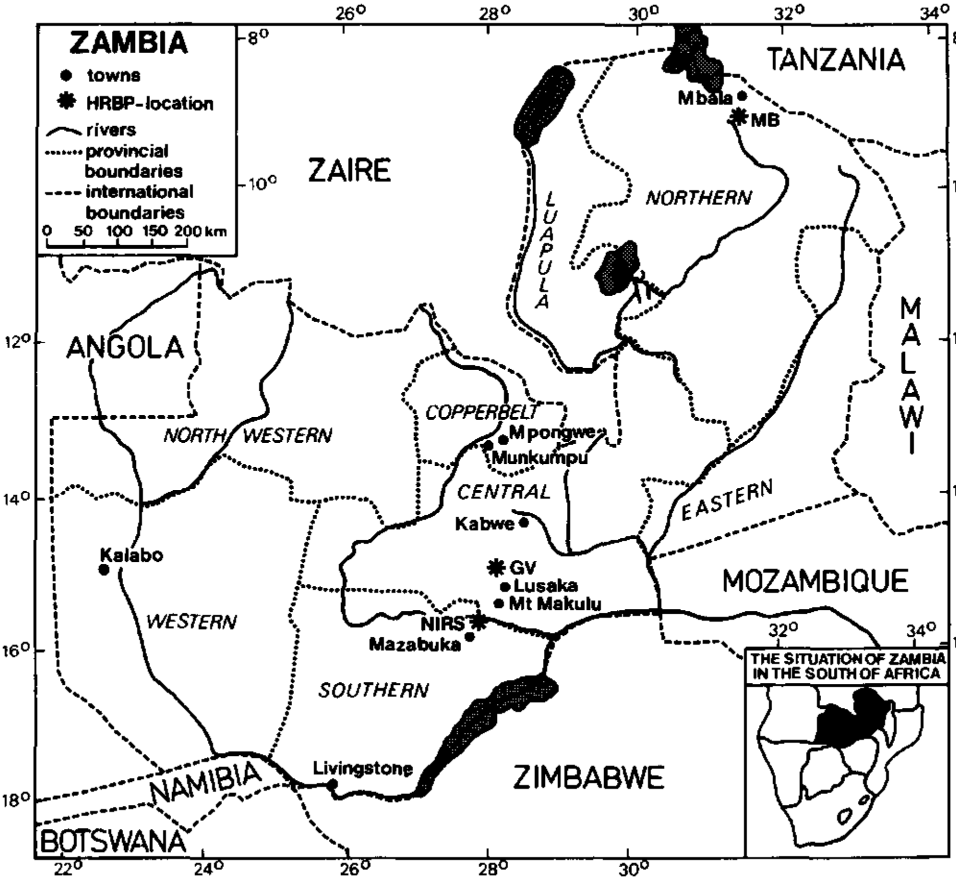

Figure 2.1. Map of Zambia.

2.1.3. Soils and water resources

Zambia is situated on the high interior plateau of Africa which consists mainly of old rocks; the soils are generally infertile. In southern Zambia, processes of weathering and leaching of the soil are less rapid than in the rainier north. Mäckel (1971) distinguished eight major soil groups. They can be grouped in 3 classes on the basis of their suitability for agriculture (Table 2.1).

A. Deep fertile soils, medium acid to slightly alkaline (pH 5 to 7), on which most crops will produce good yields under recommended management. Wheat yields are above 3 mt/ha after fertilizer application.

B. Deep to shallow soils, sandy loams to loamy sands, with a moderate base status, or extremely acid to strongly acid soils (pH 3.5 to 5), or cracking clays (pH 5.7 to 7.3, increasing to 8.3 in the subsoil), on which, in most cases, locally adapted crops will produce moderate yields with careful management. Dambo soils (Subsection 2.2.1) form a separate minor soil group (suitability class B). Seepage soils (Subsection 2.2.1) belong to the flood plain soils. Wheat yields tend to remain below 3 mt/ha after fertilizer application. Many of these soils are suitable for grazing, forests and wildlife habitat.

C. Sands, rocks and swamps best suited to permanent cover by woods and grass.

The division of soils in 8 groups is a gross simplification imposed by scale and lack of knowledge. The division of soils in 3 classes of agricultural suitability is also a generalization. Since 1971, information on soils in Zambia has increased: by 1971, only 7 soil survey reports had been produced by the soil survey unit of the Department of Agriculture; by 1979, there were 62. This new information may increase the area to be assigned to class A by a small percentage, thus decreasing class B.

Fertile soils producing high yields cover only a few per cent of the total area of Zambia, mainly in the southern, central and eastern parts of the country. Only 1 to 3% of the total land area is permanently under cultivation (FAO, 1980; TNDP, 1979); a very small fraction of its potential arable land. Major uncultivated areas are in the North Western Province, which also has fertile soils, and in the Western Province.

Zambia is well-endowed with water resources in the form of lakes and rivers (Figure 2.1 and Table 2.1). The present area under irrigation is estimated at 10,000 ha, including a sugar estate of 7,500 ha. Only a small fraction of the potentially irrigable land is being used.

Table 2.1. Generalized agricultural suitability, classes A to C (explanation see text) of the 8 soil groups in Zambia. The area per soil group, determined from a map by Mäckel (1971), is expressed as a percentage of the total area. The total area (75,260,000 ha) includes the area covered by lakes (2%).

Agricultural suitibility					
A		B		C	
Soil group	%	Soil group	%	Soil group	%
Fersiallitic	4	Southern ferrallitic	12	Barotse sands	23
		Northern ferrallitic	30	Lithosols	15
		Vertisols of Kafue flats	1	Swamp	2
		River valleys	6		
		Flood plains	5		
Total	4		54		40

Most of the soils need a high level of management and require inputs to improve their suitability for agriculture (Brammer, 1973, 1975). For wheat production, the application of fertilizers is a common practice. Occasionally, use is made of manure, mainly by traditional and emergent farmers.

2.1.4. Climate

Introduction. The climate of Zambia is described as category V-3 by Landsberg et al. (1966): "Wet and dry tropical climates with 7 to 4.5 humid and 5 to 7.5 arid months: rainy-green dry wood and dry savannah". On the basis of rainfall and temperature patterns the year can be divided into three distinct seasons (Archer, 1971 c; Figure 2.2):

a) a cool and dry season (April to August),
b) a hot and dry season (September to October),
c) a warm and wet season (November to March).

In accordance with local practice, the entire period (April to October) of the dry season (DS) is referred to as the irrigation season (IS), and the warm and wet season (November to March) as the rainy season (RS). The RS is the main season for crop production.

Irrigation season. In the cool DS, the sun is furthest north and temperatures are at their lowest. In the coldest month, July, mean minimum air temperatures (monthly and annual means of the lowest recorded each day) range from 3 to 15 C (Meteorological Department, 1975). Clear skies at night over most of the country permit rapid loss of heat from the surface. Temperature inversions frequently develop in valleys and lower areas of the plateaux. Associated frost, especially ground frost, may occur locally over a substantial part of the country between June and August. Frost days (the number of days when the ground minimum thermometer records frost) are most frequent in the south-west (Sesheke area), where there is an average of 10 frost days per year. Most areas have only a few frost days per year. Only a few parts of the Northern and Luapula Provinces have no frosts at all (Frost, 1968; Archer, 1971 c). Mean maximum air temperatures (monthly and annual means of the highest recorded each day) are lowest in June and July and vary from 20 to 31 C (Meteorological Department, 1975). As there is little cloud cover, bright sunshine is usually in excess of 8 hours per day throughout the cool DS. Daily relative humidities in July range from 60 to 80% in the early morning and from 20 to 40% in the afternoon, with locally higher values in the vicinity of lakes and permanent swamps (Archer, 1971 c). Relative humidity decreases steadily from April to September. The wind is predominantly from the east throughout the country (Figure 2.3); wind speeds are generally higher than in the RS. Following the southward movement of the sun in August, the temperatures rise sharply, marking the arrival of the hot DS.

In the hot DS, mean maximum temperatures may reach 39 C at low altitudes and 29 C at high altitudes. Nights also become warmer; occasionally the mean minimum temperature is above 21 C. From August, winds strengthen and their direction changes gradually to become north-easterly. In October the humidity begins to rise, due mainly to maritime Zaire air, which can appear suddenly. There are occasional thunderstorms, first in the north-west, then spreading to the rest of the country in November and December.

Rainy season. Rainfall is almost wholly restricted to the RS. The mean annual rainfall decreases from 1000 to 1380 mm in the north to 660 to 950 mm in the south (Meteorological Department, 1975).

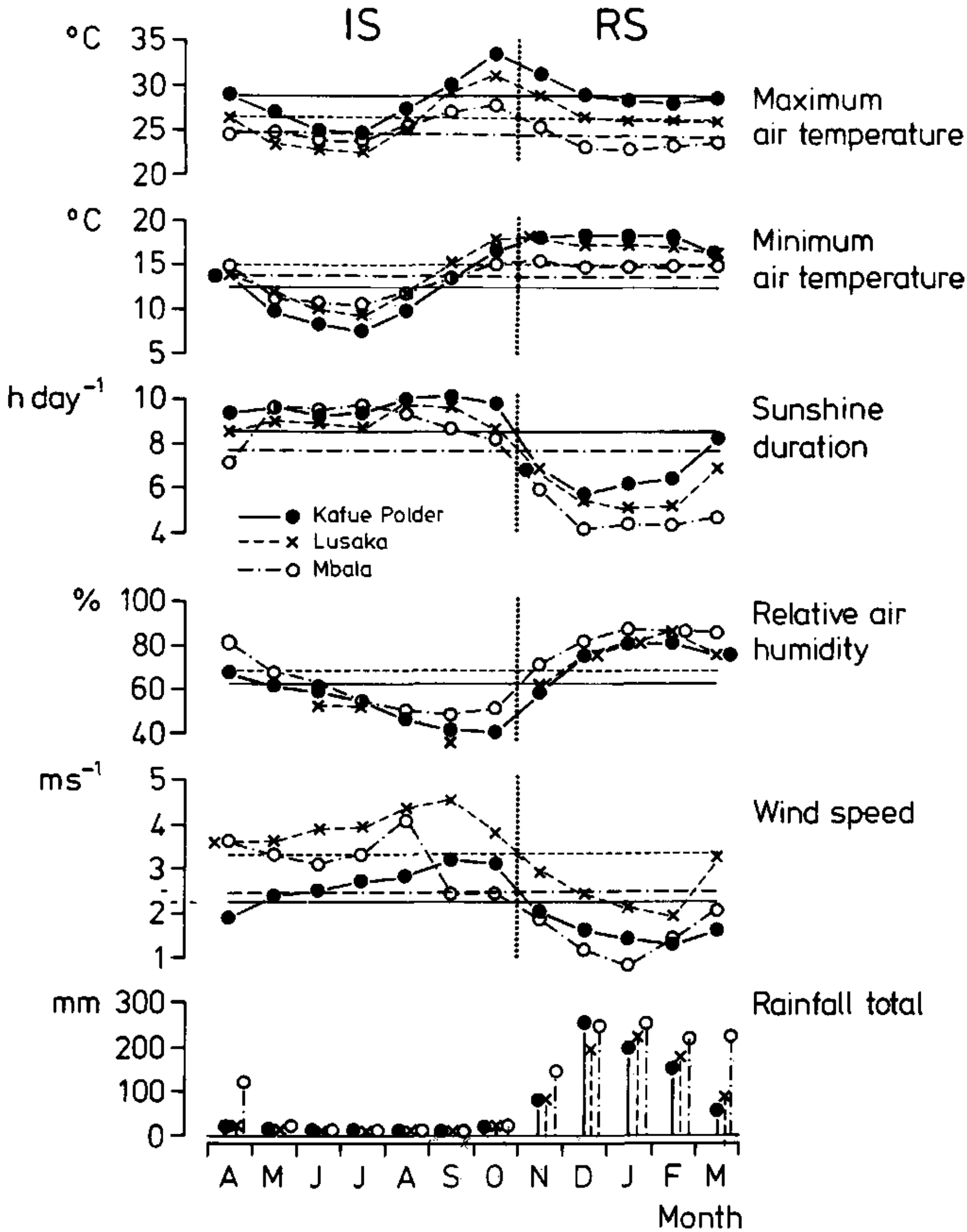

Figure 2.2. Monthly averages of meteorological data (weather screen) from Kafue Polder (1958 to 1970), Lusaka City Airport (1941 to 1966) and Mbala (1951 to 1970), based on data from the Meteorological Department (1975), Zambia.

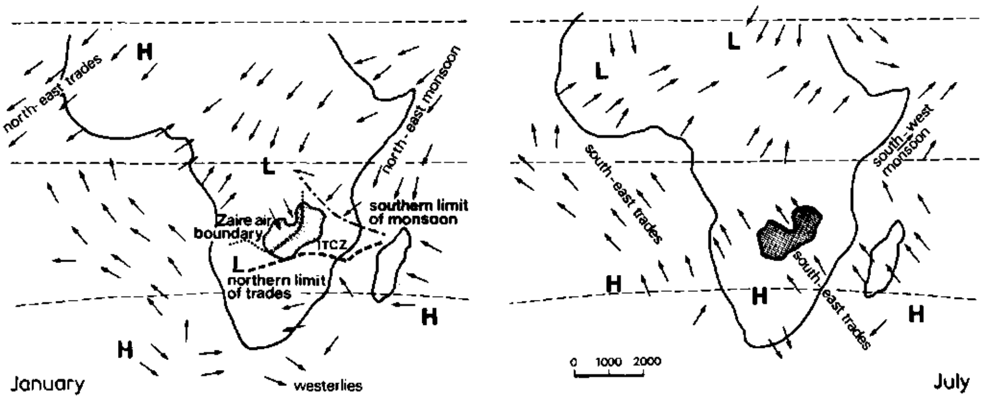

Figure 2.3. Generalized air-flow patterns above Africa, after Archer (1971 b) and Chi-Bonnardel (1973).

Usually a single rainfall peak is observed (Figure 2.4), occurring in December in the south and in January in the north. Precipitation can be heavy (more than 25 mm per h) and tends to be local and irregular. During the rains, virtually all crops may be subject to extensive damage which may be aggravated by parasites, attacking damaged tissues (Bailey, 1969). Water logging as well as drought occur (Simango and Das, 1977). The average duration of the period with rains (FAO, 1968) varies from 190 days in parts of the Luapula and Northern Province to less than 120 days in the south-west (Archer, 1971 c). There are substantial variations from year to year in the duration and the amount of rainfall (Figure 2.4). The onset of the rains usually occurs in November or December; the ending of the rains is usually in March in the south and April in the north. After the hot DS, the maximum temperature decreases. Differences in the mean maximum air temperatures between altitudes tend to be more pronounced during the RS than during the DS. Due to differences in altitude, temperatures at locations near the equator may be lower than those at locations near the tropic of Capricorn. The cloud cover reduces the loss of heat from the surface, so that the minimum temperature is higher than in the cool DS. Towards the end of the RS, the cloud cover decreases causing an increase in temperature during daytime (increase in the mean maximum temperature and longer periods of sunshine). Easterly winds are still dominant in the RS in the south and east but winds from the north-west quadrant become dominant over much of the north and west. Winds are usually light but there may be heavy squalls associated with thunderstorms. In January, relative humidity reaches 95% in the early morning and 60 to 70% by mid-afternoon. Mist and fog patches may develop in the early morning but they disperse quickly after sunrise. Monthly sunshine ranges from an average of 4 hours in the north to an average of 5 or 6 hours in the south.

The principal airstreams affecting Zambia in the RS are (Figure 2.3):
- Zaire air,
- the south-east trades from the Indian Ocean (dominant during the cool DS) and
- the north-east monsoon, originating in the Asiatic high pressure system.

The place where these airstreams meet is referred to as the Inter-Tropical Convergence Zone (ITCZ). Most rainfall occurs near the margins of ITCZ along the Zaire air boundary and at the northern limit of the south east trades. Rainfall is particularly prevalent when there are surges in the airstreams and the boundaries are being actively moved forward. Less precipitation occurs in the central area of the ITCZ or within the airstreams. Persistent rain or drizzle also occurs when high pressure cells move eastward from the South Atlantic Ocean across the continent. Counter-clock-wise circulation around high pressure cells often causes an invasion of cool moist air from the south-east or south and causes surges in the south-east trades. This condition is most common in the east and south. Tropical cyclones, originating in the southern Indian Ocean, may occasionally penetrate inland as far as Zambia. By this time, they usually move slowly, but may release heavy precipitation.

2.2. Agriculture and crop production

2.2.1. Introduction

In 1976, the contribution of agriculture (crops and livestock) to the total gross domestic product was estimated to be 14%, including almost 9% subsistence agriculture (TNDP, 1979). The total internal demand exceeds the estimated production for 3 crops only: wheat, barley and tea.

There are 3 main categories of farmers: traditional, emergent and large scale commercial farmers, the latter category including managers of parastatal farms. They cultivated approximately 78, 18 and 4%, respectively, of the total area harvested in 1974. Emergent and large scale farmers produce most of the cash crops. Traditional farmers are subsistence farmers and rarely produce cash crops. Three sub-categories of emergent farmers can be distinguished.

- Improved village farmers, who rely largely on manual labour and draft animals for cultivation. Such farmers rarely have more than 10 ha of crops per season. They are estimated to have cultivated 11% of the total area harvested in 1974.
- Organized smallholders, operating in settlement schemes and rural reconstruction centres created by Government. Individual farmers rarely have more than 10 ha of crops per season.
- 'Middle-sized emergent farmers', who use machinery and hired labour. Most cultivate not more than 50 ha of crops per season. They are estimated to have used 4% of the total area harvested in 1974.

Most crops are produced in the RS, although all categories of farmers produce some crops during the DS. Mechanized irrigation is largely restricted to some large scale farmers, while the use of seepage and dambo soils is restricted mainly to traditional and emergent farmers. Seepage soils are supplied with water by seepage from higher ground during part or all of the DS. The strips of seepage soil are of limited width, usually from 1 to 200 m or more. In Kalabo, for example, the average width of the strip where wheat can be grown is 50 m. The total area of the strip is approximately 350 ha (Offergelt and De Milliano, 1979). A dambo is a low lying area, often grassland, which remains wet during part of the dry season.

Terminology in the following Subsections such as farming system, cropping system, intensive fallow system, and sequential cropping is used in accordance with Westphal et al. (1981).

2.2.2. Subsistence and emergent farmers

Poor soils and low population densities have resulted in traditional farming systems based on pastoralism or shifting cultivation with long fallow, using various combinations of the 5 main staple crops: maize, finger millet, bulrush millet, sorghum and cassava (Siddle, 1971). Three broad categories of farming systems can be distinguished.

- Chitemene system. Irregular areas of 4 to 8 ha are cleared. Branches are usually heaped and burnt and the seeds sown in the ash, either broadcast or by using a planting stick. Crops grown are: pumpkins, sweet potatoes, cowpeas, groundnuts, common beans and finger millet. Home gardens contain relish crops or cassava. Suitable valley or dambo soils are often reserved for relish crops (okra, Amaranthus spp., pumpkin and rape), fruits and roots. Caterpillars, grasshoppers and small mammals form a valuable protein supplement. Most farmers have only a few chickens or goats. Farmers rarely produce cash crops. The introduction of new crops, such as wheat, is of questionable value until traditional crops are grown commercially.
- Fallow system in transition with the use of ash. An attempt is made to produce cash crops such as maize and bulrush millet, making use of fertilizers. Cassava is a common crop. Some of these farmers may soon use fallow systems in the process of becoming permanent cultivation systems, in which wheat may be used as a cash crop.
- Fallow systems in the process of becoming permanent cultivation systems. Land preparation is with hoe or plough. Soils are generally selected carefully. Mounding is used. Grass-manuring is practised rather than fertilizing of the soil by burning. After 5 or 6 years of single cropping a fallow period with an equal duration may occur. A high proportion of land may be under permanent cultivation. Typical staples are cassava, bulrush millet and maize. In addition, special crops (vegetables, tubers, rice, tobacco, fruits) are cultivated in subsidiary gardens. Animal husbandry often plays a role in the systems' economy. Transitions to ox and tractor ploughing for commercial crops are made by these emergent farmers. In the Western Province, wheat was introduced on the initiative of the farmers in the DS. It is grown in addition to relish crops and other crops such as sweet potatoes.

Emergent farmers making use of ox and tractor ploughing may be interested in growing wheat. To increase production in general and wheat production in particular, it may be necessary that the use of ox- or tractor-drawn ploughs becomes more widespread. The use of oxen is restricted by their availability (particularly limited in the Copperbelt, Luapula, North Western and Northern Provinces) and a lack of training in their use. The fact that animal husbandry already plays a role in the systems' economy may facilitate the introduction of work oxen. Tractors of the size required for a 30 ha holding, in the range 11 to 40 hp, are at present not available (TNDP, 1979). Purchase and operating costs are likely to limit their use in the near future, and this may favour the use of work oxen.

2.2.3. Large scale farmers

Large scale farmers make use of an intensive fallow system for production of the major commercial crops. Major commercial crops are maize, sorghum, groundnuts, tobacco, vegetables and cotton. Commercial crops such as sugarcane, rice, sunflower, soybeans, pineapple, coffee and bananas are less widely cultivated. Sequential cropping occurs. Wheat is grown in sequential cropping (double or tripple cropping) with cash crops, and is grown during the DS only. For further information see Wilson (1971) and Lombard and Tweedie (1974).

2.3. Wheat

2.3.1. Production

General. Zambia was self-supporting from the 1940s, when wheat was first introduced, until the early 1960s. This was due to the very low consumption of bread, the main food product for which wheat is used. Most wheat was grown under irrigation (Hurd, 1981). During the 1960s wheat production decreased and it virtually disappeared in the 1970s. This coincided with a large increase in consumption, high prices for wheat on the world market, and a reduction in the price of copper which is Zambia's main source of foreign exchange. The total wheat demand for 1983 is estimated at 190,000 mt (TNDP, 1979).

Cropping methods. The cropping methods for wheat in Zambia are set out below.
a) Early rainfed wheat. In areas where the rains stop towards the end of March, wheat is sown between November and January. Crop growth and development is entirely dependent on rain water and residual moisture. At Mount Makulu Research Station, wheat has been grown in this way since 1954 (Mounter, 1961; Kajimo, 1969; Zam-Can, 1979, 1980 a, 1981). Grain yields ranged from 0.2 to 3.2 mt/ha. Before 1960, the maximum yield, the yield of the highest yielding cultivar, was 1.5 mt/ha. Currently, the maximum yield surpasses 3.5 mt/ha (Raemaekers, 1981 a). Adapted cultivars give yields of 1.0 and 2.0 mt/ha when use is made of mechanization, seed rates of 90 to 100 kg/ha and fertilizer application per ha of 100 kg N, 50 kg P2O5, 25 kg K2O and 4 kg 'Solubor'. Few farmers (less than 50) adopted this cropping method, and little or no information on yields is available. Early rainfed wheat production seems feasible in areas where annual rainfall is between 600 and 800 mm.
b) Late rainfed wheat. Wheat is sown in January or February or even later. Crop growth and development is entirely dependent on rain water and residual moisture. The later stages of development of the plant are dependent on the availability of residual moisture. In 1981, more than 1000 ha of late rainfed wheat was grown, that is virtually all wheat in the Northern Province and approximately 1000 ha cultivated by the Zambia-Canada wheat development project (Zam-Can) at Mbala (MB), see Subsections 2.5.1 and Section 9.2. Smallholders are being trained by the Integrated Rural Development Co-operation in Kasama to adopt wheat production, and holders of more than 20 ha in the Mbala area are being trained by Zam-Can (England, 1981). Between 1954 and 1960, grain yields in experimental plots were generally low, 0.4 to 0.6 mt/ha. The general assumption was that water storage capacity of soils was too low (Mounter, 1961; Kajimo, 1969). Since 1976, commercial yields at MB ranged from 0.3 to more than 1.0 mt/ha and in trials certain cultivars have yields exceeding 2.0 mt/ha, when management is practised similar to that described above for early rainfed wheat at Mount Makulu. At MB, 2 mt of lime was applied per ha as soils tend to be extremely to very strongly acid (Zam-Can, 1979, 1980 a, 1981).

This production method seems feasible for areas were rain falls until late April, generally those areas with more than 800 mm per year. In areas where less rain falls, wheat may be double-cropped with tobacco (Snead, 1975).
c) Partly rainfed wheat. Sowing may be between January and April. Crop growth and development depends on rain water and irrigation water. This cropping method is experimental. Yields up to 2.0 mt/ha were obtained, using only limited mechanization, seed rates of 60 to 150 kg/ha and fertilizer applications per ha of 90 kg N, 60 kg P2O5 and 30 kg K2O (NIRS, 1980; De Milliano, 1981).
d) Irrigated wheat. The wheat is sown between late April and late May. In certain areas sowing must be postponed until mid May to avoid frost damage (Kajimo, 1969; Kotschi, 1976). Crop growth and development depends entirely on

irrigation water and residual moisture. In 1975, a small number of farmers began growing irrigated wheat on a modest scale (Table 2.2).

Table 2.2. Statistics of irrigated wheat production in Zambia, 1975 to 1977 (Jones and Pope, 1977).

	1975	1976	1977
Number of farmers	9	18	32
Total wheat area (ha)	220	940	1700
Mean wheat area per farm with wheat (ha)	24	52	53

By 1980, some 2600 ha of irrigated wheat was produced, primarily in the Central, Southern and Copperbelt Provinces (Hurd, 1981); this amounted to 11,000 mt of wheat or 4.2 mt/ha. In the 1950s, the maximum yield was approximately 4.0 mt/ha (Mounter, 1961) and in the 1960s 5.0 mt/ha (Kerkhoven, 1964). Recent trials with a high level of mechanization, seed rates of 90 to 100 kg/ha and fertilizer applications per ha of 120 kg N, 60 kg P205 and 30 kg K20, have produced maximum yields of more than 7.0 mt/ha (Zam-Can, 1980 b; Little, 1982) and 8.0 mt/ha (Little, 1983). Widespread production of irrigated wheat is possible as many areas have sufficient water available.

e) Seepage wheat. Wheat is sown in April or May. Crop growth and development depends on seepage water and residual moisture. At present, very few farmers grow seepage wheat. In 1979, about 40 farmers in the Kalabo District in the Western Province, had an average yield of 0.6 mt/ha. The highest yields exceeded 2.0 mt/ha. No mechanized equipment was used, seed rates were 90 kg per ha, and fertilizer applications per ha only 30 kg N, 60 kg P205 and 30 kg K20. The wheat area per farm varied from 0.2 to 2 ha (Offergelt and De Milliano, 1979). Yields up to 2.0 mt/ha were also obtained in trials on manured plots, conducted between 1954 and 1960 (Mounter, 1961; Kajimo, 1969) and along the Luena river near Mangango in the Western Province, where management conditions were similar to those at Kalabo. Wheat may possibly be grown on alluvial river banks of the Luangua and Gwembe river if supplementary irrigation facilities are made available (Ferreira, 1977).

f) Dambo wheat. Wheat can be grown in dambos (Ferreira, 1977; Offergelt and De Milliano, 1979). Wheat is sown in April or May. Wheat growth and development depends on residual moisture and seepage water. Dambos occur throughout the country, but their area, expressed as a percentage of the total area is very small. Very few farmers grow wheat in the dambos. In the Western Province, near Kalabo, the yields were below 1.0 mt/ha under the same management conditions as for seepage wheat. Ferreira (1977) suggests that most dambos are suitable for wheat production. Brammer (1975), however, reports that dambo soils may be strongly weathered and the topsoil strongly acid, making these dambos or part of these dambos less suitable or unsuitable for wheat production.

In Zambia cropping methods of wheat are the subject of much discussion (Subsection 2.4.2). A brief summary of advantages and disadvantages of the major cropping methods is given below.

Advantages of rainfed wheat as opposed to irrigated wheat are:

- low costs of production,
- a limited level of education in agriculture is required,
- availability of larger areas for cultivation,
- absence of night frost during the season,
- a long dry period for harvesting,

- low risk of damage from birds and other animals, as an abundant natural supply of food is then available,
- the short period of development from sowing to ripening, so that wheat can be grown in sequential cropping, for example, after tobacco.

Disadvantages of rainfed wheat are:

- relatively high temperatures which are partly responsible for low yields,
- high risk of severe weed infestations and of high disease severities, especially helminthosporium and rusts,
- water quantities which cannot be regulated,
- storm damage, sometimes causing lodging of wheat and soil erosion,
- occasional water stress during critical periods of crop development,
- risk of droughts.

  Rainfed wheat production may reduce the production of staple crops such as maize and rice.

Advantages of irrigated wheat are:

- the possibility of high yields (above 4.0 mt/ha),
- small yield losses because of diseases,
- employment throughout the year.

Advantages of seepage wheat and dambo wheat are:

- infrequent occurrence of rusts,
- provision of a supplementary crop, a high quality food crop and a cash crop,
- good storage qualities (for example, compared with vegetables).

Disadvantages of seepage wheat and dambo wheat are:

- difficulties in the choice of fields which requires a good knowledge of the soil pH and of the behaviour of the water table,
- difficulties with seedbed preparation and crop husbandry (lack of knowledge as well as physical problems),
- high soil conservation requirements,
- fairly small hectareage,
- yields which are generally low (less than 3.0 mt/ha),
- high risk of damage to wheat by cattle, pigs, sheep or goats,
- high risk of damage to wheat by Quelea, other birds and wild animals,
- frost damage in some areas.

  The infrastructure of the area is often not well developed, adequate facilities for delivery of seed and fertilizers when needed, transportation of grain to the market and storage of the harvested grain are nonexistent or very limited. The isolated location of these areas, results in high costs for marketing, machinery usage and extension. Shortage of farmers occurs, partly due to migration to the towns.

In general, solutions can be found for most of the technical problems associated with irrigated wheat. Other cropping methods present problems which may be difficult to solve. Increased wheat production in both the RS and the DS seems feasible. Conditions (soil, human) seem to be present for an expansion of wheat production, particularly near the railways, and in the North Western and Eastern Provinces.

2.3.2. Break-even and target yields

The break-even yield is the quantity of grain necessary to cover the total production costs, using the local producer price. The target yield is a hypothetical yield. The breeder attempts to develop cultivars with a yield higher than the break-even yield, when grown by farmers following current recommendations. The maximum yield (Subsection 2.3.1) is the upper limit for the target yield under experimental conditions. The difference between the break-even and the target yields may be an incentive for farmers to produce the specific crop. Cost/benefit analyses are performed for highly mechanized, high input wheat production (Donovan, 1952; Snead, 1975; Levy, 1979). Snead gives break-even yields for 1975 (Table 2.3).

Table 2.3. The break-even yield (at Zambian currency K 16.00 per 90 kg bag) in mt/ha in relation to area of production in ha, for highly mechanized wheat production (tractor, machinery), using certified seed (100 kg/ha), fertilizers (per ha 120 kg N, 60 kg P2O5, 30 kg K2O) and herbicides (4 l 2,4 D/ha) after Snead (1975).

		Area (ha)		
		25	50	100
Rainfed wheat		1.71	1.53	-
Irrigated wheat	Furrow	1.67	1.53	1.58
	Conventional sprinklers	2.47	2.34	2.40
	Travelling rain gun	2.75	2.20	2.16

On the basis of these data and 1975 yields under actual farming conditions, target yields for highly mechanized, high input rainfed and irrigated wheat in 1975 were approximately 2.0 and 5.0 mt/ha, respectively. Cost/benefit analyses for wheat production under conditions of low mechanization are not available. As most Zambian soils have low fertility, particularly the ferrallitic, dambo and seepage soils, fertilizers are essential to improve yields. Cost/benefit analyses are, therefore, essential for wheat produced with little mechanization and different levels of fertilizer inputs.

Traditional and emergent farmers in other African countries south of the equator, for example in Rwanda (Camerman, 1975; Boury et al., 1980), Zaire, Malawi and Tanzania (Toogood, 1981), produce rainfed wheat with little mechanization and low fertilizer inputs, and have actual yields of only 1.0 mt/ha. Actual irrigated yields may also be 1.0 mt/ha (Croon, 1976). These examples suggest that break-even and target yields may be lower for highly mechanized wheat production.

The break-even yield is composed of the variables, production costs and producer price. Zambia has a guaranteed producer price, which is increasing at present. The producer price for a 90 kg bag of wheat delivered at any depot was in Zambian currency K 16.00 (Snead, 1975) in 1975; in 1979 it was K 20.00 (Ministry of Lands and Agriculture, 1978). Presently, especially in highly mechanized, high input wheat production, producer costs are also increasing. However, the increase in producer price and producer costs are not necessarily consistent. Thus break-even yields may be lower for some farmers due to a relatively large increase in producer price, and be higher for other farmers due to a relatively large increase in producer costs. As financial gain may be an important incentive for farmers to grow wheat, it is important that cost/benefit analyses are made annually for various farmers' groups.

Since 1954, actual and maximum yields have increased for all major cropping methods of wheat (Subsection 2.3.1). As a result, benefits may occur that were impossible in the past.

2.3.3. Diseases and pests

In the RS, severe yield losses in early rainfed wheat may be caused by helminthosporium (Table 2.4, Subsections 3.3.4).

Table 2.4. Estimate of possible yield losses in wheat in Zambia, due to diseases and pests (Subsection 2.3.3 and Chapter 3).

0 = no loss.
T = loss in a susceptible cultivar less than 1%.
M = loss in a susceptible cultivar less than 5%.
S = loss in a susceptible cultivar more than 5%.
? = no information.

	Rainy season		Irrigation season	
	Early sown	Late sown	Irrigated	Seepage and dambo
Diseases				
Helminthosporium sativum	M-S	T-S	T	T-M
Puccinia graminis	0-M	0-S	0-S	0-S ?
Puccinia recondita	0-M	0-M	0-S	0-S ?
Puccinia striiformis	0-T	0-S	0-T	0-T
Septoria nodorum	0-S	0-M	0-T	0-T
Septoria tritici	0-S	0-S	0-T	0-T
Erysiphe graminis	0-M	0-M	0-S	0-M ?
Fusarium spp.	T-M	0-M	0-T	0-M ?
Ustilago tritici	0-T	0-T	0-T	0-T
Bacteria	0-S	0-S	0 ?	0 ?
Virus	T-M	T-M	T-M	0-M
Insects and other pests				
Aphids	T	T	T-M	T-S
American bollworm	0-S ?	0-S	0-S	0-S ?
Stem borers	0-M	0-M	0-M	0-M
Termites	0-S	0-S	0-S	0-T ?
Locusts, Acrididae	T-S	T-S	T-S	T-S
Sucking/piercing insects	T	T	T	T
Leaf-eating ladybirds	0-M	0-T	0 ?	0 ?
Nematodes	0-S	0-S	0-S	0-S
Rats and mice	0-M	0-M	0-M	0-M
Quelea birds	0-M	0-S	0-S	0-S
Other animals	0-M	0-S	0-M	0-S

Losses in late rainfed wheat may be severe, due to helminthosporium and stem rust (Section 4.5, Subsections 8.1.4, 8.2.4 and 8.3.4). Yield losses from result of helminthosporium are expected to be lower for late sown wheat than for early sown wheat because conditions are less humid (Subsections 8.2.4 and 8.3.4). At higher altitudes, stripe rust may cause yield losses as the current commercial cultivars are susceptible (RDTN results, Section 4.4). As yet, however, stripe rust is rare and has not yet caused yield losses > 1%. Presently, Septoria spp. and bacteria are also unimportant pathogens. Many pests may attack wheat during both the RS and IS. At present, termites and the American bollworm are the most common pests (Subsection 3.3.5). Army worm is an unimportant pest, but caused losses in neighbouring countries (Valles, 1962; Northwood, 1970; Pedgley, 1982). Conditions are favourable for development of stored-grain insects, and post-harvest losses caused by these insects can be very large (Subsection 6.3.2). Common stored-grain insects are: the maize weevil, lesser grain borer, larvae of Angoumois grain moth and Indian meal moth.

In the IS, severe yield losses are occasionally caused by stem rust, leaf rust, powdery mildew, and possibly virus (Table 2.4). However, in dambo and seepage wheat, there are no records as yet of severe losses due to these pathogens. Pests which may cause severe yield losses are termites, locusts, American bollworm, nematodes and Quelea birds. A potential pest are aphids. Little is known about pests in seepage and dambo wheat, however, as fields are generally small, wild animals and cattle can easily destroy a large part of the crop.

2.4. Research

2.4.1. General

Scientific research in the field of agriculture is carried out by:
- National Council for Scientific Research, which is responsible for co-ordination of research efforts,
- University of Zambia, established in 1965, and to which the National Council for Scientific Research allocates funds, equipment, facilities and staff,
- Research Branch of the Ministry of Agriculture and Rural Development (Chimutengwende and Chimutengwende, 1975).

The objectives of the Research Branch are to make agriculture more profitable, to develop self-sufficiency in agriculture in Zambia and to provide a support service for the farming industry (CARIS, 1978). The head office of the Research Branch at Mount Makulu encompasses specialized sections in plant protection, soils, advisory service and a library. Eight regional stations also conduct research in agronomy of tropical crops.

The co-ordination and budgeting of all national projects is carried out at Mount Makulu. All provincial projects and funds for the regional research stations are controlled by the provincial permanent secretaries. Recurrent expenses are estimated by the Chief Agricultural Research Officer of each station. The research programme for each year is determined at a series of meetings and field tours which culminate in sessions of the Annual Research Commodity and Specialist Committees, where results of the past year are discussed and the programme is finalized (CARIS, 1978). Separate meetings are held for rainfed and irrigated wheat.

Technical officers and agricultural assistants are trained at:
- Natural Resources Development College in Lusaka,
- Zambia Colleges of Agriculture at Monze and Mpika.

2.4.2. Agronomy

Research was mainly production oriented (Kajimo, 1969; Tout, 1974; Moono, 1980; Toogood, 1981) including subjects such as:
- wheat production in various areas and various soils,
- effect of pH and trace elements on wheat growth,
- soil management and rotation,
- timing of sowing, seed rate, spacing and ridging,
- damage by parasites,
- pesticides, herbicides and fungicides.

Research programmes concentrated on yield, adaptibility and resistance to parasites (Mounter, 1961; Kajimo, 1969; Salmon, 1977; Zam-Can, 1979, 1980 a, b; Moono, 1980; NIRS, 1980; De Milliano, 1981; Toogood, 1981). Results of research in wheat agronomy and breeding are discussed in Chapters 6, 7 and 8.

In the period 1954 to 1965, wheat research included all major cropping methods of wheat. It took place in all provinces (26 stations) and included research on specific soils such as the heavy black clays and seepage soils (Kajimo, 1969). Irrigated wheat was considered the most satisfactory cropping method. Mounter (1961) suggested that problems in rainfed wheat could in the long run be overcome to a great extent.

From 1965 to 1972, virtually no wheat research was done. In 1972, it was taken up again, using small quantities of mostly new, introduced genotypes. Wheat had a low priority because:
- irrigation means were limiting,
- wheat was not considered as suitable a crop for traditional and emergent farmers compared, for example, with oil-seed crops.

The general opinion was that wheat should be confined to areas within 100 km of the railway line, and to areas where water was available. It was also thought that small scale production could alleviate, but not satisfy the Zambian requirements (Duff, 1972).

Until 1976, emphasis was on irrigated wheat; no research was conducted in provinces lacking railway services, such as the Western, North Western and Eastern Provinces. Results of rainfed wheat research and development were anticipated in the medium rather than short term. The assumption that wheat yields could surpass the break-even yields seemed dubious to some observers (Lombard and Tweedie, 1974). Although production during the DS expanded to some extent (Table 2.2), it was limited by irrigation means.

In 1976, further development of rainfed wheat was considered desirable (McPhillips, 1976). With support from the Zambia-Canada wheat development project (Zam-Can), which started operations in November 1975 (Salmon, 1977), rainfed wheat production was attempted at several locations between Livingstone (in the south) and Mbala (in the north). Attention was focussed mainly on highly mechanized, high input wheat production. In the HRBP, low input wheat production was also receiving attention (NIRS, 1980; De Milliano, 1981). In 1979, research into low input wheat production (seepage and dambo wheat) was taken up at Kalabo (Offergelt and De Milliano, 1979). In 1981, teams began to collect information on farming systems in various provinces and on performance of 'on farm trials'. The overall objective of these so called Adaptive Research and Planning Teams is to produce recommendations relevant to all farmers. Only in the Luapula, North Western and Eastern Provinces few or no wheat trials were performed from 1976 to 1981.

2.4.3. Breeding

From 1954 to 1965, breeding involved crossing and evaluation of off-spring and genotypes; from 1965 to 1976, only evaluation of genotypes. Since 1976, crossings were also made by a number of breeders: De Milliano, 1976 to 1979; Salmon, 1977; McBean, 1979 and 1980; Raemaekers, since 1981; and Groot, 1982. With the exception of De Milliano and Groot, both of the HRBP, breeders aimed at developing complete resistance to various individual parasites. Except in the HRBP, the pedigree method of breeding was employed; several generations of wheat were grown per year. Most breeders did not study the effect of season on various off-spring generations. In order to obtain an F2 quickly, the F1 was even multiplied in an off-season (Table 2.5). Artificial screening for agronomic characteristics and rusts generally began in the F3.

Certified seed production is under supervision of the Seed Service of the Department of Agriculture. Distribution and marketing of certified seed is undertaken by the National Agricultural Marketing Board.

Table 2.5. Breeding scenario after McBean (1981).

Generation	Year	Period	Cropping method	Activity
P	1	May - Sep	irrigated	crossing
F1	1	Sep - Dec	partly irrigated	multiplication at 1 location
F2	2	Jan - Apr	rainfed	multiplication at 2 locations
F3	2	May - Sep	irrigated	selection
F4	3	Jan - Apr	rainfed	selection

Ter Horst (1981) stimulated discussions among plant breeders on their contributions to traditional farmers. He suggested that the most promising fields of research are those requiring little or no extra inputs in view of the traditional farmers' limited possibilities for cash and labour inputs. He stated that breeding is such a field of research and that seed improvement by means of breeding may be beneficial to traditional farmers.

2.5. Research stations

2.5.1. Location

The location of the 3 stations where HRBP trials were conducted are indicated in Figure 2.1 and Table 2.6. The head office of the project was at the National Irrigation Research Station (NIRS), in the Southern Province, at the village Nanga, 25 km east of the town of Mazabuka and 1 km south of the Kafue river.

Table 2.6. Location of 3 stations with HRBP trials after Aeppli (1977 a), Spaargaren (1969) and Slørdal (1978), respectively.

Station	Latitude	Longitude	Altitude (m)
NIRS, Nanga	15 45' S	27 56' E	985
GV, Golden Valley	14 53' S	28 28' E	1125
MB, Zam-Can Farm	9 2' S	31 22' E	1685

Since 1979, work was also done at Golden Valley Farm (GV) and at the Zam-Can Farm (MB), also known by the name Katito Wheat Scheme. GV is located in the Central Province, about 50 km north-west of Lusaka, east of the Wanga river. MB, the farm used by Zam-Can, is in the Northern Province, 22 km south of Mbala township, on the Mbala-Kawambwa plateau, with the Lungu stream to the west and the Lunzua stream to the south.

2.5.2. Soils

At NIRS, the soil on which the HRBP trials were conducted belonged to Mazabuka and Nakambala series (Aeppli, 1977 a). Soils of the Mazabuka series were medium deep to deep (50 cm and deeper), well drained, dusky red to reddish brown clays to sandy clay loams, occasionally with a sandy clay loam top layer. Soils of the Nakambala series were medium deep to deep, well to moderately well drained, reddish brown clays, occasionally with a sandy clay loam topsoil. The terrains were flat or gently sloping ($< 1\%$) and were suitable to very suitable for irrigation. Water storage capacity in top 100 cm soil of the various soils was 120 to 150 mm. The soils had a high fertility and were suitable for wheat and a wide range of crops. The Nakambala series makes higher demands on the management as a proper field preparation is possible only within a rather narrow range of soil moisture.

At GV the soil was a Makeni clay loam (Spaargaren, 1969), a deep soil (> 160 cm) with dark reddish brown to very dark grey clay surface horizon. The subsoil was a reddish brown to yellowish red clay with a moderate grade of structure, and was well drained. The pH in the top 60 cm was 4.8 to 5.7, and below 60 cm 5.7 to 6.6. The soil had a high fertility and was suitable for wheat and a wide range of crops. With good management and proper fertilization high yields could be expected. Because of the high clay and silt content of the surface soil, the soil will tend to compact if mismanaged.

At MB the most commonly used soils were the Konkola clay and sandy clay (Slørdal, 1978). These soils were deep (> 160 cm), well drained. The terrain was flat to very gently sloping (< 1%). The top 10 cm was a dusky red sandy clay to clay. From 10 to 20 or 30 cm there was a dark reddish brown sandy clay to clay and from 20 or 30 cm to 160 cm a sandy clay. Before liming, the pH of the topsoil was 4.3 to 4.9 and the fertility was moderate to low. For most crops, including wheat, the soils had less favourable physical or chemical characteristics or were only moderately responsive to good management. Wheat and crop production can only be maintained by good farmers using proper fertilizers and lime, a suitable rotation and soil conservation practices.

The soils at NIRS and GV, on which the HRBP trials were performed, belong to the agricultural suitability class A (Table 2.1). Many of the emergent and large scale farmers farm on this type of soils. At MB, the soils belong to the northern ferrallitic soils, soil suitability class B. Soils of this soil class cover some 40% of the total area of Zambia. They occur in the North Western, Western, Copperbelt, Luapula and Northern Provinces. Few of the emergent and large scale farmers farm on these soils.

2.5.3. Weather

Since 1958, there has been a meteorological station at Nanga, under supervision of the Meteorological Department in Lusaka. Data for the periods ending December 1970 are given in Figure 2.2. Originally the station was set up in the Kafue polder, and was known as the Kafue Polder Station. In 1974, when a dam was constructed across the Kafue River, the polder was flooded and the station moved to a new site within the present boundaries of NIRS. The new meteorological station is still incorrectly referred to as Kafue Polder. The transfer of the station should be kept in mind when recent climatological data are compared with old records. FAO (1968) gives details about rainfall and hydrology of the Kafue River Basin, in which NIRS is situated. From 1975 to 1980, one season occurred with a high annual rainfall (1977-78 RS) and one season (1976-77 RS) with a very low rainfall (Figure 2.4). In 1975, 1976 and 1978, the relative humidity was high in April and May.

At GV there is no meteorological station and the nearest stations are: Lusaka City Airport, which is no longer used, but gives data for 1941 through 1966 (Figure 2.2); Lusaka International Airport, with data from 1967; and Kabwe which has been in use since 1944. Rainfall was recorded at GV from 1975 until May 1979 (Figure 2.4).

The official meteorological station nearest to Zam-Can Farm is at Mbala, where data has been collected since 1951 (Figure 2.2). The Boma meteorological station at Mbala is no longer in use, but data are available for the period 1941 to 1950. Data from Mbala for the period 1969 to 1978 are reported by Slørdal (1978). At the Zam-Can Farm, the rainfall has been recorded since January 1979 (Figure 2.4; Zam-Can, 1979, 1980 a, 1981).

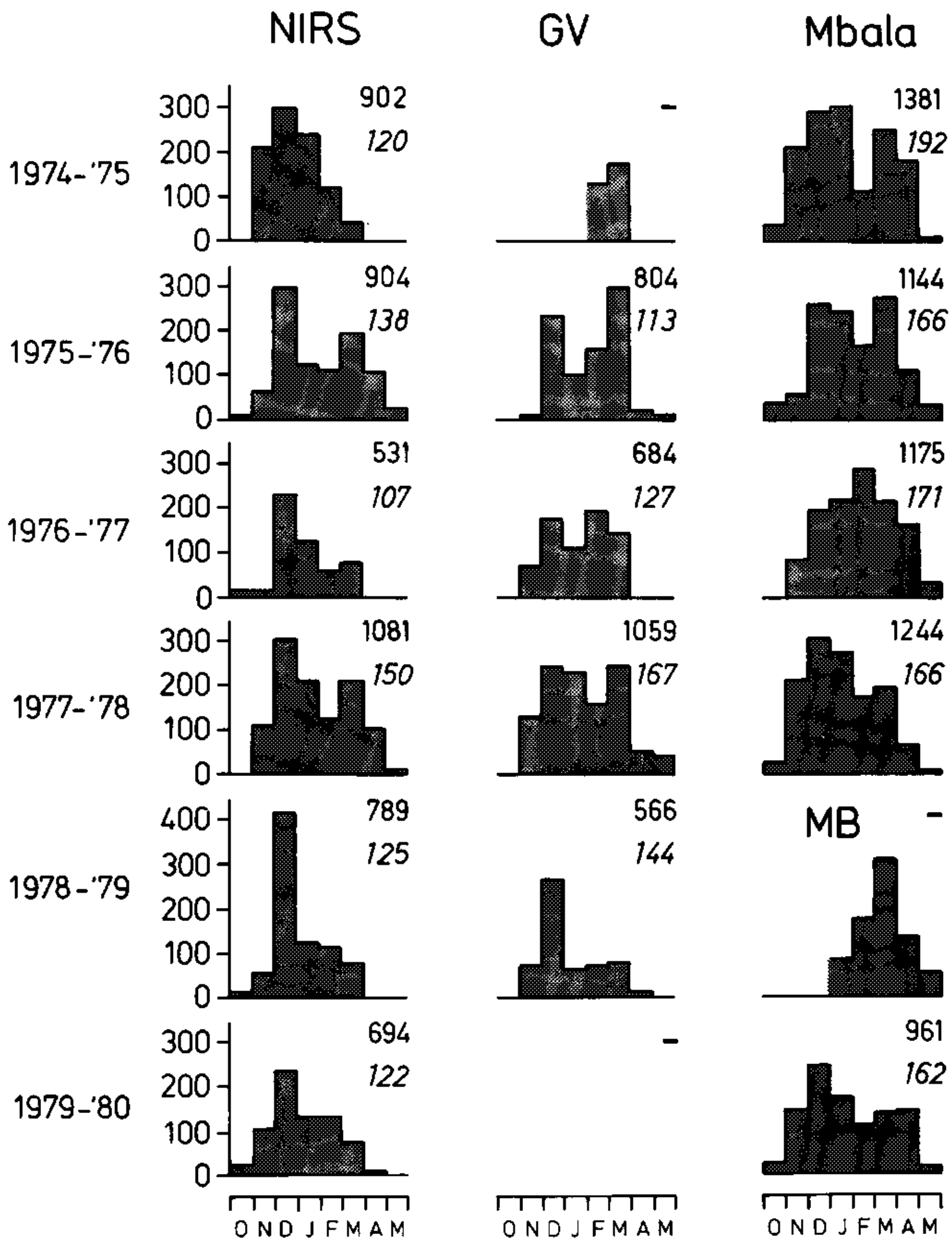

Figure 2.4. Rainfall and rainfall duration at locations with HRBP trials.
Columns - monthly rainfall in mm.
Roman figures - total annual rainfall in mm.
Italic figures - rainfall duration in days.

2.6. Conclusions

- Wheat can be produced in Zambia, but break-even yields can not be obtained throughout the country. Soils, climate and relief are of importance for yield.
- Actual and maximum yields have been increasing for all major cropping methods of wheat since 1954.
- In general, technical solutions can be found for most of the problems associated with irrigated wheat. Other cropping methods present problems which may be difficult to solve.
- Increased wheat production in both the rainy season and the irrigation season seems feasible. Conditions (soil, human) seem to be present for an expansion of wheat production, particularly near the railways and in the North Western and Eastern Provinces.
- Wheat can be produced by all categories of farmers. The question of which categories of farmers should be encouraged to produce wheat remains unanswered.

3. MATERIALS AND METHODS

A wheat improvement programme was initiated and developed using local facilities (finance, personnel, infrastructure). The materials and methods used, with the exception of those related to breeding (Chapter 7), are described in this Chapter. The objectives of the HRBP were new, but working conditions were not always modern. The materials and methods applied were the result of a process of development, based on local working conditions and local requirements (farmers, input levels). A similar programme elsewhere would inevitably require modifications in materials and methods, when work conditions and breeding objectives differ. This Chapter discusses agricultural practices (Section 3.2), diseases and pests and crop protection (Section 3.3), collection of agronomic data (Section 3.4), pest and disease assessment (Section 3.5), reference cultivars (Section 3.6), design of trials (Section 3.7), and data processing and analysis (Section 3.8). Some diseases and pests mentioned in this Chapter were of minor importance in Zambia during the period covered by this report.

3.1. Seed material

Cultivars and lines. The term cultivar is used in accordance with the International Code of Nomenclature for Cultivated Plants (1980), "it denotes an assemblage of cultivated plants which is clearly distinguished by any characters (morphological, physiological, cytological, chemical, or others) and which, when reproduced (sexually or asexually) retains its distinguished characters".
The term line refers to descendants through self fertilization of a single plant obtained by at least 5 generations of selfing. All members of a pure line (7 generations of selfing) are of the same genotype and are homozygous within the limits set by the probability of new gene mutations (Liegler, 1976).
No information about the percentage of cross-fertilization in wheat in Zambia was available. A hundred per cent self-fertilization was assumed.

There were 2 parent Groups; Group 1, composed in the 1976 IS, had 22 entries and Group 2, added in the 1977 IS to increase the total number of entries of the gene pool, had 12 entries. The entries with short names, such as Zambesi I and Condor, were commercial cultivars. Entries with names such as CNO'S'-Gallox... were lines grown only by breeders and agricultural institutes.

To study yields (Chapters 6 and 8) and resistance to diseases and pests of the newly bred material in relation to parent and foreign material (Chapters 4, 5, 6 and 8), 4 commercial reference cultivars (REFCVs) were selected, 3 parent cultivars and Jupateco 73 (Section 3.6).

The names of the cultivars and lines have been abbreviated to 3 letters, often the first 3 letters of the name (List of abbreviations and symbols). This cultivar code was used for the registration of material in trials, in the field, and in computer processing. Administration of the seed material also included codes for: trial, entries, seed origin, seed storage, breeding scenario, sifting and selection.

Breeding scenario and generations. The breeding scenario (Section 7.7) is recorded using a set of letters which indicate the type of generation produced during a certain season. The breeding scenario is composed of the letters: C for crossing generation; S or G for selfing generations; and O for not grown. A selfing generation between 2 crossing generations is indicated by S. The first selfing generation after a crossing generation produced with the intention of creating lines is called the G1. The generation index increases by one after every selfing. Thus in the second season of selfing after the last cross the

G2 seed is sown, and the next season the G3 seed, and so on.

Entry identification. Each cultivar, line, segregating population, or mixture used in a trial is called an entry. There were rarely more than 32 entries in a performance trial, and never more than 160 entries.

Seed origin. Entries in a performance trial were usuallly from one location only. The seed origin code, i.e. the series of letters indicating locations where the seed of a particular entry had been produced and one letter for each cropping season, was used to select entries produced at the same location.

Sifting and selection. Sifting was usually done just before sowing, using a sieve with triangular openings with sides of 4.5 mm, and only the largest seeds were retained. From 1979, a sieve was used with openings with a width of 3 mm. Threshed grain of unselected as well as selected heads was sifted.

Seed storage. If no control measures are taken, insects (Subsection 3.3.5) attack grain stored in paper as well as in plastic bags. As a result of temporary shortages of paper bags, grain was sometimes stored in plastic bags. These plastic bags favoured the development of fungi and several samples became mouldy and unsuitable for further use. Total spoilage of seed samples occurred, especially in grain which was moist because of early harvesting or late ripening; in grain in which green weeds, especially *Amaranthus* spp., were present; and in grain which was infested by storage insects. Total spoilage of seed stored in paper bags rarely occurred.

Seed harvested at the end of the RS and sown in the following IS suffered very little insect damage, because time was too short for insects to attack the seed severely. Seed harvested at the end of the IS had to be stored for several months until the next sowing and thus it was subject to insect damage.

Seed attacked by storage insects and fungi. Seed severely attacked by storage fungi was not sown in performance trials because its capacity to germinate was reduced. Seed severely attacked by storage insects, provided it had not become too mouldy, could generally still germinate to a certain extent and was sown for selection purposes.

3.2. Agricultural practices

3.2.1. Blocks and cropping methods

HRBP trials were performed in 8 blocks (Subsection 3.2.2) differing in cropping methods and soils. All crossing and part of the selection was done in the breeding block (BB) at NIRS. Selection was also done in the selection blocks (SBs) at NIRS, GV and MB.

The breeding block (BB) in the south-east corner of NIRS sloped upwards to the north and consisted of soils of the Mazabuka series. The southern part of the BB consisted of a sandy loam, and the northern part of a sandy clay loam. Selection block 1 (SB1) consisted of soils of the Nakambala series and included soils which were medium deep, 50 to 100 cm. In the BB several crops were grown, including horticultural crops, maize and sunhemp. Since 1976, wheat was virtually the only crop and it was grown as a single as well as a sequential crop. The largest part of SB2 consisted of soils of the Mazabuka series; soils of the western part belonged to the Nakambala series. SB3 consisted of soils of the Mazabuka series. In the southern part, the soil was a deep sandy loam whereas in the northern part it was a deep sandy clay loam. Water from the Kafue river was used for irrigation. It contained Ca and Mg carbonates (Aeppli, 1977 a). The pH values of the soil may be assumed to have increased since 1976 (Subsection 2.5.2).

In SB4 at GV, wheat had been cultivated before 1979. In SB5, soybeans had been ploughed back in 1979-80 RS after drought. Trifluralin (Treflan) was applied to the soybeans, presumably at the rate of 5 l/ha. The wheat sown on this soil developed normally. The soil at GV was a Makeni clay loam (Spaargaren, 1969). Water for irrigation was drawn from bore holes. No chemical analysis of the water was available.

SB6 at MB had a virgin soil with a pH of 4.3 (Slørdal, 1978). Land was cleared of trees in May and June, 1978, and the wood windrowed and burnt afterwards. In 1979, the strip with ashes passed through part of the plots, thus giving soil variations within plots. The soil was a Konkola sandy clay (Slørdal, 1978). In SB7, lime was applied to raise the very low pH level.

3.2.2. Land preparation

During RS at NIRS, land was prepared occasionally by means of ox-drawn plough and spike harrow, or by hoe only. Usually, during both RS and IS, tractors were used to prepare the land. As the sowing was done by hand in the trials at NIRS and GV, a fine seed-bed was required. Land preparation was, therefore, intensive. All preparations were done twice: ploughing, disc harrowing, treatment with the cultivator, and sometimes spike harrowing and/or treatment by rotavator. Successive preparations were done crosswise. It was not always possible to do the land preparation properly, resulting in coarse and uneven seed-beds. As land of the BB at NIRS sloped slightly, contour ploughing was necessary to prevent erosion.

In the IS, ploughing was done 2 to 3 days after 4 to 6 hours of irrigation, as moist soil is easier to prepare than dry soil.

Sunhemp was ploughed back at 25% flowering. Maize and sunflower stubble was ploughed back, but stems were removed from the fields. Wheat straw was burnt to avoid delays in ploughing and to obtain a flat seed-bed. In the selection blocks wheat straw was occasionally ploughed back.

3.2.3. Sowing

Sowing periods. In the RS, sowing was not restricted to the optimum period (Aeppli, 1977 b). At NIRS and GV, it was done between December and March. Wheat sown in February and March was often partly irrigated to avoid extended periods of drought stress. At MB rainfed wheat was sown in January and February. At MB, the rains stopped at a later date than at NIRS and GV, thus allowing rainfed wheat to be sown until February at MB but not at NIRS and GV.

In the IS, sowing was done between April and July. The sowing period sometimes extended into July because sowing was done by hand and because there were many plots to be sown. Another reason for sowing in June or July was that some rainfed wheat or partly irrigated wheat was harvested in June or July.

Methods of sowing. Most farmers use the recommended spacing of 18 to 22 cm (Moono, 1980). This spacing was also applied in the HRBP.

Seed rates during the RS were somewhat higher (up to 225 kg/ha) than during the IS (up to 150 kg/ha) to compensate for poor germination and low tillering at high temperatures. No corrections were made for thousand kernel weight at sowing (TKWp), which varied considerably between genotypes (Subsection 6.6.2) and seasons, because seed weight (seed rate) had little effect on yield (Aeppli, 1977 b; Moono, 1980).

Before sowing the plots were marked by wooden or iron pegs. The wooden pegs were sprayed (Dieldrin 75% WP), to prevent termite attack. Iron pegs were painted so that they could be easily recognized. Marking of the plots, and sowing, were done on a dry topsoil. At NIRS and GV, sowing was done by hand according to the single drill or the rake method. In the single drill method, drills were made with an iron rod pushed along a rope. The end of the rod was bent and had a sharpened point. Ten labourers could sow 320 plots in one day. After 1979 IS, drills were made with a wooden 6-drills marker enabling 4 labourers easily to sow 200 plots in one day. Sowing was done by 2 to 4 experienced sowers. The seed was covered with soil using a garden rake or an iron rod.

Sowing by machine was standard practice for large crossing plots, G4 and later generations grown on a large scale. At MB, sowing was done by machine; spacing was 20 cm.

3.2.4. Fertilizer application

At all locations fertilizer was applied twice, a basal dressing at the time of sowing and a top-dressing at tillering (30 DC, according to Decimal Code (Zadoks et al., 1974)), 4 to 6 weeks after sowing. Various types of fertilizers were used because the availability of fertilizers varied between years and locations. At NIRS and GV, fertilizers were usually applied by hand at sowing and incorporated into the soil using a Dutch hoe or an iron bar. Occasionally, fertilizer was spread with a Vicon distributor or applied by machine before discing. The basal dressing was usually a compound fertilizer. Top-dressing was with a fertilizer containing nitrogen only. At NIRS, during several RSs and during the second cropping period of 1977 IS no top-dressing was applied as its usefulness seemed dubious. At MB, part of the basal dressing was applied with the seed and the remainder was spread and harrowed immediately after sowing. Boron (Solubor) was applied as a top-dressing in 1980, sprayed 5 weeks after sowing. To increase the pH, lime applications of 2 mt/ha were incorporated into the soil at MB in August 1979.

3.2.5. Irrigation

Introduction. Sprinkler irrigation was standard practice at NIRS and GV. The riser height was about 1.0 m, and the distance between sprinklers 12 by 12 m (Figure 3.1, Section 3.7). Irrigation was controlled by trained teams. It was not always possible to irrigate an entire trial in one day. Due to the heavy demand on the limited number of pipes trials sometimes had to be irrigated with only one or 2 lines of sprinklers. The pipes were, in some cases, moved immediately after irrigation, causing disturbances of the soil. The sprinkler at the end of a line did not always extend outside the trial area, so edges received less water than the remaining area. At times, leakages at pipe joints or disconnected risers caused a high local water output, which disturbed the soil structure.

The filling of the soil to field capacity was completed after sowing. To permit germination, the first irrigation treatment was given immediately after sowing, and the second one, 3 to 5 days later.

NIRS. During IS at NIRS, cumulative net application of water differed between sowing dates (Section 6.1) and between years (Table 6.2). The average gross application rate was 9 mm/h, varying from 6 to 10 mm/h, and the net application rate 6 mm/h. From 1976 to 1978, water applications were moderate to high while in 1979 and 1980 they were moderate to low, to test the performance of wheat under varying moisture conditions. Low applications during the generative stages of wheat resulted in stress, which manifested itself in leaf drooping or curling during the daytime. Irrigation intervals were fixed at 7, 10 or 14 days, beginning with 4 h/application, and increasing to 6 h after booting (50 DC).

To stimulate development of rusts, applications were made at shorter intervals and, when necessary, before application of 2-chloroethylphosphonic acid (Ethrel). Immediately after application of top-dressing, the fields were irrigated for 1 to 2 h to dissolve the top-dressing and to allow the nitrogen to be taken up by the soil. The crop was not irrigated for 2 days following an Ethrel application.

GV. During IS at GV, there were frequent but irregular light waterings of up to 4 h/application. The frequencies and total amount of water applied were not recorded. During the second half of March, 1980, the fields were irrigated every 2 days for less than 2 h/application with 7 applications in total. This was done also to favour rust development.

Supplementary irrigation was applied at NIRS and GV, during RS (Table 3.1). The crop was irrigated when rain was insufficient at development stages 47 to 64 DC. There was no supplementary irrigation in 1977-78 RS because of the continuously wet conditions. In 1978-79 RS at GV, one application of 3 h in February and one of 7 h in mid- March were followed by an application of 4 h every 10 days until the hard dough stage (87 DC).

Table 3.1. Irrigation in HRBP trials at NIRS during the rainy season, 1975 to 1980. One hour of irrigation equals 9 mm water gross or 6 mm net.

	1975-76	1976-77	1977-78	1978-79	1979-80
Hours	6	20	0	12-19	12-17

3.2.6. Crop production

In the HRBP, 2 crops were grown per year with the aid of irrigation. In one year, 3 successive crops of wheat were grown: one crop between January and April, one between April and September, and one between September and December. The cropping periods between sowing and harvesting were approximately 110, 140 and 100 days, respectively. The growing period, the period from sowing to ripening (93 DC), was about 10 days shorter than the cropping period. In all years, wheat was present in the field from December to October. In 1977, wheat was also sown in October at NIRS.

3.2.7. Harvesting

When all entries were ripe, the wheat was harvested by hand or with a plot-combine harvester. Single head selections were removed by hand, by breaking the stem or cutting. Individual heads were threshed by hand. From 1979 IS, samples required for the determination of agronomic variables were threshed with an electric head thresher. Plant selections and single drill (row) selections were cut with a sickle and threshed with an electric head thresher or by hand. Bundles of wheat from one plot were threshed with an electric home-made thresher. Moist wheat samples were dried in the sun before weighing.

During the RS, wheat of NIRS and GV was hand-threshed. At NIRS bundles were transported in gunny sacks to a permanent threshing place. In 1980, the GV harvest was transported in gunny sacks to NIRS for threshing. A 'Hege' combine harvester was used at MB. The IS plots at NIRS were usually harvested by a 'Walther Wintersteiger' combine harvester but because of mechanical breakdowns the wheat had sometimes to be harvested by hand. In 1980 IS, the wheat at GV was harvested with a 'Hege'.

3.3. Crop protection

Control of diseases, pests and weeds was deliberately restricted; pesticides were used only to a very limited extent. Crop protection was also incidentally restricted because land preparation was not always optimal; the timing was not always appropriate and labourers sometimes lacked training and equipment. From 1976 to 1978, the use of pesticides was restricted to study the short-term and long-term effects of 2-chloroethylphosphonic acid (Ethrel), without the influence of other agro-chemicals. From 1979 onwards, pesticides were used regularly to:

a) reduce labour in activities such as weeding,
b) reduce variability in yield trials as a result of damage to seed during storage and damage by weeds and termites during crop growth,
c) select lines and eliminate those which responded negatively to a specific treatment (Subsection 3.3.3).

3.3.1. Restriction of crop protection

To test the resistance of wheat to pests and diseases under a variety of conditions, including varying input levels, conditions with only few crop protection activities were simulated. Due to sub-optimal land preparation weeds were so abundant that they had to be controlled during the cropping period. Wheat was exposed to various degrees of competition from weeds; wheat with a low competitive ability could thus be eliminated. Crop rotation was restricted to test resistance to soil-borne pests and diseases and other possible pests and diseases, which may appear after repeated wheat growing. The use of pesticides was also restricted as much as possible to permit development of pests and diseases in the field and to avoid impairment of biological control.

3.3.2. Seed protection during storage

Seed for performance trials was given a pre-storage treatment with a mixture of Captan and Malathion (Captasan-M), which was applied at 2 g/kg seed. Captan is a stable organic fungicide, a dicarboximide with a non-specific fungitoxicity, compatible with most other pesticides, and non-corrosive and non-phytotoxic (Martin and Worthing, 1977). As a seed treatment it can repel seed-pulling birds (Ware, 1978). Malathion is a non-systemic insecticide and acaricide with a low mammalian toxicity and a brief to moderate persistence. There were no post-storage treatments of seed.

From 1979, seed was treated once or twice during the RS with Phostoxin, after strict safety precautions had been taken. This measure gave temporary control of storage insects.

3.3.3. Weeding and herbicides

NIRS. Before 1979, weeding was done by hand, and was sometimes continued until flowering (64 DC). A Dutch hoe was used with a blade of about 16 cm wide. During the RS, a strip of the main paths within the BB with a width of 0.8 m was left unweeded to prevent erosion. The weeds in the paths were kept short. A strip of 6 m wide around each block was disk-harrowed or rotavated twice per cropping season. The grass near the trials was cut twice during a cropping season, either by hand or by machine. These measures may have prevented leafhopper infestation of the wheat, thus reducing virus infection. From 1980 onwards, weed growth around trials was left undisturbed.

In 1977, small areas of nutgrass (Cyperus esculentus L. and C. rotundus L.) occurred in one block (SB1) at NIRS. Root nodules were dug up at the end of 1977 IS, when nutgrass had reduced wheat yields. During 1978-79 RS, nutgrass had spread widely in SB1 and also appeared in other blocks (BB and SB2). It became a threat to the uniformity of the trials. To control nutgrass, the isopropylamine salt of N-phosphonomethyl glycine (Roundup) was used before sowing of wheat. Roundup applied at 5 l/ha gave temporary control. After an application, trials could be carried out for one season without disturbance from nutgrass. When a mat of C. rotundus was present, 2 applications with an interval of 6 weeks did not give complete control, possibly because the chemical had less effect during the early development stages of nutgrass (Martin and Worthing, 1977). Roundup gave complete control of other weeds.

After 1979, 58% 2,4-D a.i. (Shellamine 7.2) was applied in most trials. Applied at rates varying from 1.5 to 3.0 l/ha, generally 2.0 l/ha, it gave good control of broadleaves but not of grasses and sedges. Development stages at the time of application varied from seedling growth to stem elongation (14 to 31 DC). 2,4-D only slightly damaged wheat entries, but some burning of the leaves occurred, and some lines responded by deformations.

GV. During 1978-79 RS, 2,4-D was applied at GV at 1.5 l/ha in some trials whereas others were hand-weeded. During 1979-80 RS, when 2,4-D was not well mixed with water, herbicide damage occurred: burnt leaves, deformations and sterility. During 1979 IS the wheat was hand-weeded. In 1980, a dual application of dichlofop 33% and 2,4-D, both at 2.0 l/ha, was given. Dichlofop 33% was applied just after emergence, and 2,4-D about 2 weeks later.

MB. During 1978-79 RS, herbicides were not applied at MB. The only weed present was an unidentified species of bracken. During the 1979-80 RS, dichlofop 33% was applied at the early post-emergent stage (11 to 13 DC) for grass control, and 2 weeks later 2,4-D was applied for control of broadleaved weeds, both at the rate of 2.0 l/ha.

3.3.4. Fungi and fungicides

Introduction. When HRBP began in 1976, stem rust and helminthosporium were thought to be the most important wheat diseases in Zambia. Several other fungi, however, cause yield losses in wheat in Zambia (Mounter, 1961; Angus, 1965; NIRS, 1975 a, b, 1976, 1977, 1979, 1980; Raemaekers, 1981 b). Stem rust (Puccinia graminis Pers. f. sp. tritici Eriks. & Henn.), leaf rust (P. recondita Rob. ex Desm. f. sp. triticina (Eriks. & Henn.) c.n.) and powdery mildew (Erysiphe graminis DC. f. sp. tritici E. Marchal) occasionally cause yield losses during the IS. Helminthosporium sativum Pammel, King & Bakke and Fusarium spp. frequently, and stem and leaf rust occasionally cause yield losses during the RS. Stem rust and leaf rust are discussed in more detail in Chapters 4 and 5. Diseases which rarely occur are: stripe rust (P. striiformis Westend.), leaf spot diseases (Septoria nodorum (Berk.) Berk. and S. tritici Rob. ex Desm.) and loose smut (Ustilago tritici (Pers.) Rostr.). An estimate can be made of possible yield loss caused by each pathogen (Table 2.4).

In HRBP no fungicides were used except in seed dressings. Stem rust, leaf rust, powdery mildew and helminthosporium were the most common diseases.

Stripe rust and powdery mildew require leaf wetness and daily mean temperatures of approximately 16 C for infection and development (Zadoks, 1961; Hendrix, 1967; Bruehl, 1967; Wiese, 1977); they are therefore unlikely to cause yield losses higher than 5% at lower altitudes during the warm RS. Stripe rust has been observed during the IS in the Northern Province (Mbala District) by Angus (1965), in the Central Province (NIRS, 1977), and the Southern Province (Muchinda, 1978). Powdery mildew has been observed during both RS and IS in the Central Province (Angus, 1965; Moono, 1980) and the Southern Province (NIRS, 1976, 1979).

Since 1976, powdery mildew has been almost absent at NIRS during the RS but present during the IS, appearing in only a few trials in July and August, and disappearing when the temperature began to rise in September. In 1979, there were significant yield reductions of JUP due to powdery mildew (NIRS, 1980). Powdery mildew has not been observed on plots of the HRBP at locations other than NIRS, and yellow rust has not been observed at all by the author.

Septoria nodorum, seed-borne and with a wide range of host plants (Shearer and Wilcoxson, 1980), can be imported or transported from one area to another. It can survive on wheat debris and possibly on wild plants and volunteer wheat. It may become a serious threat to wheat production in Zambia. The role of susceptible grasses is unknown, as is the distance over which inoculum can be carried by various agents, especially wind; spread to nearby fields is likely to occur (Shipton et al., 1971). Inoculum spreads by means of splash dissimination. Infection by *S. nodorum* depends largely on the air temperature and the period of high humidity after inoculation. Infection is reported to occur with periods of high humidity from 1 to 24 h (Shipton et al., 1971; Holmes and Colhoun, 1974). Requirements for infection are: a relative humidity at inoculation > 63%, temperatures 24 h after inoculation > 6 C, at least 4 h of relative humidity above 90% during the first 24 h after inoculation, not more than 4 h of relative humidity < 60% during the first 24 h after inoculation (Jeger et al., 1981). It follows that in the RS, when there are long periods of high humidity and leaf wetness, humidity is not probably a major limiting factor for infection and development. The expression of symptoms requires that the length of the humid period be at least 72 h and that the temperature is between 18 and 30 C (Shipton et al., 1971). Possibly, there is a certain amount of masking of *Septoria* spp. by necrosis caused by helminthosporium, *Pyrenophora* spp. and bacteria. During the IS, humidity may be a limiting factor to infection and symptom expression, as leaf wetness generally lasts for less than 24 h and air humidity is low.

S. nodorum is a common disease in countries surrounding Zambia, where damage to rainfed and irrigated wheat was recorded (Burton, 1927, 1928; Wallace, 1935). In Zimbabwe it had little effect on irrigated wheat (Cackett, 1972). Angus (1965) reported that *Septoria* spp. seriously attacked some cultivars in the RS. He isolated *S. nodorum* from rainfed wheat samples from the Northern (Isoka District) and Central Provinces.

Septoria tritici is not seed-borne, and it has a narrow range of host plants (Brokenshire, 1975 a, Shearer and Wilcoxson, 1980). It may survive, however, in the remains of dead wheat (Brokenshire, 1975 b) and on volunteer wheat. Infection is favoured by temperatures between 16 and 21 C (Shipton et al., 1971), 35 h of leaf wetness after inoculation followed by 48 h with high humidity. Infection only occurs if free water is present for at least 15 h and if temperatures during the first 2 days after inoculation are over 7 C (Renfro and Young, 1956). The disease development proceeds for a wider range of temperatures (Shipton et al., 1971).

Present importance of leaf spot diseases. Although S. nodorum and S. tritici have been recorded at Mount Makulu and MB, they do not appear to be of any great importance. The 2 pathogens were not isolated from samples collected at NIRS and GV, although they may have been overlooked, as the search was not very intensive. Theoretically, the RS in Zambia should favour the development of S. nodorum and S. tritici; therefore, the diseases should be considered potential threats to wheat grown during the RS.

Control of leaf spot diseases. Cleaning of seed is likely to prevent the spread of S. tritici by straw and other parts of wheat. Practices such as crop rotation and removal of straw are likely to give good results. Quarantine measures may help to control S. tritici and S. nodorum.

Tolerance tests under field conditions have given useful results (Shipton et al., 1971). Resistance has been shown to be inherited, and governed by one or several genes, for S. nodorum as well as for S. tritici (Narvaez and Caldwell, 1957; Shipton et al., 1971; Eyal et al, 1973; Eyal, 1981).

Loose smut is seed-borne; it infects the wheat heads at flowering. Optimum air temperature for infection is 15 to 20 C with 75 to 100% humidity. (Holton, 1967). Symptoms were observed in the RS and the IS in the Central Province (Angus, 1965), Southern Province (Angus, 1965; NIRS, 1976) and Western Province (Offergelt and De Milliano, 1979). Resistance of local cultivars to the disease may explain the low importance of loose smut in Zambia (Angus, 1965). To control the disease, healthy seed should be used. In HRBP, loose smut was only observed at NIRS and only on a few parent genotypes such as EMU and BOB; few plants showed symptoms. The disease was not observed after 1979.

Other fungi have been recorded but were of little or no importance in HRBP fields. Angus (1965) isolated Sporidesmium sp. and Periconia byssoides Pers. & Schw., associated with helminthosporium, and Fusarium spp. Raemaekers (Zam-Can, 1980 a) recorded Sclerotium rolfsii (Sacc.) Curz. and the saprophytes Alternaria alternata (Fr.) Keissler, Cladosporium herbarum (Link) Fr., Phoma glomerata (Corda) Wr. & Hochapf, Phoma sp. and Curvularia lunata (Wakker) Boedijn. Rhizoctonia solani Kühn was isolated from plants at GV by Raemaekers (1980-81 RS). Root rots caused by Sclerotium rolfsii Sacc., Fusarium culmorum (Smith) Sacc. and other Fusarium spp. were observed occasionally by Raemaekers.

3.3.5. Insects and insecticides

In HRBP, insecticides were used only for control of termites and American bollworm.

Aphids. The wheat aphid (Schizaphis graminum Rond.) was observed in wheat in Zambia as early as 1938 (Angus, 1965). In the late 1950s, damage occurred in susceptible cultivars after attack at early stages. However, resistance was common, as were natural enemies (Mounter, 1961). In HRBP at NIRS, unidentified green, pink and dark purple aphids were present at low levels (less than one aphid/culm) throughout the year. They reached moderate to high levels (over 20 aphids/culm) only in susceptible cultivars (e.g. GIZ) during the 1977, 1978 and 1980 ISs. Mortality due to predators (larvae of ladybirds) and parasites (braconid wasps) has been observed. At other locations aphids were present at low levels only.

Harvester termites were present at all locations of HRBP throughout the year, and attacked wheat at all stages of development as well as harvested wheat in sheaves. Attack before booting had no serious effect, because of compensatory tiller production. After heading, attack caused more damage because there was no compensating growth. To prevent termite damage, wheat sheaves could be left in the field for a few days only.

Mounter (1961) stated that subterranean termites were common, and may have been responsible for the failure of many attempts to grow wheat in the RS. For control he recommended seed dressings containing Dieldrin. Subterranean termites have been observed in HRBP at NIRS, since 1980. They attack wheat at the seedling stage and after booting. The termites bore into and hollow the stem from the base of the plant, and the head and stem become prematurely white. In 1979, damage occurred in several trials at GV. Until 1980, a spot application of Dieldrin 2% dust was used to control termites when the damage was first observed. In 1980 at NIRS, Dieldrin 75% WP was sprayed before sowing, at the rate of 60 g/20 l water. At GV it was sprayed at the rate of 250 g/20 l water, and at MB 'Dieldrex' e.c. was applied at 3 l/ha.

Stem borers. Mounter (1961) and Angus (1965) reported stem borer infestation of wheat during all seasons, but the percentage infestation was generally low. Symptoms caused by a dipterous stem borer and by Sesamia calamistis Hmps. (Noctuidae) were recorded by Mounter (1961). Raemaekers (Zam-Can, 1980 a) reported Sesamia sp. as a pest on rainfed wheat. Stem borers were observed in the Central Province on rainfed wheat (Angus, 1965; Zam-Can, 1980 a), in the Western Province on seepage wheat (Angus, 1965; Offergelt and De Milliano, 1979) and in the Southern Province on rainfed wheat (Angus, 1965). In the HRBP, stem borers also caused premature white heads, the base of the stem remaining green. Stem borers occurred at NIRS and GV in the RS and the IS. No chemical control was attempted, because less than 1% of the culms were infested.

Maize leafhoppers. In Zimbabwe, Cicadulina storeyi China, C. mbila (Naudè) and C. parazeae Ghauri were shown to transmit streak virus to wheat (Cacket, 1972). In HRBP, Cicadellidae were present at NIRS and GV throughout the year. Streak symptoms often became visible 3 weeks after sowing. All entries appeared to become infected with this virus.

Leaf miners. Agromyza sp., possibly A. parvicornis Loew, also present in Zimbabwe, was first observed at MB in 1980 (Zam-Can, 1980 a). In HRBP, leaf miners were present at all locations throughout the year at very low levels.

The American bollworm (Heliothis armigera (Hbn.)) was not found in Zambia in 1965 (Angus, 1965), but was reported as a pest in rainfed wheat in 1979 (Zam-Can, 1979). The caterpillars attacked the grains in the wheat heads at GV during the 1980 IS, and at MB during the 1979-80 RS. At MB, they may have caused a small yield loss in trials before the application of Carbaryl at the rate of 2 kg/ha (87 DC).

Grasshoppers and sucking and piercing insects. The flood plains of the Kafue are known to have fairly large permanent populations of the red locust (Nomadacris septemfasciata (Serv.)). In 1964 the area was officially recognized as an outbreak area (Whellan, 1964). In the 1950s, grasshoppers and sucking and piercing insects attacked wheat throughout Zambia and there is one example of serious damage. In 1959-60 RS about 30% of the heads of one cultivar failed to set grain in the upper half, which died, and in some cases fell off. This damage is assumed to have been due to the insect piercing in the middle portion of the head (Mounter, 1961). A number of locusts and grasshoppers attacked the

HRBP crops, but no important damage appeared to occur. In 1980, edible grasshoppers (Homorocoryphus nitidulus (Scop.)) attacked irrigated wheat after flowering at GV, and rainfed wheat at Mount Makulu. At NIRS, elegant grasshopper (Zonocerus elegans (Thunb.)), green stink bug (Nezara viridula (L.)), irridescent bug (Calidea dregei (Germar)) and seed sucking Hemiptera were occasionally found in wheat. Red locust and other grasshoppers (Acridoidea), unidentified leaf eating caterpillars and some species of leaf-eating beetles of the genus Lagria were present throughout the year.

Leaf eating Coccinellids. During the 1976-77 RS, wheat was severely attacked after heading by Epilachna similis (Thunb.) at Kabwe Research Station.

Armyworm. During the 1977-78 RS, rainfed wheat was attacked at the tillering stage by the armyworm (Spodoptera exempta (Wlk.)) at MB, but was able to recover through compensatory growth.

Beetles. Roots were attacked by the larvae of chafer beetles, Scarabaeidae (Zam-Can, 1979) and larvae of Melonthidae (Zam-Can, 1980 a).

Storage insects. In July 1980, maize weevils (Sitophilus zeamais Motsch.) were observed on wheat heads. During storage Indian meal moth larvae (Plodia interpunctella (Hbn.)) damaged seed by eating wheat germs. The larvae of the Angoumois grain moth (Sitotroga cerealella (Oliv.)) completed part of their life cycle in wheat kernels.

3.3.6. Nematodes

Damage from nematodes has been recorded at several locations in the Southern, Central and Northern Provinces (Zam-Can, 1979). Nematodes have also been recorded on seepage wheat in the Western Province. Anguina tritici (Steinb.) Chit. was found in the Southern Province in the Kafue Polder (Angus, 1965).

At NIRS no nematode symptoms were observed, with the exception of a few plants with wrinkled leaves, symptoms similar to those caused by A. tritici. No samples were collected for identification. At GV, in 1979-80 RS, stubby root symptoms were observed in some parts of a field with HRBP entries. At MB, particularly in the 1978-79 RS, wheat growth was stunted, and plants had stubby roots. After liming in 1979, stubby root symptoms did not appear; no explanation could be found. Unidentified nematodes were extracted from soil samples. A study of the nematode population in the 1976-77 rainfed crop at Livingstone (Southern Province) showed that similar symptoms were caused by the ectoparasites Longidorus sp., Xiphinema sp. and Paratrichodorus sp. (Zam-Can, 1979).

3.3.7. Other harmful agents and their control

Bacteria. In 1980, Xanthomonas campestris pv. translucens (Jones, Johnson & Reddy) Dye, also known as black chaff, and Pseudomonas syringae pv. coronafaciens (Elliot) Young, Dye & Wilkie, or bacterial blight, were recorded by Raemaekers at Mount Makulu. Resistance of entries to these bacterial diseases varied, but many were susceptible (Zam-Can, 1979, 1980 a). These bacteria have not yet been isolated from production crops.

Virus. In Zimbabwe, maize streak virus is considered a potential threat to irrigated wheat. Symptoms of the virus include stunting, a marked decrease in the number of heads formed, and development of chlorotic streaks along the veins. The streaks may join to form continuous yellow bands over the entire length of the leaf. The virus is transmitted by several species of leafhoppers. The insects remain infectious for a considerable period of time. Many grasses, including maize and barley, are hosts. Apart from resistance, the virus can be controlled by avoiding overlap of sequential susceptible crops, eliminating volunteer maize and careful weeding of grasses (Cacket, 1972). In HRBP, maize streak was present in wheat throughout the year at NIRS and GV.

Birds. Rainfed wheat does not usually suffer from animal and bird damage. This may be explained by the abundance of natural food supplies during the RS (Mounter, 1961). Finches do not form large flocks until April or May, so damage to December-sown wheat tends to be slight. Damage by birds has been reported, however, in the Northern Province, possibly caused by *Quelea quelea intermedia*, the main bird threat to cereals in the province (Jones and Pope, 1977).

Damage by birds to irrigated wheat has been reported in the Central and Southern Provinces (NIRS, 1975 a, b, 1977; Jones and Pope, 1977), but is generally < 5% (Jones and Pope, 1977). Two subspecies of red-billed Quelea may cause serious damage to wheat in Zambia. *Q. q. intermedia* is found mainly in east Africa; it also occurs in the north of Zambia. *Q. q. lathami* occurs throughout the rest of southern Africa and also in the middle and south of Zambia. The birds migrate and return to Zambia from February through to April (Jones and Pope, 1977). Serious crop damage occurs only in years in which the Quelea population is high. A massive influx of breeding birds may result in high reproduction. As a result the natural seed supply is exhausted early in the season (Jones and Pope, 1977). The Zambian Government has taken measures, including purchase of avicides, to be able to control serious Quelea outbreaks. Damage by seed eating birds, such as weavers (*Ploceus* spp.), is less serious.

In most years irrigated wheat at NIRS and GV was attacked by *Q. q. lathami* and weavers. The birds seem to prefer wheat at the milky stage (70 to 80 DC). At NIRS damage was confined mainly to field edges and to late-sown and late-ripening wheat, whereas at GV early heading wheat was damaged. A wire mesh cage was constructed to prevent birds from attacking the selections. From early August to early September, people had to chase birds away, especially at sunrise and at sunset. At GV, partly rainfed wheat, sown late in February, was severely damaged (> 80% loss). Birds even stripped heads at late dough (87 DC).

Rodents and wild animals. There are no records available on serious damage to commercial wheat by rodents, though rodents were reported to cause damage to wheat trials (NIRS, 1975 a, 1976, 1977). Serious damage by wild animals has been reported occasionally (NIRS, 1975 a, 1977; Zam-Can, 1979). Damage by wild animals or cattle is of particular importance to wheat growers with less than 2 ha, as a few animals can destroy a substantial part of the crop.

In the HRBP fields, there was no control of rodents because they did little damage. Rodents were observed in irrigated wheat at NIRS only in 1976, and in partly rainfed wheat at GV in March and April 1979. These attacks were observed at the milky to soft dough stage (73 to 85 DC).

3.4. Agronomic observations

Agronomic observations were made
a) to obtain information about crop development and crop growth in Zambia, and thus gain a better understanding of the type of wheat required for production and selection,
b) for purposes of selection.
Agronomic observations made in the field were stand (Subsection 3.4.2), crop development (Subsection 3.4.3), plant height and shoot weight (Subsection

3.4.4). Germination (Subsection 3.4.1), number of spikelets/head (Subsection 3.4.4), number of kernels/head (Subsection 3.4.5), grain weight per plot (Subsection 3.4.4) and weight of kernels/head (Subsection 3.4.5) were determined in a laboratory. The derived variables calculated by computer include: actual emergence, expected emergence, realized emergence, number of heads/plant (Subsection 3.4.2), days to 50% heading (54 DC), days to early ripening (90 DC) (Subsection 3.4.3) and harvest index (Subsection 3.4.4). The computer was used also to calculate the number of heads/m2 (derived from heads/m), yield in mt/ha (Subsection 3.4.4) and thousand kernel weight at harvesting (Subsection 3.4.5). The names of the variables were abbreviated to codes used in calculations by the computer (List of abbreviations and symbols).

3.4.1. Germination

Germination, expressed as a percentage, was tested at the Seed Testing Laboratory at Mount Makulu, Chilanga, using 4 replicates of 100 seeds per entry. Germination was tested of seed from plants with different stem rust severities (Subsection 6.2.2).

3.4.2. Stand and emergence

Stand was assessed several times during crop development. Each plot was assessed independently by 2 observers. One or 2 stand counts were made, 8 to 15 days after sowing. A stick with a length of 1 m was placed at random along a row and the number of seedlings/m was counted (NOP). The actual emergence (AEM), number of plants/m2, was calculated with

$$AEM = ANOP / SDIS \qquad (3.1)$$

where ANOP is the average number of plants/m, and SDIS the distance between drills in metres.

The expected emergence (EEM), i.e. the number of plants expected in a 1 m2 plot according to seed rate and thousand kernel weight, was calculated as

$$EEM = SERT / TKWp \qquad (3.2)$$

SERT is the seed rate in g/m2, TKWp the thousand kernel weight at sowing in grammes.

The realized emergence (REM), the actual emergence divided by the expected emergence, was calculated as

$$REM = AEM / EEM \qquad (3.3)$$

REM gives an indication of the condition of seed-bed and topsoil. It is low when the seed-bed is coarse or the topsoil dry, or when soil temperatures are high.

During further crop development, up to 6 stand counts were made, beginning immediately after heading. Generally, only 2 counts were done, the first 20 days before ripening (93 DC), and the second a few days before harvesting. A stick of 1 m length was placed at random along a drill and the number of heads/metre was counted (NOH). Each plot was independently assessed by 2 observers. The mean number of heads per m2 over 2 observers (ANOH) was calculated. The average number of heads/plant (ANOT) was calculated as

$$ANOT = ANOH2 / AEM \qquad (3.4)$$

where ANOH2 is the average number of heads/m2 at harvesting. ANOH2 was a selection criterion. ANOT was used as an indicator of tillering conditions, a high number of heads/plant indicated good conditions for tillering.

Lodging, another selection criterion, was assessed just before harvesting, one assessment per plot. Three categories were distinguished: lodged, slightly lodged and not lodged. Straw that had an inclination < 54 degrees (0 being completely lodged) was classified as lodged, straw at an angle of about 72 degrees as slightly lodged, and straw standing upright as not lodged. Physiological and pathological lodging occurred in both the RS and the IS. Physiological lodging occurred only in tall and medium strawed entries sensitive to rainfall or heavy irrigation. Pathological lodging occurred in all entries, and was caused by stem rust or by helminthosporium.

3.4.3. Crop development

Crop development (DVS) was assessed by means of the Decimal Code (DC) (Zadoks et al., 1974). Before 1979, the mean, maximum and minimum DVSs were assessed, from 1979 only the plot mean. The mean and the maximum were highly correlated. The minimum value gave little additional information. In crop development studies many assessments were made during the cropping period. In other studies, only 2 assessments were made, one around heading (54 DC) and one at ripening (93 DC). Days to 50% heading (54 DC) and days to early ripening (90 DC) were determined by interpolation and used as selection criteria.

3.4.4. Crop growth

Crop growth was measured by means of the variables: plant height (PHT, in cm), shoot weight (SHW, g/plot), grain weight (GRW, g/plot) and number of spikelets/head (NOS). PHT, a selection criterion, was measured after flowering, in most cases just before harvesting. Two measurements were made per plot, in cm, and the awn length was included. APHT is the mean of 2 observations. Very few entries were awnless.

SHW was determined just before threshing, only if wheat had been cut by hand. The harvest index (HAI), calculated as

$$HAI = GRW / SHW \qquad (3.5)$$

was used as a selection criterion. HAI may vary with moisture content, which was not determined.

Number of spikelets (NOS), another selection criterion, was counted for 30 heads/entry, by 5 people, each making 6 head counts/plot. The average number of spikelets/head (ANOS) was then calculated.

GRW was determined immediately after threshing and cleaning. Before harvesting, heads of offtypes were removed from plots with lines or cultivars. The weight of heads/m2 harvested before final harvesting (WHH) included kernel weight of offtypes, and kernel weight of heads removed for assessments. Grain yield (GRY) was expressed in mt/ha and was calculated taking into account WHH, and actual number of drills sown (NOD).

3.4.5. Yield components

The components of GRY are number of heads/m2 and grain weight/head. The components of grain weight/head are number of kernels/head and kernel weight. Immediately before harvesting, 5 to 10 heads, a total of 30 per entry, were taken from each plot. The n heads from one plot were threshed and cleaned and kernels were counted (NKn) and weighed (KWn, in g). Before 1980, kernels were counted by 5 people, each making the same number of readings per plot. From 1980, the kernels were counted with a Numigral grain counter for wheat (Waterreus C.V.). The kernels were counted twice, and the mean was recorded. The thousand kernel weight at harvest (TKWh, in g) was calculated as

$$TKWh = 1000 \times KWn / NKn \qquad (3.6)$$

The thousand kernel weight at sowing (TKWp, in g) was determined by weighing 6 batches of 100 kernels from each entry.

3.5. Pest and disease assessment

Pest assessment. Assessments were made of pests which seemed to cause damage. Variables recorded per plot were: number of heads infested by stem borers (given by the number of dead heads, NDH) and percentage of area damaged by termites, by birds, or by rats. Damage by harvester termites and subterranean termites was recorded separately.

Disease assessment. Diseases assessed were stem rust, leaf rust, helminthosporium and powdery mildew. Non-destructive assessments were made of disease severity, plant response and disease incidence.

Disease severity was assessed using the disease assessment keys developed by James (1971). For stem rust on lower (PSL) and flag leaves (PSF), the key for powdery mildew was used. For helminthosporium the keys for Septoria leaf and glume blotch were used, as the symptoms indicated on these keys were the most similar to the actual symptoms. Severity was expressed as a percentage of the actual leaf, stem or head area. For each disease, several assessments were made during crop development for head (H), flag leaf (F), lower leaves (L) each and/or stem (S). Until 1979, disease was assessed by one observer. Since 1979, the value recorded was the mean of the assessments made by 2 observers. Disease severity at various developmental stages of the plant was determined by interpolation. Disease severity was used to estimate yield loss and was used also as a selection criterion.

Plant response to rusts was also used as a selection criterion. Loegering's (1959) scale was applied with one modification, namely that the code MS, moderately susceptible, also included small sized uredia with distinct chlorosis. In the 1976 IS and 1976-77 RS reaction types were determined for leaf and stem rust on different cultivars in the vegetative phase (10 to 23 DC). In the 1976 and 1978 IS, reaction types were also observed in the generative phase (60 to 77 DC). In the 1976 IS there were 10 observations/entry on 10 observation dates, without replication. In the 1978 IS there were 10 observations/entry on one observation date. As a result of selection, almost all entries in performance trials had infection types MS and S (susceptible), and no records were made of response to rusts after 1978.

Occasionally, disease incidence was scored, as for Fusarium spp. in the head at late dough (85 to 90 DC), or number of plants with symptoms resembling those of maize streak (NOM). The number of infected heads or plants was counted, and expressed as a percentage of the total.

3.6. Reference cultivars

The reference cultivars (REFCVs) ZAM, TOK and UMN were bred and put on the market in Zimbabwe in the late 1960s; JUP was bred by CIMMYT (List of abbreviations and symbols), and put on the market in Mexico in 1973. ZAM was developed from CIMMYT material. ZAM, TOK and UMN were among the commercial cultivars grown in Zambia in the 1970s, and were parent cultivars in the HRBP. ZAM and TOK were also used as REFCVs in trials performed between 1974 and 1977 (NIRS, 1975 a, 1975 b, 1976, 1977) and in Zimbabwe (Edwards, 1969; Alvord, 1972; Oosterhuis, 1972). JUP became a commercial cultivar in Zambia in 1978 for both the RS and the IS. ZAM was selected as a REFCV because of its comparatively stable yield (Figure 6.8), TOK because of its high leaf rust susceptibility, UMN because of its high stem rust susceptibility, and JUP because it gave very high yields during the IS, and relatively high yields during the RS.

3.7. Design of trials

The trials had a randomized design (1976-78), or a randomized block design (from 1979). From 1976, one 'field' contained 4 x 8 = 32 plots, with a total area of 12 x 12 m (2 irrigation pipes covered 12 m), designed to facilitate irrigation management (Figure 3.1). In the 1979 and 1980 trials, one replicate (statistical block), covered one or more of these 'fields' for irrigation. Most experimental variables had high coefficients of variation (CVs). To reduce variance the number of replicates was kept as high as possible, given the local conditions. Three replicates were used for G4 and G5 selections, with only a small quantity of seed, 6 for selections with larger quantities of seed; and 4 replications were used for HRBP lines in multilocational trials performed by the Research Branch.

Plot areas were 2.3 m2 (0.9 x 2.6 m) in 1976, 2.8 m2 (1.0 x 2.8 m) in 1977 and 1978, and 3.0 m2 (1.08 x 2.8 m) or 5.0 m2 (1.0 x 5.0 m), from 1979. At NIRS and GV, the plot area was equal to the harvested area. At MB, the harvested area was 3.0 m2 while the plot area was 5.0 m2.

3.8. Data processing and analysis

Statistical analysis was not sophisticated and could be done with only a pocket calculator. To process the large quantity of information collected and to obtain additional information, a computer was used from 1978. Data analysis by computer was sometimes delayed one or 2 years, because no adequate computer facility was available to HRBP. In the meantime, selection continued. Beginning with the 1979-80 RS, a copy of the observation sheet was sent to the Computer Centre of the Agricultural University in Wageningen, the Netherlands, and processed in a DEC10 computer (Digital Equipment Co-operation). Since 1981, data have also been processed in Zambia at the Computer Centre of the University of Zambia, in Lusaka, or at NIRS.

The punch card was chosen as a reliable and permanent medium for data storage and for feeding data into the computer. Every line of data on the observation sheet was punched into a computer card. All cards relating to one trial were kept together in one data set. For the transfer of the original data from the observation sheets to cards, in Wageningen, 10 card types were designed (Table 3.2). Cards contained information on the variable observed, but also additional information: year, season, block (each 1 digit code), generation, row, column or plot number (3 digit codes), card sequence (1 digit code), date of observation (day and month, 4 digit code), location (1 digit code) and variable observed (3 digit code).

Before the data could be analyzed by means of the computer, matrices of the data sets had to be reorganized. This was done by means of FORTRAN-10 programmes. In 1980, programmes became available that could regroup information of all card types.

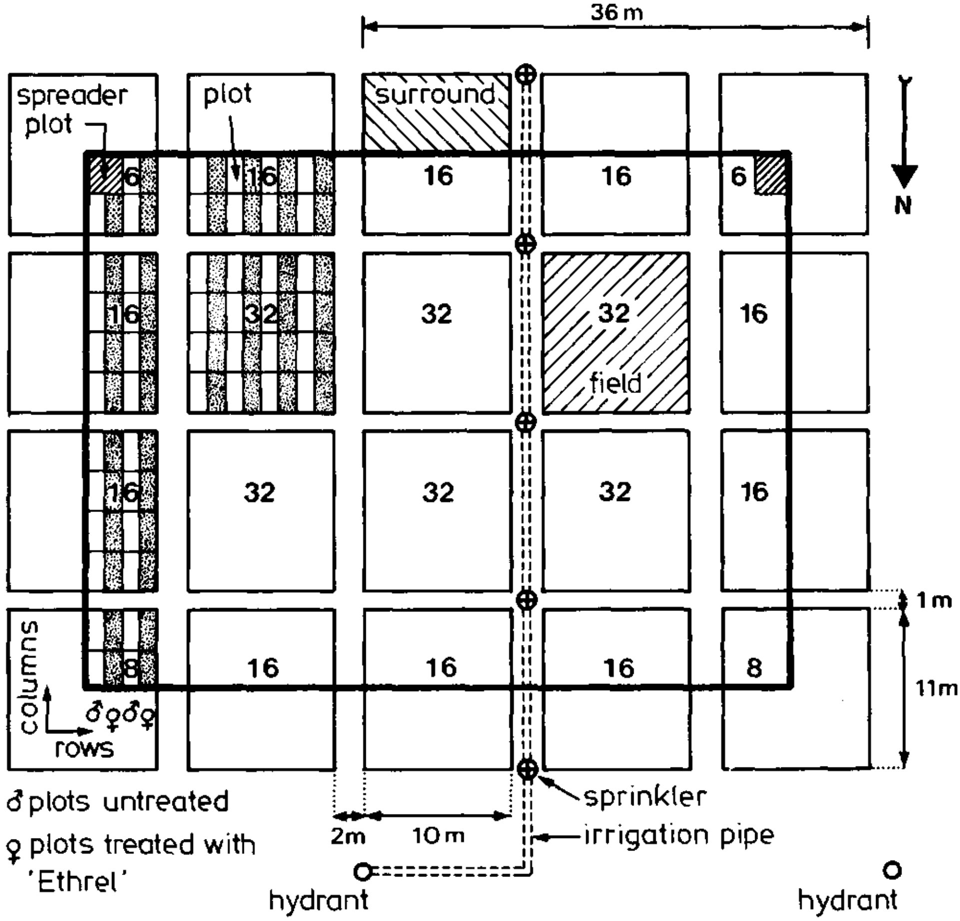

Figure 3.1. Lay-out of the breeding block (BB) of the HRBP, 1976 IS.

Data analysis was performed using SPSS, an integrated system of computer programmes designed for the analysis of social science data, but it can also be used for the analysis of agricultural data (Nie et al., 1975). SPSS provides the user with a comprehensive set of procedures for data transformation and file manipulation, and it offers a large number of statistical routines. Four statistical routines were used for data analysis; Breakdown, Oneway (SNK-test), ANOVA (two-way interactions excluded) and Pearson correlation. Breakdown was run for all variables to calculate mean, standard deviation and number of observations per entry. For some variables a Oneway analysis was performed (e.g. DVS, ANOH2) to obtain a ranked grouping of entries. For more detailed differentiation between entries for all variables used as selection criteria, a two-way ANOVA was performed for all entries and all replicates.

Table 3.2. Card types used to transfer data of the HRBP from observation sheets to punch cards. A card contains 80 digits.

Card type	Use	Number of digits	Card identification
1	Numerical observations < 1000	48 = 16x3	NOP, NOH, etc.
2	Grain weight with plot number	70 = 10x(3+4)	-
3	Numerical observations < 10000	56 = 14x4	-
4	Disease observations	50 = 10x5	PSS
5	Grain weight data in grammes	48 = 12x4	GRW
6	Yield components	22 = (5x3)+3+4	YCP
7	Scenario	2xn	GEC
8	Entry identification, seed origin	2xn	EID
9	Field lay-out	48 = 16x3	000
10	Field lay-out	48 = 12x4	001

In a second run, additional transformations (arcsine, or square root) were applied. A Pearson correlation coefficient was calculated to obtain information on the interdependency of variables.

3.9. Summary

- Within the organization of the Zambian Research Branch a programme to improve wheat was initiated and developed with local financing of materials, personnel and running costs. Materials and methods are described.
- A small team of 8 persons or less, ran the wheat improvement programme and performed multi-locational trials.
- The programme made use of various levels of mechanization and input, and attempted to simulate crop production conditions of emergent farmers as well as of large scale farmers.
- Not only stem rust and helminthosporium but also various other diseases and pests caused yield losses to wheat in Zambia. Several potential pests and diseases are discussed briefly.
- The sophistication of statistical analysis in Zambia was kept at the level of the pocket calculator.

4. STEM RUST

4.1. Introduction

Chapters 4 and 5 give information about stem rust and leaf rust, in particular the information to enable breeders in Zambia to make a balanced choice between the use of incomplete and differential resistance. Incomplete resistance may vary in the proportion of disease affected area. Rate of development of the epidemic as well as time of onset of the epidemic may be influenced (Parlevliet, 1979). The response is of the susceptible infection type in all development stages (Parlevliet, 1975), or is composed of different reaction types (Eskes, 1983). The inheritance of resistance reducing the rate of development ranges from a single gene to many genes (Nelson, 1978; Parlevliet, 1979). It is attempted to avoid simply inherited resistances. The type of resistance sought for has the characteristics of uniform (horizontal) resistance as described by Vanderplank (1963, 1968, 1975) and supposedly prevents large yield losses resulting from race shifts. Differential resistance is the resistance which gives high protection against at least one, but little protection against other isolates (or races) of a fungus (or a pest). The response often is of the hypersensitivity type, with necrotic tissue at the site of infection. Differential resistance may delay the onset of epidemics (Vanderplank, 1975) and may also reduce the rate of development of the epidemic (Parlevliet, 1979). As a result of a race shift, large yield losses may occur (Vanderplank, 1963).

Differential resistance implies a differential interaction between host and isolate genotypes. Uniform resistance implies that there is no such differential interaction. The type of resistance can be determined by a test for statistical interaction (ANOVA) or by a test for constant ranking (Vanderplank, 1968). The ranking test appears to be preferential (Vanderplank, 1968; Parlevliet, 1976 b). The type of resistance required may differ according to the local situation, and consideration should be given to the frequency of rust occurrence, the frequency of race shifts within the country and in neighbouring countries, and yield losses. A race is defined here as an entity of a fungus (or a pest) distinguished from other entities by at least one major difference in relative resistance on a differential set of host genotypes.

Recent literature on stem rust in Zambia and in neighbouring wheat growing countries is reviewed. Races and race shifts are discussed (Section 4.2). Occurrence of stem rust in Zambia since 1974 (NIRS Annual Reports, Section 2.4.2), its development after inoculation, its development in relation to wheat development and date of sowing, the effect of overlapping production periods, and possibilities for perennation are discussed (Section 4.3). Resistance to stem rust of several parent genotypes used in HRBP and of some commercial cultivars, in Zambia and neighbouring wheat growing countries, is described (Section 4.4). Yield loss and its analysis are discussed (Section 4.5).

4.2. Importance

4.2.1. Zambia, 1950 to 1974

Mounter (1961) considered stem rust to be one of the main diseases of the rainy season (RS), next to helminthosporium, and the only disease of importance during the irrigation season (IS). Stem rust appeared occasionally (often together with leaf rust), wherever wheat was grown, from Livingstone in the south to Mbala in the north (Angus, 1965). Uredia and telia were produced on all parts of the plants and most epidemics caused some yield reduction. In susceptible cultivars the quality of the grain was impaired by shrivelling and in very susceptible cultivars total loss of the crop was observed. Spread in rainfed wheat did usualy not occur until late March or April (Mounter, 1961). In irrigated wheat rust did not usually spread extensively, until the second half of August, unless wheat was sown in February or early March.

Angus (1965) presumed an asexual infection cycle only, because no alternate hosts were found. No information is available on the origin of stem rust inoculum in Zambia or on the possible role of grasses and volunteer wheat. Rust appearance was irregular during the IS and severe epidemics were confined to certain localities for example, epidemics developed only to the east of Lusaka (Mounter, 1961). In the Kafue Polder, near NIRS, where 20 to 50 ha of wheat were grown each IS from 1954 to 1964, there was little or no infection in the first few years, but after a few years infection became common and severe epidemics occurred. Mounter related irregular appearance of stem rust to the small hectareage of wheat and the isolated situation of the fields. He considered the example of the Kafue Polder as an indication that, with an increasing hectareage of wheat, epidemics would become more important, especially when wheat areas would be large and continuous. He recommended breeding for resistance and rejection of wheat growing during the late RS.

Herd (1960) found only a few races; many of the available cultivars were immune or very resistant. It was thought likely that new races would appear severely attacking previously resistant cultivars so that replacement would become necessary. It was believed that breeding may keep ahead of new races.

4.2.2. Countries around Zambia

General epidemiology. In the wheat growing countries surrounding Zambia, stem rust is a disease of economic importance (Hogg et al., 1969). In the 1960s and 1970s the importance of stem rust resistance was stressed: for Kenya, Evans et al. (1969) and Pinto and Hurd (1970); for Mozambique, Mota (1971); for Zimbabwe, Herd (1960) and for Angola by Santiago (1967) and Barradas et al. (1974). In local breeding programmes stem rust resistance was an important objective.

Genotypes distributed by CIMMYT, such as Siete Cerros, Super X and Chenab 70, were used for breeding and production (Rajaram and Dubin, 1977). In Africa, these cultivars were resistant to stem rust, yellow rust, powdery mildew, loose smut, and bunt at the time of release. They were less resistant to leaf rust but reselection provided moderately resistant lines (Saari and Wilcoxson, 1974). Races of all 3 rusts appeared, however, that could attack these cultivars (Prescott, 1978). Resistance to leaf rust was generally found to be adequate but resistance to stem rust and stripe rust was usually inadequate. In areas, where race shifts are infrequent, the resistance of the CIMMYT wheats was thought to be adequate, but the sudden appearance of a stem rust epidemic during favourable weather was considered to be possible (Saari and Wicoxson, 1974).

In Kenya, the average time lapse between the release of a resistant cultivar and the first observation of a stem rust isolate with compatible virulence was estimated to be 4.4 years (De Pauw and Buchannon, 1971, 1974). No data are available on the average time lapse in other countries. Race shifts, the appearance of an old race after a long absence, the appearace of a new race, or the disappearance of a race, have been reported for Kenya and Tanzania (Harder et al. 1967), Mozambique (Fonseca, 1972, 1974) and Zimbabwe (Herd, 1981). In Zimbabwe the race position does not change as rapidly as in Kenya (Hogg et al., 1969). Since race shifts have occurred in neighbouring countries, it is possible that they have occurred in Zambia.

Due to the wide variation in cropping seasons, rust inoculum is present throughout the year in Kenya and Tanzania (Harder et al., 1972), and races have a good chance to perennate. Perennation may occur in Malagasy, Zimbabwe, Malawi, Zambia and Angola, which have 2 cropping seasons. In Mozambique, with only irrigated wheat, volunteer wheat is likely to suffer from severe competition from grasses, so only small quantities of rust may perennate, unless there are other hosts.

Pinto and Hurd (1970) suggested that in Kenya stem rust on wheat came from grasses. Surveys in Kenya indicated that the grass species investigated were not important in the epidemiology of stem rust, but no definite conclusion could be drawn as large grassland areas were not surveyed (Harder et al., 1972). In Zimbabwe, wheat is thought to be the only host. There is no barberry, nor have any wild grasses been found to serve as reservoirs of infection (Hogg et al., 1969). In the summer rainfall area of South Africa (SA), infection foci occur throughout the year on wheat (Hogg et al., 1969). Absence of an alternate host breaks the life cycle of the rust and eliminates the creation of new races by hybridization. Assuming that an alternate host does not exist in Africa south of the equator, new races in a specific country must be blown in, or appear locally by mutation, heterokaryosis, or somatic hybridization (Nelson et al., 1955; Zadoks, 1959; Johnson et al., 1967).

Airborne inoculum. Uredospores are known to survive long travels through the air and Puccinia paths occur in many parts of the world. The spores usually travel from a permanent source to another place or migrate between two areas (Hogg et al., 1969). In the 3 principal air streams in Africa south of the Sahara, uredospores may move in various directions (Figure 2.3). Many guesses but few real data are available about the transport of spores. Santiago (1967) did not know the origin of stem rust infecting wheat fields in Angola. He assumed local overwintering and oversummering. Guthrie (1966) reported that the north-east monsoon carried spores from the wheat growing areas of Ethiopia to those of Kenya, a distance of some 600 km, and the study of Harder et al. (1972) also suggests an exchange of inoculum between Ethiopia and Kenya or a common source of inoculum. They believed that rust inoculum, having travelled some 800 km from West Kilimanjaro over a dry savana to Njombe, could still infect wheat.

Races. Table 4.1 lists the "standard" races of stem rust found in some African wheat growing countries in 1970. The numbers of "standard" races per county was between 2 and 6. Several races were found in more than one country and this suggests an exchange or a common source of inoculum in the region (Hogg et al., 1969; Harder et al., 1972). Standard races 11, 34 and 40 were found in Ethiopia, Kenya and Tanzania. Other examples are: race 34 present in Kenya, Tanzania, Mozambique, Zimbabwe, Zambia, and Angola, but also in the Netherlands, Saudi Arabia and Morocco (Santiago, 1971; Antunes, 1972); race 21 and 194 in Mozambique, Malagasy, Zimbabwe and Angola. Races 21 and 222 were found in the same countries and also in Sudan, Tunisia, Morocco, Saudi Arabia, Israel and Europe (Santiago, 1971; Antunes, 1972). Race 21 is found in SA too (Hogg et al., 1969). Because SA and Zimbabwe have several races in common (Hogg et al., 1969) as have Angola and Zimbabwe, stem rust epidemics in Zimbabwe also may originate from these 2 countries, as was suggested by Hogg et al. (1969). In 1970, Zimbabwe and Kenya had differences in rust race spectra (Table 4.1). Hogg et al. (1969) suggested that Zimbabwe is not subject to spore showers from Kenya. Southward movement of spores may be hampered by the isolated situation of the wheat fields and the fact that the wheat area between Kenya and Zimbabwe is small, especially in Zambia (Table 5.1).

The number of races that can be detected depends on the differential capacity of the differential set used. The set of East African differentials is able to distinguish more races (EA races) than the "standard" set.

Table 4.1. "Standard" races of stem rust in some African wheat growing countries. EA races are grouped as subraces of standard races. EA means East Africa race number (Harder er al.,1972); + indicates identifications by Santiago (1970), Fonseca (1972), Herd (1981); ETH, Ethiopia; KEN, Kenya; TAN, Tanzania; MOZ, Mozambique; MAL, Malagasy; ZIM, Zimbabwe; ZAM, Zambia; and ANG, Angola.

Country	Year	Standard race											Total	
		11	15	17	21	34	40	83	143	194	222	295	Standard	EA
ETH	1970	EA 9				EA5	EA7						3	3
KEN	1970	EA15	EA10			EA5 EA13	EA7 EA8	EA18				EA4	6	8
TAN	1970	EA15				EA5 EA16	EA7 EA11 EA12		EA17			EA4	5	8
MOZ	1970				+	+				+	+		4	-
MAL	1970				+					+	+		3	-
ZIM 1)	1982			+	+					+			3	-
ZAM 2)	1975	EA15				EA13							2	2
ANG	1966				+	+				+			3	-

1) In 1981, only 2 stem rust races were found, race 34 and 222.
2) Only few rust samples were tested by the National Plant Breeding Station, Njoro, Kenya.

The 9 "standard" races detected in Kenya by 1979 could be differentiated into 19 EA races. The standard differential set underestimates the number of races. Race shifts may be overlooked, e.g. the presence of EA16 masks the disappearance of EA5 when using the standard differentials (Table 4.1).

4.2.3. Discussion

Assuming that neither the alternate host nor any grass hosts are present in Zambia, new races must be blown in from neighbouring countries, or appear locally. It is likely that airborne races are of great importance to Zambia. In the 3 principal airstreams, Zambia may receive inoculum from neighbouring countries, whose race spectra vary. The appearance of stem rust is variable in time and severity, particularly during the IS. With the use of differential resistance to stem rust, severe epidemics and heavy yield losses are likely to occur occasionally at lower altitudes. With an increasing hectareage of wheat, epidemics will probably occur more frequently.

4.3. Zambia, 1974 to 1980

4.3.1. Introduction

Unless stated otherwise, the present information refers to uredospores. An epidemic is any seasonal increase in the amount of a rust. Information concerning the period 1974 to 1980 is limited almost entirely to experimental fields with many genotypes (NIRS Annual Reports; Zam-Can Annual Reports; Raemaekers, 1981 a, b; Little, 1982). Some observers had received little training in the recognition of rusts under different growing conditions, so records may not always be accurate. There are no published data on quantities of rust spores in the air, or on the time of observation of the first sporulating pustule. Diseases were usually not recorded before flowering and/or ripening of the crop. Consequently, there is little information on disease development. This Section gives information on these subjects.

During the RS, stem rust was recorded in the Southern, Central, Lusaka and Northern Provinces. At NIRS and Mount Makulu, it occurred during at least 3 out of the 6 RSs of observation. At MB, stem rust did not occur every year. Epidemics had a patchy distribution, the rust occurred at one location but not at another. In early February 1977, it was observed at NIRS. In mid-February, it was absent from susceptible cultivars such as SA4, CON, SOH and CER at all Zambian wheat growing locations south of NIRS (Choma, Zimba and Livingstone) and at Kabwe. To the north of NIRS, at Mount Makulu, there was a trace. At the University Farm near Lusaka, it was present too.

During the IS, stem rust was recorded in the Southern Province at NIRS, Lusaka Province at University of Zambia, the Central Province at Mount Makulu,and GV, and in the Copperbelt Province at Munkumpu. In the Western Province, a rust was observed but not identified. At GV, one of the few locations with more than 2 seasons of observations, stem rust occurred at least once in 6 seasons. In the 1977 IS, it occurred at Munkumpu but not at NIRS.

Rust occurrence is variable and patchily distributed during both RS and IS. In Zimbabwe the occurrence is variable too (Hogg et al., 1969). Raemaekers (1981 a) had the impression that stem rust is usually more important during the IS than during the RS and that epidemics only develop towards the end of the IS.

4.3.2. Materials and methods

Inoculum. Artificial inoculation by means of spreader plants ensured the presence of stem and leaf rust, and sprinkler irrigation ensured the take-off of the epidemic. Local rust epidemics can thus be differentiated according to the way of introduction of inoculum at the take-off of the epidemic, which was either spontaneous or artificially induced, and the origin of inoculum, which was either local or from outside sources. Spontaneous epidemics are assumed to have appeared from outside sources.

There were 4 artificial sources of inoculum.

a. Point sources. One sporulating spreader plant (50-70 DC) of one cultivar was planted every 2 plots, on the main path, which was situated up-wind. The epidemic in the 1978 IS thus developed from 10 point sources.
b. Point sources. One sporulating spreader plant of one cultivar for every 2 plots along all main paths in the north-south direction. The epidemics at NIRS in 1979 and 1980 and at GV during the 1978-79 RS developed from such point sources. Spreader plants died within one week after transplanting.
c. Plot sources. In the 1976 IS, there were 2 plots with sporulating spreader plants of various genotypes, in 2 corners of the BB (Figure 3.1). The spreader plants were planted on 11 May 1976.
d. Field sources. Spores travelled from one trial to another, from RS wheat to irrigated wheat, or from irrigated wheat to irrigated wheat. In the 1979 IS at GV, epidemics developed in the irrigated wheat which was situated down-wind of the rusted rainfed wheat. This epidemic is described as 'artificial', with inoculum from local sources (Table 4.2), as the rust in the RS had been introduced from outside sources.

Spreader plants were obtained from: NIRS, 1976, 1979 and 1980 IS; Mount Makulu Research Station, 1978 IS, and 1978-79 RS; and University of Zambia Farm, 1979-80 RS. Since spreader plants came from several sources, different rust races may have been present. By using spreader plants of one genotype only it was attempted to introduce one race only, which was recommended for selection purposes (Parlevliet, 1983 a, 1983 b).

Rust increase was studied in the REFCVs UMN, ZAM, TOK and JUP. Assessments were made of severities on the stem, flag leaf and lower leaves, at different days after sowing. Three parameters were used to estimate rust increase: the terminal severity, the mean daily increment (MDI) and the logistic infection rate (LIR). Terminal severity requires least effort to be obtained, and has least explanatory value. MDI gives additional information as the time dimension is included but, as with the terminal disease severity, the shape of the disease progress curve is ignored. Use of LIR assumes regular increase of the disease severity, but the regression of ln (x/(1-x)) on time is purely empirical (Vanderplank, 1969). Within limits, logit lines adequately describe epidemics of a number of diseases such as *Puccinia striiformis* (Zadoks, 1961), *P. graminis* and *Phytophthora infestans* and (Vanderplank, 1963). The equations for MDI and LIR are:

$$MDI = \frac{x2 - x1}{t2 - t1} \qquad (4.1)$$

$$\text{logit } xt = \ln \frac{xt}{1-xt} \qquad (4.2)$$

$$LIR = \frac{1}{t2 - t1} \cdot (\text{logit } x2 - \text{logit } x1) \qquad (4.3)$$

x2 and x1 are rust severities expressed as a percentage of the area infected (for MDI) or as a proportion of the area infected (for LIR), on days t2 and t1. MDI and LIR can be calculated for every plant part separately. t2 (DAYPSS) is the Julian day at which the terminal severity of the stem rust was recorded or the Julian day of an earlier recording. MDI1 was calculated with t1 as the Julian day of observation of the first sporulating pustule (DAYFSP). DAYFSP is the Julian day of finding the first sporulating pustule of a spontaneous infection or the Julian day of introduction of spreader plants. MDI2 was calculated with t1 as the Julian day on which the host reached 35 DC, when at least 2 nodes are present: the stage at which rusts start attacking upper plant parts. In calculating MDI1 and MDI2, x1 was assumed to be 0% at t1.

For practical reasons the logistic infection rate was calculated making use of the linear regression Equation (4.4).

$$\text{logit } x = a_0 + a_1 \times DAY \qquad (4.4)$$

DAY being the time interval from approximately 40 days after sowing to harvesting. To facilitate comparison with stem rust data recorded with modified Cobb scale as e.g. by Vanderplank (1963), severities in Tables 4.5 and 4.6 were multiplied by 2. Then, LIR and log10 (x/(1-x)) were calculated (Vanderplank, 1963), and log10 (x/(1-x)) was plotted against DAY (Figures 4.1 and 4.2).

4.3.3. Occurrence

At NIRS, stem rust symptoms were absent during 2 out of 6 RSs and 2 out of 6 ISs (Table 4.2). Spontaneous epidemics did not always occur. When occurring their onset (DayFSP) at NIRS was in February or March and at GV in March.

During RS and IS, at NIRS and at GV, epidemics of stem rust (and leaf rust) developed after artificial inoculation and, if inoculum from outside sources had appeared after artificial inoculation, its effect would have been obscured by the artificial epidemics.

4.3.4. Rust development

At NIRS, stem rust developed during RSs and ISs. In some trials, up to 60% of the actual stem area of plants of the susceptible genotype UMN was covered (Tables 4.3 and 4.4). In RS, terminal severities were higher than in IS, except on very susceptible genotypes.

During RS, high severities (> 10%) on the stems of the highly susceptible UMN occurred after mid March; and on moderately susceptible genotypes, such as ZAM and TOK, in April, when the wheat was almost ripe (Table 4.4). In susceptible genotypes, such as UMN, TSS was lower in trials sown before 1 February than in those sown later, as result of a late appearance of the rust.

Table 4.2. Stem and leaf rust epidemics in HRBP, Zambia, with spontaneous (s) or artificial (a) inoculation, with inoculum from local (l) or outside (o) sources. DayFSP, date of observation of first sporulating pustule. For further explanation, see text. At MB, no wheat was grown in the irrigation season.

Location		Stem rust		Leaf rust	
	Year	Epidemic	DayFSP	Epidemic	DayFSP
	Rainy season				
NIRS	1974-75	absent	--	absent	--
	1975-76	s,o	11 Mar	s,o	11 Mar
	1976-77	s,o	5 Feb	s,o	8 Feb
	1977-78	absent	--	absent	--
	1978-79	a,o	16 Mar	a,o	16 Mar
	1979-80	s,o	14 Mar	a,o	25 Mar
GV	1978-79	a,o	21 Mar	a,o	21 Mar
	1979-80	s,o	31 Mar	absent	--
MB	1978-79	absent	--	s,o	29 Apr
	1979-80	s,o	9 Jun**	s,o	15 Mar
	Irrigation season				
NIRS	1975	absent	--	s,o	13 Jun
	1976	a,l	7 May	a,l	10 May
	1977	absent	--	absent	--
	1978	a,o	13 Jun	a,o	13 Jun
	1979	a,l	7 May	a,l	7 May
	1980	a,l	May*	a,l	May*
GV	1979	a,l	18 Jun**	a,l	18 Jun**
	1980	absent	--	absent	--

-- Not applicable. * Date not recorded. ** Approximation.

Table 4.3. NIRS, Rainy season, 4 REFCVs, Julian days of dates of sowing, and of stem rust recording, observation periods (t2-t1) in days, stem rust severity on stem (PSS) in % (James' Scale, 1971) at t2 (means of 2 to 6 replicates/genotype), and mean daily increments MDI1 and MDI2 expressed in per cent units per day.

Year	1977	1979				1980					Mean	Total mean
Date of sowing	3 Jan	5 Feb	15 Feb	7 Mar		1 Feb	12 Fe	19 Feb		10 Mar		
DAY of sowing	3	36	46	66	66	32	43	59	59	69		
DAYPSS = t2	80	136	136	123	180	99	140	132	150	141		
DAYFSP = t1	64	75	75	75	75	73	87	85	85	91		
t2 - t1	16	61	61	48	105	26	53	47	65	50		
	PSS at t2											
Umniati	20	45	45	4	50	0.001	29	33	50	25	30	
Jupateco 73	-	24	28	3	36	0.3	20	26	39	6	20	
Tokwe	5	18	19	5	33	1.2	8	14	21	12	14	
Zambesi I	2	14	19	8	25	0.2	10	15	31	11	14	
	MDI1											
Umniati	1.25	0.74	0.74	0.08	0.48	0	0.55	0.70	0.77	0.50	0.58	
Jupateco 73	-	0.39	0.46	0.06	0.34	0.01	0.38	0.55	0.60	0.12	0.32	
Tokwe	0.31	0.30	0.31	0.10	0.31	0.05	0.15	0.30	0.32	0.24	0.24	
Zambesi I	0.13	0.23	0.31	0.17	0.24	0.01	0.19	0.32	0.48	0.22	0.23	
Means MDI1		0.41	0.45	0.10	0.34	0.02	0.32	0.47	0.54	0.27		0.34
Means MDI2		0.46	0.62	0.62	0.52	0.01	0.33	0.83	0.77	0.52		0.48

Table 4.4. NIRS, Irrigation season, 4 REFCVs, Julian days of dates of sowing, and of stem rust recording, observation periods (t2-t1) in days, stem rust severity on stem (PSS) in % (James' Scale, 1971) at t2 (means of 2 to 6 replicates/genotype), and mean daily increments MDI1 and MDI2 expressed in per cent units per day.

Year	1978		1979							1980						Mean	Total mean
Date of sowing	14 May		19 Apr		8 May		14 May		29 May	22 Apr	30 A	15 May		23 M	6 June		
DAY of sowing	134	134	109	109	128	128	134	134	149	112	120	135	135	143	157		
DAYPSS = t2	226	247	169	177	208	242	208	233	270	240	246	238	258	244	280		
DAYFSP = t1	164	164	127	127	152*	152*	152*	152	171*	135*	135*	157*	157*	166*	182*		
t2 - t1	62	83	42	50	56	90	56	81	99	105	111	81	101	78	98		
	PSS at t2																
Umniati	5	60	11	19	25	40	6	8	15	34	33	35	32	40	18	25	
Jupateco 73	-	-	1.3	18	3	17	1	0.1	20	6	9	8	14	7	1	8	
Tokwe	0.01	7	0.6	14	2	12	0.4	1	8	20	13	4	12	12	7	8	
Zambesi I	1.5	2.5	0.4	9	2	8	0	0.01	11	9	6	2	11	6	-	6	
	MDI1																
Umniati	0.08	0.72	0.26	0.38	0.45	0.44	0.11	0.10	0.15	0.32	0.30	0.43	0.32	0.51	0.18	0.32	
Jupateco 73	-	-	0.03	0.36	0.05	0.19	0.02	0	0.20	0.06	0.08	0.10	0.14	0.09	0.01	0.10	
Tokwe	0	0.08	0.01	0.28	0.04	0.13	0.01	0.01	0.08	0.19	0.12	0.05	0.12	0.15	0.07	0.09	
Zambesi	0.02	0.30	0.01	0.18	0.08	0.09	0	0	0.11	0.10	0.05	0.02	0.11	0.08	-	0.08	
Means MDI1			0.08	0.30	0.15	0.21	0.03	0.03	0.13	0.17	0.14	0.15	0.17	0.21	-		0.15
Means MDI2			0.32	0.45	0.26	0.29	0.07	0.04	0.18	0.21	0.19	0.23	0.22	0.28	-		0.22

* Estimate

During IS, severities on the stem became > 10% after mid June. TSS in trials sown in June were lower than in those sown in April or May. Epidemics developed from few infection sources; the 1978 IS epidemic was initiated from 10 point sources in a wheat field of 66 x 50 m.

Foci were not clearly discernible in most epidemics at NIRS. Only in wheat sown on 1 February 1980, could focus development be seen. On March 14 (DAYFSP = 73) the first sporulating pustules were found on lower leaves in one plot of UMN only. 26 days later (DAYPSS = 99) the focus was still discernible, rust severity had hardly increased and no symptoms were found at a distance > 12 m.

Mean daily increments, MDI1 and MDI2, had high values in all 4 REFCVs in various trials, especially during the RS, when the rate of increase of stem rust tended to be higher than during the cooler IS. Values differed between trials and between (t2 - t1) periods. During IS, mean values of MDI2 from JUP, TOK and ZAM, did not differ significantly, but significant differences were found during RS (Wilcoxon, two-tailed test, S(9,10) = 60* and S(9,10) = 64*, respectively). Possibly, MDI2 values of JUP were relatively high due to a genotype x temperature interaction. MDI1 and MDI2 values were significantly correlated. For RS, Pearson's r of the REFCVs was 0.78*** (36 df, two-tailed test) and for IS, 0.91*** (53 df). Thus, MDI1 values are indicative for MDI2 values and vice versa. MDI1 values of JUP were also relatively high during RS, but differences were not as distinct as for MDI2 (Tables 4.3 and 4.4)

LIR for stem rust on the stem differed between genotypes, and their ranking order varied with sowing dates (Table 4.5). High values of LIR were found during both RS and IS. The linear regression of logit x on time was significant, in most cases (exception, e.g. TOK sown on 3 January 1977).

At GV, high terminal severities occurred in various trials during RS and IS (Table 4.6). In 1978-79 RS, high severities on the stem (> 10%) of moderately susceptible genotypes did not occur before late April, and in 1979 IS not before mid August. In 1980, sporulating pustules were observed in one plot of UMN sown 22 February. No rust was detected in the surrounding trials, and at ripening of the crop no rust was found at a distance of more than 6 m from the plot where rust was first observed. The severity within the focus had increased little.

Slow rusting occurred on the stem of TOK: LIR and TSS were low. In a commercial field of JUP at GV, sown 30 January 1977, stem rust developed to 21%, and as a result yield was < 1 mt/ha, TKWh was low (20 g), and ANOK moderately low (33 kernels per head). So during the RS, high stem rust severities may occur in commercial fields.

Table 4.5. NIRS, stem rust severities (James' Scale, 1971) and parameters of logit lines. For explanation see text and List of abbreviations and symbols.

Sowing date		Days after sowing 40	50	60	70	80	85	90	100	120	LIR	r2
3 Jan 1977		Stem rust on stems										
	UMN	2	5	8	-	-	14	18	-	-	0.05	0.91*
	ZAM	0	0	0	-	-	2	-	-	-	0.14	0.96*
	TOK	1	3	5	-	-	5	-	-	-	0.03	0.63
7 May 1976		Stem rust on stems										
	UMN	-	-	0.1	3	14	-	-	38	45	0.13	0.88*
	ZAM	-	-	0.1	0.5	2	-	-	9	14	0.08	0.93*
	TOK	-	-	3	5	6	-	-	11	15	0.03	0.98**

Table 4.6. GV, stem rust severities (James' Scale, 1971) and parameters of logit lines. For explanantion see text and List of abbreviations and symbols.

Sowing date	Days after sowing 43	51	84	86	112	125	126	133	LIR	r2
20 Feb 1979	Stem rust on stems									
UMN	0.01	2	25	-	-	46	-	-	0.10	0.91*
JUP	0	0	8	-	-	12.5	-	-	0.11	0.82
ZAM	0.01	0	10	-	-	9.5	-	-	0.08	0.71
TOK	0.01	0.001	10	-	-	15	-	-	0.07	0.92*
23 May 1979	Stem rust on stems									
UMN	-	-	-	0.5	32.5	-	42	40	0.13	0.90*
JUP	-	-	-	0	0.5	-	11	7.0	0.17	0.96**
ZAM	-	-	-	0	0.35	-	2	2.3	0.14	0.97***
TOK	-	-	-	0.25	1.5	-	10	6.5	0.08	0.92*

\- No assessments made.

Selection for a low rate of development. The onset of the epidemic, DAY with $\log10\ (x/(1-x)) = -2$, was always later in ZAM than in UMN (Figures 4.1 and 4.2). The progress of the disease (= rate of development of the epidemic) differed between seasons. ZAM did not always have a lower rate of development than UMN, but always had lower terminal severities. This demonstrates, that the selection for a low rate of development, as suggested by Vanderplank (1963), was not reliable in Zambia.

4.3.5. Crop development

During the RS, the period from sowing to early ripening (90 DC) lasts between 68 and 92 days and the period from early anthesis (60 DC) to 90 DC lasts 26 to 30 days only at locations with relatively high temperatures for wheat growth, such as NIRS (Figure 4.3). The duration of the period from sowing to 90 DC is between 90 and 120 days at locations with favourable temperatures and sufficient water for wheat growth. The period from 60 DC to 90 DC lasts approximately 45 days (Figure 4.4). The duration of the vegetation period increases with decreasing temperatures (Cackett and Wall, 1971), and thus increases with increasing altitude; so the duration of the vegetation period is longer at MB and GV than at NIRS. Since rust does not normally attain high severity levels before late March or April, wheat sown in December or early January has a good chance to reach the milky stage (70 to 80 DC) or dough stage (80 to 90 DC) before any serious build up of stem rust. It follows, that all but the most susceptible cultivars have a good chance of escaping serious yield losses. At MB, the relatively low temperatures will furthermore result in slower rust development.

During the IS, the duration of the period from sowing to 90 DC is between 110 and 150 days. At locations at altitudes above 1100 m, such as GV, the period from sowing to 60 DC may last up to 100 days, and the period from 60 DC to 90 DC lasts 30 to 59 days (Figure 4.4). At lower altitudes, as at NIRS, the period from sowing to 90 DC lasts 60 to 80 days and the period from 60 DC to 90 DC 40 to 55 days. At lower altitudes, flag leaves appear by mid June in all genotypes sown before 1 May. Severities $>$ 10% occurred by mid June after artificial inoculation. On wheat sown late in May and in June, the flag leaves appear after mid July, when conditions for infection become less favourable because of a decrease in the humidity of the air, and may thus escape high severities.

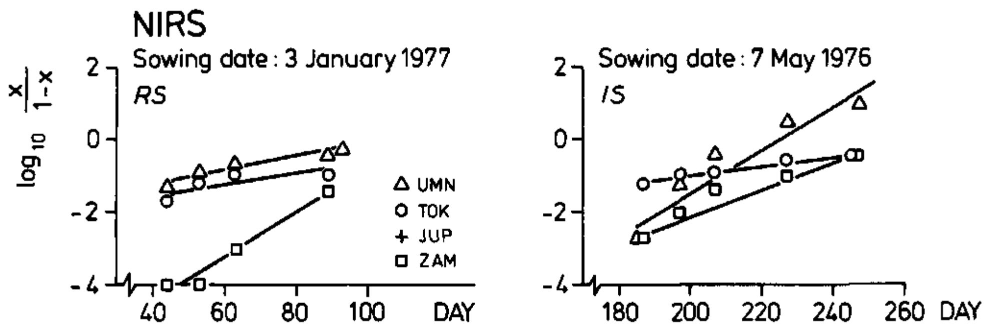

Figure 4.1. Progress of stem rust in wheat at NIRS. DAY means Julian day.

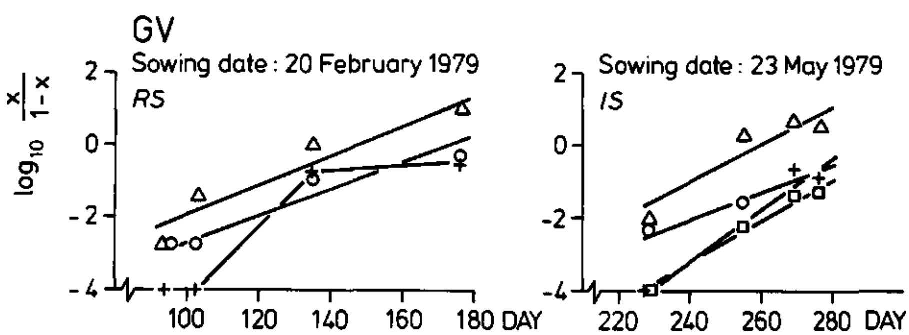

Figure 4.2. Progress of stem rust in wheat at GV. DAY means Julian day.

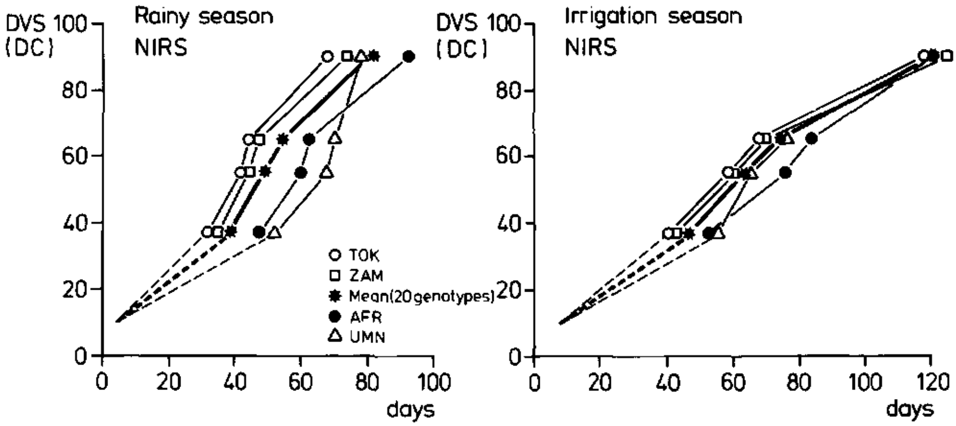

Figure 4.3. Crop development at NIRS during the rainy and irrigation season.

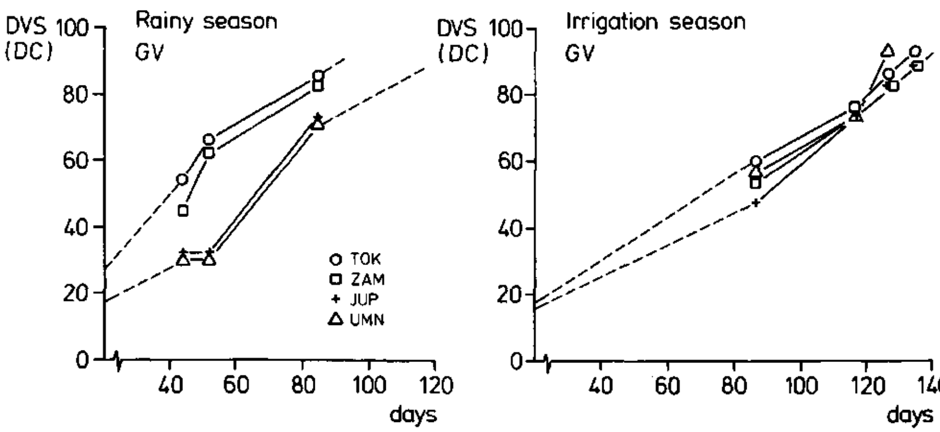

Figure 4.4. Crop development at GV during the rainy and irrigation season.

4.3.6. Overlapping production periods

In 1979 at NIRS, wheat was sown not only in February but also in March. Stem rust spread from one trial to another, and caused forced ripening in susceptible genotypes sown in March. Seventy days after sowing, up to 85% of the heads had died in the susceptible genotypes, and the vegetation period was reduced by almost 20 days. The best yielding genotypes gave a yield of only 1 mt/ha, most moderately susceptible genotypes gave a yield of 0.4 mt/ha, and susceptible genotypes even less. The calculated yield was between 2 and 4 mt/ha (Van Keulen and De Milliano, 1984). This example illustrates the danger of overlapping production periods of wheat, which occur in both the RS and IS. With increase in wheat hectareage, overlapping production periods may become common, thus increasing yield loss due to stem rust.

4.3.7. Perennation

From IS to RS. Except at a few locations, e.g. NIRS and GV, there is only one generation of wheat per year. For perennation, rust must survive on volunteer wheat or other hosts. It is not known whether stem rust perennates in Zambia from September to December (in the south) or February (in the north).

Chances for rust survival on wheat from September to December are thought to be low because of: microclimatic conditions which are unfavourable for infection; crop rotation (one wheat crop is rarely followed by another, and other crops are grown after wheat from October onwards); land preparation (volunteer wheat is often controlled by ploughing soon after harvest of wheat); almost no scattering in irrigated wheat, and thus there are few volunteer plants before harvest.

From RS to IS. Rust may spread from RS wheat to irrigated wheat. Presently, because of geographical separation of rainfed and irrigated wheat, isolated situation of fields, the small size of the total wheat area, and the variable occurrence of rust, spread from rainfed wheat to irrigated wheat is thought to be rare. Spread of rusts from RS wheat to irrigated wheat, however, may become important with an increase of wheat production.

The absence of rust during RS and IS at locations with 2 generations of wheat per year, including NIRS and GV, may indicate that there is little or no perennation. Absence of rust from susceptible cultivars at locations where wheat has not been grown commercially, such as Zimba, Choma and Kabwe (Figure 2.1), may indicate that airborne spores were absent, and may also indicate that rusts were not spreading from the local vegetation to wheat. With an increase of the wheat hectareage, chances for perennation are expected to increase.

4.3.8. Source-target relations

The trajectories of air masses are important for the movement of spore clouds over long distances, from a few hundred to a few thousand kilometres. Areas with wheat outside Zambia might be sources of inoculum of rust epidemics within the country. The area of wheat in Zambia is called the target area or target.
A major source-target relation is expected to occur when wheat hectareage at the source is large, when the source is up-wind of the target in the direction of one of the main trajectories of air masses, and when spores are produced in the source at the time of wheat production in Zambia. A minor source-target relation is expected to occur when the wheat hectareage at the source is small, when the source is situated in a direction deviating from the principal directions of the air stream(s), or when periods of wheat production at the source and at the

target have little overlap. Differences in source-target relations are expected to occur between the central and southern parts of Zambia, with an annual precipitation of 800 mm and below and the northern part of Zambia, with an annual precipitation above 800 mm.

The wheat hectareage in Zambia and countries around Zambia is discussed in Subsection 5.2.2. Information on the main periods of stem rust inoculum production at the various sources is not available, with the exception of Kenya (Green et al., 1970; Harder et al., 1972), Tanzania (Harder et al., 1972), Zimbabwe and SA (Hogg et al., 1969).

Rainfed wheat in the central and southern parts of Zambia. The first sporulating pustules of spontaneous stem rust epidemics were found in February or March. Major source-target relations are likely to occur with sources in Zimbabwe and South Africa. Minor source-target relations are likely with other wheat growing countries around Zambia.

Rainfed wheat in the northern part of Zambia. The first sporulating pustules of spontaneous epidemics were found in June. However, few observations were made and it is possible that sporulating pustules occurred earlier. Major source-target relations with Tanzania and Kenya are likely. At Njombe, in Tanzania, the main period of spore production is between May and July (Harder et al., 1972). At Kitale and Njoro, main periods of production occur before May.

Irrigated wheat in the central and southern part of Zambia. The first sporulating pustules of spontaneous epidemics were found in July or August. Major source-target relations are expected to occur with Zimbabwe and SA.

Irrigated wheat is not yet grown in the northern part of Zambia. When irrigated wheat will be introduced there, wheat areas in central and northern Mozambique and Malawi, may become major sources of inoculum.

4.3.9. Discussion and conclusions

Physical conditions for stem rust infection are favourable when there is free water in the form of dew, guttation or rain, and when temperatures are near to 20 C (Sharp et al., 1958; Zadoks, 1968; Kranz et al., 1977). At 20 C, the latency period is approximately 8 days. At lower temperatures it is prolonged up to 45 days (Mehta, 1923; Joshi et al., 1972). Certain phases of the infection process appear to be favoured by temperatures over 20 C (Sharp et al., 1958).

During RS in Zambia, temperatures are not so extreme as to entirely prevent infection. There is sufficient moisture, not only in the form of rain water or irrigation water but also as dew, and a high relative humidity (Figure 2.2). Symptoms of spontaneous epidemics were sometimes observed as early as March and April, but, also in February. This finding appears to confirm that stem rust does not normally spread until late March and April (Mounter, 1961). However, with an increase in wheat hectareage spread in February may become normal, especially in areas with extended dry periods.

At locations with an annual precipitation of 800 mm or less, e.g. Livingstone, Zimba, Choma, NIRS, Mount Makulu and GV, monthly mean air temperatures are usually above 20 C and periods with no precipitation last several weeks. These conditions favour infection. High severities did occur and severities were even higher than in the IS (Tables 4.3 and 4.4). Stem rust was not observed every year. Rust may be absent because there are no local sources of inoculum, or because of low inoculum densities. Supposedly, heavy rain to some extent prevents wheat to become infected in February and March, and rust dispersal is more common during days without rain. The 2 examples of wheat sown at NIRS on 1 February 1980 and at GV on 22 February 1980 indicate that spontaneous epidemics not necessarily result in high severities. In both cases, severities remained low on a very susceptible cultivar.

The locations with more than 800 mm annual precipitation vary in altitude. At Kabwe (Figure 2.1), the altitude is 1200 m, and monthly mean temperatures tend to be over 20 C. At Mbala, with an altitude of 1673 m, monthly mean temperatures are below 20 C, with monthly minimum temperatures of 14 to 15 C. Periods of one to 3 weeks without precipitation do occur, but are less frequent than in areas with less precipitation. At MB, conditions for infection appear to be relatively favourable, but stem rust severities remained below 5%. Infection may be limited by the lack of dew. Infective spores may be rare as the frequent rain showers wash spores from the leaves. Temperatures in the area are likely to lead to latency periods of > 8 days.

During IS in Zambia, temperatures are not so extreme as to entirely prevent infection. Moisture may be insufficient during some months: there is no rain water, relative humidity decreases and is low compared to the RS (Figure 2.2), and dew periods may become too short. Rapid drying of leaf surface may result in a decrease in infection (Rowell et al., 1958). Raemaekers (1981 b) suggested that epidemics develop towards the end of IS. In this study, however, severities > 10% occurred at the beginning of IS (from June onwards).

At locations between 950 and 1100 m altitude, conditions are generally favourable for rust development in April and May. The lower temperatures in June and July may reduce the rate of increase of rust but infections can still take place and stem rust can increase. During these months there is sufficient leaf wetness, either as dew or as irrigation water. During the months of August and September, when temperatures become high and dew periods may become too short for successful infection, the crop has reached the development stage at which it needs most water. Sprinkler irrigation is often applied weekly for 6 hours or more per application, so there is at least one day each week with enough free moisture on the leaves for rust infection. As a result, wheat which is sown on different dates in April and May can become severely infected (Table 4.4). Wheat sown in late May or early June may have a low severity. Unfortunately, high temperatures in August and September may reduce the ripening period drastically so that yield is lost, due to "early ripening".

Overlap in periods of production of RS wheat and irrigated wheat prolongs the period available for the development of rust epidemics. Thus, severe yield losses can occur in later sown irrigated wheat. To restrict dispersal of rusts from field to field, production seasons can be kept short by shortening the period of sowing. By postponing sowing of irrigated wheat until 1 May, the period of wheat growing is shortened and the dispersal of rusts from rainfed to irrigated wheat is restricted. Overlap in production periods of rainfed and irrigated wheat can be avoided by geographical separation, e.g. by growing rainfed wheat in areas with an annual precipitation of 800 mm and more and irrigated wheat in areas with less than 800 mm. Partly irrigated wheat, sown between 1 February and 1 April, is growing at the time when conditions may be favourable for rust build up and when airborne inoculum may be present. At present, this production method has not shown such economic advantages that it justifies endangering irrigated wheat production.

Resistance to stem rust would help to reduce the build up of inoculum, especially at altitudes below 1200 m, and this in turn could reduce the chances for perennation. In order to prevent serious build up of rust, genotypes are needed with an MDI1 < 0.10 throughout both RS and IS.

4.4. Host resistance and rust races

4.4.1. Introduction

This Section analyses the stability of stem rust resistance in Zambia and in some other African countries south of the Sahara, between 1974 and 1980. A wheat genotype is considered to be rust resistant when it has terminal rust severities < 10 (James' Scale, 1971). Stability of rust resistance is evidenced by the absence of drastic increases in terminal severities or relative resistances and absence of changes in reaction type. An attempt was made to test the hypothesis that selection for incomplete and stable resistance at one location (NIRS) leads to stable resistance at other locations in Africa.

4.4.2. Materials and methods

Rust severities were studied at 5 locations (Table 4.7) in different trials (Table 4.8). In the HRBP there were 34 (parent) genotypes, and JUP and Tanori 71 (TAN). Regional Disease Trap Nurseries (RDTN) were introduced in many countries (54 by 1980). In the RDTN, there were 8 parent genotypes (AFR, FA , GIZ, ZAM, PEN, CHE, SUP, CER) and 2 cultivars commercially grown in Zambia, JUP and TAN. With kind co-operation of CIMMYT and Ir. P. Kampmeijer, data were obtained on these 10 genotypes for stem rust, leaf rust and stripe rust, in Zambia, Zimbabwe, Tanzania and Kenya. In the RDTN, rust severity and reaction type were recorded following Loegering (1959). In Zimbabwe and in Kenya, 1980, reaction types were recorded using a scale with 8 classes. Rust recording methods for HRBP were described in Chapter 3. Rust recordings for HRBP apply to IS, with the exception of data for 1977, which apply to the 1976-77 RS. During the 1977 IS at NIRS, rusts remained absent.

Table 4.7. Locations with rust recordings between 1974 and 1980.

Country	Code	Station	Altitude (m)	Latitude	Longtitude
Zambia	ZAMB	NIRS	978	27 55' E	15 16' S
Zimbabwe	ZIMB	Chiredzi	426	31 33' E	21 01' S
Tanzania	TANZ	Lyamungu	1280	37 53' E	3 14' S
Kenya	KEN1	Njoro	2160	35 56' E	0 20' S
	KEN2	Molo	2780	35 45' E	0 15' S

Table 4.8. Trials with rust recordings at 5 locations between 1974 and 1980.

Code	Trial	1974	1975	1976	1977	1978	1979	1980
ZAMB	HRBP	-	+	+	+	+	+	+
	RDTN	-	-	+	-	-	-	-
ZIMB	RDTN	-	-	-	+	+	-	-
TANZ	RDTN	+	+	-	+	+	-	+
KEN1	RDTN	+	+	+	+	+	+	+
KEN2	RDTN	-	-	-	-	+	+	+

+ = Observations available. - = No observations available.

Relative resistance (RRES) is calculated using Equation (4.5) (Zadoks, 1972).

$$RRES = 1 - RDIS = 1 - TS(t)/TS(s) \quad (4.5)$$

RDIS, is the relative disease severity,
TS(t), the terminal severity of test cultivar, and
TS(s), the terminal severity of most susceptible cultivar of the trial.
Data sets were used only when 25% of the susceptible cultivars had disease symptoms and when TS(s) > 20.

Section 4.2 argued that stem rust races appear and disappear, and that different locations may have different populations of races. If the virulence matching the resistance of a host is present in a population, that host will show a high TS(t) and a decreased RRES. When the matching virulence is absent from that population the host will show a low TS(t) and a high RRES. Differences in the 'virulence spectra' of rust populations are indicated by large differences in RRES-values of one or more genotypes grown at different locations or in different years. Significant differences between RRES values in a 2 x 2 contingency table suggest the existence of genetically-based differences in population composition, assuming that all other factors influencing RRES remain comparable. When there are 2 wheat genotypes with significantly different and opposite RRES-values (close to 0 or 1), the test (called quadratic check) provides fairly convincing evidence. When changes in RRES-values occur in only a few genotypes, RRES-values of 2 tests will be correlated significantly, with a correlation coefficient close to 1. When changes in RRES-values occur in many genotypes, the significance of the correlation of RRES-values may disappear. The absence of a significant rank correlation may indicate differences between rust populations. Spearman rank correlation coefficients were calculated, and tested one sided for significance. Pairs with missing values were excluded from the computations (Nie et al., 1975).

In HRBP, epidemics were usually started by artificial inoculation (Table 4.2), and auto-infection (Robinson, 1976) occurred after the first allo-infection. The terminal severity is the result of both allo- and auto-infection. RDTN-fields are often situated on research stations using many different cultivars, and generally have a continuous bombardment with spores from neighbouring fields (allo-infection).

Interplot (interplant) interference may cause cryptic errors; because of proximity to susceptible genotypes, genotypes with incomplete resistance are relatively more affected than in a pure stand. The result is an underestimation of the resistance of cultivars with incomplete resistance (Vanderplank, 1963). This effect can be considerable (Parlevliet and Van Ommeren, 1975).

Between season differences in RRES can be expected due to different testing conditions. Large difference in RRES could be attributed to differences in racial composition of the rust populations.

4.4.3. Reaction type

In the RDTN, parent genotypes of the HRBP and JUP all had a susceptible reaction type to all 3 rusts at one or more locations. In several genotypes, the reaction type at a specific location changed from resistant to susceptible, but also, inversely, from susceptible to resistant or even immune. Such data suggest differences in rust populations, between years and locations. When genotypes were ranked according to reaction type, there was no constant ranking (Table 4.9), an indication for differences between rust populations (Vanderplank, 1963).

Table 4.9. Genotypes in RDTN with and without drastic changes in reaction type to stem rust at several locations and in various years.
For explanation of codes see List of abbreviations and symbols.

ZIMB	1977	1978	TANZ	1975	1978	KEN1	1977	1978
AFR	0	S	JUP	0	0	JUP	0	MS
JUP	MR,MS	MR	SUP	S	0	GIZ	0	S
GIZ	S	M	GIZ	S	MS	SUP	R	S
SUP	S	S	AFR	S	S	AFR	S	S

4.4.4. Severity

At Njoro in Kenya and at Lyamungu in Tanzania all 3 rusts occurred, at Molo in Kenya only stem rust and stripe rust, at Chiredzi in Zimbabwe and NIRS in Zambia only stem rust and leaf rust. Stem rust reached moderate severities at Lyamungu and high severities at the 3 other locations. Seven parent genotypes (AFR excluded), JUP and TAN, all showed a severity > 30% during one or more seasons. At Molo and Njoro, the 8 parent genotypes and JUP and TAN, all showed a severity > 30% during at least one season.

4.4.5. Relative resistance

In the period of 1975 to 1980, distinct changes in RRES-values occurred at NIRS (Figure 4.5), in a few CIMMYT bred genotypes, e.g. PAK, PEN, CHE and SOH, and also in genotypes bred in Zimbabwe, e.g. SHA, ZAM and TOK.

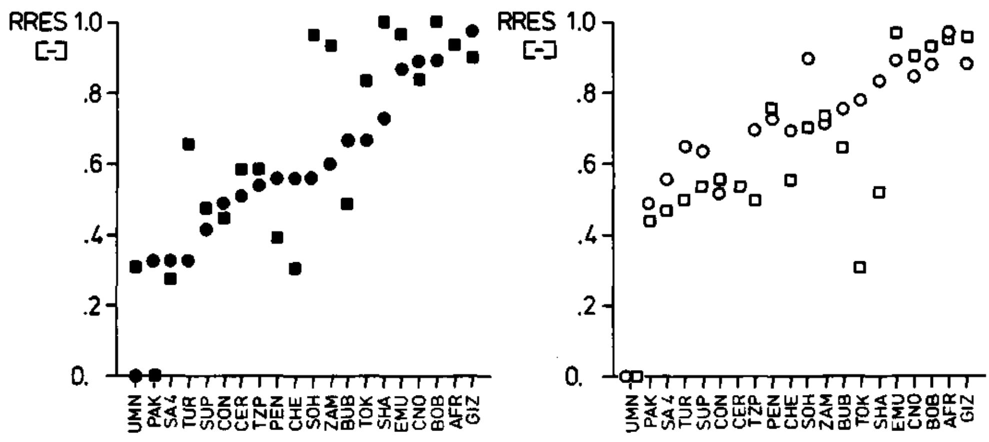

Figure 4.5. Relative resistance (RRES) to stem rust at NIRS, of 20 parent genotypes (abscissa) used by the HRBP.

- ● 1976 IS (1 block/genotype, 10 replicates/block)
- ■ 1976-77 RS (1 block/genotype, 10 replicates/block)
- ○ 1978 IS (13 blocks/genotype, 1 replicate/block)
- □ First sowing 1980 IS (4 blocks/genotype, 1 replicate/block)

Several genotypes showed changes in RRES-values, including opposite changes (compare data of 1976 IS and 1976-77 RS, Figure 4.5). Some of these changes may be related to seasons. For example, RRES of PAK was 0 in the 1976-77 RS, but approximately 0.4 in IS. Possibly, the relative high temperature in RS was responsible for a relatively low RRES. A similar change was seen in the TSS of JUP (Tables 4.3 and 4.4). A few significant changes in RRES-values occurred in following ISs, for example comparing 1978 and 1980 for PEN and TOK (Table 4.10). A quadratic check was not present. Nevertheless, the interpretation of the results is, that virulence shifts of stem rust do occur at NIRS in Zambia.

RRES-values at NIRS showed few changes and differences between years were often small (Figure 4.5). The rank correlation for wheat genotypes over the years was highly significant (Table 4.11). Significant rank correlation occasionally occurred at other locations (Table 4.11).

Quadratic checks occurred between years at Njoro, and between locations (Table 4.12). Occasionally, the RRES-values at NIRS and Chiredzi or Njoro had a significant rank correlation (Table 4.11). Stem rust populations at NIRS in Zambia may have similarity to stem rust populations at Chiredzi in Zimbabwe and occasionally also to populations at Njoro in Kenya. Stem rust populations at NIRS appear to be relatively stable in time compared to populations at Njoro.

At least 7 parent genotypes (possible exception is ZAM), JUP and TAN showed differential resistance, with a low RRES at one location at least. Incomplete and stable resistance to stem rust in Zambia was not associated with a stable resistance at other locations (Figure 4.6). ZAM may have a stable resistance, but it has a rather low RRES level. With multilocational testing (5 locations) the differential resistance of several parent genotypes could be demonstrated with one year of testing only.

Table 4.10. Two by two table and ANOVA for relative resistance to stem rust in wheat, NIRS. SD, standard deviation of preceding mean; N, replicates.

Two by two table

Year		1978			1980		
	Genotype	Mean	SD	N	Mean	SD	N
	Tokwe	78	14	10	31	24	4
	Penjamo 62	74	15	10	76	4	4

ANOVA

Source of variation	df	SS	MS	F
N	1	134414		
Year	1	2791	2791	7.9*
Residual 1	12	4227	352	
(Total 1)	(14)	(141432)		
Genotype	1	700	700	6.2*
Genotype x year	1	3430	3430	30**
Residual 2	12	1360	113	
Total	28	146922		

Table 4.11. Ranking of relative resistance to stem rust of 8 parent genotypes, JUP and TAN, at NIRS in Zambia (ZAMB), Cheredzi in Zimbabwe (ZIMB), Lyamungu in Tanzania (TANZ) and Njoro in Kenya (KEN1).

0	= P > 0.05	+,-	= P < 0.05	+ and - indicate the sign of r
++,--	= P < 0.01	+++,---	= P < 0.001	. means auto-correlation

Stem rust	Year	ZAMB 1976	ZAMB 1978	ZAMB 1979	ZAMB 1980	ZIMB 1977	ZIMB 1978	TANZ 1975	TANZ 1978	KEN1 1975	KEN1 1976	KEN1 1977	KEN1 1978	KEN1 1980
ZAMB	1976	.	+++	++	++	0	0	0	0	+	0	0	0	0
	1978	+++	.	+++	+++	++	0	0	-	0	0	0	0	0
	1979	++	+++	.	+++	0	0	0	-	0	0	0	0	0
	1980	++	+++	+++	.	+	0	0	0	0	0	0	0	0
ZIMB	1977	0	++	0	+	.	++	0	0	0	0	0	-	0
	1978	0	0	0	0	++	.	0	0	0	0	0	0	0
TANZ	1975	0	0	0	0	0	0	.	0	0	0	0	0	0
	1978	0	-	-	0	0	0	0	.	0	0	0	0	0
KEN1	1975	+	0	0	0	0	0	0	0	.	0	0	0	0
	1976	0	0	0	0	0	0	0	0	0	.	+	0	0
	1977	0	0	0	0	0	0	0	0	0	+	.	0	0
	1978	0	0	0	0	-	0	0	0	0	0	0	.	0
	1980	0	0	0	0	0	0	0	0	0	0	0	0	.

Table 4.12. Quadratic checks for relative resitance to stem rust in wheat at various locations.

	ZAMB 1980	TANZ 1975
AFR	0.99	0.00
JUP	0.70	1.00

	ZAMB 1980	KEN1 1980
FA	0.97	0.33
SUP	0.62	1.00

	ZIMB 1977	TANZ 1978
AFR	1.00	0.83
CER	0.00	1.00

	ZIMB 1977	KEN1 1975
CER	0.00	0.99
TAN	0.90	0.17

	TANZ 1978	KEN1 1980
GIZ	0.83	1.00
CER	1.00	0.67

	KEN1 1975	KEN1 1980
JUP	0.99	0.44
TAN	0.17	0.88

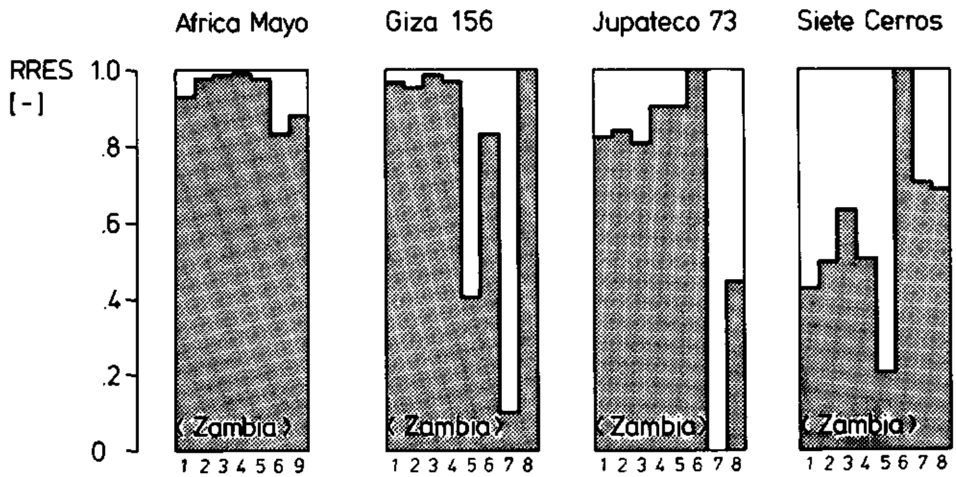

Figure 4.6. Relative resistance (RRES) to stem rust of 2 parent genotypes and JUP at various locations during various seasons.

Season			Highest severity (%)	
1 NIRS	Zambia	1976	45	
2 NIRS	Zambia	1978	43	
3 NIRS	Zambia	1979*	44	
4 NIRS	Zambia	1980*	33	
5 Cheredzi	Zimbabwe	1978	100	
6 Lyamungu	Tanzania	1978	60	
7 Njoro	Kenya	1978	100	
8 Molo	Kenya	1978	90	* = mean of 2
9 Njoro	Kenya	1979	90	sowing dates

4.4.6. Discussion and conclusions

At NIRS, race shifts appear to occur for stem rust as there were significant changes in RRES-values in certain parent genotypes. However, race shifts did not occur every year, not even after the introduction of spores from another location (1976-1978 comparison). The infrequency of changes in RRES-values, and the fact that the changes occur in only a few genotypes, indicate that the virulence spectrum of the rust population has remained fairly stable.

In Zambia and Zimbabwe (Herd, 1981), this relatively stable rust situation may lead to the selection of genotypes with differential resistance such as FA (Table 4.12) which appear to have stable incomplete resistance. It follows, that genotypes developed in a local breeding programme, exhibiting an apparently incomplete and stable resistance in fact have a differential resistance. Especially rusts coming from the north, may form a threat to these genotypes with incomplete resistance, but are likely a threat to genotypes with complete resistance.

Certain commercial cultivars in Zambia are vulnerable to attack by races from other wheat growing countries which match the resistance of the cultivars. It is for this reason that breeding and selection for resistance is necessary.

Evidence based on reaction type, severity and relative resistance indicates that several parent genotypes of the HRBP, JUP and TAN, had matching rust genotypes. This means that these genotypes contain differential resistances.

4.5. Yield loss

4.5.1. Introduction

A summary of types of losses is given by Zadoks and Schein (1979). In this Section primary losses of yield and quality are considered without paying attention to the economic and social effects of the diseases beyond their immediate agricultural impact. The terminology of the FAO Manual, Crop Loss Assessment Methods (Chiarappa, 1971) and of Zadoks and Schein (1979) is followed. Yield is the amount of wheat grain at harvest time. Crop loss is the difference in either quantity and/or quality of yield between 2 yields, generally between actual and attainable yield. Emphasis is on quantitative losses. The attainable yield is calculated as the intercept a0 of the linear regression

$$Y' = a0 + a1 \times TD \tag{4.6}$$

Y' being the estimated grain yield in mt/ha and TD the terminal disease severity in per cent. The actual yield is the yield measured under current experimental conditions.

This Section examines some aspects of the relationship of stem rust severity and grain yield on a plot basis, with the hope that such data can eventually be used for regional and national investigations.

4.5.2. Materials and methods

Yield losses due to diseases were determined for parent genotypes and JUP grown at NIRS during the 1975 to 1980 ISs. Special attention is given to the 1976 IS, it being a season when conditions were favourable for both crop and disease development, and to 1978 IS when stem rust developed well while leaf rust developed poorly. The design and management of the trials is described in Chapter 3.

In order to perform crop loss analyses, data of the 1976 parent genotypes have been grouped into 3 groups:

- Group 1 contained the data for 5 parent genotypes with a low susceptibility to stem rust and a low to moderate susceptibility to leaf rust, and a high attainable yield (above 6 mt/ha): GIZ, BOB, EMU, CNO and BUB;
- Group 2 contained the data for 10 parent genotypes susceptible to both stem rust and leaf rust, and a high attainable yield: ZAM, PEN, CHE, SOH, TUR, SUP, CER, CON, PAK and UMN;
- Group 3 contained data for 20 parent genotypes, including the 15 genotypes of Group 1 and 2, and 5 genotypes with a high susceptibility to leaf rust or a low attainable yield: AFR, SHA, TOK, TZP and SA4.

In 1976, group means were calculated using one mean value per genotype. Differences between groups were tested with a Wilcoxon test, either one-tailed for Y, ANOH, ANOK, TKWh, RTKWh and disease observations, or two-tailed for other variables (Table 4.13).

Four methods were used to estimate yield loss (YLOS').

a) Comparing yields of 2 groups of genotypes according to Equation (4.7).

$$YLOS' = 1 - Y(\text{Group 2}) / Y(\text{Group 1}) \tag{4.7}$$

in which YLOS' is expressed as a fraction, Y(Group2) and Y(Group1) are yields expressed in mt/ha or in g/m2, Group 1 containing genotypes virtually free of rust, Group 2 containing genotypes with rust. Loss estimate and genotype

differences can be confounded and loss estimate depends strongly on disease severities. This method was only used for the 1976 data.
b) Comparing yields of genotype(s) according to Equation (4.8).

$$YLOS' = 1 - Yd / Yo \qquad (4.8)$$

Yd, yield in mt/ha or in g/m2 of genotype(s) with disease. Yo, yield in mt/ha or g/m2 of the same genotype(s) without disease. An equation of the same form as (4.8) was also used to calculate the weight loss of kernels (KWLOS') in which KWLOS' substitutes YLOS', (TKWh)d = Yd, and (TKWh)o = Yo. In 1975, (TKWh)o was estimated by using the heighest TKWh of the 3 sowings, and in 1976 by using thousand kernel weight at sowing (TKWp). The fraction TKWh/TKWp is called the relative thousand kernel weight (RTKWh). This method eliminates genotypic differences. The estimate is based on a selected (group of) genotype(s), and depends strongly on the disease severities. The method was used only for 1975 and 1976 data.
c) When there were several paired values for TSS, and Y Equation (4.6) was used to determine Y' and a0 (single regression), applied to either one or several genotypes. Yield loss was calculated with Equation (4.8), in which Yd = Y', Yo = a0. In this method yield losses are estimated taking into account disease severity and the attainable yield of a (group of) genotype(s) when disease is absent. The method was used for all stem rust assessments on the stem.
d) In 1978, the availability of several paired values for TSS and Y enabled the use of multiple regression analysis. The nominal scale variable genotype was inserted into the regression equation by means of a set of dummy variables. A set of dummy variables is 'created' by treating each category of a nominal variable as a separate variable and assigning arbitrary scores for all cases depending upon their presence or absence in each of the categories (Nie et al., 1975). The scores 0 and 1 were used for genotypes. The multiple regression equation was:

$$Y' = a0 + a1xROW + a2xCOL + a3\,xTSS_{i\,ij} + a4\,xGEN_{i\,ij} \qquad (4.9)$$

where Y' represents the estimated value for Y; a0, the Y intercept; a1 to a4, the regression coefficients; TSS, the terminal stem rust severity on the stem (0 < TSS < 60), James' Scale (1971). GEN represents the genotype with the value 0 or 1. Equation (4.9), the 'additive model', was used when interaction was not significant. When it was not known whether interaction was significant Equation (4.10), the 'saturated model', was used.

$$Y' = a0 + a1xROW + a2xCOL + a3\,xTSS_{i\,ij} + a4\,xGEN_{i\,ij} + a5\,xTSS_{ij}\,xGEN_{ij} \qquad (4.10)$$

Interaction may be due to non-linearity of the regression or due to a phenomenon causing the differences in Y' in genotypes with a similar attainable yield and similar TSS. When the effect of interaction is negligible, it is assumed that tolerance is absent. ROW (0 < RO < 21) and COL (0 < CL < 34) are factors correcting for spatial variations (in the row (ROW) and column direction (COL)) in the trial area.

The attainable yield, Yo', in the additive model may differ between genotypes and Yo' = a0 + a3ij. Yield loss can be calculated with Equation (4.8), in which Yd = Y' and Yo = Yo'. In this method, yield loss can be calculated over all differences in attainable yield between genotypes and all differences in disease severity. Deviation from linearity can be checked.

Methods mentioned above are applicable to trials with many genotypes grown in plots of different sizes, from small to very large. In the 1978 IS, genotypes were, to some extent, grouped according to susceptibility, which may have reduced interplot interference; interplot interference was possible, so calculated yield losses therefore probably underestimate real yield losses. It is difficult to extrapolate from trials to practice, as the effects of interplot interference were not quantified.

4.5.3. 1976 Irrigation season

Stem and leaf rust developed to high severities. The value of TSS was sometimes more than 7 times that of TSF or TSL (Table 4.13). The interdependence of stem rust severities is obvious. There were significant positive correlations between TSS, TSF and TSL (Table 5.5). Genotypes with a high TSS did not necessarily have a high value of TSF because of differences in susceptibility between genotypes, and microclimatic differences between lower and upper leaf layers. TSS was not correlated with TFL or TLL. Of all stem rust scores, TSS was most significantly correlated with Y. It has also a highly significant correlation with TKWh (Table 5.6). It was less time consuming to make the TSS score than any other score. Furthermore, the stems (including leaf sheaths) are practically free from leaf rust.

Kernel weight, kernel production and stand appeared to be influenced by stem rust (Table 5.6). Genotypes of Group 2, with high values of both TSS and TSF, had significant negative correlation coefficients for all yield components. Because stem rust is able to influence all yield components it can cause very severe losses.

The linear regression of Y on TSS was highly significant, using the mean values for a number of genotypes, after the crop had reached 54 DC (Table 4.14). The coefficient of determination increased with crop age. This is another consideration for using TSS to predict loss.

Table 4.13. NIRS, 1976 IS. Means of variables for two groups of genotypes. Group 1 and 2 contained 5 and 10 genotypes, respectively. There were at least 5 replicates of each genotype. For explanation of codes see List of abbreviations.

Variable	Units of measurement	Group 1		Group 2		Significance of difference (Wilcoxon)
		Mean	SD	Mean	SD	
Y	mt/ha	5.9	0.1	3.8	0.2	**
ANOH2	m2	399	44	411	87	ns
ANOK	-	45	5	42	7	ns
TKWh	g	49	8	33	7	**
RTKWh	%	93	10	68	16	*
DVS37	day	44	6	46	6	ns
DVS55	day	61	5	68	6	*
DVS65	day	71	5	78	6	*
DVS90	day	115	8	121	4	ns
TSS	%	7	5	27	8	***
TSF	%	1.2	1.3	2.2	2.3	ns
TSL	%	1	2.2	4	6	**
TLF	%	5	6	10	4	ns
TLL	%	5	4	15	6	**

Table 4.14. NIRS, 1976 IS. Linear regression of Y (yield, means per genotype) on PSS (stem rust severity on stem, means per genotype) using 15 data pairs (genotypes of Group 1 and 2) at different days after sowing (DAS). For further explanation see *text* and *List of abbreviations and symbols*.

DAS	DC	r2	a0	a1	p
57	43	-	-	-	ns
68	58	0.40	5.5	-0.8	**
89	73	0.49	5.6	-0.2	**
106	80	0.58	6.1	-0.1	***
126	90	0.63	6.7	-0.1	***
135	94	0.70	6.9	-0.12	***

The estimated attainable yield, the intercept a0, increased with crop age. Some genotypes were attacked only at later stages. The low actual yield of these genotypes caused the a0 to be low at early development stages. The estimated attainable yield of the genotypes without disease at late development stages was higher, because they did not have severe yield losses due to late attacks. Infection of the stem before anthesis caused relatively high losses as was indicated by high values of a1, the regression coefficient of Y on TSS.

YLOS' estimated by method 1 was 36% and KWLOS' was 33%. YLOS estimated by method 3 for a mean TSS of 20% over 15 genotypes of Group 1 and 2, was 35%. Method 1 and 3 gave comparable estimates of YLOS.

Rust may influence crop development, resulting in early senescence and early ripening of the crop, as was observed on UMN at NIRS. As significant differences in yield and TKWh between the 2 groups of parent genotypes were associated with significant differences in rust severities, it is likely that rusts were responsible for at least a part of these differences. Group 1 and 2 differed significantly in crop development, genotypes in Group 2 being some 7 days slower than genotypes in Group 1. This difference was also observed during seasons with no rusts. Consequently, differences in development stage could be attributed to genotypic differences rather than to differential responses to rusts. Rust severities differed significantly between groups, except for stem rust on the flag leaf. The exposed position of the flag leaf and the low humidity of the air in July and August may have caused the observed lack of infection.

When stem rust is absent, a long duration of the tillering period and/or of the period from anthesis to ripening may be advantageous to produce high yields. When stem rust is present, early maturity may allow the crop to escape infection (Hooker, 1967; Ruszkowski, 1972; Feekes, 1978). This capacity combined with adequate yields may be preferable to later maturity. In Group 2 the period available for stem rust was extended by 7 days. Corresponding stages were subject to higher spore densities than in early-ripening genotypes. Rust resistance tends to increase towards ripening (Hooker, 1967; Calpouzos et al., 1976), so high spore bombardments at early stages may cause relatively high severities.

The slow development of Group 2 genotypes was due mainly to the 7 day prolongation of vegetative phase of development, so the period that wheat tends to be susceptible was extended. For Group 1 the period to ripening (94 DC) was approximately 120 days, and in this period yields of over 6 mt/ha were produced. Genotypes were infected soon after sowing. This illustrates, that severities can remain low and that acceptable yields can be obtained with genotypes with incomplete resistance, even with early infection and high spore densities.

4.5.4. 1978 Irrigation season

The disease pressure during crop development was moderate and TSS-values were not very high (Table 4.15). The effect of TSS and of CV on TKWh was highly significant (Table 4.16). The interaction GENxTSS was significant, but the F-value was small, too small to have practial importance. In the additive model, using the multiple regression Equation (4.9), KWLOS for the 22 genotypes at a TSS of 10% (James' Scale, 1971) was between 8 and 14%, with a mean of 11%.

In the single regression model, using Equation (4.6), in which the genotype effect is included in a1, KWLOS for the 22 genotypes at a TSS of 10% was between 8 and 22%, with a mean of 12%. The best estimate of kernel weight was made using TSS and GEN, but a good estimate can be made using the TSS of a genotype.

Single regression of Y on TSS was also significant. TSS explained more of the variation in TKWh than Y; r2-values were higher. Values for KWLOS and YLOS corresponded well (Table 4.15). 63% of the variance in YLOS can be explained with its linear regression on KWLOS, so YLOS can be estimated with KWLOS. Single regression of TKWh on TSS was significant provided TSS was > 5%. KWLOS could not be estimated for, e.g. AFR with a TSS of 1 (Table 4.15). In order to estimate Y, the actual TSS had to be > 8%. There was a significant simple regression of Y on TSS when the mean values of number of genotypes were used (1978 data, Table 4.17), and the estimated yield loss at 10% TSS (James' Scale, 1971) was 13%. This result corresponds well with the yield loss estimated by means of other methods, which were all more energy demanding.

As the regression appeared to have a quadratic component, 2 more equations were tested using the 1978 data:

$$Y' = a0 + a1 \times TSS + a2 \times TSS2 \qquad (4.11)$$
$$Y' = a0 + a2 \times TSS2 \qquad (4.12)$$

Table 4.15. NIRS, 1978 IS, results of crop loss assessment method b), Equation (4.6), and method d), Equation (4.9) for some parent genotypes and JUP.

			Method b)					Method d)
Genotype	TSS	TKWh	Attainable TKWh (a0)	a1	p	KWLOS (%) at 10% TSS	YLOS (%) at 10% TSS	KWLOS (%) at 10% TSS
AFR	1	39	39	0	ns	-	-	12
EMU	4	45	48	-0.6	***	13	-	10
CNO	6	46	50	-0.4	***	8	-	10
BUB	9	35	38	-0.3	***	8	11	12
JUP	8	38	43	-0.7	***	16	16	12
TOK	10	38	45	-0.7	***	16	16	11
ZAM	11	38	44	-0.6	***	14	18	11
TZP	13	39	44	-0.4	***	9	10	11
TUR	15	28	41	-0.9	***	22	27	14
CER	21	36	44	-0.4	***	9	14	11
UMN	43	28	50	-0.5	***	10	10	10
Mean	12	39	45	-0.48		12	15	11
SE	2	2	1	0.05		0.9	1.3	0.3

Table 4.16. NIRS, 1978 IS. Analysis of covariance to test interaction between genotype (GEN) and TSS. N = 280, 22 genotypes, 13 replications, 6 missing cases.

Source of variation	df	SS	MS	F	p
Spatial effects =					
linear row and linear column effect	2	0.19	0.09500	186	***
GEN adjusted for TSS and spatial effects	21	0.33	0.01570	31	***
TSS adjusted for GEN and spatial effects	1	0.14	0.14000	275	***
GEN x TSS adjusted for GEN, TSS and spatial effects	21	0.02	0.00095	1.9	*
Residual	234	0.12	0.00051		
Total (N-1)	279				

Use of Equation (4.11) resulted in a non-significant a1, and a significant a2 for Y as well as TKWh. The relationships (4.6) and (4.12) were both highly significant. The value of the intercept ao of Equation (4.12) was closer to the actual Y or actual TKWh than the a0 of Equation (4.6).

4.5.5. Other seasons

Significant simple regression of Y on TSS occurred using the data pairs of various genotypes (Table 4.17), excluding those genotypes with a high susceptibility to leaf rust or with low attainable yields. Attainable yields differed between seasons and were low for seasons with moisture stress (1979 sowing 1 and 1980 trials). Values of a1 for seasons with moisture stress did not appear to differ from those for seasons without moisture stress. Apparently, moisture stress did not change susceptibility to rusts, but mainly reduced the attainable yield, thus increasing loss.

Table 4.17. NIRS, 1976 to 1980 ISs. Simple regression of actual grain yield Y (means per genotype) on terminal severity of stem rust on the stem TSS (means per genotype) and loss (%) at a TSS of 10% (James' Scale, 1971) using 15 data pairs (Group 1 and 2). For further explanation see text.

Year	r2	a0	a1	p	loss at 10% TSS
1976	0.70	6.9	-0.12	***	17
1978	0.48	5.2	-0.07	**	13
1979/1	0.65	4.4	-0.07	**	16
1980/1	0.50	4.6	-0.09	**	20
1980/2	0.27	4.2	-0.07	*	17

An attempt was made to estimate yield losses for various data sets using simple regression.

- Set 1. Greaney (1935). Stem rust on one rainfed spring wheat genotype. Relative yield was calculated using actual yields of rusted and rust-free wheat, grown at one location in Manitoba from 1925 to 1932.
- Set 2. Kingsolver et al. (1959). Stem rust on one rainfed winter wheat genotype, at one location in Maryland, one season. The rust-free wheat was 400 m up-wind of the experimental area.
- Set 3. Stem rust on irrigated spring wheat, 15 genotypes of Groups 1 and 2, at

NIRS, 1976 IS. The relative yield was calculated using the actual yield and the highest yield of all 15 genotypes.
- Set 4. Stem rust on irrigated spring wheat, 21 parent genotypes and JUP, at NIRS, 1978 IS. The relative yield was calculated using the actual yield and the attainable yield of each genotype.

TSS values, scored according to James' Scale (1971) in set 3 and 4, were multiplied by 2 to obtain scores of the same magnitude on modified Cobb-scale.

Table 4.18. Simple regression of relative yield RY (means per genotype or per season) on terminal severity of stem rust TSS (means per genotype or per season) and loss YLOS (%) at a 10% severity (5% according to James' Scale, 1971) using various data sets. SE is the standard error of the preceding value. N = number of data pairs. For further explanation see text and List of abbreviations.

Data set	Year	N	r2	a0	SE	a1	SE	p	YLOS (%) at TSS of 10%
1.	1925 to 1932	8	0.90	113	10	-0.98	0.13	***	9
2.	1959	30	0.83	84	9	-0.90	0.08	***	11
3.	1976	15	0.70	103	14	-0.91	0.16	***	9
4.	1978	22	0.67	88	6	-0.45	0.07	***	5

Highly significant simple regressions were found for all data sets (Table 4.18). The method was applicable to data of wheat grown in various countries, spring and winter wheat, rainfed and irrigated wheat, one or several genotypes, grown during one or several seasons, with a disease score on the stem (sets 3 and 4), or on the entire plant (sets 1 and 2). YLOS was 5 to 11% at a TSS of 10% (modified Cobb scale). YLOS for sets 1 and 2 was similar to yield losses in very susceptible genotypes used in HRBP such as TUR or CON.

These results indicate that by means of a single regression model, with variables Y and TSS, an estimate can be made of YLOS due to stem rust under various growing conditions, including those in Zambia.

The simple regression of actual yield on TSS gave the same results as the simple regression of relative yield RY on TSS (1976 data in Tables 4.14 and 4.17). As calculation of the RY requires an extra calculation step, but gives the same estimate for YLOS as the actual yield, the use of the actual yield is to be preferred above that of RY.

4.5.6. Conclusions

- Stem rust influenced yield of all genotypes. The mean yield loss per genotype was 15% for a terminal severity of 10% (James' Scale, 1971).
- Stem rust may cause severe yield losses at NIRS, in Zambia. It is suggested that high severities could occur at other locations too, especially at lower altitudes.
- Stem rust appeared to influence all yield components.
- Yield losses corresponded with losses reported by Vanderplank (1963) and Calpouzos et al. (1976).
- The best estimate of yield loss was made using multiple regression. By means of simple linear regression of actual yield, of a genotype or a group of genotypes, on TSS, YLOS could be adequately estimated under various growing conditions; this supports the hypothesis of Vanderplank (1963), who suggested that loss is proportional to the amount of disease.
- The interaction TSS x genotype was significant, but the F-value was small

compared to other F-values. The interaction was of little importance to yield, so tolerance is considered to have no practical importance.
- Yield loss could be accurately estimated using methods other than multiple regression.
- Because yield loss increases with terminal severity of stem rust on stem, a low TSS is an important selection criterion.
- Considering the frequency of occurrence and the quantity of yield loss caused by stem rust, selection critera suggested are: TSS < 5 and RRES > 0.80.
- Under conditions favourable for crop and disease development, genotypes with an early maturity and incomplete resistance gave yields over 6 mt/ha.

4.6. Summary

- Stem rust occurred in one to 3 seasons out of 6 at certain locations in Zambia and had a patchy distribution.
- Stem rust race shifts occur in Zambia and in neighbouring wheat growing countries.
- Race shifts in Zambia were not frequent.
- Because of the 3 principal airstreams, Zambia may receive inoculum from virtually all neighbouring wheat growing countries, of which some differ in virulence spectra.
- Several genotypes with stable incomplete resistance were found in Zambia.
- Genotypes with incomplete and stable resistance did not, as a rule, have stable resistance in other countries.
- Stem rust influenced the yield of all genotypes. The mean yield loss per genotype was approximately 15% for a terminal severity of 10%.
- The selection criteria suggested are a terminal stem rust severity on the stem of less than 5% (James' Scale, 1971) and a relative resistance of more than 0.80.

5. LEAF RUST

The importance of leaf rust in Zambia and countries around Zambia as mentioned in the literature is reviewed (Section 5.1). Inoculum production and dispersal is discussed (Section 5.2) and results of recent investigations concerning host resistance, rust races and yield loss are presented (Sections 5.3 to 5.5).

5.1. Importance

5.1.1. Zambia, 1950 to 1974

Leaf rust (Puccinia recondita Rob. ex Desm. f. sp. tritici) was commonly present on wheat in the Northern, Central, Lusaka and Southern Provinces (Angus, 1965), and was more frequent than stem rust. Uredia and telia occurred mainly on the leaves. On susceptible cultivars, heavy infection resulted in retardation of heading and yield losses. Except for a few susceptible cultivars, however, yield losses during rainy season (RS) were negligible compared with those caused by stem rust or helminthosporium. During irrigation season (IS), yield losses due to leaf rust did not normally occur. Attacks were usually confined to the undersides of lower leaves and leaf sheaths. Selection for resistance was recommended. No mention was made of races.

5.1.2. Countries around Zambia

Leaf rust was recorded in all wheat growing countries south of the equator. In Kenya, where it was widespread at elevations between 1900 and 2300 m, 2 physiological races were identified (Harder, 1971). In Zimbabwe several races were present (Dept. Research, 1972). No wild grasses were found which could serve as reservoirs of infection (Hogg et al., 1969). In South Africa (SA), in the winter rainfall areas of the Cape, a considerable amount of oversummering occurred on Agropyron distichum, which appeared to be a general host susceptible to all prevalent races. Infection foci occurred throughout the year on wheat in the summer rainfall area of SA (Hogg et al., 1969) and around the equator (Green et al., 1970; Harder et al., 1972). Resistance to leaf rust seemed to be adequate (Saari and Wilcoxson, 1974; Prescott, 1978).

5.2. Inoculum production and dispersal

5.2.1. Wheat area and genetic uniformity

In the 1960s and 1970s, the wheat area in virtually all wheat growing countries south of the Sahara, including Zambia, represented only a minute part of the total area (Table 5.1). Genetic uniformity was not avoided; as a result of breeding activities and international contacts, cultivars with wide adaptation were grown commercially in several countries (Table 5.1), or were used in different breeding programmes (as in the HRBP in Zambia). Widespread use of certain important genetic characters might pose a threat to stable wheat production (Nat. Acad. Sciences, 1972).

5.2.2. Source-target relations

Wheat areas outside Zambia might be sources of inoculum for leaf rust epidemics in Zambia. Information on the main periods of inoculum production at the various sources is not available, except for Kenya (Green et al., 1970; Harder et al., 1972), Tanzania (Harder et al., 1972), Zimbabwe and SA (Hogg et al., 1969).

Table 5.1. Wheat cultivars in some African countries: Angola (ANG), Ethiopia (ETH), Kenya (KEN), Malagasy (MAG), Malawi (MAL), Mozambique (MOZ), Tanzania (TAN), Zambia (ZAM) and Zimbabwe (ZIM). Areas after FAO (1980).

Cultivar	Country ANG	ETH	KEN	MAG	MAL	MOZ	TAN	ZAM	ZIM
CER	+	-	-	-	?	-	-	+	-
ZAM	-	-	-	-	?	-	-	+	+
AFR	-	?	+	?	?	?	-	-	-
Tai	-	+	+	-	-	?	+	+	-
Ram	-	?	+	?	?	?	?	+	-
Limpopo	-	-	-	-	?	-	-	+	+
Romany	-	-	-	+	+	?	-	-	-
Area (x 1000 ha)									
Country	124,670	122,190	58,265	58,704	11,848	78,303	94,509	75,261	39,058
Wheat in 1969-71	14	782	133	?	?	10	59	?	14
Wheat in 1979	13	511	117	0.6	0.4	5	50	2	35

+ Commercially grown — CER = 8156 (Zeven et al., 1976)
- Not grown — ZAM = 8156//Lee/ND74 (Zeven et al., 1976)
? No information — Ram = Romany 2/Africa Mayo = K 6290-17 (McBean, 1981)
Tai = K 4500-2 = W 3697 = Enkoy (McBean, 1981)

Rainy season in Zambia. The principal directions of movement of air masses are south-east, north-east and south (Figure 2.3). Central and northern Zambia is crossed by air masses which have moved over Angola and Zaire; part of northern Zambia is traversed by air masses coming from Tanzania and Kenya. Part of southern Zambia is crossed by air masses which have moved over Zimbabwe.

The total hectareage of rainfed wheat in the central and southern part of Zambia is currently less than 100 ha; isolated fields tend to be < 2 ha. Major source-target relations are expected to occur with sources in Zimbabwe while less important relations are likely with sources in Angola, Botswana, SA, Malagasy, Malawi, Tanzania, Kenya, Rwanda, Burundi and Zaire.

The nearest source is situated in Zimbabwe at a distance of over 500 km from locations such as Livingstone, NIRS and GV. In Zimbabwe, leaf rust is common on rainfed wheat, grown from December to April (Hogg et al., 1969). The hectareage of rainfed wheat is not known, but is probably only a few hundred hectares. The main production of airborne spores is expected to occur in February and March, the months that symptoms are first observed in Zambia.

The sources in SA have a large hectareage of wheat and a production of uredospores throughout the RS, but are situated over 1000 km to the south. The source in Botswana is at a distance of over 500 km to the south-west of the target. Sowing is in February (Kingma, 1978); the main inoculum production is probably in April. In Angola the sources is at a distance of over 500 km and is situated to the west of the target. Rainfed wheat is sown between December and March (Mirrado, 1965); the main spore production probably takes place in May and June. The wheat hectareage is not known, but is possibly only a few hectares. In Zaire and Burundi, sowing tends to be in April (Kingma, 1978); the wheat hectareage is small. In Rwanda, situated over 1500 km to the north of NIRS, the wheat hectareage is estimated to be 1000 to 2000 ha (FAO, 1980). Sowing is in October (Camerman, 1975); the spores are probably produced mainly in January. The sources in Tanzania and Kenya, at least 1000 km to the north-east, have a relatively large hectareage of wheat; uredospores are produced throughtout the RS. The source in Malagasy is at a distance of over 2000 km to the south-east of the target. RS wheat is sown in January (Rakotondramanana, 1981), the main inoculum production is expected to take place in April and May. The wheat hectareage is estimated to be some 300 ha only. The source in Malawi is at a distance of over 600 km to the east of the target. Rainfed wheat is grown solely for trials (Mnyenyembe, 1981) and the wheat hectareage is estimated to be less than 100 ha. Sowing is in March; the main spore prodution is in May and June.

The great distance (over 500 km) and small area of the sources, the small size of the target, and the vagaries of the weather during spore transportation may explain the variability in the occurrence of leaf rust in southern and central Zambia. As a small target area is reached by inoculum (in February), a target with a larger hectareage would certainly be reached by inoculum, perhaps even at an even earlier date.

The total hectareage of rainfed wheat in the northern part of Zambia is less than 1500 ha, including the wheat scheme at MB of nearly 1000 ha. This target was reached by inoculum of leaf rust; at MB the first sporulating pustules were found as early as mid March. Little is known about the first arrival of the rust, because there were few observations per year, and few years of observation. Major source-target relations are expected to occur with sources in Tanzania and possibly Rwanda and Kenya. Minor source-target relations are expected to occur with sources in other wheat growing countries around Zambia.

The nearest source is situated to the north-east near Njombe, at a distance of over 300 km from MB. The wheat hectareage here, in southern Tanzania, is over 2000 ha (Edwards, 1981); sowing tends to take place in February; the main spore production is in May and June (Harder et al., 1972). Spore densities tend to be low in March and April, and spores will not reach the target, or infection at the target will stay below the detection threshold. At West Kilimanjaro, there is some wheat susceptible to rust attack at most times of the year, and Harder et al. (1972) suggested that some inoculum produced here reaches Njombe, approximately 800 km to the north east. These spores may reach MB too, at some 1000 km. The Rwanda source is situated to the north, at a distance of over 800 km from MB. At Njoro in Kenya, over 1500 km to the north east, leaf rust spores are present throughout the year (Green et al., 1970); the main spore production is between June and November (Harder et al., 1972).

In Zaire and Burundi, wheat is sown usually in April. The source in Malagasy is situated to the south-east, at a distance of over 2000 km and has a small wheat hectareage. In Malawi a small source area is at a distance of over 700 km. To the south and south-east, more than 1000 km away, are the small wheat areas in Zimbabwe and Botswana, and at a distance of over 2000 km are the large wheat hectareages of SA, where inoculum is produced throughout the RS. The source in Angola is situated at least 1500 km to the south-west of the target; here the wheat hectareage is up to 2000 ha. The main spore production probably occurs in May and June.

The fairly large distances between sources and target and the washing of spores from the air by rain are likely to be the main factors determining the variable occurrence of leaf rust in northern Zambia. At present, even the target with a relatively small hectareage is reached, so a target with a larger hectareage would certainly be reached. It is possible that early epidemics would develop to high severities, particularly at lower altitudes.

Irrigation season in Zambia. The predominant wind direction during the IS is south-east (Figure 2.3). The total wheat hectareage, including irrigated, seepage and dambo wheat, is less than 3000 ha. At present, wheat areas are situated in the Western Province (less than 100 ha in total), in the Lusaka, Central, Southern and Copperbelt Provinces. The mean wheat area per farm with irrigated wheat is approximately 50 ha (Table 2.2), and is less than 2 ha for seepage and dambo wheat. The occurrence of outbreaks was sporadic; sporulating pustules from spontaneous epidemics were first observed in June. Major source-target relations are expected to occur with sources in Zimbabwe and SA. Minor source-target relations are expected to occur with sources in other neighbouring wheat growing countries.

Zimbabwe has a large wheat hectareage (Table 5.1), situated to the south-east at a distance of over 500 km from the target. Sowing is in May. The main spore production is in June and August.

The source in Botswana is over 500 km south west of the target area in the Western Province, and spores produced in April could serve as inoculum for early sown seepage or dambo wheat. The source in southern Mozambique is situated to the south-west at a distance over 1000 km from the target. An area of some 10,000 ha is sown with wheat in March and April (Mota, 1971).

When irrigated wheat is produced in the north of Zambia, wheat areas in central and northern Mozambique, in Malawi, and possibly in Malagasy may become major sources of inoculum for Zambia.

5.3. Zambia, 1974 to 1980

5.3.1. Occurrence

During the RS, leaf rust occurred twice in 6 seasons at NIRS (NIRS, 1975 a to 1980). At Mount Makulu, the frequency of occurrence was approximately the same. At MB, it occured twice in 2 seasons (Zam-Can, 1979, 1980 a). In early February 1977, leaf rust was observed at NIRS. In mid-February, it was absent from susceptible cultivars such as SA4, CON, SON and CER, at all Zambian wheat growing locations south of NIRS (Choma, Zimba and Livingstone), and west of NIRS, e.g. Kabwe, but was present near Lusaka (Figure 2.1). In the HRBP at NIRS, no symptoms were found during 2 out of 6 RSs, when stem rust was also absent, and during one IS (Table 4.2). Symptoms were first observed between February and June at NIRS, and in March or April at GV and MB.

During the IS, leaf rust was the most commonly observed rust in trials (NIRS, 1975 a to 1980). In 1974 and 1975, wheat was grown in trials at some 10 locations throughout Zambia and only leaf rust was recorded. Leaf rust was recorded in the Southern Province at Siatwinda and NIRS, in the Lusaka Province at Mount Makulu and the University of Zambia, in the Central Province at GV and in the Copperbelt Province at Munkumpu. In the Western Province, rust was observed but not identified. At GV, one of the few locations with more than 2 seasons of observations, leaf rust occurred at least 4 times in 6 seasons and at Munkumpu 3 out of 4 seasons. In 1977, leaf rust was absent from NIRS but it occurred at Munkumpu, Chisamba and GV. In the HRBP, there was only one spontaneous epidemic, which was first observed in June.

Leaf rust occurs sporadically in Zambia, and also in Zimbabwe, and has a patchy distribution during RS and IS.

5.3.2. Rust development

General. Leaf rust developed to severities of 25% in very susceptible genotypes in 1975 IS and 1976 IS at NIRS, and in 1978-79 RS and 1979 IS at GV. Leaf rust developed after inoculation. At GV in 1978-79 RS, it increased to a severity of 25% in 55 days (MDI1 = 0.45, Subsection 4.3.2). Severities over 10% were not reached before late April. During RS at NIRS and MB, severities remained below 5%. The reference cultivars TOK and ZAM were good leaf rust indicators because leaves were susceptible to leaf rust but resistant to stem rust.

1975 Irrigation season. The terminal leaf rust severity (TL) differed significantly between sowing dates (Wilcoxon, *two-tailed test*). TL tended to decrease with later sowing (Figure 5.1). At NIRS, the first symptoms were observed on 13 June. The spores infecting wheat probably arrived in late May or early June, at the time when flag leaves had appeared from all genotypes sown on 2 April. For genotypes sown on 12 May, flag leaves appeared late in June or in July. Conditions for infection became unfavourable after mid-July because of a decrease in the duration of leaf wetness. Susceptible genotypes sown on 2 April had leaf rust on all plant parts, while the same genotypes sown on 12 May had little or no leaf rust. This shows that susceptible genotypes can escape leaf rust from outside sources, if sowing is postponed until May.

1976 Irrigation season. Leaf rust spores came primarily from a neighbouring field with volunteer wheat and from spreader plants. By 24 May, sporulating pustules were found on seedlings of all parent genotypes. As a result of infection early in the development of the host, leaf rust had a long period for development, and high severities occurred on all leaves of very susceptible genotypes, such as TOK. On TOK the rust increased in 73 days to a severity of 25% on the lower leaves (MDI1 = 0.34). Severities over 10% on the lower leaves were reached after late June and, on the flag leaves, after mid July.

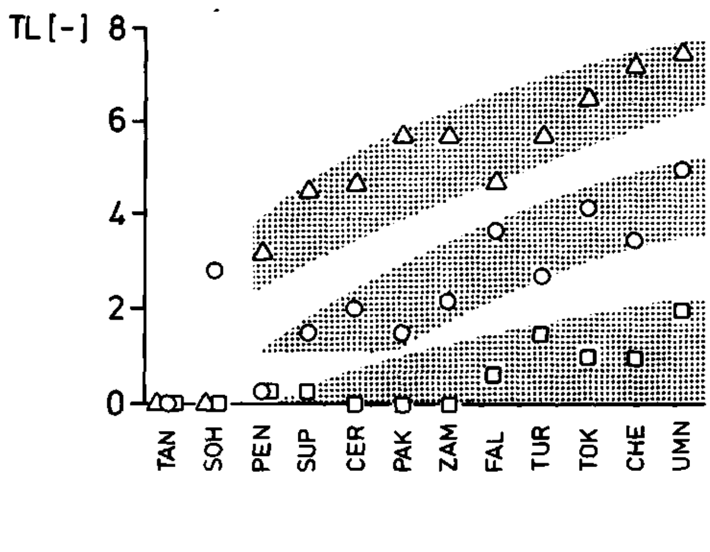

Figure 5.1. 1975 IS, NIRS, mean terminal leaf rust severity (TL) on a scale from 0 to 9, for 12 genotypes with 3 sowing dates, 2 April (△), 21 April (○) and 12 May (□), respectively. TL is the mean of 4 replications.

Other irrigation seasons. In 1977, leaf rust remained absent at NIRS. Although leaf rust was introduced artificially before mid June, severities on susceptible genotypes remained below 10% in the 1978, 1979 and 1980 IS, at NIRS.

5.4. Host resistance and rust races

5.4.1. Reaction type

In the Regional Disease Trap Nursery (RDTN), 8 parent genotypes and Jupateco 73 (JUP) all had a susceptible reaction type to leaf rust at one location at least. The cultivar TAN had a resistant reaction type: R at NIRS, and 0 at other locations. Differences occurred between years and locations. With several genotypes, the reaction type at one location changed in time from 0 to R and S, but also, inversely, from S to various resistant reaction types, including absence of visible infection. This observation suggests either differences in rust populations between years and locations, or strong genotype-weather interactions. When genotypes were ranked according to reaction type, there was no constant order (Table 5.2). This suggests differences between the various leaf rust populations.

5.4.2. Severity

In the RDTN, leaf rust occurred at Njoro in Kenya, Lyamungu in Tanzania, Chiredzi in Zimbabwe and at NIRS in Zambia. In Kenya, it was rarely recorded, either because the disease was not present or because recording was not considered worthwhile in view of low severities. The 8 parent genotypes (AFR, FA ,GIZ, ZAM, PEN, CHE, SUP, CER) suffered infections of only moderate severity. JUP had a high severity at Lyamungu in 1975, but low severities at Lyamungu in other seasons and at other locations. The cultivar TAN had very low severities at all 4 locations.

5.4.3. Relative resistance

In the RDTN, AFR had a high relative resistance (RRES, Equation (4.5)) at NIRS and at Chiredzi, but a low RRES at Lyamungu in 1977 and at Njoro (Table 5.3). The opposite was found for CHE and SUP, which had a low RRES at NIRS and Chiredzi, between 0 and 0.44, and a high RRES in Lyamungu and Njoro, over 0.80. The parent genotype FA had an RRES of 0.75 at Lyamungu in 1975 and a low RRES in 1977. JUP, however, had a low value of RRES at Lyamungu in 1975 and an RRES of 0.67 in 1977. These findings suggest that the populations of races differed between locations and years. RRES-values from NIRS and Chiredzi, however, and from Njoro and Lyamungu, were significantly correlated (Table 5.4). This suggests that the populations of races at some locations were similar.

Table 5.2. Genotypes in RDTN with and without changes in reaction type to leaf rust at several locations (Chiredzi and Lyamungu) and in various years.

Chiredzi	1977	1978	Lyamungu	1975	1977
Africa Mayo	0	0	Penjamo 62	0	0
Jupateco 73	0	R	Zambesi I	S	0
Penjamo 62	S	R	Jupateco 73	S	S
Zambesi I	S	S	Africa Mayo	S	S

Table 5.3. Relative resistance (RRES) to leaf rust at various locations (NIRS, Chireszi, Lyamungu and Njoro) in various years. Underlined values suggest differences in leaf rust populations. TS(s) means terminal stem rust severity of most susceptible genotype.

Genotype	NIRS		Chiredzi		Lyamungu		Njoro
	HRBP 1976	RDTN 1976	RDTN 1977	1978	RDTN 1975	1977	RDTN 1979
Africa Mayo	0.99	-	1.00	1.00	0.75	0	0.50
Chenab 70	0.44	0.33	0	-	0.81	0.83	-
Super X	0.40	0	0	-	0.88	0.99	1.00
FA	-	0.33	0.90	-	0.75	0	0.50
Jupateco 73*	0.99	1.00	1.00	0.50	0	0.67	0.75
TS(s) (%)	25	30	50	100	80	30	40

* Commercial cultivar in Zambia. - Missing value.

RRES for the same genotypes in RDTN microplots and HRBP plots at NIRS in 1976 showed a highly significant correlation. Corresponding correlations of RRES for genotypes in RDTN at NIRS with RRES at other locations, and for RRES in HRBP with RRES at other locations, had the same levels of significancy. These findings suggests, that observations in RDTN and HRBP were in close agreement with one another.

RRES-values from NIRS were more similar to those at Chiredzi than to those at Lyamungu or Njoro. Apparently, leaf rust populations at NIRS were more similar to populations at Chiredzi than to those at Lyamungu or Njoro. Rust populations at Lyamungu and Njoro also seemed similar to one another.

In the RDTN, all 8 parent genotypes and JUP showed differential resistance, with the RRES being low in at least one season (or location) and high in at least one other season (Table 5.3, Figure 5.2). TAN had high levels of RRES at all locations. The level of RRES at NIRS in Zambia was a good predictor of the RRES at Chiredzi in Zimbabwe (Table 5.4).

Table 5.4. Ranking of relative resistance to leaf rust of 10 genotypes at 4 locations. Further explanation see text and Subsections 4.4.2. and 4.4.5.
0 = p > .05 ++ = p < .01 + indicates the sign of r
\+ = p < .05 +++ = p < .001

			NIRS HRBP		Chiredzi RDTN	Lyamungu RDTN		Njoro RDTN
			1975	1976	1977	1975	1977	1979
NIRS	HRBP	1975		+	++	0	0	0
	RDTN	1976	+	++	++	0	0	0
Chiredzi	RDTN	1977		+		0	0	0
Lyamungu	RDTN	1975		0			+++	+
		1977		0				+++

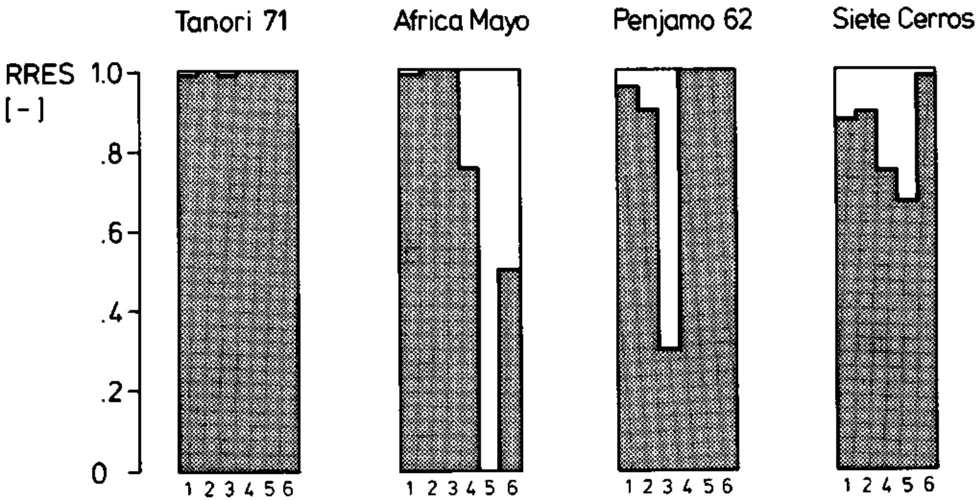

Figure 5.2. Relative resistance (RRES) to leaf rust of 3 genotypes used in HRBP and cultivar TAN at various locations during various seasons. For further explanation see text and Subsection 4.4.2.

Season				TS(s)
1	NIRS	Zambia	1976	25
2	Chiredzi	Zimbabwe	1977	50
3	Chiredzi	Zimbabwe	1978	100
4	Lyamungu	Tanzania	1975	80
5	Lyamungu	Tanzania	1977	30
6	Njoro	Kenya	1979	40

5.5. Yield loss

The 1975 IS and 1976 IS provided valuable information, but from 1978 to 1980, leaf rust had little effect on yield at NIRS, GV and MB.

5.5.1. 1975 Irrigation season

Yield (Y) differed significantly between sowing dates (Wilcoxon, two tailed-test) and was higher for the second sowing date (21 April) with the lower TL-scores. Means per sowing date, 2 and 21 April, were 4.3 and 5.2 mt/ha, respectively (SE = 0.4 mt/ha). Y and TL were not significantly correlated, even in the first sown trial with high TL-scores. Though severities were high, especially on the lower leaves, only 2 genotypes suffered a loss in thousand kernel weight (KWLOS) of more than 5%. In the cultivars TOK and FAL, although KWLOS was 16% and 12%, the thousand kernel weights at harvest (TKWh's) were 40 g and 37 g respectively. Heads, flag leaves and flag leaf sheaths are the most important parts of the wheat plant for photosynthesis (Lupton and Pushman, 1975). Because severities on these plant parts remained low, reductions in the photosynthetic capacity of the plant must have been relatively low. Because of the relatively late appearance of the rust, it is unlikely that yield components other than TKWh were significantly affected by leaf rust. Consequently, yield loss due to leaf rust remained low. It follows, that leaf rust is not responsible for the whole difference in yield between sowing dates. Other factors, such as temperature, must have contributed to these differences.

Postponement of sowing in the IS in Zambia may have 2 advantages: it reduces the duration of the period with favourable conditions for leaf rust infection and gives low terminal severities, so little or no yield loss occurs.

5.5.2. 1976 Irrigation season

High severities on the flag leaf (TLF) tended to be associated with high severities on the lower leaves (TLL). TLF and TLL did not show a significant correlation with any of the terminal stem rust scores on stem (TSS), flag leaf (TSF) and lower leaves (TSL), when 20 parent genotypes were included in the analysis (Table 5.5, Group 3). With the genotypes of Group 2, both TSF and TSL had a significant negative correlation with TLF. Thus, a high leaf rust severity on the flag leaf tended to be associated with a low stem rust severity, and vice versa.

Though boths rusts appeared approximately at the same time, leaf rust infected a larger area of the leaves than stem rust; the mean values of TLF in Groups 1 and 2 (Subsection 4.5.2) were almost 5 times larger than the means of TSF. This was true also for lower leaves (Table 4.13). Presumably, leaf rust was more successful in infecting the leaves during the cold part of the IS. The better adaptation to lower temperatures during June, July and early August may have given leaf rust an advantage in the competition for leaf tissue. Furthermore, a genotype which was resistant to leaf rust might be susceptible to stem rust and vice versa.

Preferential scoring, especially on very susceptible tissue, may have contributed to the negative correlation between TLF and TSF. Preferential scoring occurred when it was difficult to distinguish pustules of leaf and stem rust. It follows, that scores of leaf and stem rust on the leaves were not independent for all genotypes. Consequently, yield analyses using disease scores of the leaves have to apply multiple regression analysis and not single regression to account for the interactions rust x rust and rust x genotype.

Though it is likely, in view of the high severities observed that leaf rust contributed to yield loss, and that yield and yield components were influenced, this effect could not always be confirmed statistically (Table 5.6).

Table 5.5. NIRS, 1976 IS, Pearson's r and levels of significance (one-tailed test) for correlations between terminal rust severities, for 2 groups of genotypes. Group 3 contained 20 genotypes (18 df), Group 2 contained the 10 most susceptible genotypes (8 df). Means per genotype were taken over 9 replicates. Results of Group 3 are in the bottom left, of Group 2 in the top right of the Table. For further explanation see List of abbreviations and symbols and Subsection 4.5.2.

			Stem rust			Leaf rust		
			TSS	TSF	TSL	TLF	TLL	
	Stem	TSS	-	0.85***	0.61*	ns	ns	Group 2
	rust	TSF	0.50*	-	0.81**	-0.60*	ns	
		TSL	0.60**	0.68***	-	-0.56*	ns	
	Leaf	TLF	ns	ns	ns	-	ns	
Group 3	rust	TLL	ns	ns	ns	0.64***	-	

Table 5.6. NIRS, 1976 IS, Pearson's r and level of significance (one-tailed test) for correlations between rust severities and grain yield (Y), stand (ANOH2), kernels per head (ANOK) and thousand kernel weight (TKWh), for 2 groups of genotypes. For explanation see text, List of abbreviations and symbols and Subsection 4.5.2.

	Variable	Stem rust TSS	TSF	TSL	Leaf rust TLF	TLL
Group 3 (N=20)	Y	-0.68***	-0.48*	-0.46*	ns	ns
	ANOH2	ns	-0.44*	ns	ns	ns
	ANOK	ns	-0.43*	-0.44*	ns	ns
	TKWh	-0.71***	ns	ns	ns	-0.44*
Group 2 (N=10)	Y	-0.82**	-0.78**	ns	ns	+0.58*
	ANOH2	-0.66*	-0.77**	-0.55*	ns	ns
	ANOK	-0.62*	-0.80**	ns	ns	+0.62*
	TKWh	-0.53*	ns	ns	ns	ns

TLL had a significant negative correlation with TKWh in Group 3, but not in Group 2. Curiously, TLL in Group 2 had a significant positive correlation with mean number of kernels per head (ANOK) and Y. A similar finding was reported by Dinoor (1981) in Israel, who assumed that under semi-arid conditions leaf destruction by leaf rust and Septoria spp. towards the end of the season was beneficial to yield because of the shift of activity from leaves to sheaths and heads, and a reduction of evapotranspiration. In Zambia ripening conditions are hot too. Possibly, this water conservation effect is operating in Zambia.

Leaf rust scores did not have a significant negative correlation with mean number of heads per m2 (ANOH2) or ANOK, which indicates that stand and kernel number were not much influenced. Yield loss is due apparantly to interference with the kernel filling (TKWh).

5.6. Discussion

Physical conditions for leaf rust infection are favourable when there is free water in the form of dew, guttation, or rain, and when there are temperatures of approximately 20 C (Chester, 1946). The latency period is about 6 days at 20 C and 50 days (Overlaet, 1963) at low temperatures.

During the RS in Zambia, temperatures are not extreme enough to prevent infection. There is sufficient moisture, in the form of rain water or irrigation water and also in the form of dew, and there is a high relative humidity (Figure 2.2). In this study, spontaneous epidemics were observed first usually in March and April, but, also occasionally in February. This confirms that leaf rust does not normally spread in the central and southern part of Zambia until late March or April (Mounter, 1961). However, with an increase in wheat hectareage, spread in February may become normal, especially in areas with extended dry periods.

At locations with an annual precipitation of 800 mm and below, as at Livingstone, Zimba, Choma, NIRS, Mount Makulu and GV, monthly mean temperatures tend to be over 20 C and periods without precipitation may last several weeks (Mounter, 1961; Meteorological Department, 1975; Simango and Das, 1977). At these locations conditions for early infection are expected to be favourable. The dispersal of uredospores is probably greatest during days without rain, particularly when the rains have come to a complete stop, because then there are no spore removal effects of rain.

The locations with an annual precipitation of over 800 mm differ in altitude. Monthly mean temperatures above 20 C occur at Kabwe, situated in the centre part of Zambia (Figure 2.1), and of below 20 C, with monthly mean minimum temperatures of 14 to 15 C, at MB. Periods without precipitation lasting one or 3 weeks do occur, but they are less frequent than in areas with lower precipitation. Conditions for infection may be favourable at locations with a high precipitation. At MB, however, leaf rust severities remained below 5%. Even when leaf rust was present as early as mid March only light attacks followed. Possibly, infection is limited by the scarcity of dew. Because of the high frequency of rain showers, spores will be washed away from the leaves. The temperature will be responsible for latency periods well over 6 days. Low severities may therefore be normal at higher altitudes. At lower altitudes with higher temperatures, high severities might occur, especially when the wheat hectareage is large.

In April and May, conditions are generally favourable for rust development between 950 and 1100 m altitude. The lower temperatures in June and July reduce the rate of increase but infections can take place and the rust can increase in quantity; there is usually moisture on the leaves, either as dew or as irrigation water. During August and September, when temperatures are high and dew periods are short or absent, the number of leaf wetness hours may no longer be sufficient for successful infection. This is also the time that the crop is most in need of water; so sprinkler irrigation is applied for at least 6 hours per week. There is thus at least one day per week with enough free moisture on the leaves for rust infection. This means that wheat sown at different dates in April and May can become severely infected (Table 4.4). Wheat sown in late May and early June may be attacked only lightly but the high temperatures in August and September may reduce the period to ripening so drastically that yield is lost, due to "early ripening".

With the increasing hectareage of wheat, resistance to leaf rust would help to reduce the build up of inoculum, especially at lower altitudes,thus reducing the chance of perennation.

During the warm RS, the levels leaf and stem rust severities on ZAM and TOK were similar. During the colder months of the IS, leaf rust can increase more quickly than stem rust. This may give the illusion that leaf rust appeared before stem rust. In the examples discussed, however, the 2 rusts were introduced simultaneously.

Airborne inoculum coming from neighbouring countries may generate spontaneous epidemics in Zambia. However, with the increase of the wheat area, there is a chance that local sources will become important too.

The reaction type, the severity, and the relative resistance indicated that the parent genotypes of the HRBP all had matching races of leaf rust. The results confirm the statement by Saari and Wilcoxson (1974) that there are races of leaf rust that can attack CIMMYT wheats bred in the 1950s such as CER and SUP. Cultivars bred in the region, such as AFR and ZAM, were also attacked, as well as more recent CIMMYT cultivars, such as JUP. In most genotypes, leaf rust reached moderate severities only.

Though leaf rust occurs frequently in wheat, it is not a disease which causes high losses. Severe epidemics occurred only one year out of six. During severe epidemics leaf rust generally caused losses in TKWh of 3 to 5%, although in the most susceptible genotypes losses of over 20% occurred. TKWh was the only yield component which was significantly influenced, after an early onset of the epidemic. With TLL < 10 and RRES > 0.80, it is unlikely that yield losses due to leaf rust exceed 10%.

5.7. Summary

- Leaf rust occurs more frequently in Zambia than stem rust.
- Spontaneous epidemics can begin in February. Severities of more than 10% can occur in late April in rainfed and in late June in irrigated wheat.
- Different races are present in neighbouring countries.
- Race shifts occur in neighbouring countries.
- Because of the 3 principal airstreams, Zambia may receive inoculum from virtually all neighbouring wheat growing countries.
- Few genotypes were severely attacked.
- Most genotypes used had differential resistance; only some may have had uniform resistance.
- After epidemics with an early onset, losses in kernel weight were generally less than 5%, although in the most susceptible genotypes losses of over 20% occurred.
- Kernel weight was the only yield component to be significantly influenced, after an early onset of the epidemic.
- Selection criteria suggested were: terminal severity of leaf rust on lower leaves of less than 10 and a relative resistance for lower leaves of more than 0.80.
- With an increase in wheat hectareage, resistance to leaf rust might be of importance to reduce yield loss during rainy season and irrigation season and to reduce chances for perennation, especially at lower altitudes.
- Postponement of sowing to May might serve as a measure to prevent high leaf rust severities during the irrigation season.

6. PARENT GENOTYPES

Qualitative plant characteristics of the parent genotypes used in the HRBP are described (Section 6.2). During various irrigation seasons (ISs), trials were performed with several groups of genotypes to obtain information about several quantitative plant characteristics and about variations among trials, groups, and genotypes. Emergence, crop development, stand counts, yield components and yield are discussed (Sections 6.3 to 6.7) for irrigated wheat. Some comments on selection in Zambia are also given.

6.1. Introduction

A parent genotype is a cultivar or line used for crosses by HRBP in the 1976 and 1977 ISs. Parent genotypes were handled in 4 groups (Table 6.1). Groups 1 and 2 consisted of the genotypes used in the HRBP. Groups 3 and 4 consisted of genotypes used by the Research Branch (NIRS, 1975 b; Kotschi, 1976); these were the most advanced Zambian wheat genotypes.

Except for the sowing date studies, the trials were carried out in the breeding block (BB). There were up to 4 sowing dates (trials) within one year. A 2 figure code is used to indicate year and sowing sequence: 6,0 = 1976 IS, HRBP trial; 6,1 = 1976 IS, sowing date 1; 9,2 = 1979 IS, sowing date 2; 0,1 = 1980 IS, sowing date 1. Three designs were used.

- Randomized design: HRBP, 1976 and 1977 ISs.
- Randomized block design: 1975 sowing date study; HRBP, 1978, '79 and '80 ISs.
- 4 x 9 Factorial design; 4 sowing dates, 9 genotypes, with randomized blocks and 4 replicates/genotype/sowing date: 1976 sowing date study.

In 1975, there was a standard application of 4 h of overhead sprinkler irrigation per week. In the 1976 sowing date trial, irrigation took place at weekly intervals. The amount of water to be applied was calculated (Kotschi, 1976; Aeppli, 1977 a) taking into account the development stage (DVS) of those plots with the highest water requirement. Water application was lower for the second and third sowing dates than for the first date (Table 6.2), because of the shorter duration of growing periods of the wheat. The wheat from the fourth sowing date required a higher application than that of the third, due to high temperatures. In the HRBP, total net application was < 550 mm. In 1976, 1977, and 1978, irrigation was adapted to crop requirements and temperature. In the first sown trial of 1979 IS, the rainfall had ended early in March, and little residual moisture was present at sowing.

Table 6.1. Information on groups of genotypes.

Group	Years	No of entries	Objectives	Genotypes
1	1976-1980	22	HRBP	AFR, BOB, BUB, CE2, CER, CHE, CNO, CON, EMU, GIZ, JUP, PAK, PEN, SA4, SHA, SOH, SUP, TOK, TUR, TZP, UMN, ZAM
2	1977-1980	12	HRBP	7CE, CN8, CNF, FA , FAL, HIN, KAL, KIT, MXP, SON, SOP, X1
3	1975	12	Sowing date study	PAK, PEN, TUR, and genotypes of Group 4
4	1976	9	Sowing date study	CER, CHE, SOH, SUP, TAN, TOK, TUR, UMN, ZAM

Table 6.2. End of rains, sowing dates, and cumulative net application of water at different days after sowing, with a net application rate 6 mm/h, NIRS, IS. Residual moisture at sowing was not recorded.

Year	Group	End of rains	Sowing date	Days after sowing 40	60	80	100	Total at harvest
1975	3	15 Mar	2 Apr	200	275	350	425	529
1976	4	11 Apr	15 Apr	-	-	-	-	599
			1 May	-	-	-	-	571
			15 May	-	-	-	-	558
			1 Jun	-	-	-	-	585
1976	1,2	11 Apr	21 Apr	155	220	280	350	535
1977	1,2	19 Mar	29 Apr	190	230	310	385	504
1978	1,2	22 Apr	14 May	125	170	220	285	391
1979	1,2	7 Mar	27 Apr	120	170	220	275	372
			7 May	180	220	270	300	400
1980	1,2	8 Mar	22 Apr	115	160	200	260	302
			16 May	110	150	190	220	340

During 1980 IS, the water supply was intentionally kept low, to test the performance of the entries under conditions of water stress. In the first sown trial, the second application of water took place 10 days after sowing. Stress manifested itself by leaves drooping and curling during day time.

Data were submitted to the SPSS programme Breakdown (Nie et al., 1975), to perform a oneway analysis of variance for testing differences among genotypes. Occasionally, a two-way analysis of variance was performed with or without covariates, as for the 1976 sowing date trial. To test differences among sowing dates for genotypes and Groups, a Wilcoxon test was used. The pooled s2 (Snedecor and Cochran, 1967) of the within-sample variance was used to calculate the standard deviation within genotypes (SD-within). Occasionally, the SD-within was expressed as a percentage of the mean (CV-within). The Pearson correlation coefficient r was calculated to measure the linear relationship among two variables.

To simplify calculations, dates were expressed in DAYs of the Julian calendar. The average of the daily mean temperature for the first 10 days after sowing (Td10), for the first 70 days after sowing (Td70), and for other periods, were calculated for various sowing dates. For materials and methods see also Chapters 3 and 4.

6.2. Plant characteristics

Plant characteristics were described for identification of genotypes and were used as genetic markers.

6.2.1. Qualitative plant characteristics

Leaves. The cultivar TOK had a mottling of the leaf at about 44 DC because of a defective chlorophyll condition (Oosterhuis, 1972). Several genotypes showed wax formation on the foliage at 54 DC. The colour of auricles and ligules was light green, white or pink at 54 DC.
Peduncles. Colours of peduncle were white, cream or golden yellow at 93 DC. Most genotypes formed wax on the stem.
Head shape. Most parent genotypes had a fusiform or an oblong head shape,

except the cultivars GIZ, SHA, BUB, TUR, KIT, FA, which had dense heads. GIZ and TUR had strikingly broad heads. GIZ showed some spikelet infertility.
Glumes. Glume colour was brownish for ZAM, SUP, CER, PAK and CN2. All other genotypes of Group 1 had a light glume colour. GIZ, TUR and SA4 had pubescent glumes, while all other genotypes had glabrous glumes. The tightness with which the glumes clasped the kernels was such that all entries were resistant to shattering, but could be threshed easily.
Awns. All genotypes of Group 1 and most of Group 2 were fully awned. KIT, FA and FAL were awnless. All awns were barbed. Awns of certain GIZ heads became black towards ripening, while others remained white. As head selections of both types of heads did not segregate, GIZ may have been a mixture of lines.
Anthers. Ripe anthers of GIZ were purplish-pink, those of BOB and CNO were white, and those of all other genotypes of Group 1, light yellow. The anther colours of genotypes of Group 2 were not recorded.
Kernel. 23 Genotypes (13 of Group 1) had a brownish kernel, and 11 genotypes (9 of Group 1) had a whitish kernel colour: GIZ, CNO, CHE, CER, TZP, CON, PAK, UMN, CE2, MXP and KAL.

6.2.2. Quantitative plant characteristics

Crop development, tillering, plant height (APHT), number of spikelets per head (ANOS), number of kernels per head, kernel weight, and grain weight per head were among the quantitative plant characteristics studied.

Plant height. The mean APHT of Groups 1 and 2 did not differ significantly. Differences among trials were significant. The first sowing dates of 1979 and 1980 had a low mean APHT (Figure 6.1), the CV-within for genotypes was relatively high. Drought (irrigation) may be the major factor influencing mean APHT, but temperature and land preparation may have had an effect. Differences among genotypes were highly significant for all sowing dates.

Genotypes could be grouped into 3 classes of APHT: short, APHT $<$ 80 cm, e.g. TOK, UMN, FAL; medium tall, 80 cm $<$ APHT $<$ 105 cm, e.g. ZAM, CER, CHE; tall, APHT $>$ 105 cm, e.g. HIN, FA , AFR. The majority of the genotypes were medium tall (Figure 6.1). Tall genotypes did not occur in Groups 3 and 4, because tall straw was not considered to be a desirable characteristic for irrigated wheat in Zambia. Under certain growing conditions, differences between short and medium tall genotypes were relatively small at DAY = 112. Differences in mean APHT among genotypes were most distinct in trials sown after 1 May, with a cumulative net water application at harvest $>$ 400 mm. Under these conditions selection for plant height will be most effective.

Tall genotypes tended to respond more sensitively than shorter genotypes to differences in growing conditions. The SE-within was high, and differences in APHT among sowing dates were distinct.

The mean APHT was higher after sowing in early May than in April-sown wheat. For wheat sown in April, temperature in the period to heading was relatively high (16.9 C $<$ Td70 $<$ 19.0 C). For wheat sown in May, however, temperature in the period to heading was relatively low (15.6 C $<$ Td70 $<$ 17.7 C), so conditions were more favourable for cell elongation.

High rust severities did not appear to reduce mean APHT within genotypes. In 1976 IS, when rust severities were relatively high, the mean APHT was relatively high and the CV-within genotypes was relatively small (6%).
Tall genotypes tended to have lower rust severities, of TSS ($r = -0.45^*$, 18 df) and of TLF ($r = -0.53^{**}$, 18 df). This correlation may be due, to some extent to interplot interference. Conditions for infection may be more favourable in shaded plots than in unshaded plots, because of longer duration of leaf wetness.

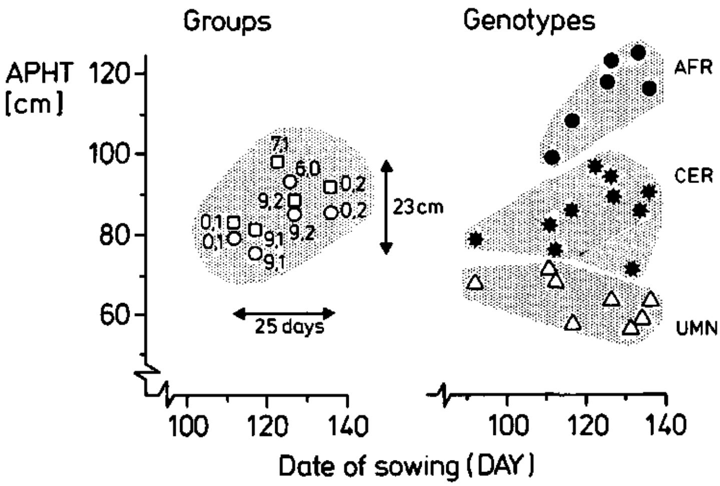

Figure 6.1. Mean plant height (APHT) in cm, for Groups 1 (o) and 2 (□) and some characteristic genotypes, for various sowing dates in Julian DAYs, NIRS, 1975-1980.

Number of spikelets per head. The means of ANOS did not differ significantly between Groups 1 and 2. There were significant differences among trials. Differences among genotypes were highly significant for sowing date 2 of 1979 and for sowing date 1 of 1980. In other trials differences were not significant. Variability was high: e.g. FAL had the lowest mean ANOS for sowing date 1 of 1980 but the highest for sowing date 2. As a result, genotypes could not be grouped in fixed classes for this characteristic.

The mean ANOS was relatively low in 1979 and 1980 (Figure 6.2). For the first sowing date of 1979, a low cumulative net water application (Table 6.2) was associated with relatively high air temperature. Formation of spikelet primordia takes place during tillering. Water stress lowers assimilate availability. Water deficit may have been responsible for reduced spikelet formation, reducing mean ANOS, and causing low ANOS values in all genotypes. Water deficit likely was an important cause of the low mean ANOS in 1980. Td70 had a similar range in 1976, 1979 and 1980, so temperature differences are not expected to be an important cause of observed differences among years. In all trials, stem and leaf rust severities were low before 40 DC, so rusts are unlikely to have been responsible for the differences.

The mean ANOS tended to decrease with increasing temperatures. This effect appeared to be more distinct for early flowering (e.g. TOK) than for late flowering genotypes (e.g. UMN), see Figure 6.2. Increasing temperatures reduce the period for spikelet formation. Differences among genotypes are most distinct for early sowing dates, when Td70 is relatively high.

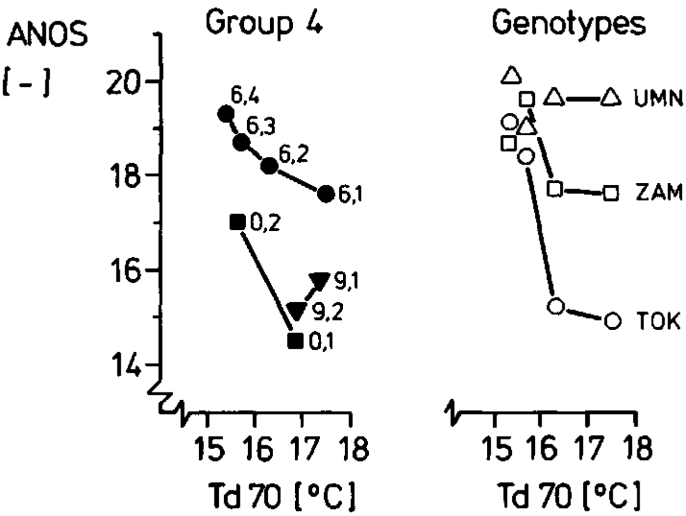

Figure 6.2. Response to Td70 by mean number of spikelets per head (ANOS), for Group 4 and some characteristic genotypes, 1976 IS. LSD(0.05)-sowing dates was 0.8. (6,3 means 1976, third sowing date).

6.3. Emergence

Emergence is described in terms of the proportion realized emergence (PREM), the actual emergence expressed as a fraction of the expected emergence (Subsection 3.4.2).

6.3.1. General

Means of PREM did not differ significantly between Groups 1 and 2. The total mean was < 0.60 for all Groups; means per Group and per sowing date were between 0.36 and 0.78. There were significant differences among sowing dates in 1976 IS. Differences among genotypes were not significant, except in Groups 1 and 2 in 1976 IS and 1978 IS.

Emergence can be effected by, among others, damage to seed during storage (Wilbur et al., 1971), dormancy (Subsection 6.3.2) (Lamb, 1967; Austin and Jones, 1974), rust infection of the mother plants (Subsection 6.3.2), shallow sowing (Subsection 6.3.3), and differences in soil (Subsection 6.3.4) (Lamb, 1967; Schlehuber and Tucker, 1967; Austin and Jones, 1974).

Harvesting of unripe seed and seed dormancy occurred, but no trials were carried out to determine whether these were major factors responsible for a low mean PREM. In Zambia, sprouting in the head does not normally occur, so dormancy is unnecessary.

In 1976, seed of CHE, CON, TUR, and AFR was infested by weevils during storage. Only the seed of AFR, with 14% of the kernels having weevil emergence holes, had a low mean PREM (0.42; grand mean 0.65). In 1980, seed of one replication for each of the 2 sowing dates had not been dressed, and had become infested during storage. Several entries had a severely reduced mean PREM in comparison to the grand mean (CHE, TUR, FA , HIN, KAL, CER, JUP and CE2) and significant differences occurred among genotypes. So selection for resistance to storage insects may be possible.

Mean PREM increased with TKWp (r = 0.62**, 18 df). Genotypes with a low kernel weight and small kernels tended to have a lower mean PREM than those with a high kernel weight and larger kernels, perhaps because they contained less moisture. As sowing was done by hand, kernels were at various depths, and only poorly covered with soil. The top-soil may have become too dry for germination and emergence of all seeds, especially small seeds. It follows that rusts, which reduced mean TKWh, may have reduced mean PREM. For a given genotype, large seeds give large seedlings, which are better able to withstand adverse environmental conditions and competition from neighbouring plants than smaller seedlings are (Austenson and Walton, 1970). Large seed size is therefore a valuable selection criterion. Shallow sowing and selection for rapid emergence may, to some extent, compensate for tendencies to poor emergence (Austin and Jones, 1974).

6.3.2. Germination

At NIRS, germination in the laboratory after 5 months storage varied significantly among genotypes (Table 6.3) with a range from 57% to 93% and a mean of 78%. GIZ, EMU and BOB, with a low PREM in 1980, had a low germination.

To obtain information on the effect of stem rust infection of the mother plants on seed germination in the laboratory, 5 genotypes with a low TSS during the previous growing season and 5 with a high TSS were tested. A high TSS was expected to cause a low germination percentage, especially in genotypes with a low kernel weight (e.g. TUR and SA4).

Table 6.3. Germination (%) of 1976 IS seed in the laboratory after 5 months of storage at NIRS, terminal stem rust severity TSS (%) in 1976 IS, and thousand kernel weight TKW (g). Date of observation 16 Feb 1977. Four replications per genotype.

Genotype	Germination Mean	Germination SD	TSS Mean	TKW Mean
GIZ	63	3	1	53
CNO	84	2	4	48
BOB	72	6	6	55
EMU	69	9	8	57
BUB	86	3	9	36
SHA	72	6	11	35
TOK	89	4	16	28
PEN	82	3	20	47
TUR	78	9	26	22
SA4	82	5	27	29
Grand mean	78	5		

Oneway, germination by genotype, $F(9,39) = 9.2$***.
Oneway, germination by rust level, $F(1,8) = 1.2$.

Germination in the 2 groups of genotypes did not differ significantly (Table 6.3). Apparently, stem rust during seed set in the preceding season does not necessarily cause low germination. Harvesting of unripe wheat, moist storage conditions during the RS, and dormancy are thought to be the major factors responsible for the low mean germination.

6.3.3. Sowing date and temperature

Mean PREM tended to be slightly lower for sowing dates up to mid-May than for later sowing dates. In April, most wheat was sown in a dry seed-bed with a coarse soil structure, as in 1976 date of sowing trial, 1979 and 1980 trials; daily mean air temperatures were between 17 and 22 C. Later in the season, the seed-bed tended to be moist with a fine structure, as in 1976 and 1978 HRBP trials; daily mean air temperatures were between 14 and 20 C. Crust formation occurred in several trials and may have reduced emergence. For the first sowing date in 1980, mean PREM was 0.36, perhaps due to the lack of water during the first 10 days after sowing. Irrigation 7 days after sowing was found to be important for the establishment of wheat (NIRS, 1979).

In 1976 IS, mean PREM decreased with increasing Td10, with an observed range of $15.5 < Td10 < 22.5$ ($r = -0.98^{**}$, 2 df). PREM was significantly correlated with Td10 in some years only. In 1978 IS, mean PREM was approximately 0.80, though Td10 was 19.2 C. Non-dormant seed will germinate over a wide range of temperatures, the optimum temperature is between 12 and 25 C (Austin and Jones, 1974). At temperatures of 35 C germinating seed suffers irreversible heat damage (Onwueme and Laude, 1972). It is unlikely that temperature directly reduced emergence in the trials. Coarse soil structures and crust formation may occur more frequently at daily mean temperatures of 19 C than at 16 C.

6.3.4. Soil type

Differences in soil type in the breeding block caused only minor differences in mean emergence (ANOVA, $P < 0.1$). In 1976, for example, mean PREM was highest (0.70) in a sandy clay loam and lowest (0.61) in a sandy loam soil.

6.4. Development

6.4.1. Development stage

The mean DVS of Groups 1 and 2, for observations made on the same day, did not differ significantly. There were obvious longitudinal differences between the curves for various genotypes. Transversal differences were largest between 50 and 90 days after sowing (Figures 4.3 and 4.4), and CV-entire population was highest (Table 6.4). Selection for development stage can best be performed when differences between genotypes are most distinct, which is between 50 and 90 days after sowing during the IS. At 120 days after sowing, differences were a few scale units only. Differences among genotypes were highly significant from 58 to 125 days after sowing. The CV-within was low, even when there was water stress as in 1979 and 1980. Apparently, development stage is relatively insensitive to water stress and variations in soil fertility or structure.

6.4.2. Development periods

The mean number of days to reach a particular development stage differed among sowing dates for Groups and genotypes (Figure 6.3). Per genotype, development periods in days to 37, 40, 54 and 64 DC were all correlated

Table 6.4. Development stage (DVS, mean) of Groups 1 and 2 in DC and coefficients of variations at various days after sowing (DAS), at NIRS, IS.

Year	DAY	DAS	DVS	CV-entire population	CV-within genotypes
1979	117	90	74	6	3
	127	80	65	11	2
1980	112	58	46	19	7
		112	75	5	3
		125	91	2	2
1980	136	83	66	6	3
		117	90	3	2

significantly for various sowing dates. Some genotypes, with a short period to flowering, sometimes had a long period to early ripening (e.g. ZAM). Only when the period to anthesis (DVS64) constituted a large part of the period to early ripening (DVS90), was DVS90 significantly correlated with other periods. Thus, periods to heading and flowering are not necessarily indicative for the period to ripening, and need separate selection.

DVS54-values for Groups as well as for genotypes could be estimated by means of a temperature sum, the sum of the products of the number of days within each month for the period from sowing to 54 DC and the monthly air temperatures (Tm). The total mean temperature sum per Group and per sowing date for DVS54 was 1144 degree.days (SD = 35, 10 trials). Early-heading genotypes required a lower temperature sum than later-heading ones (TOK, 1047 degree.days; TUR, 1377 degree.days).

Group and genotype means for the number of days from sowing to 50% heading (DVS54) gave a significant linear regression on the average daily mean air temperature over that period (Td54) (Table 6.5). DVS54-values decreased with increasing temperature.

Mean period from 50% anthesis to early ripening (mean PEAR) differed significantly among sowing dates. The duration of PEAR declined with an increase in the average daily mean temperature for the period from anthesis to ripening (TdPEAR), as was found by Vos (1981).

In 1976 IS, differences among genotypes were not significant, but UMN and TUR had distinctly shorter PEARs (Figure 6.4). Possibly, the period from anthesis to ripening was reduced by severe stem rust infection. UMN and TUR are very susceptible to stem rust and were very severely attacked in 1976 IS.

Table 6.5. Linear regression of period in days from sowing to 54 DC (DVS54) and mean daily air temperature (Td54), for genotypes grown in 1975 and 1976, and Groups grown in 1975 to 1978. DVS54 = a + bxTd54. 15 C < Td 54 < 20 C.

		mean DVS54	a	b	r2	df
Genotype	TOK	62	144.8	-4.86	0.85**	5
	ZAM	65	162.4	-5.71	0.96***	5
	CER	69	181.4	-6.58	0.88***	5
Groups		68	137.5	-4.10	0.88***	8

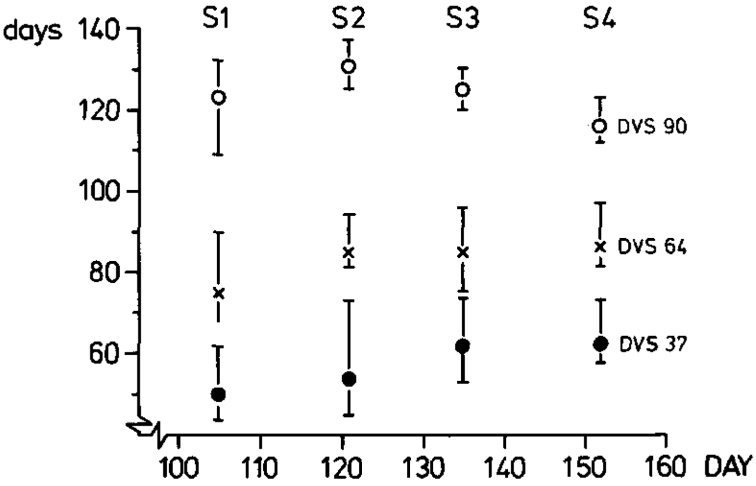

Figure 6.3. Mean number of days to reach various characteristic development stages (DVS37, DVS64 and DVS90) for Group 4, lowest and highest mean per genotype (means of 4 replicates) at 4 sowing dates (S1 to S4), 1976 IS.

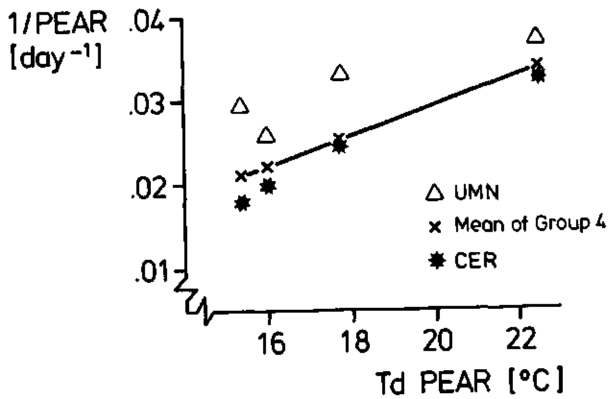

Figure 6.4. Inverse of period from 50% anthesis to early ripening (1/PEAR) for Group 4 and some characteristic genotypes at various temperatures (TdPEAR). 1/PEAR = 0.0018 x Td - 0.0064 (r2 = 0.999**, 2 df).

6.5. Stand

The term stand is used to indicate the population density of plants (during the vegetative phase of development) or heads (during the generative phase).

6.5.1. Stand at emergence

Means of stand at emergence (ANOP) did not differ significantly between Groups 1 and 2. Differences between sowing dates were significant, and mean ANOP tended to be lower for trials sown in April than for later sown trials ($r = 0.79$***, 11 df), probably due to changes in seed-bed structure (coarse at sowing dates 1 and 2 in 1976) and mean daily temperature. Genotypes differed significantly because of insect damage (1976, Group 1; 1980).

6.5.2. Stand at harvest

Means of stand at harvest (ANOH2) did not differ significantly between Groups 1 and 2. Mean ANOH2 differed distinctly for various cumulative net water applications at 80 days after sowing, and was positively correlated with a cumulative net application ($r = 0.68$**, 12 df).

Differences in ANOH2 among genotypes were not significant except in 1980. Mean ANOP differed significantly among sowing dates and genotypes, and was lowest for the first sowing date. Mean ANOP was lower for EMU than for SOH (Figure 6.5). Total mean ANOH2 did not differ significantly among sowing dates, but differed significantly among genotypes. Mean ANOH2 differed significantly among genotypes for sowing date 1, but not for sowing date 2. Though EMU had some compensatory tillering (ANOT was approximately 4.0), it was insufficient to compensate for the low ANOP. Probably, tillering in EMU was inhibited by water stress and by relatively high temperatures during tillering.

6.6. Yield components

The components of grain yield (Y) are heads/m2 (Section 6.5) and kernel weight per head. Kernel weight per head is composed of the number of kernels per head and the weight per kernel. For practical reasons the thousand kernel weight at harvest (TKWh) was used.

6.6.1. Kernels per head

Means of kernels per head (ANOK) did not differ significantly between Groups 1 and 2. Differences among sowing dates were significant. In 1976, rust severities were relatively high, and stem rust influenced ANOK (Subsection 4.5.3), but the mean ANOK was still approximately 40. In 1977, mean ANOK was < 40, though rusts were absent and the total net water application was relatively high. In July, when anthesis occurred, relative humidity was low, and the irrigation interval was 14 days, so conditions may have been too dry for optimal germination of pollen and optimal fertilization. In 1979 and 1980, there was water stress, a relatively low total net water application, and infection by stem rust and leaf rust, but nevertheless the mean ANOK was > 40.

For Groups 1 and 2, mean ANOK-values appeared to increase for later sowing dates ($r = 0.70$*, 8 df) and mean ANOH2 increased (Figure 6.6). This indicates that a relatively high density of heads and a high number of kernels per head could occur simultaneously. ANOK was probably influenced by both the availability of water and the temperature during development from 47 DC up to 64 DC.

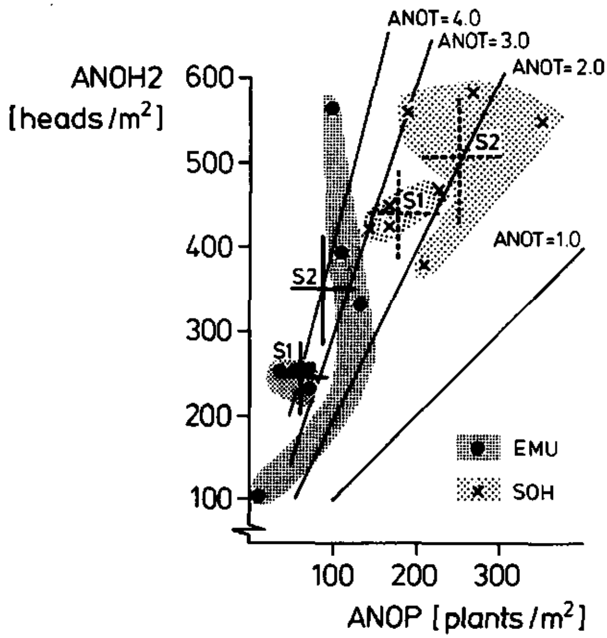

Figure 6.5. Number of plants per m2 after emergence (ANOP) and number of heads per m2 at harvest (ANOH2) for 2 genotypes at 2 sowing dates (S1 and S2), NIRS, 1980 IS. ANOT (slope of lines) is the number of heads per plant. Crosses represent means per variety-sowing date combination.

Differences between genotypes were significant. In the first-sown trials of 1979 and 1980, mean ANOK of most genotypes was 30 to 50 kernels/head. SOH and UMN had less than 30, CER over 50. In the other trials of 1979 and 1980, mean ANOK of most genotypes was 40 to 60. TOK and UMN had fewer than 40; GIZ, EMU, CER, PAK, TZP and CON had a mean ANOK > 60. Mean ANOK of UMN was lower than for other genotypes because of high susceptibility of UMN to stem rust. In TOK, mean ANOK was reduced by stem rust and leaf rust.

6.6.2. Thousand kernel weight at harvest

The means of TKWh did not differ significantly between Groups 1 and 2. Differences among sowing dates were significant. In 1975 IS, mean TKWh was > 45 g (Figure 6.6), though leaf rust was observed some 70 days after sowing. In 1976 IS, mean TKWh was < 36 g, due to early epidemics of stem and leaf rust (Subsections 4.5.3; 5.5.1). In 1977, mean TKWh was relatively low, though water application was not restricted and rusts were absent. Temperatures in 1977 were relatively high in late August and in September. This caused forced ripening, especially in late-heading genotypes. In trials performed after 1977, TKWh was reduced by stem rust (Subsections 4.5.4 and 4.5.5). For wheat sown between DAY 110 and 136, the correlation of mean TKWh with sowing date was not significant. Mean TKWh had a significant negative correlation with mean ANOH2 ($r = -0.87^{***}$, 8 df), probably due to competition for nutrients.

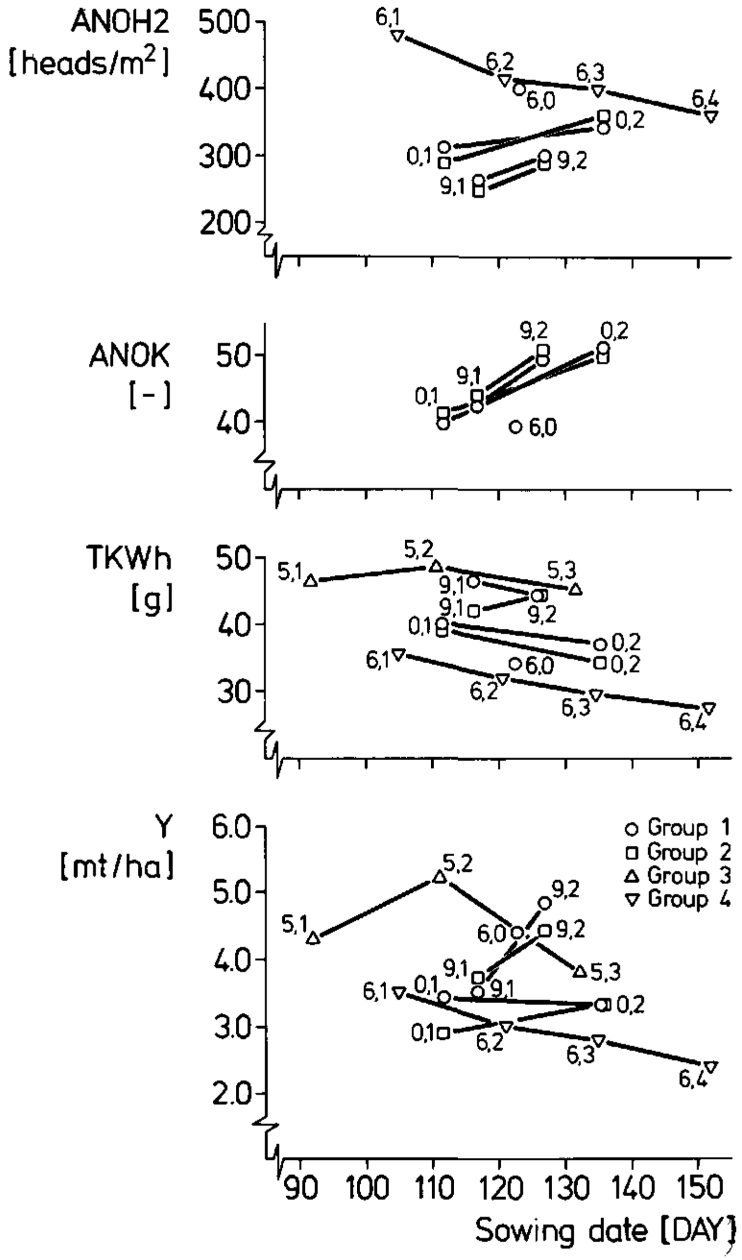

Figure 6.6. Yield and yield components per Group and per sowing date (in DAYs), NIRS, ISs, 1975, 1976, 1979 and 1980. (6,1 means 1976, sowing date 1).

Differences among genotypes were highly significant. In 1979, several genotypes had a mean TKWh between 40 and 50 g. GIZ, BOB, EMU, CE2 and SA4, had a mean TKWh > 50; SHA, BUB, CON, FAL, HIN, SUP and UMN had a mean TKWh < 40. Genotypes with high stem rust severities, e.g. UMN and TUR, had relatively low mean TKWh (< 35 g).

6.7. Grain yield

Mean grain yields (Y) of Groups 1 and 2, consisting of parent genotypes used in the HRBP, did not differ significantly; they were higher than those of Groups 3 and 4, consisting of pre-registration genotypes and commercial cultivars. Difference in yield between Groups (Figure 6.7) could be explained largely by differences in stem rust resistance. Groups 1 and 2 had lower severities.

Differences in yields between sowing dates were significant in some years, as in sowing date trials in 1975 and 1976 IS and for sowing date 1 and 2 for Group 1 in 1979 IS (Figure 6.6). In 1979, mean yield was 3.5 mt/ha for a sowing date late in April, and 4.8 mt/ha for a sowing date 10 days later. Where a difference of 10 days may lead to differences in yield of more than 1 mt/ha, sowing date is evidently a critical factor. Mean yields remained relatively low, < 4.0 mt/ha, as a result of a low total net application of water (370 mm) and/or stem rust.

Differences among genotypes were highly significant in all trials. Genotypes with high yields under favourable conditions also tended to have high 4 years' mean yields, but exceptions occurred. Selection for a high ranking mean yield was effective, provided total mean stem rust severity was above 8%. Several genotypes, e.g. CHE and TUR had a high ranking yield in the absence of stem rust, but had a low ranking yield in the presence of stem rust. It follows, that selection for high yield should not be performed without selection for stem rust resistance.

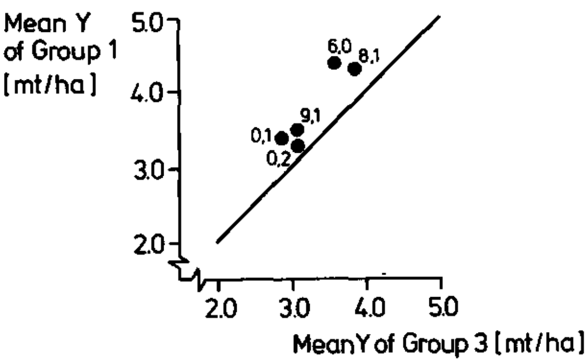

Figure 6.7. Mean grain yield (Y) of Group 1 versus mean Y of Group 3. Yields in mt/ha. (8,1 means 1978, sowing date 1).

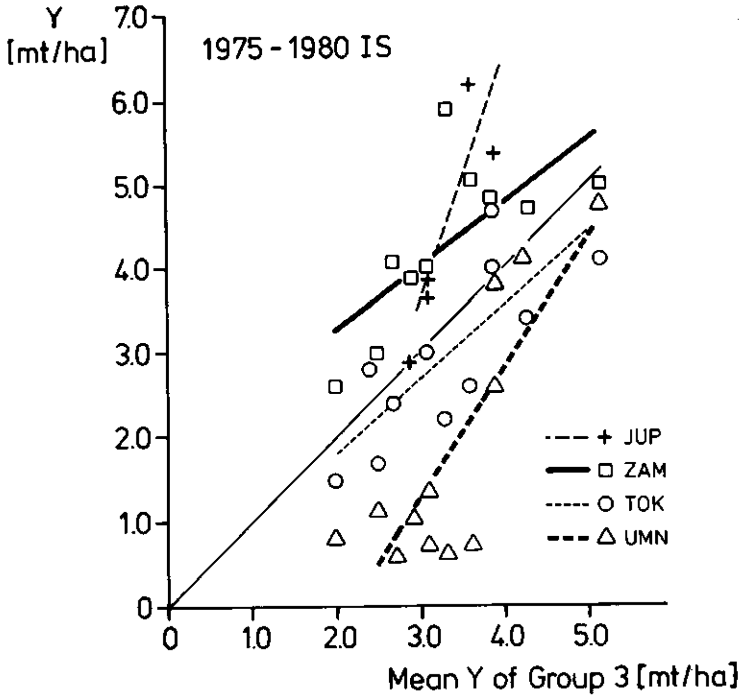

Figure 6.8. Mean grain yield (Y) of various genotypes versus mean Y of Group 3. A shallow slope of the regression line as for ZAM indicates a wide adaptability, a steep slope as for JUP indicates a less wide adaptability. Symbols represent trials scattered over a 6 years' period.

Genotypes were ranked according to the mean yield of 6 trials (4 years' mean). TZP, a genotype with relatively high severities of stem rust and leaf rust, had the highest ranking mean yield of 4.8 mt/ha, but never had the highest rank in any single trial. So genotypes with incomplete resistance to rusts can have relatively high yields during rust years.

The genotype ranking highest in yield varied between trials. The highest yield varied strongly among trials, from 4.4 to 7.2 mt/ha. Genotypes that combined a high four years' mean yield (> 4.4 mt/ha) with a low CV among trials (< 15%) were: GIZ, CNO and SOP. Interestingly, these 3 genotypes failed to produce yields over 6.0 mt/ha. Cultivars EMU and JUP, which were able to produce yields over 6.0 mt/ha under favourable growing conditions, had 4 years' means of 4.4 mt/ha and CVs of 30. These 2 genotypes suffered severe yield reductions under less favourable conditions. It follows that selection for a high yield under favourable conditions does not necessarily lead to stable yield (a low CV among trials). Selection for stable yield therefore requires special attention.

AFR, FA and SA4, tall-strawed genotypes with relatively high yields during the RS, had low yields during the IS, with four years' mean yields < 3.2 mt/ha. This indicates that genotypes suitable for the RS are not necessarily suitable for the IS; selection criteria must be so different that it will be inefficient to combine selection for irrigated and rainfed conditions.

Mean yields of the reference cultivars were compared with mean yields of Group 3, the most advanced Zambian wheat genotypes (Figure 6.8). Simple regression between yield of each reference cultivar and yield of Group 3 was significant. The value of the regression coefficient for JUP was relatively high (steep slope of the regression line), suggesting that the potential yield of JUP was higher than that of the other REFCVs. JUP did not have a stable yield, as adverse conditions led to comparatively large yield depressions. ZAM and TOK had a decrease in mean Y with a decrease in mean Y per Group, but the slopes of the regression lines were not as steep as for JUP. These cultivars were more widely adaptated. ZAM had relatively high yields compared to TOK and Group 3. UMN, which is very susceptible to stem rust, had yields < 1 mt/ha when there was an epidemic of stem rust. When stem rust severities remained low, however, mean yield of UMN, TOK, and Group 3 did not differ.

6.8. Discussion

Main factors which influenced quantitative variables were water stress, temperature and stem rust. Water stress and stem rust did not occur in all trials. By coincidence, water stress occurred only when stem rust occurred. Little explanation can be given for responses of TKWh and Y, as they were the result of confounded effects of various factors. The plant has the ability to produce a given yield by a variety of routes and displays partial compensation for periods of environmental stress (Austin and Jones, 1974).

Mean daily temperature for optimum growth and tillering of wheat is between 15 and 20 C (Doorenbos et al., 1979); temperatures during the IS are close to the optimum.

Water requirements, expressed as maximum evapotranspiration, for high yields are 450 to 650 mm, depending on climate, quantity of water applied per application, time of application of water, and duration of the period from sowing to 93 DC (Doorenbos et al., 1979). Water stress must have occurred in 1979 and 1980, when total net applications were < 370 mm. Adequate water supply is critical during germination and seedling growth; at 30 DC, when ANOH2 is determined; between 31 and 35 DC, when ANOS is determined; at 47 to 64 DC, when ANOK is determined; and at 70 to 80 DC, when TKWh is determined (Doorenbos et al., 1979). The importance of water and temperature could be demonstrated for PREM and ANOP. The effect of water stress was clearly noticeable in variables which are influenced in the vegetative phase of development; APHT, ANOS, ANOH2, and ANOK. Cool weather reduces the demands of evapotranspiration, thus reducing stress and delaying its onset (Denmead and Shaw, 1962); this allows increases in APHT, ANOS, ANOH2 and ANOK.

During the IS at NIRS, duration of daylight increases from 11.19 h in June to approximately 12.00 h in September (Smithsonian Physical Tables, 1956). Because short-cycle wheat is relatively insensitive to daylength, and because deviations from 12 h light were small, duration of daylight is thought to have little importance for phenological development.

Theoretically, soil-borne diseases could have had higher population levels in the BB in 1979 and 1980 because of continued wheat growing, but surprisingly, no increase of symptoms was observed. The effect of soil-borne diseases was therefore considered to be of no importance.

Means of Group 1 and 2 did not differ for any variable. During the IS, the addition of Group 2 genotypes did not increase genotypic variation for t he quantitative variables discussed. The usefulness of the addition of another 12 genotypes to the 1976 genepool is therefore doubtful.

6.9. Summary

Agronomic performance of parent genotypes

- Proportion realized emergence, plant height, number of spikelets per head, development period, stand count at harvest, thousand kernel weight and grain yield, all had differences among sowing dates and among genotypes.
- Harvesting of unripe wheat, moist storage, storage insects, and possibly dormancy were major factors responsible for a low germination and a low stand at emergence.
- Large kernel size appeared to be favourable for effective emergence.
- The most advanced Zambian wheat genotypes were short or medium tall.
- Tall genotypes (APHT > 105 cm) were more sensitive to growing conditions than shorter genotypes.
- Genotype differences in plant height at NIRS were greatest in trials sown late in May (DAY > 125).
- Differences in number of spikelets were greatest in April-sown trials.
- Development rate was relatively insensitive to water stress, variations in soil fertility and soil structure.
- The period to heading or flowering was not always indicative of the period to ripening.
- Period to 50% heading for Groups as well as for genotypes could be predicted from the temperature sum.
- Periods to 50% heading, and from anthesis to ripening, decreased with increasing temperatures.
- Water deficit was a major factor reducing the number of spikelets per head, the number of kernels per head, and the number of plants per m2.
- Irrespective of sowing date, genotypes showed differences in stand count at harvest, thousand kernel weight and yield.
- Kernel weight and stand had a negative correlation.
- Some genotypes with incomplete resistance to rusts had relative high yields during rust years.
- Genotypes suitable for the rainy season were not always suitable for the irrigation season.
- JUP gave relatively high yields only when yields of advanced Zambian genotypes were high, but JUP did not have a stable yield.
- ZAM had slightly higher yields than TOK and advanced Zambian genotypes under various conditions and appeared to have a wide adaptability.
- UMN had relatively low yields when stem rust severities were high, and was a good indicator of stem rust.

Selection

- A large kernel size is a favourable selection criterion in Zambia.
- Short or medium tall plant height is preferred for irrigated wheat.
- Selection for plant height can best be performed in trials sown late in May.
- Selection for number of spikelets should be performed in trials sown in April.
- Selection for heading and ripening has to be performed separately.
- Selection for a high ranking mean yield over trials was effective, provided stem rust severity was above 8%.
- Selection for high yield under favourable conditions did not lead to stable yield. Selection for stable yield needs separate attention.

7. BREEDING

This Chapter describes breeding objectives and the activities performed in HRBP in the attempt to accomplish these objectives.

7.1. Breeding objectives

The objectives of HRBP in Zambia were to breed lines with:
a) good yield,
b) resistance to all locally important pests and diseases, irrespective of races, preferably durable resistance,
c) wide adaptation to different seasons of the year, various sources of water (rainfed, irrigated, dambo, seepage), different climatic conditions, various soils, and various management conditions.

Activities performed in the attempt to accomplish breeding objectives included: avoidance of differential resistance (Section 7.2), selection of parent genotypes (Section 7.3), performance of crosses and development of crossing methods (Section 7.4 and 7.5), selection of offspring (Section 7.6), management of crossing and selection trials (Sections 7.4 and 7.6) and testing of breeding scenarios (Section 7.7).

7.2. Avoidance of differential resistance

To test for differential resistance, genotypes should be exposed to individual races (Vanderplank, 1963), but, in 1976, no identified races were available in Zambia. Neither was information about races available. No facilities to maintain pests and diseases were available at NIRS. Initially, there were strong objections against artificial inoculations, especially with rusts, as the presence of these pathogens might bias then current trials on irrigation. So local constraints forbad the use of a specific technique to avoid differential resistance:
a) Exposure of genotypes to one differential race and selection of fully susceptible genotypes (Parlevliet, 1975; Beek, 1976; Parlevliet, 1979, 1983 a).
Some other techniques required too much time or money:
b) Genetic analysis of resistance.
c) Selection for prolonged latency periods (Parlevliet, 1975).
d) Multilocational testing of parent genotypes.
Some techniques were considered unsuitable to avoid differential resistance (Parlevliet, 1979, 1983 a, 1983 b):
e) Assessment of the apparent infection rate (Vanderplank, 1963). This technique only demonstrates that the resistance is incomplete. In Zambia, results could not be interpreted easily (Subsection 4.3.4).
f) The 'saturation approach', whereby a range of identified races is applied to genotypes with a possible differential resistance to 'break' whatever differential resistance might be present.

As the programme had to start rapidly, differential resistance to certain pests and diseases may unintentionally have been included in the parent genotypes. In 1978, when rusts had been absent during 2 seasons, inoculation was permitted at a small scale. Thus, it became possible to influence the day of onset of the epidemic and the distribution of the disease in the field. The rust populations occurring in HRBP trials were likely mixtures (Chapters 4 and 5). Selection of major genes is then almost impossible to avoid (Parlevliet, 1983 a). To avoid differential resistance in the offspring, genotypes were tested during several years at a number of locations in an attempt to expose them to different races. Genotypes with incomplete resistance were selected that exhibited a slow disease development and low incidence levels of insects. Although none of these techniques guarantees complete absence of differential resistance or the durability of the resistance selected, a combination of these techniques might lead to the desired result. To test the uniform and incomplete nature of the resistance (Section 4.1) thus selected, 12 lines of the HRBP were exposed to 5 Dutch leaf rust isolates, representing at least 4 different races, in the Netherlands between 1982 and 1983 (Subsections 8.1.5, 8.2.6 and 8.3.5).

7.3. Selection of parent genotypes

In the early part of 1976, most genotypes present in Zambia had been tested only during the irrigation season (IS) at high input levels. Local information on the susceptibility of the parent genotypes to leaf rust was available (NIRS, 1975 b). Susceptibility to both stem and leaf rusts was tested in 1976 IS and 1976-77 RS. Initially, 22 parent genotypes were selected (Group 1) from genotypes tested at NIRS before 1976. All 22 genotypes performed well during IS, but poorly during rainy season (RS) (Table 7.1). In 1977, 12 genotypes were added (Group 2), which were somewhat better adapted to RS conditions. Selection criteria for genotypes of Groups 1 and 2 are given below.

a) Susceptibility to diseases and resistance to pests. It was assumed that 'loss of resistance' to bacteria, viruses and insects was so infrequent that selection for resistance could lead to stable resistance.
a1) Seedling susceptibility to stem rust and leaf rust, with sporulating pustules that were not surrounded by necrotic tissue. Selection for seedling susceptibility and adult plant resistance was proposed by Parlevliet (1975), Hooker (1976), Knott (1982) and other authors.
a2) Sporulating pustules of leaf and stem rust during the further development of the plant.
b) Genotypes from different origins, such as Zimbabwe, Kenya, Mexico (CIMMYT), Pakistan, Australia and North Africa.
c) Genotypes with a diversity of characteristics, such as short and long straw, early and late flowering/ripening (Chapter 6).
d) A minimum yield during IS of 4.0 mt/ha in the absence of rusts.

Selection criteria b) and c) were to obtain a wide genetic diversity and a wide adaptation, criterion d) was to obtain good yields.

Tabel 7.1. Mean and standard deviation (SD) for various characteristics of 22 parent genotypes at NIRS, 1976 IS and 1976-77 RS. For explanation of codes see List of abbreviations and symbols.

Variable		Irrigation season		Rainy season	
		Mean	SD	Mean	SD
Y	(mt/ha)	4.2	1.6	0.2	0.1
ANOH2	(m-2)	400	75	140	40
ANOT	(-)	2.8	0.7	0.8	0.2
ANOK	(-)	39	7	21	9
TKWh	(g)	38	10	10	5
SHW	(mt/ha)	11.5	3.0	2.0	1.0
SFL	(cm2)	39	6	17	2
APHT	(cm)	93	14	53	10

Robinson (1976) stated that it is probably safer to risk 'too narrow a gene base' than to encounter intermediate levels of differential resistance. In this case, a wide gene base was preferred as conditions to avoid differential resistance were suboptimal and as there were high demands for adaptation.

All adult plants showed sporulating rust pustules. The majority of the plants had a reaction type S for stem rust and leaf rust. Some genotypes had pustules that were surrounded by necrotic tissue and in some other genotypes certain plant organs did not show rust symptoms (Table 7.2). Parent genotypes were susceptible to helminthosporium.

The genotypes selected could be divided into 3 categories: commercial cultivars used in Zambia: ZAM, TOK and UMN; cultivars tested on many locations for several years such as SHA, BUB, CHE, CER, SUP and TUR; and cultivars tested only once or twice at only a few locations, such as AFR, GIZ, EMU, CON and SA4.

7.4. Crossing

Wheat is an autogamous (self-fertilizing) crop. To obtain large quantities of cross-fertilized seed, a male gametocide, a chemical which caused male-sterility, was applied. Pollination was free. This method was chosen because it has several advantages over crossing by hand: few persons can perform a large number of crosses to obtain large G1 populations and little training is needed to effect the crosses. The method has also several advantages over genetic male sterility: it is easier to use, can be applied to any genotype immediately and its effects are not inheritable.

The 1976 cross with genotypes of Group 1 was a "composite cross" as the G2 population was composed of offspring of several crosses. In subsequent generations the cross was a "polycross" as all material was grown under conditions of random pollination (Briggs and Knowles, 1977).

In the HRBP, no means were available to perform crosses in all future areas of cultivation. Crosses were performed only at NIRS, the site where most attention could be given to the breeding material. Crossing was restricted to IS (Section 7.5). The number of crossing generations, generations where outcrossing was allowed, did not exceed 4, because the usefulness of additional crossings was dubious because sufficiently satisfactory results were obtained by breeding scenarios with fewer crossing generations.

Table 7.2. Reaction types of stem rust on parent genotypes, at day 90, NIRS, 1978 IS. Other parent genotypes had reaction types S or MS on all organs. (0 = chlorosis and/or necrosis, no pustules, S = no chlorosis, many large abundantly sporulating pustules, X = several reaction types).

Genotype code	Head	Flag leaf	Lower leaves	Stem
Group 1				
GIZ	0	MR	0	MR-R
BOB	S	MR-MS	MS	MS-S
BUB	MS	MR-MS	MR	MS
SUP	MS-S	MR-MS	MR	MS-S
Group 2				
SOP	S	S	MR-MS	S
KIT	0	MS	MS	MR-MS
HIN	S	MS-S	MS	MR-MS
FA	0	0	X	0

7.5. Use of Ethrel

7.5.1. Introduction

Efficiency requires that the gametocide produce almost 100% sterility in the female parent without affecting crossability or female fertility. For the production of hybrid wheat seed, male gametocides are also sought (Chopra et al., 1960; Jan et al., 1975; Johnson and Brown, 1976). Several products have a good male gametocidal effect but some of these have not been marketed. Ethrel, 2-chloroethylphosphonic acid, is a product which can be obtained in some countries but it rarely produces 100% cross-fertilization with open pollination. Information on Ethrel as a male gametocide was given by Rowell and Miller (1971), Bennett and Hughes(1972), Oggema (1974), Hughes et al. (1974), Rowell and Miller (1974) and Hughes et al. (1976). The effectiveness of Ethrel as a male gametocide in wheat under Zambian conditions was not known. Information on Ethrel became available through local research and also through contacts with IPHR-projects, in particular M. Beek (Brazil) and the Plant Breeding Station at Njoro, Kenya.

7.5.2. Materials and methods

Twenty genotypes can be paired in 380 different combinations. Assuming that reciprocal crosses give identical results there are 190 combinations. The 190 pairs used in the 1976 IS were randomized to obtain random pollination.
Ten genotypes were used 9 times and 10 other genotypes were used 10 times as a female parent. Equal amounts of seed were retained from all female plots. Parent genotypes differed in development. Anthesis was synchronized by staggered sowing, taking in consideration the duration of the period to anthesis for each genotype, with 7 sowing dates for Group 1, and 6 for Group 2.

De Vries (1974) demonstrated the importance of wind for cross-pollination in wheat. At NIRS, the field lay-out was adjusted to the prevailing easterly wind. In later seasons, the field lay-out was a copy of the 1976 lay-out (Figure 3.1), and seed mixtures were sown in strips with 3 to 6 male rows. Either staggered sowing was applied, using the duration of the period from sowing to anthesis of the "female" in the first polycross as a guideline, or a single sowing was used. Undesired outbreeding of parent genotypes was avoided by various measures. The breeding block was situated upwind of other wheat trials, at a distance of more than 500 m from foreign wheat introductions. Flowering of the breeding material was planned for a later date than the flowering of wheat in other trials. The breeding material was surrounded by a 6 m wide strip, composed of wheat genotypes susceptible to the rusts. This strip was sown 3 weeks before the breeding material, so that the wheat in the strip was beyond the anthesis stage when crossing began.

Between 1976 and 1979, crosses were made using Ethrel applied by knapsack sprayer. Ethrel was sprayed on every second strip of the plots, perpendicular to the direction of the prevailing wind direction (Figure 3.1). In 1976, each plot was given 3 applications (1500 ppm active ingredient in about 2000 l liquid per ha per application). The liquid was sprayed until run-off. The quantities of liquid per m2 per spray varied from 0.15 l to 0.40 l. Fifteen ml of a spreader sticker (No-film) was used per 10 l liquid. The development stages at the time of Ethrel application were 39, 45 and 55 DC, respectively. Spraying took place from 17 June to 21 July, 1976. In the following years, only one or 2 applications were made per plot, as there were no indications that 3 sprays resulted in a higher percentage cross-fertilization.

To obtain information about the effectiveness of Ethrel as a male gametocide, percentages cross-fertilization and self-fertilization in heads treated with Ethrel were assessed by bagging. Transparent plastic bags (5 x 17 cm) were placed over the heads at the development stage 58 DC of the head. During the bagging period, bags 'crept off' the heads, helped by wind, in 5 to 50 % of the awned heads. Daily inspection of bagged heads was necessary to pull the bags down and prevent exposure of the heads to pollen. The bags remained on the heads for 3 to 5 weeks. The mean number of kernels per head was determined for: Ethrel treated, bagged heads (Tb); untreated, bagged heads (Ub); Ethrel treated, unbagged heads (Tu); and untreated, unbagged heads (Uu). Per genotype, ANOK was determined in one plot with Ethrel treated plants and in one plot with untreated plants. A low Tb value indicates a high sterilizing effect of Ethrel, provided damage due to bagging is low and Tu values are relatively high. Damage due to bagging was determined in untreated plants (Uu-Ub). In 1976 IS, over 50 heads were bagged per plot, at least 10 heads per drill; ANOK was determined for 50 heads per plot. In the C2 generation (Sections 3.1 and 7.7) of 1977 IS, ANOK was determined for 30 heads per plot.

Segregation was checked in G2 plants originating from plants treated with Ethrel. During 1976-77 RS, 9 to 10 G1 seed samples of each parent genotype were sown (seed rate 150 kg/ha). At harvest, the 10 best looking heads per plot were selected. During 1977 IS, these heads were planted unthreshed and segregation was scored. A G1 head was scored as segregating if at least one of its G2 heads had a phenotype different from that of the original female parent. PSEH was the percentage G1 heads with segregating G2 heads.

7.5.3. Results

Ethrel. Tu and Tb-values differed significantly from Uu and Ub-values. Ethrel treated plants had fewer kernels than untreated plants (Tables 7.3 and 7.4). The application of Ethrel significantly influenced mean number of kernels per head. Differences between genotypes for Tb, Tu, Ub and Uu, were highly significant. Genotypes differed in response to Ethrel.

Table 7.3. Mean number of kernels per head (ANOK) for heads treated with Ethrel with bags (Tb) and without bags (Tu), and untreated heads with bags (Ub) and without bags (Uu). For the parent genotypes the number of heads per sample was 50, for the G1 or C2 generation 30.

	Uu	Ub	Tu	Tb
Parent genotypes, 1976 IS				
Giza 156	45	32	33	7
Sa 42	36	13	13	1
Tokwe	31	24	16	11
Pakistani	47	40	23	17
Overall mean of 22 genotypes	40	33	24	13
Offspring of female parents, G1 or C2 generation, 1977 IS				
Giza 156	41	44	32	20
SA 42	52	30	30	15
Tokwe	37	32	32	24
Pakistani	50	47	42	29
Overall mean of all entries	43	35	37	21

Table 7.4. Mean number of kernels per head (ANOK) for characteristic genotypes and all 22 parent genotypes for heads treated with Ethrel with bags (Tb) and without (Tu) and for 5 drills, NIRS, 1976 IS. Drill 1 was situated up-wind, drill 5 down-wind. Per drill, 10 heads were observed per sample group.

Drill number Distance from pollen donors (m)	1 0.40	2 0.58	3 0.76	4 0.58	5 0.40	 Mean
Tb						
Giza	14	5	2	3	11	7
SA 42	3	0	1	0	1	1
Tokwe	5	6	15	13	16	11
Pakistani	12	18	23	11	19	17
Overall mean of 22 genotypes	13	12	12	12	14	13
Tu						
Giza	36	30	28	40	30	33
SA 42	19	15	8	12	11	13
Tokwe	16	12	19	18	16	16
Pakistani	15	20	25	24	29	23
Overall mean of 22 genotypes	26	25	22	23	23	24

Kernels were produced in bagged heads treated with Ethrel (see Tb values in Table 7.3). Absolute sterility rarely occurred. Ethrel can induce male sterility in wheat if applied at the right time (Rowell and Miller, 1971; Bennett and Hughes, 1972). The degree of male sterility induced is greatly affected by the development stage at which Ethrel is applied. In both glasshouse and field grown wheat Ethrel had to be applied before meiosis is initiated in the oldest florets of the head. To ensure full emergence of sterilized heads, the application had to be made as close to this stage as possible. Concentrations between 1000 and 2000 ppm a.i. caused complete male sterility (Hughes et al., 1974). In the field, there is always a range of development stages even within a uniform genotype. Therefore the spraying of Ethrel will be inappropriately timed for a part of the crop, resulting in incomplete emergence of heads and high percentages of self-fertilization. Possibly, the Ethrel concentration of 1500 ppm a.i. was too low to induce full male-sterility in some parent genotypes, e.g. PAK, with a high Tb value. Tb values were lower in 1976 than in 1977, indicating that seasonal differences occur in response to Ethrel.

Tu values may be low due to a number of reasons. a) Only few airborne pollen reach the female flowers because of poor matching anthesis periods in males and females, b) large distance between males and females, c) large differences in height between males and females, d) incomplete emergence of Ethrel-treated heads, e) insufficient opening of florets for pollen to enter, f) little air-movement (De Vries, 1974), or g) a possible toxic effect of Ethrel causing sterilization of female flowers (Hughes et al., 1974) (not discussed). a) An overlap of periods of anthesis was realized by means of staggered sowing (Figures 7.1 and 7.2). The period of anthesis is defined as the period in days from the day the first ripe anther is observed until the day on which all florets reach the watery ripe stage (70 DC). Up to 90% of the entries were flowering simultaneously. Early in July, and in August, only some genotypes were flowering simultaneously (Figure 7.2). Cross-fertilization occurred even when the number of overlapping periods of anthesis was low, as in SA4 (Figures 7.3 and 7.4). Thus, some assortative mating will have occurred. Sufficient airborne pollen were present to fertilize male sterilized flowers even if only a few entries were flowering.

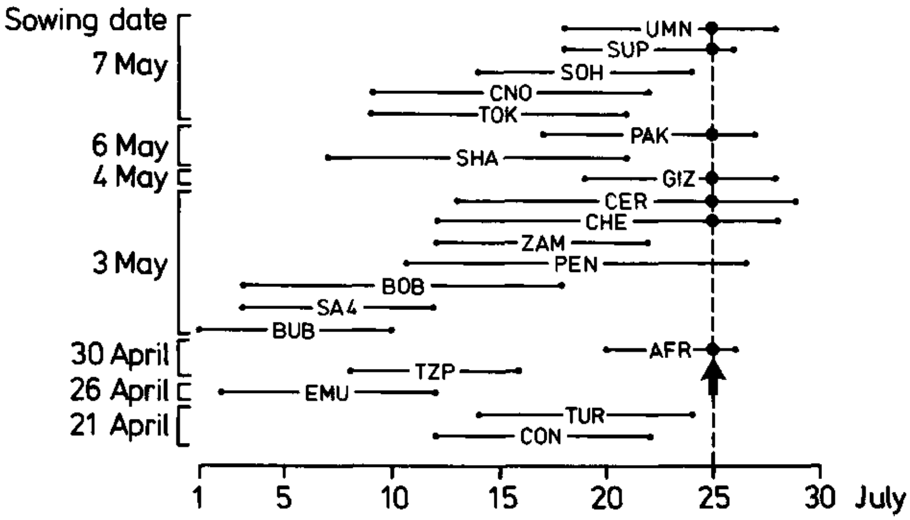

Figure 7.1. Periods of anthesis for 20 parent genotypes of HRBP sown at different dates, 1976 IS. On 25 July, for example, 8 genotypes had overlapping 'periods of anthesis'.

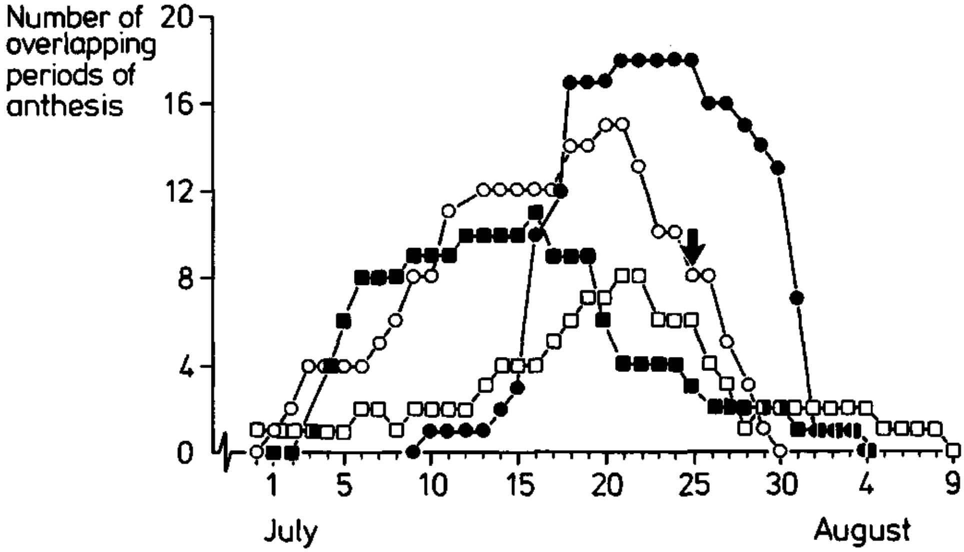

Figure 7.2. Variation in time of the number of overlapping 'periods of anthesis' in wheat crossing generations, NIRS. The 8 genotypes with overlapping periods of anthesis of Figure 7.1 can be seen on 25 July, curve 1976 IS.
(○) 22 C1-genotypes of Group 1, 1976 IS,
(□) 12 C1-genotypes of Group 2, 1977 IS,
(●) C2-populations from Group 1 parent genotypes, 1977 IS,
(■) C2-populations from Group 2 parent genotypes, 1978 IS.

b) Overall mean Tu values in drills 3, 4 and 5 were slightly lower (2 to 4 kernels per head) than in drills 1 and 2 (Table 7.4). However, Tu values did not differ significantly between drills. Possibly, a slightly lower seed set occurred in down-wind drills than in up-wind drills, when the anthesis periods of males and neighbouring females were not synchronized. In the HRBP, plot width was 1 m. De Vries (1972) showed that pollen density at 1 m distance from the donor was still 90 to 100% of the density at the donor site. Differences in pollen densities due to differences in distance to pollen donors were probably of minor importance.

Male : female ratio was 1 : 1. De Vries (1974) found that the efficiency of different male: female ratios depends also on the width of the female strip. Using cytoplasmatic sterile males, a female strip with a width of 2 m and a male : female ratio of 1 : 1 had a yield of 83% of the yield from a male : female ratio of 1 : 2. In local studies and in Brazil it was found that male strips of 1 m were able to produce sufficient pollen to give a good seed set in female strips with a width of 2 m or less (Beek, 1976; 1977; 1979 a). Assuming that the findings of De Vries (1974) with cytoplasmatic sterile males can be applied to plants male-sterilized by Ethrel, it seems likely that female seed production can be improved. In the HRBP, however, the quantity of seed was not a limiting factor.

c) Differences in plant height may influence seed set by influencing pollen dispersion. De Vries (1972) found a greater pollen density below the head level of pollinator plants than at or above head level. Ethrel significantly reduced plant height and this may have favoured spread of pollen over all drills as well as seed set. Less than 20% of the parent genotypes had a plant height < 80 cm or > 105 cm. As tall female plants received pollen from more donor plots other than the neighbouring ones, the dwarfness of male plants was of only minor importance to seed set.

d) Incomplete emergence of heads occurred in all female plots.

e) Gaping of the florets commonly occurred after treatment with Ethrel but may have been insufficient in some genotypes, for example GIZ.

f) In view of the low overall mean Tu value in the 1976 IS compared to that of the 1977 IS (Table 7.3), the 3 applications of Ethrel in 1976 may have caused slightly more sterilization of female flowers than the 2 applications in 1977.

In addition to its limited efficiency, Ethrel had several undesirable side effects, which made selection in Ethrel treated plots difficult.

- The physical appearance of the plants was affected. Ethrel influenced plant height and emergence of heads; some genotypes were more affected than others. Phytotoxic effects occurred on the leaves and especially leaf tips became necrotic. Ethrel slightly reduced the number of spikelets per head and the length of the awns. Necrosis occurred at the tips of heads and awns.
- Ethrel influenced crop development. It delayed and enhanced tillering, delayed flowering by several days and ripening by as much as 2 weeks.
- Wheat treated with Ethrel tended to have higher stem rust severities and higher numbers of aphids than untreated wheat; this caused the TKWh to be lower than in untreated wheat. Similar responses of wheat to Ethrel were described by Rowell and Miller (1971), Hughes et al. (1974, 1976) and Beek (1977). Beek (1977) also noted a much higher infection of Septoria spp. in Ethrel treated wheat. The high stem rust severities in Ethrel treated plants may be due to the retarded development causing a prolonged exposure to stem rust especially at relatively susceptible stages of development. Delayed tillering may have been responsible for the high number of aphids, particularly on late tillers.

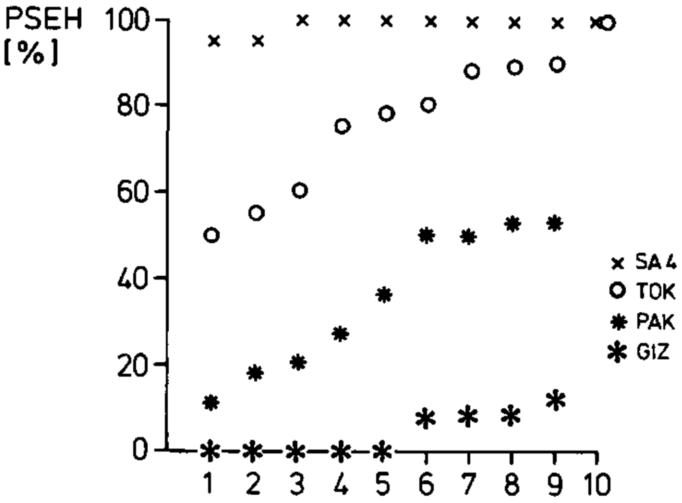

Figure 7.3. Mean percentage G1 heads with segregation (PSEH), 1977 IS. Each of the 9 or 10 sample groups consisted of 10 G1 heads (abscissa, ranking number of sample groups).

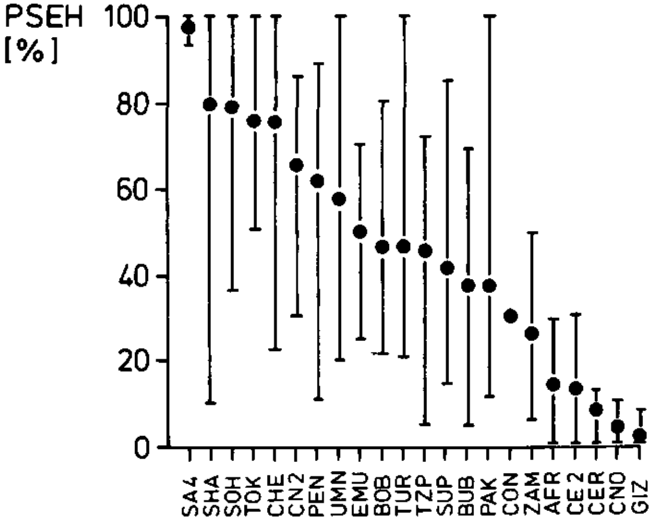

Figure 7.4. Maximum, mean and minimum percentages of G1 heads with segregation (PSEH), 1977 IS, for 22 female parents (abscissa). The mean value of PSEH was determined from 90 or 100 G1 heads. The minimum and maximum PSEH values were calculated from sample groups consisting of 10 G1 heads.

Bagging. Bagged heads had significantly fewer kernels than unbagged heads. Genotypes responded differently to bagging (Tables 7.3 and 7.4). The plastic bags increased temperature and humidity and condensation droplets were continuously present inside the bags. As a result, bagging

a) reduced the number of kernels per head,
b) gave higher severities of stem rust on the heads,
c) induced excessively high levels of helminthosporium and black moulds, and
d) occasionally led to premature senescence of heads.

Effectiveness of Ethrel. In some genotypes the combined effects of Ethrel and bagging caused Tb to be low for unknown reasons, for example in GIZ (Table 7.3). As a result, bagging could not be used as a method to obtain a reliable assessment of cross-fertilization.

Segregation (PSEH) in the G2 generation varied distinctly between genotypes and sometimes within genotypes (Figure 7.3). After the polycross in 1976, GIZ had the lowest mean PSEH and SA4 the highest, 3% and 99%, respectively. Mean PSEH for all genotypes was 47% and the standard deviation between genotypes was 27%. Figure 7.4 gives the mean, minimum and maximum PSEH values for all parent genotypes of Group 1.

Season. During the RS, crossing at NIRS proved to be very inefficient. Adverse weather conditions prevented timely application of Ethrel or washed away the Ethrel applied. The anthesis period was only 1 to 3 days in some genotypes due to high temperatures which likely limited cross-fertilization. The yields, low even without Ethrel (in some cases less than 1 mt/ha) were further reduced by treatment with Ethrel.

During the IS, the conditions for crossing were better. Yields after treatment with Ethrel were frequently higher than yields of untreated crops grown during RS. The mean grain yield for 22 genotypes treated with Ethrel, however, was some 60% of the untreated wheat.

Heterosis. Although temperatures were relatively high during crop development of the C2 generation, mean grain yield (Y) for all populations was 5.9 mt/ha, the lowest Y was 4.8 mt/ha and the highest Y was 7.0 mt/ha. These high yields may have occurred as a result of heterosis.

7.5.4. Discussion

Data for bagging and from segregation studies indicated that cross-fertilization did occur by open pollination when Ethrel was used as a male gametocide.

Assuming that the PSEH is indicative for the percentage segregating G2 heads, and assuming a G1 head with 30 kernels and one G2 head per kernel, 10,000 / (30 x 0.99) = 337 G1 heads of SA4 (with a mean PSEH of 99%) and 10,000 / (30 x 0.03) = 11,111 G1 heads of GIZ (with a mean PSEH of 3%) would be needed to produce 10,000 G2 heads. Assuming a low stand of 150 heads/m2, as in 1976-77 RS, 2.2 m2 for SA4 and 74 m2 for GIZ would be needed to produce 10,000 G1 heads. It follows, that for most genotypes an acceptable number of cross-fertilized offspring can be produced. Modern breeding programmes use as many as 40,000 F2 plants per season (Harrington, 1970). This number of plants could easily be produced using Ethrel.

The response to Ethrel differed distinctly between seasons, years and genotypes, and even within genotypes. As a result, the efficiency of Ethrel as a male gametocide for certain genotypes and certain locations may be too low to be of practical use. If only a few genotypes need to be crossed and F1-populations can be easily multiplied, crossing by hand may be preferred over application of Ethrel, as it is more reliable. If conditions are similar to those for HRBP Zambia, Ethrel may be preferred because of its advantages over crossing by hand (Section 7.4).

7.6. Selection of offspring

Selection was done according to:
a) sifting (selection for grain size and, to some extent, grain filling),
b) grain weight per head in relation to stand, or
c) performance in plots and fields.
Ethrel affected plant characteristics to such an extent that selection in a crossing generation was complicated. Selection was performed mainly in selfing generations. Details about selection are given in Chapter 8.

Selection in early generations generally took place at NIRS. Since 1979, selection and performance trials have also been carried out on segregating material and lines in 2 other potential wheat growing areas, to obtain lines suitable to different regions in Zambia. Selections were made at GV, during both RS and IS. During RS, supplementary irrigation was applied in order to avoid extreme drought stress. At MB, selections were made in rainfed wheat only.

Various methods, all of which differed only slightly from that used in scenario 1 (Figure 7.5) were used to handle populations. The term scenario is explained in Sections 3.1 and 7.7. Populations were handled in bulk for one or for several generations. Hill plantings were made for early generations, G2 (scenario 1) to G5 (as in scenario 2). Head-to-row sowings were also made in early generations, G3 (scenario 1) to G6 (scenario 2). The earliest performance trials with G3 or G4 families had 2 to 4 replications per sowing date at each location. Later performance trials had 6 replications per sowing date at each location with at least one location having several sowing dates. After a minimum of 2 performance trials, a line could be submitted for admission to the National Test, which consists of successive multilocational trials. These multilocational trials were performed at various locations (up to 6) during both IS and RS, with 4 replications per trial. To become accepted as a cultivar a line had to perform better than commercial cultivars and other entries over a period of 3 years. Lines with lower yields than the highest yielding commercial cultivar were discarded.

To test lines under actual farming conditions, seed samples were distributed to commodity demonstrators. In 1980 and 1981, lines were tested under irrigation in fields of 1 to 10 ha at NIRS, and on 2 farms near Mazabuka. They were also tested on seepage soils at Kalabo and Mongu in plots of 25 m^2. Several lines produced good yields in field tests.

Seed multiplication took place at NIRS by HRBP. Seed multiplication also took place at several locations by the Research Branch or the Seed Inspection Service. For line multiplication a lower seed rate was applied, 20 kg/ha, and further management was normal (Subsection 2.3.1). Thus plants were allowed to tiller extensively and segregating plants could be recognized. Segregating plants were rogued. Some lines were multiplied in head-to-row plots according to local practices and the entire row plot with an off-type was eliminated.

Segregating offspring were generally sown in randomized plots, often in trials also having lines and cultivars. Head selections were sown in single drills or, after breaking the heads in 2 parts, in duplo in hills (0.3 x 0.3 m). Drill length was 2.0, 2.5, or 3.0 m; the distance between drills was 0.3 m.

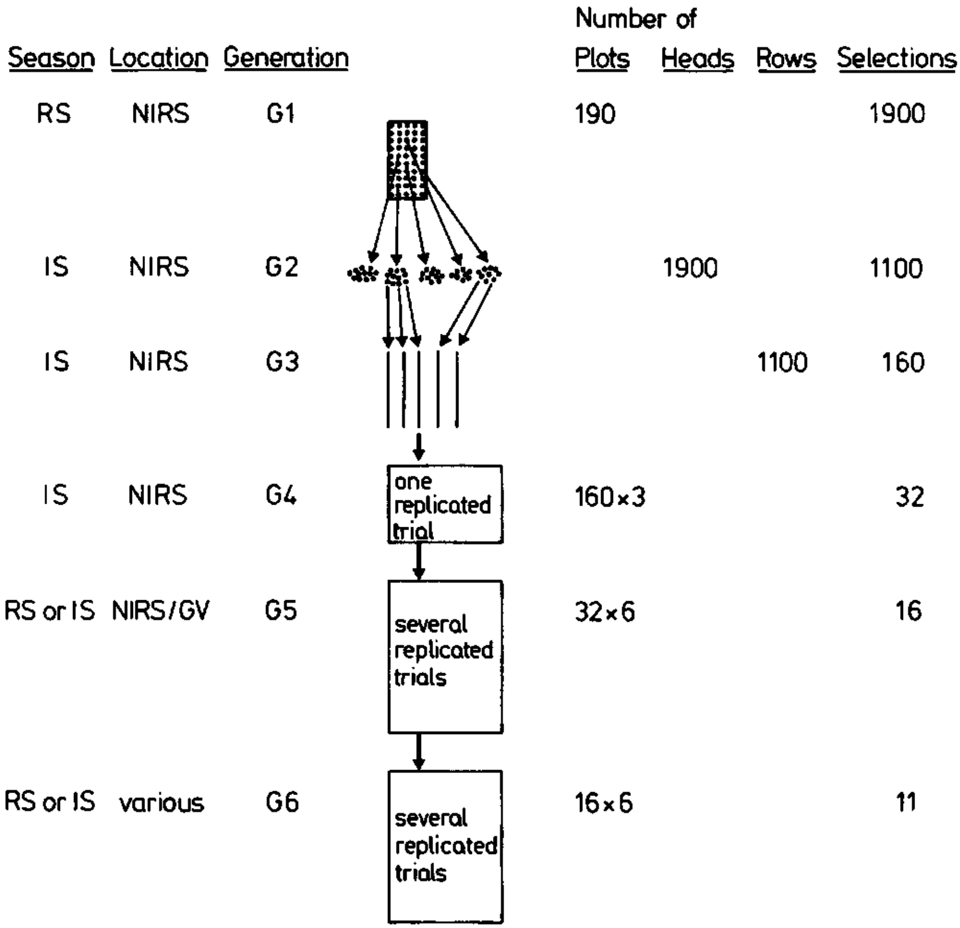

Figure 7.5. Diagram of the method of handling populations in scenario 1. Dots indicate populations grown as bulk and examined as single heads; lines represent families examined as rows; rectangles are populations grown as G1 bulk populations, G2 as mixture (heads) and thereafter as family selections; arrows show the route of materials from one season to the next.

In 1979, breeding material at MB was sown in a single strip 1 m wide (5 drills, 0.20 m apart) and 100 m long. Before 1979, plot sizes of performance trials varied (Section 3.7). Since 1979, the distance between drills was 0.18 m and the plot size was 3 m2, with the exception of MB, where the distance between drills was 0.20 m and plots were 5 m long. At MB, only 3 m2 of the plot was harvested. Performance trials had a randomized block design at all locations.

Whereas National Test trials were generally performed with high input levels, using expensive equipment, HRBP attempted to stimulate a number of existing production methods and various management levels. HRBP grew wheat throughout the year, with various sources of water and under various management conditions (Chapter 3), including management with hoeing but no herbicides and very few fungicides or pesticides.

During the RS, late sowing was done to avoid problems with weeds. As a result plants with a low drought tolerance were eliminated, but selection for helminthosporium resistance was not well possible due to their low levels.

During the period 1976 to 1978, weeding was done by hoeing. In later years herbicides were also applied. After heading, weeding by hand continued, plants which could not withstand late weeding were discarded.

Between 1976 and 1978 no insecticides were applied, except Dieldrin 2%, which was dusted when termite damage was observed, to control harvester termites. During storage, seed was severely attacked by storage insects but, again, no insecticides were applied. Seed which was very susceptible to storage insects thus could be eliminated. After 1979, Dieldrin WP was applied before sowing of performance trials and seed was treated against storage pests and fungi to reduce variation within the plots.

To select for disease resistance, no fungicides were applied and diseases were introduced by means of sporulating spreader plants of a susceptible cultivar when natural infections failed to appear in sufficient quantities at tillering. Storage fungi occurred and severely attacked material was destroyed.

Fertilizer levels were high up to G4, in order to create optimal conditions for the development of crop and diseases. Later generations were exposed to varying levels of fertilizer.

During the IS, sufficient water for optimum growth was applied up to G3 or G4 by means of overhead sprinkling irrigation, but later generations were occasionally subjected to moisture stresses as indicated in Table 6.1 for the years 1979 (first sowing date) and 1980. Supplementary or more frequent irrigation was applied to favour the development of rust and/or to compensate for drought.

Harvesting and threshing methods caused an elimination of entries with poor resistance to scattering and poor threshing qualities.

Although baking quality has a low priority in Zambia, it was a criterion for selection among lines with equal yields. Ten samples of 1 kg were tested in Sweden in 1979 (Swedish Seed Association, 1979). Baking quality of wheat grown during RS at 3 locations (21 samples of 300 g) was tested in the Netherlands (Meppelink, 1981).

7.7. Breeding scenarios

Different breeding scenarios (Section 3.1) were applied (Table 7.5). Time of selection, selection method and inputs vary. Results of scenarios 1 to 9 are discussed in Chapter 8.

Table 7.5. Breeding scenarios of the HRBP.
C = Crossing generation, S = Selfing generation between 2 crosses,
G = Selfing generation, after a cross with less than 100% cross-fertilization, grown to produce a line, 0 = No wheat grown.

Year	Season	Scenario 1	2	3	4	5	6	7	8	9
1976	IS	C1	C1	C1	C1		C1	C1	C1	C1
1976-77	RS	G1	G1	S	0		G1	0	S	0
1977	IS	G2	G2	C2	C2	C1	G2	C2	C2	C2
1977/2	IS	0	0	0	0	0	0	G1	0	0
1977-78	RS	0	G3	G1	G1	G1	0	G2	0	0
1978	IS	G3	G4	G2	G2	G2	G3	G3	G1	C3
1978-79	RS	0	G5	G3	G3	G3	G4	G4	G2	G1
1979	IS	G4	G6	G4	G4	G4	G5	G5	G3	G2
1979-80	RS	G5	G7	G5	G5	G5	G6	G6	G4	G3
Remaining selections 1979-80	RS	16	1	14	2	1	1	4	-	-

7.8. Summary

- Differential resistance to certain pests and diseases, including rusts, may unintentionally have been included in the parent genotypes.
- A total of 34 parent genotypes were used, all with incomplete resistance to stem rust and leaf rust.
- To obtain large quantities of cross-fertilized seed the male gametocide Ethrel was used with reasonable success.
- After application of Ethrel, cross-fertilization occurred in several genotypes by open pollination.
- The percentage cross-fertilization varied distinctly between genotypes and sometimes within genotypes.
- Crossing by means of Ethrel was very inefficient during the warm rainy season. It was more efficient during the cooler irrigation season.
- Several breeding scenarios were described.

8. SELECTIONS

In view of the strong pressure for new lines and cultivars (Section 2.3), most of the resources at the disposal of HRBP in the period from 1976 to 1980 were used to develop lines quickly. The interest was in scenarios whereby G5 populations were produced in 5 years (Table 7.5). Scenarios 1 to 7, whereby G5 populations were available within 5 years, are described. Scenarios were tested as well, whereby G5 populations were produced in 6 or 7 years (scenarios 8 and 9, Section 8.3). Crop performance during various seasons and the problem caused by helminthosporium during rainy season are discussed briefly.

Three generations per year were seldom grown.

a) The facilities available did not permit all the data to be processed before the following generation was sown.
b) To avoid extreme selection pressures. During the hot part of the irrigation season and during the rainy season, few plants survived.

8.1. Scenario 1

Scenario 1 had one crossing generation (Table 7.5). In early generations selection was done at one location during both rainy season (RS) and irrigation season (IS). In later generations selection was performed at various locations during both seasons. Handling of material is described in the following Subsections (see also Figure 7.5).

8.1.1. 1976 and 1977

G1 seed from each plot treated with Ethrel (10 g/m2) was sown in the breeding block (BB) in the 1967-77 RS. Only 100 to 150 heads/m2 resulted due to high temperatures, drought and diseases. From each plot the 10 heads with the best outward appearance were selected. Entire G1 heads were planted in the BB in 1977 IS. For each of 22 female parents, 50 G2 heads were selected (1100 in total), differing from those of the female parents and with a good outward appearance. No selection for rust resistance could be made, as rusts were absent.

8.1.2. 1978 Irrigation season

During the 1978 IS, the G3 seed was sown head to row in 2 m drills in selection block 3 (SB3). For each female parent there were 60 drills: 2 times 5 drills for each parent genotype, and 50 drills for populations. Fifty selections made in Jupateco 73 (JUP) were included, as JUP seemed to consist of several lines. Preharvest selection was for homogeneity of the wheat row, good tillering and absence of lodging. The entire row was harvested. Populations with a row yield below 100 g or a TSS above 25% were discarded. 160 populations were retained.

Significant differences occurred for yield as well as stem rust severity between the mean of a female parent and the mean over populations (Figure 8.1). Therefore it may be assumed, that selection effects occurred. Row yields and severities were only indicative. The number of heads per row differed noticeably, due to differences in the number of kernels sown and in tillering. As populations were not replicated, there may have been strong site effects. Interrow interference could occur because of differences in plant height and disease severity. Tall strawed wheat shaded shorter strawed wheat, and differences in susceptibility caused underestimation of genotypic differences in disease and yield assessments. Errors thus caused can be considerable (Parlevliet and Van Ommeren, 1975).

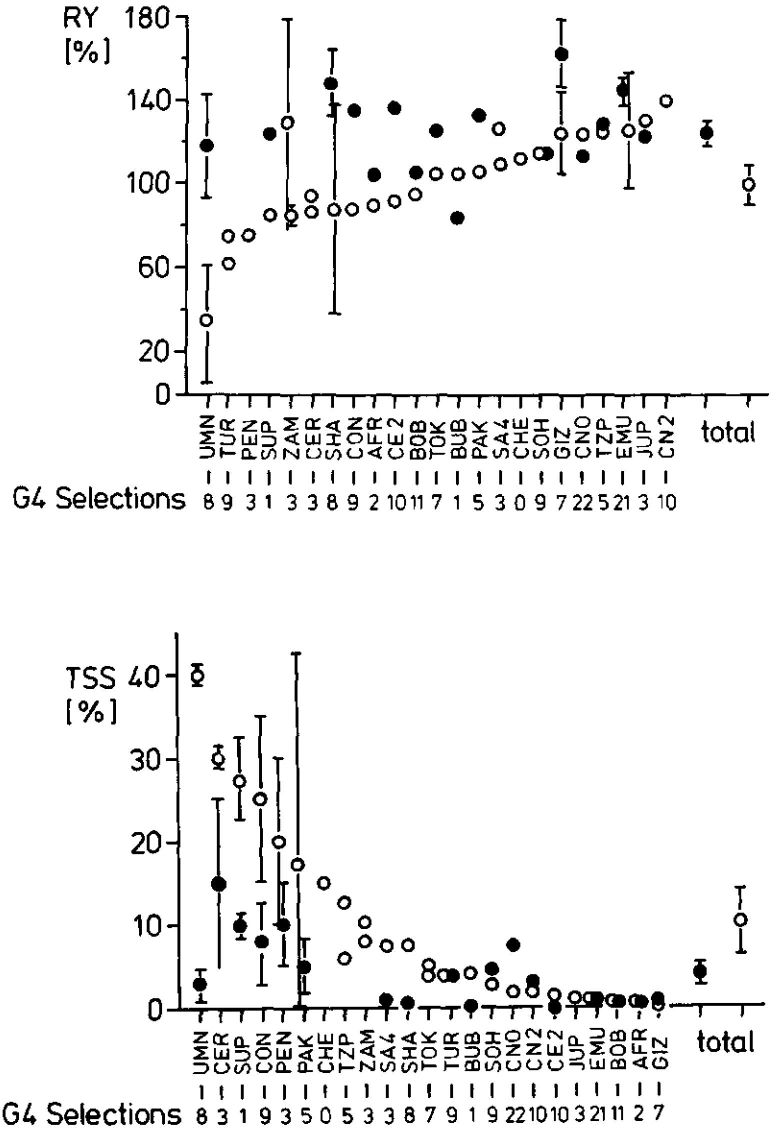

Figure 8.1. Relative yield (RY) in % and terminal percentage of stem rust on the stem (TSS) for parent genotypes (○) and retained G3 populations (●) at NIRS, 1978 IS. 100% = 235 g/0.6 m2. Per parent genotype there were 2 measurements, per G3 population 1 measurement. The 95% confidence intervals are indicated for some means. The number of G4 selections (per fifty G3 populations) is specified.

8.1.3. 1979 Irrigation season

General. In the 1979 IS, the 160 G4 populations (3 replications) were tested in SB1. At harvesting, 35 entries were selected with a relative yield > 80% (yield expressed as a percentage of the best yielding entry) and a TSS < 10. Baking quality of 10 relatively high yielding selections was determined.

Grain yield. The reference cultivar (REFCV) with the highest yield was ZAM, with 3.3 mt/ha (Table 8.1). 118 of 160 selections had a mean yield of 3.3 mt/ha or more. High yield occurred in offspring of nearly all parent genotypes.

1979 selections accepted by the Research Branch, for pre-registration trials, had a higher mean yield (relative yield) than the highest yielding REFCV (Table 8.1); however, differences were significant for only a few selections. LSD values were high, due to insufficient replication, leakage of irrigation pipes, weeding, handling of wheat during and after harvesting, variation in disease severity and other factors.

Two of the 3 selections made in JUP had a mean yield which differed significantly from the mean yield of JUP. Apparently, JUP consisted of lines with some genetic diversity. Possibly, other genotypes present in Zambia, including several parent genotypes are mixtures of several lines. The results with JUP indicate that yield of these cultivars could be improved by selection within the genotype, without a recombining cycle.

Table 8.1. Mean relative yield (%) of some of the selections accepted by the Research Branch (REBR) and reference cultivars. 100 % = the yield of the highest yielding REFCV (mt/ha). (* means R=2, loc = locations). For explanation see text and List of abbreviations and symbols.

Code	Irrigation season							Rainy season						
	HRBP				REBR			HRBP				REBR		
	NIRS 1979 R=3	80/1 R=4	80/2 R=6	80/3 R=6	GV 1980 R=4	4 loc 1981 R=4	6 loc 1982 R=4	NIRS 9-80 R=6	NIRS 0-81 R=4	GV 9-80 R=6	MB 0-81 R=4	GV 1-82 R=4	MB 0-81 R=4	MB 1-82 R=4
Selections														
3. 1	126	-	-	-	112	86	-	94	-	69	-	-	22	-
4. 2	124	114	105	101	-	-	98	113	112	56	98	139	95	95
5.14	156	100	113	-	104	86	-	-	-	-	-	-	-	-
5.16	144	101	106	-	103	-	-	81	-	63	-	-	-	-
7.20	137	103	91	-	-	-	115	-	-	-	-	-	-	-
10. 2	116	100	109	-	-	95	-	-	122*	-	112*	72	-	17
16. 2	124	123	97	-	-	104	88	-	126*	-	-	-	-	-
17. 7	121	117	117	-	-	99	98	-	93	-	98*	-	-	-
27. 6	130	108	108	101	-	98	98	119	108	50	71	112	109	72
Reference cultivars														
EMU	-	-	-	-	100	100	100	-	-	-	-	-	-	-
JUP	97	100	84	100	-	98	105	81	97	100	100	100	100	100
ZAM	100	93	100	85	-	-	-	100	77	81	33	-	-	-
TOK	95	79	86	83	-	-	-	88	74	44	56	-	-	-
UMN	22	25	-	-	-	-	-	38	100	75	95	-	-	-
LSD 5%	44	34	24	23	16	-	-	35	-	25	-	-	-	-
100%	3.3	3.6	4.4	6.4	5.7	5.8	5.9	1.6	1.5	1.6	0.9	1.2	0.7	0.6

Baking quality. Flour yield (65 to 72%) and falling numbers (279 to 416) of G5 seed samples were satisfactory. Protein content of the flour (7.6 to 13.1% of dry matter) and gluten content (11.8 to 31.0% of dry matter) were very low in all samples except for one selection (Selection 3.1). Baking properties and crumb quality were very good, much better than was expected considering the low protein content. The bread quality (general appearance) was acceptable. On the whole, the baking properties were surprisingly good despite the low protein level (Swedish Seed Association, 1979).

Crop performance. Mean yields of selections and REFCVs remained below 5 mt/ha, likely as a result of a low total net water application (360 mm), relatively warm growing conditions, and the presence of stem rust and leaf rust. Mildew occurred only in some plots and had little effect on mean yields. Stands did not differ between selections; there were about 110 seedlings/m2 and 300 heads/m2. High temperatures and restricted water application may have caused this thin stand. In other trials the stand was 400 or 500 heads/m2.

To select for yield, the following variables which varied distinctly with yield were chosen: SHW, HAI, ANOK and TSS (Table 8.2). Populations with high mean yield and plant height < 110 cm tended to have a high shoot production (leaves, stems, heads), a high harvest index, a long period to anthesis, and a low disease severity. The duration of the period from sowing to anthesis varied among populations, with a range of 2 weeks. High yield was not associated with a high head count or a high number of spikelets per head but with a high number of kernels per head (ANOK) and a kernel weight of approximately 43 mg (Table 8.2).

Table 8.2. Agronomic performance of G4 selections and ZAM, NIRS, 1979 IS. Total cases = 480. Missing cases = 9. Dates of sowing 11 May and 14 May 1979. For further explanation see text and List of abbreviations and symbols.

Variable		ZAM		All selections		Selections with a yield above 4.0 mt/ha		4.5 mt/ha		5.0 mt/ha	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Cases		6		471		128		58		25	
Y	(mt/ha)	3.3	14	3.6	24	4.6	12	5.1	9	5.5	7
SHW	(mt/ha)	8.7	14	9.3	18	11.0	12	12.0	11	12.0	14
HAI	(-)	0.38	16	0.39	15	0.42	13	0.43	12	0.46	17
ANOS	(-)	15	17	16	6	16	6	16	6	16	6
ANOP	(-)	110	30	110	30	105	32	110	30	110	30
ANOH2	(m-2)	285	12	285	22	295	21	305	16	300	19
ANOK	(-)	43	16	42	22	44	19	45	19	47	18
GR5	(g)	8.1	30	8.9	45	9.5	27	9.5	26	10.1	24
TKWh	(g)	39	19	42	19	43	19	42	21	43	19
DVS	1207 (-)	55	5	46	15	46	15	45	13	44	11
PSS	2108 (%)	1	-	2	-	1	-	1	-	0.3	-
RRES	2108 (-)	0.95	-	0.89	-	0.95	-	0.95	-	0.98	-
TSS,	1978 (%)	8.5	-	4	-	3	-	2	-	2	-
RRES,	1978 (-)	0.79	-	0.90	-	0.93	-	0.95	-	0.95	-

Table 8.3. Mean relative resistance in fractions (mean RRES) to rust of some selections and reference cultivars. At MM wheat was inoculated with stem rust. For further explanation see text and List of abbreviations and symbols.

Code	TSS NIRS	TSS NIRS	TSS NIRS	PSS MM	TSS NIRS	PRL NIRS	PL Mpongwe
	1978IS R=1	1979IS R=3	1980IS/1 R=6	1980IS -	1979-80RS R=6	1979IS R=3	1981IS -
Selections							
3. 1	0.98	1.00	-	0.93	0.79	0.93	-
4. 2	0.99	0.98	0.79	-	0.76	0.29*	-
5.14	0.93	0.99	0.89	0.93	-	1.00	-
5.16	0.99	1.00	0.92	0.93	0.79	1.00	-
7.20	0.88	0.93	0.82	-	-	0.97	-
10. 2	0.88	0.96	0.92	-	-	0.12*	0.19*
16. 2	0.93	0.74	0.84	-	-	0.99	0.99
17. 7	1.00	0.82	0.92	-	-	1.00	0.50*
27. 6	1.00	0.95	0.89	-	0.79	0.96	-
Reference cultivars							
EMU	0.99	-	-	-	-	-	0.50*
JUP	0.98	0.89	0.82	-	0.31*	0.41*	0.00***
ZAM	0.79	0.94	0.74*	-	0.66*	0.79	-
TOK	0.88	0.90	0.32*	-	0.72	0.68	-
UMN	0.00***	0.00***	0.00***	-	0.00***	0.00***	
PD(s) (%)	40	14	38	60**	29	17	80**
SD	-	10	-	-	7	4	-

* Disease severities > 10% (James' Scale, 1971) ** Modified Cobb scale.
*** Susceptible check

Rusts. Low stem and leaf rust severities occurred in offspring of nearly all parent genotypes. A few selections with high rust severities on lower leaves were retained (Table 8.3), as the stem rust severities on the stem remained low and as large kernels were produced (Selections 4.2 and 10.2).

8.1.4. 1979-80 Rainy season

General. Eleven G5 populations and 5 genotypes were tested at NIRS (sown on 12 February) and GV (sown on 22 February) under partly irrigated conditions. Harvest was in late June. In previous generations, these selections had good yields, moderate to low stem rust severities, and early heading. Those entries with the best performance were further tested on seepage soils at Mongu and Kalabo. Seepage soils are wet during the vegetative development of the crop.

Grain yield. Overall grain yield was significantly higher at NIRS than at GV. Yields averaged over the 2 locations were below 2 mt/ha. At NIRS, the yield of selections did not differ significantly from that of the highest yielding REFCV. At GV, differences were significant for Y and ANOK. Several selections had a lower yield than the best REFCV (Table 8.1); most selections had a lower number of kernels per head. Selection at NIRS during the IS is not likely adequate to obtain acceptable selections for general production during the RS.

Baking quality. Contrary to the findings for IS, protein content was very high for RS, both at NIRS and GV, being 16.4 and 19.7% (of dry matter; N x 5.7), respectively (Meppelink, 1981). The protein content may have been associated with the low yield. The bread volume, an indication for baking quality, was high at NIRS and GV, even without the addition of potassium bromate, being 478 and 529 ml/100 ml flour, respectively. The high protein content will have been important for the good baking quality. The disadvantage of the high protein content was a low mixing tolerance. The dough became weak and sticky within a short time. Addition of 35 ppm potassium bromate to the flour gave a satisfactory mixing tolerance and the bread volume significantly increased (Wilcoxon, $P < 0.01$).

Crop performance. Correlations of Y on ANOH2 and Y on ANOS were not significant. Correlations of Y on ANOK were highly significant. At NIRS, correlations of Y on TKWh were higly significant. Correlation coefficients were higher for mean values per entry than for plot values (Table 8.4.a). A high yield was not associated with a high head count or spikelet count but with a high number of kernels per head and, at NIRS, with a high TKWh. Apparently, ANOK and TKWh could be used as indicators of yield in partly irrigated wheat. Some reservation may be required in view of the strong interplot interference in these small plots.

Partly irrigated wheat had a harvest index (HAI) of < 0.28. The stand average over 16 entries was near to 300 heads/m2. Shoot weight (SHW) averaged over entries was 4.5 mt/ha at GV and 6.0 mt/ha at NIRS. Apparently, crop growth was severely limited by temperature and diseases. Possibly, low pH in sub-soil (Spaargaren, 1969) was also of importance at GV during 1979-80 RS. At NIRS, entries with a high SHW tended to have a relatively high Y. This correlation also occurred for medium tall entries during ISs. The correlation was also found in genotypes grown elsewhere (Vos, 1981).

Table 8.4. Pearson's r for correlations beween various variables at NIRS and GV, 1979-80 RS, one-tailed test. For explanation see text and List of abbreviations and symbols.

a. Values per entry and per plot.

Variables		NIRS	GV
Y,ANOK	Entry	0.58**	0.66**
	Plot	0.43***	0.34***
Y,TKWh	Entry	0.64**	ns
	Plot	0.38***	ns

entry (16 pairs)
plot (96 pairs)

1) 13 pairs, excluding entries with rust severities > 10

b. Mean values per entry.

Variables		NIRS
Y, SHW		0.88***
Y, APHT	1)	0.83***
Y, DVS		0.54*
APHT,ANOK	1)	0.72**
DVS, ANOK		0.74***
PHF, PHL		0.89***
PHF, ANOH2		0.59**
PHF, ANOK	1)	-0.68**
PHL, ANOK	1)	-0.66**
PHL, DVS		0.57**
PHL, APHT	1)	-0.57*
PSS, DVS		-0.89*
NOM, ANOK		0.82***

At NIRS, Y had a highly significant positive correlation with APHT, and selections with tall straw tended to produce more kernels than selections with shorter straw (Table 8.4.b), possibly due to differences in helminthosporium severities (Helminthosporium, this Subsection). At GV, plant height was relatively low, and correlations of APHT on Y and ANOK were not significant, possibly because variation in plant height was too small.

APHT at NIRS during the 1979-80 RS correlated significantly with APHT at GV (r = 0.94***), and with APHT at NIRS during the 1980 IS (r = 0.93***, 8 df). Selection for plant height can therefore take place at NIRS during the IS.

At NIRS, 44 days after sowing, the cultivars UMN and JUP had reached a DVS of 30 DC while all populations had reached 50 to 60 DC. Selections with early heading during the IS also headed early during RS. Selection for early heading at NIRS can, therefore, take place during either season.

Helminthosporium. Helminthosporium severities, which had not been included in the selection procedure, varied greatly among populations. Severity in some populations was similar to that of the REFCV JUP, but never lower.

In 1979-80 RS at NIRS, all entries headed after the end of the rains, and all had low severities of helminthosporium on the flag leaves at day 63 (< 8). Although helminthosporium was present, severities remained low during the period to ripening and flag leaves and heads could contribute to kernel filling, so correlations of severities and TKWh were not significant. Apparently, conditions were unfavourable for development of helminthosporium after the end of the rains. However, TKWh did not exceed 40 g due to stem rust and the short period (approximately 90 days) between sowing and early ripening (90 DC).

At GV, all early heading entries headed before the end of the rains. Thus, helminthosporium was able to attack the heads severely giving a low number of kernels in all entries. Mean ANOK over all 16 entries was 24. Late heading entries headed towards the end of the rains and had a relatively high number of kernels per head, possibly because they were not as severely influenced by helminthosporium (see PHL, DVS in Table 8.4.b). Mean TKWh for most populations exceeded 40 g. An adequate duration of the growing period (approximately 120 days) and possibly also the low mean ANOK values permitted satisfactory kernel filling despite the presence of helminthosporium.

Helminthosporium severities on flag leaves and lower leaves were significantly correlated. At NIRS, but not at GV, the severity on the flag leaves (PHF) showed a highly significant correlation with ANOH2 and severity tended to increase with increasing numbers of heads per m2 (Table 8.4.b). As ANOH2 and ANOT were similar in 1979-80 RS and 1979 IS, helminthosporium probably had little influence on these variables. A thick stand may have created a microclimate favourable for helminthosporium. High severities were associated with low kernel counts. Helminthosporium reduced spikelet fertility (Grand mean < 2.1, where > 3.0 could be expected). At GV, helminthosporium severities had highly significant negative correlations with TKWh. It follows, that helminthosporium may cause both a low kernel count and a low thousand kernel weight; selection for low severities of helminthosporium is a necessity.

Entries with relatively tall straw tended to have lower severities of helminthosporium than entries with short straw (Table 8.4.b). Tall entries may, to some extent, escape from disease. Short strawed entries are more likely to receive inoculum on flag leaves and heads through splash dispersal. Also, there may be differences in microclimatic conditions, which will tend to be less favourable at the flag leaves and heads of tall strawed than of dwarf entries. The correlation of straw length and severity was also reported for Septoria nodorum in winter wheat (Feekes, 1978). Late development in tall strawed entries may have influenced disease severity.

Entries with an early heading tended to have higher severities of helminthosporium on lower leaves than entries with a later heading. Lower leaves, especially the second and third leaves (counted from the head) of early heading entries are exposed sooner to helminthosporium than those of later heading entries. Microclimatic conditions are particularly favourable for the development of helminthosporum early in the season. Early heading cultivars have a better chance of receiving sufficient moisture for kernel filling but also a higher risk of damage by helminthosporium.

Rusts. All selections had a stem rust severity equal to or lower than that of the most resistant REFCV, TOK. Most retained selections had a mean TSS of < 10. However, RRES values were only approximately 0.80, possibly as a response to rainy season conditions.

Stem rust severity on the stem had a significant negative correlation with crop development (Table 8.4.b). Early heading entries had lower terminal severities than late heading entries because of a shorter period available for stem rust development.

Virus. Three weeks after sowing, leaves showed symptoms similar to those of maize streak mosaic virus. 44 days after sowing symptoms were present in all entries at NIRS; the numbers of diseased plants (NOM) were 2 to 5 per m2. Entries with high numbers of kernels tended to have relatively high numbers of diseased plants. Possibly, vectors preferred vigorously growing entries. It is not known whether NOM values > 15 are possible. Symptoms occurred at several locations during both seasons, especially near maize. They were also observed on various wild grasses.

Stem borers. At NIRS, 'white heads' due to stem borer infestation occurred toward flowering. The number of dead heads (NDH) was 2 to 13 per m2, i.e. 1 to 4% of all heads. The NDH values varied in time and 58 days after sowing most entries had higher NDH values than 72 days after sowing. The result indicates that once borers had attacked some stems they did not damage many of the remaining stems. The highest NDH values were observed at about 73 DC. Later, dead heads gradually became less conspicuous. Assessment must be done timely.

8.1.5. Following seasons

Grain yield. Sixteen of the lines produced by scenario 1 were accepted by the Research Branch for further testing. Eight lines were tested for at least 2 seasons, including RS and IS, because of good performance (Table 8.1). Reference yields (100%) in trials of the Research Branch were above 5 mt/ha in IS, but were rarely higher than 1 mt/ha under rainfed conditions.

During ISs, yields of lines accepted by the Research Branch and the highest yielding REFCV did not differ significantly in HRBP trials (Table 8.1). Several lines produced yields > 6 mt/ha. At least 13 lines produced a relative yield, yield expressed as a percentage of the highest yielding REFCV, of at least 90% at other locations than NIRS. However, the ranking order of lines differed among locations, likely because of genotype x environment interactions. To eliminate narrowly adapted lines, multilocational testing is essential. NIRS was an appropriate location for selection of irrigated wheat, as good yields can occur.

Differences between trials were distinct, especially when yields of TOK were low (Figure 8.2) and several lines had higher yields than the REFCVs. The regression lines of mean yield of the HRBP lines on mean yield of TOK were parallel to the regression line of ZAM. Apparently, selections combined relatively high yield with comparatively wide adaptability (Section 6.7).

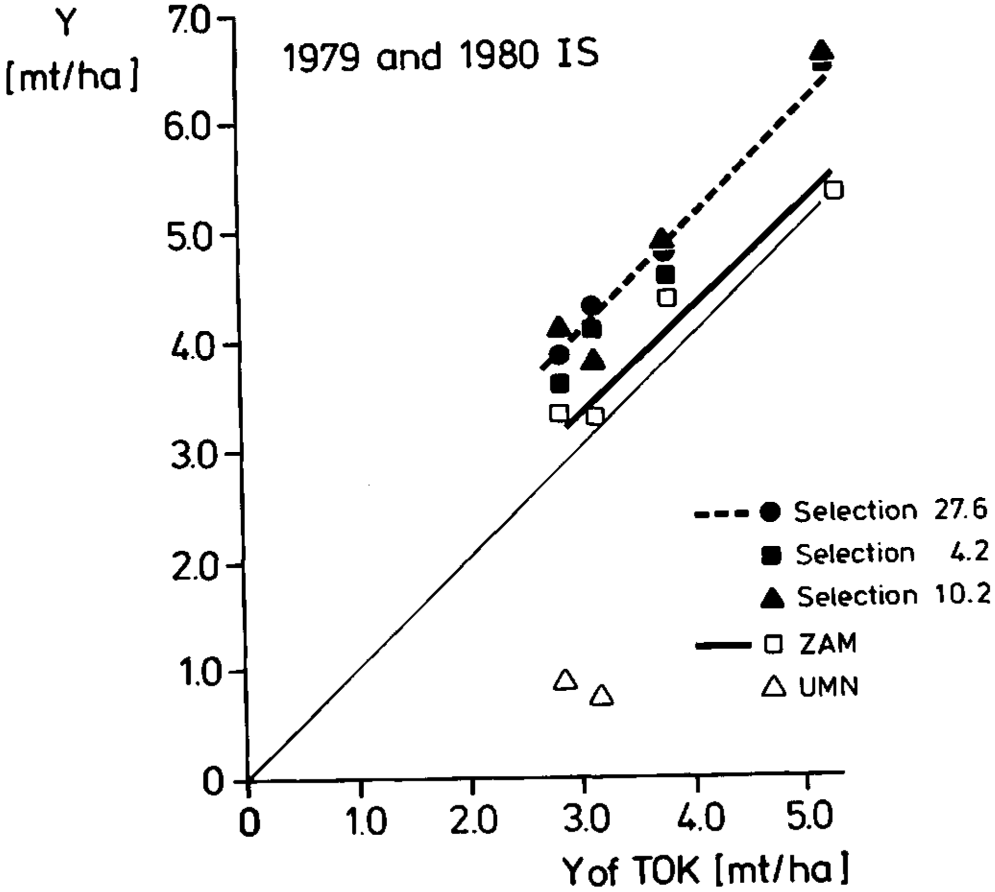

Figure 8.2. Mean grain yield (Y) of various genotypes in various trials at NIRS versus mean grain yield of TOK. As shown in Figure 6.8, a shallow slope of the regression line (ZAM) indicates a comparatively wide adaptation.

Selections mentioned in Table 8.1 were not suitable for rainfed production as yields remained below the target yield. At MB, yields of many entries were below 1 mt/ha. During RSs, there were large variations in the relative yields; insufficient tolerance to low pH and/or susceptibility to helminthosporium may have caused low yields.

During RS, yields at NIRS were not correlated with yields at GV and MB. Several entries with a good yield at NIRS had very low yields at GV and/or MB. Apparantly, mulitlocational testing is required during the RS to eliminate narowly adapted genotypes. NIRS is not an appropriate location for selection of rainfed wheat, in view of the prevailing abiotic conditions and the low yields.

Stem rust. Over a period of 3 years, mean RRES values for TSS varied little for HRBP lines, but varied distinctly for the REFCVs JUP, ZAM and TOK (Table 8.3). HRBP lines had a stable incomplete resistance. Though stem rust infections occurred soon after sowing, terminal severities of several remaining selections were < 10, suggesting that these lines are 'slow rusters'.

Leaf rust. Before 1981, resistance of populations to leaf rust was not tested effectively because leaf rust severities remained low. During the 1981 IS, a spontaneous infection of leaf rust occurred at Mpongwe, severely attacking JUP and EMU (Table 8.3). These cultivars had a very low severity at NIRS, in 1976 IS. It is not known whether change in RRES is due to genotype x environment interaction or to differences in the genetic composition of the 1976 and 1981 leaf rust populations. Several selections had high leaf rust severities in the 1981 IS. The high severity in Selection 10.2 was expected as the line also had a high severity in the 1979 IS (Table 8.3). The high severity in Selection 17.7 was not expected as this line had no leaf rust symptoms in the 1979 IS. The large difference in RRESs between years 1979 and 1981 may indicate differential resistance in these lines. If so, the selection procedure did not completely eliminate differential resistance to leaf rust (Section 7.2).

In 1982 and 1983, 4 lines of scenario 1 were tested in the Netherlands to 5 leaf rust isolates from the Netherlands. All 4 lines, including Selection 27.6 and Selection 4.2, seemed to have a uniform resistance and had low severities. Though their reaction type was susceptible in Zambia, some lines had a resistant reaction type in the Netherlands. Differential resistance may have been present in lines with a resistant reaction type in the Netherlands. As some lines had a susceptible reaction type, uniform resistance may be present in some lines.

Other parasites. Resistance to helminthosporium was incomplete and inadequate. Resistance to various insects was incomplete but adequate.

8.1.6. Summary

- By means of scenario 1, lines were produced with:
  a. high yields at various locations when conditions were favourable (irrigation season),
  b. relatively high yields during less favourable conditions (irrigation seasons with rusts and drought stress, rainy season),
  c. stable incomplete resistance to stem rust,
  d. uniform and incomplete or differential incomplete resistance to leaf rust,
  e. inadequate resistance to helminthosporium,
  f. incomplete but adequate resistance to various parasites,
  g. a good baking quality.
- The lines did not produce the target yield during the rainy season.
- Scenario 1 was effective to produce lines acceptable to the Research Branch

for pre-registration trials.

- NIRS was not an appropriate location for selection of rainfed wheat.
- NIRS was an appropriate location to select for crop development, plant height and stem rust resistance.
- Multilocational testing was essential to eliminate narrowly adapted genotypes.
- During RS, earliness limited yield loss due to stem rust, but enhanced yield loss when helminthosporium severities were high.
- During RS, short stature was disadvantageous as short strawed genotypes tended to have high helminthosporium severities.

8.2. Scenarios 2 to 5

A description of the breeding scenarios is given in Table 7.5. There were one (scenarios 2 and 5) or 2 crossing generations (scenarios 3 and 4). In the first crossing generation there were 22 (scenarios 2, 3 and 4) or 12 female parent genotypes (scenario 5). Selection began in early generations and was performed at several locations during both RS and IS. Handling of material is described in detail in the following Subsections.

8.2.1. 1976 and 1977

For scenarios 2 and 3, 24 g of seed from each plot treated with Ethrel in 1976 IS was sown in the breeding block (BB) of 1976-77 RS. For scenario 2, the G2 generation was produced in the BB of 1977 IS. For scenario 3, the C2 generation was produced in the BB of 1977 IS.

For scenario 4, 18 g of seed from each plot treated with Ethrel in 1976 IS was sown in the BB of 1977 IS; a C2 generation was produced.

For scenario 5, the C1 generation was produced in the BB of 1977 IS using the 12 genotypes of Group 2. However, pollen from other genotypes in neighbouring fields, for example of scenario 4 material, could fertilize male-sterilized genotypes of Group 2, and therefore there were more male than female parent genotypes.

8.2.2. 1977-78 Rainy season

In the trial sown on 22 December 1977, plot size was larger than usual in order to have sufficient plants per plot under conditions causing low plant densities. There were 2 plot sizes, 3.6 x 5 m = 18 m2 (scenarios 2 and 3) and 3.6 x 2.5 m = 9 m2 (scenarios 4 and 5). The seed rate was 150 kg/ha. For the second sowing date, 4 January 1978, plot size was 18 m2 and seed rate was 225 kg/ha (scenarios 3 and 4). 20 plots were used in scenarios 2, 3 and 4 and 12 plots in scenario 5.

The continuously wet conditions hampered wheat establishment but encouraged weeds, which could not be controlled effectively. Plants were so severely attacked by helminthosporium in both trials, that lodging occurred. The period from anthesis to ripening was less than 28 days. Plot yields and kernel weights per head were not worth recording, due to weeds and helminthosporium.

100 head selections or less were made from early ripening plants of the first sown trial in each plot (Selection group 3). The remaining heads were allowed to ripen. If possible, the 100 best looking heads of this latter group were selected from each plot, after all heads had ripened. In the laboratory, a further selection of the 50 best heads was made from these 100. The grain of the best heads was sifted to eliminate shrivelled grain and 3 grades of seed were produced. From the large sized kernels those with black points were eliminated (Selection group 1). The medium sized kernels were added to seed of the remaining 50 heads (Selection group 2). The small seed was discarded.

From the 2nd trial 100 heads or less were selected per plot (Selection group 4).

8.2.3. 1978 Irrigation season

Each selection group was sown as a mixture at a seed rate of 100 kg/ha. Selection criteria were: a phenotype differing from that of the parents, good appearance of plants in a mixture, terminal severities of stem rust and leaf rust < 15, and sporulating pustules of stem and leaf rusts. Scenarios 3 and 4 had a distinctly higher number of remaining selections than scenarios 2 and 5. The number of retained selections per scenario and selection groups see Table 8.5.

8.2.4. 1978-79 Rainy season

The head selections were planted in hills at GV on 20 February 1979. The crop was partly irrigated to provide sufficient moisture for kernel filling. DVS was observed on day 51. 90 hills (2%) were harvested (Table 8.5), at day 93.

Selection criteria were: relatively homogeneous appearance of the hill, thick stand in the hill, high shoot production, high number of spikelets per head, few shrivelled kernels, absence of lodging, sporulating pustules of leaf and stem rust, terminal severity of stem rust < 15. Some selections without rust symptoms remained because of their outstanding outward appearance. The mean of the terminal severity of stem rust over selection groups and scenarios was 5.0 (SD = 1.9, N = 90).

8.2.5. 1979 Irrigation season

Per remaining hill, 5 to 15 head-to-row plots were sown in SB3 at NIRS on 25 June. Differences in percentage selections (numbers of entries present in 1979 IS expressed as a percentage of the number of entries present in the 1978-79 RS) between scenarios were not significant, even after transformation.

Table 8.5. The number of selections per scenario and Selection group, grown in hills during 1978-79 RS, in head to row plots during 1979 IS, and in plots during 1979-80 RS. For further explanation see text.

Scenario	Year	Season	Generation	Selection group 1	2	3	4	Total
2	1978-79	RS	G5	0	510	30	-	540
	1979	IS	G6	0	2	2	-	4
	1979-80	RS	G7	0	1	0	-	1
3	1978-79	RS	G3	400	390	1000	300	2090
	1979	IS	G4	18	8	22	6	54
	1979-80	RS	G5	0	4	6	4	14
4	1978-79	RS	G3	470	190	410	60	1130
	1979	IS	G4	7	12	0	4	23
	1979-80	RS	G5	2	0	0	0	2
5	1978-79	RS	G3	180	490	0	-	670
	1979	IS	G4	8	1	0	-	9
	1979-80	RS	G5	1	0	0	-	1

Selection criteria were: relatively homogeneous appearance of wheat row, good tillering in comparison to neighbouring rows, absence of lodging, ripening time as JUP or earlier, absence of discoloured heads, few plants with symptoms similar to those of maize streak mosaic virus, TSS < 5 while the highest severity was 10 (TS(s) in Table 8.6), a mildew severity < 5 on the lower leaves (PML) at 64 DC (the highest severity was 25), a mildew severity on the flag leaves < 1 (the highest severity was 5). Two entries with high mildew severities were included; one entry with PML = 25 because of its good outward appearance; one with PRL = 15 but with no stem rust on the stem. Selection for stem rust resistance was mild, as RRES was > 0.5. Selections relatively susceptible to stem rust were retained, e.g. Selections 2.1.1 and 3.2.4 (Table 8.6).

The 2 best rows per entry were threshed separately and the seed was used for sowing. JUP had a mean yield per row of 202 g (SD = 20, N = 12). 18 entries were selected with a mean yield per row of 165 g to 272 g. The number of selected lines n, transformed by taking the square root of (n+1), differed significantly between scenarios. Scenario 3 produced the largest number of lines.

8.2.6. Following seasons

Grain yields. Only scenario 3 produced lines acceptable to the Research Branch; Lines 3.3.5 and 3.3.6 were tested for 2 seasons at least. High yields occurred during IS (Table 8.7), but during RS yields remained below the target yield (Section 2.3.2).

In HRBP trials, the yield of the highest yielding REFCV and the highest yielding lines did not differ significantly, both during IS and RS. Under favourable conditions a number of these lines produced yields above 6.0 mt/ha.

Table 8.6. Mean relative resistance for stem rust on the stems in fractions for some Selections produced by scenarios 2 to 5 and for reference cultivars at NIRS, in IS and RS. Code indicates scenario, Selection group, entry code in 1979-80 RS, or cultivar code. For further explanation see List of abbreviations.

Code	1979 IS	1980 IS	1979-80 RS
Selections			
2 1 1	0.80	-	0.45
3 2 4	0.70	-	0.61
3 2 11	0.85	0.93	0.82
3 3 5	1.00*	0.95	0.82
3 3 6	0.80	0.99	0.88
3 3 7	0.95	0.94	0.85
3 4 13	0.70	-	0.82
4 1 10	0.50	0.95	0.88
5 1 16	1.00	-	0.85
Reference cultivars			
JUP	0.50	0.88	0.48
ZAM	-	0.96	0.55
TOK	-	0.77	0.73
UMN	-	0.00	0.00
Mean TS(s)	10	19	33

* 15% rust on lower leaves, at day 63.

Table 8.7. Mean yields in mt/ha for some Selections produced by scenarios 2 to 5 and for reference cultivars at various locations. Code indicates scenario, Selection group, and entry code in 1979-80 RS, or cultivar code.

Code	Irrigation season			Rainy season			
	HRBP	Research Branch		HRBP			
	NIRS 1980	NIRS 1980	GV 1980	NIRS 1979-80	NIRS 1980-81	GV 1979-80	MB 1980-81
Selections							
2 2 1	-	-	-	2.2	1.6	1.0	1.0
3 2 4	-	-	-	1.9	1.4	1.1	1.0
3 2 11	6.6	-	-	1.6	-	0.5	-
3 3 5	6.4	6.4	5.6	2.1	-	0.9	-
3 3 6	5.5	5.9	5.2	2.4	-	1.1	0.9
3 3 7	6.2	-	-	2.0	1.3	0.9	1.0
3 4 13	-	-	-	2.3	1.6	0.9	0.7
4 1 10	5.9	-	-	1.1	-	0.6	-
5 1 16	-	-	-	1.5	-	1.0	-
Reference cultivars							
EMU	-	6.4	5.7	-	-	-	-
JUP	6.4	-	-	1.8	1.4	1.1	0.9
ZAM	5.4	-	-	1.6	1.1	0.9	0.3
TOK	5.3	-	-	1.3	1.1	0.6	0.5
UMN	-	-	-	0.5	1.5	1.1	0.9
LSD 5%	1.3	0.8	0.9	0.6	0.4	0.4	0.3

High yielding lines could be produced by all 4 scenarios. During RSs, however, lines generally did not produce the target yield. At NIRS, yields of 2.0 mt/ha were occasionally obtained under partly irrigated conditions, indicating that the selected lines were adapted to warm growing conditions. Between trials, lines differed in yield from ZAM and TOK, and yields were higher for several lines, e.g. Selections 2.2.1, 3.2.4, 3.3.7 and 3.4.13. The reference cultivars ZAM and TOK had yields close to the mean yield of the parent genotypes (Figure 6.8). These results indicate that selection was effective.

Crop performance. In ISs, the lines produced large kernels with TKWh > 40 g. In ISs, the hectolitre weight was was acceptable (> 77).

DVS differed among lines, but lines were neither later than JUP or earlier than TOK. Late heading selections in the IS tended to be late heading in the RS; selections heading early in the IS tended to be early heading in the RS ($r = 0.69^{***}$, 17 df). Selection during the IS for a specific developmental characteristic can in some cases be effective for the RS.

APHT of the lines differed significantly, but none were significantly taller than JUP or shorter than TOK. APHT in the IS was greater than in the RS, probably a result of differences in temperature. Differences not significant during RS could be significant during IS (compare plant height of JUP and ZAM in Table 8.8). Thus, fairly tall entries could unwantedly be retained. Several entries had a height > 1.0 m during favourable growing conditions. In the RS, tall selections usually had a height < 0.8 m. Heights > 0.8 m occurred occasionally in partly irrigated wheat. APHT at NIRS in the RS had a highly significant correlation with APHT in the IS, and with APHT at other locations in the RS.

Table 8.8. Mean plant height in cm at various locations (NIRS, GV, MB) during IS and RS. Code indicates scenario, Selection group, and entry code in 1979-80 RS, or cultivar code.

Code	1980 IS NIRS	1979-80 RS NIRS	1979-80 RS GV	1980-81 RS MB
Selections				
3 3 6	94	77	64	-
3 3 12	111	77	65	-
Reference cultivars				
JUP	99	78	59	58
ZAM	99	57	57	49
TOK	70	50	39	48
UMN	70	53	44	46
Mean of 18 entries	92	73	61	57
LSD 5%	16	13	12	-

This indicates that selection for a specific APHT at various locations in the RS can be effective at NIRS in IS, and vice versa.

Baking quality of Selection 3.3.5 was good (Meppelink, 1981). The other selections were not tested.

Helminthosporium. Helminthosporium severities differed significantly among some selections, but the severities of the best selections and the best REFCV did not differ significantly. Helminthosporium resistance was tested in 1979-80 RS under partly irrigated conditions. Under rainfed conditions helminthosporium resistance is likely to be inadequate. Severities tended to increase with decreasing plant height ($r = -0.52^{**}$, 20 df), so short stature is not an advantage during RSs with helminthosporium.

Stem rust. Mean RRES was > 0.8 for most lines for three seasons, but REFCVs had RRES values < 0.80 (Table 8.6). Lines with a TSS < 10 in 1979-80 RS also had a TSS < 10 in later seasons at several locations. Several lines had a stable incomplete resistance to stem rust, e.g. Selections 3.2.11, 3.3.5, 3.3.6 and 3.3.7. At day 101 in 1980 IS, all lines had mean TSF values < 0.5, compared to 3 for JUP and 8 for UMN. Many selections had low severities on the flag leaves.

Mean TSS values at GV in 1978-79 RS were significantly correlated with mean TSS at NIRS in 1979 IS ($r = 0.57^{**}$, 17 df) and in 1979-80 RS ($r = 0.68^{***}$, 17 df). Selection for a low susceptibility to stem rust at GV during the 1978-79 RS was also effective for NIRS. However, as several populations had a TSS > 10 in 1979-80 RS, further selection was necessary.

Leaf rust. The high susceptibility to leaf rust of Selection 3.3.5 was also observed at Mpongwe in the 1981 IS (Little, 1982). This line was retained because of its ability to produce high yields during ISs (Little, 1982), under warm growing conditions (1979-80 RS at NIRS), and its low susceptibility to stem rust and powdery mildew.

In 1982 and 1983, lines were tested in the Netherlands for resistance to 5 leaf rust isolates from the Netherlands. Only Selections 3.3.6 and 3.3.7 seemed to have uniform resistance; these lines had a resistant reaction type.
The selection procedure may not have eliminated all differential resistance to leaf rust.

Other parasites. Most entries became infested by insects, but NDH and NOM values remained relatively low (< 5% of the heads were attacked). The number of aphids per stem remained well below 20 under conditions which appeared to be favourable for aphid development. Resistance to other parasites was also incomplete and adequate.

8.2.7. Summary

- These scenarios produced lines with:
  a. high yields at various locations when conditions were favourable (irrigation season),
  b. relatively high yields during less favourable conditions (irrigation seasons with rusts and drought stress, rainy season),
  c. stable incomplete resistance to stem rust,
  d. uniform incomplete or differential incomplete resistance to leaf rust,
  e. inadequate resistance to helminthosporium,
  f. incomplete but adequate resistance to various parasites,
  g. good baking quality (only one line tested).
- Lines did not produce the target yield during the rainy season.
- Only by means of scenario 3, lines were produced which were acceptable to the Research Branch for pre-registration trials; with this scenario more selections remained than with scenarios 2, 4 or 5.
- NIRS was not an appropriate location for the selection of rainfed wheat.
- NIRS was an appropriate location to select for crop development, plant height and stem rust resistance.
- Multilocational testing was essential to eliminate narrowly adapted genotypes.
- During the rainy season, short stature was a disadvantage as short strawed genotypes tended to have high helminthosporium severities.

8.3. Scenarios 6 to 9

The breeding scenarios are given in Table 7.7a. There were 1 (scenario 6), 2 (scenarios 7 and 8) and 3 (scenario 9) crossing generations. In the crossing generations, G3 mixtures for scenarios 6 and 7, and G1 mixtures for scenario 8, selection was intended to be mild. Selection was primarily aimed at adaptation to rainfed conditions at MB, with tolerance to low pH. G1 and/or G2 generations received a severe selection for rainfed conditions as few plants/m2 remained to be harvested. Handling of material is described in the following Subsections.

8.3.1. 1976 to 1978

In scenario 6, the C1 generation was produced in the BB in 1976 IS, the G1 in the BB in 1976-77 RS, the G2 in the BB in 1977 IS, the G3 in SB1 in 1978 IS. In 1977 IS, head selections were made to obtain phenotypes which differed from the female parents and had a good appearance in a mixture.

In scenario 7, the C1 generation was produced in the BB in 1976 IS, the C2 in BB in 1977 IS, the G1 in the BB during the hot part of 1977 IS, the G2 in the BB during 1977-78 RS, the G3 in the SB1 in 1978 IS.

In scenario 8, the C1 generation was produced in the BB in the 1976 IS, the S1 in the BB in the 1976-77 RS, the C2 in the BB in the 1977 IS, the G1 in the SB1 in the 1978 IS.

In scenario 9, the C1 generation was produced in the BB in 1976 IS, the C2 in the BB in 1977 IS and the C3 in the BB in 1978 IS.

Before 1978-79 RS, the material of scenarios 6 to 9 was grown in separate unselected populations.

8.3.2. 1978-79 Rainy season

Seed from all 4 scenarios was sown on 27 February 1979, at MB, in 4 separate plots. Approximately 10 stems with a relatively good performance were tagged per m2, at day 59. At day 103, the better heads of the tagged plants were harvested. In a farmer's field at MB, head selections were made in JUP, to obtain lines from a population with a relatively low genetic diversity.

Although the cropping period was 121 days, plot yields were approximately 0.4 mt/ha for each of the 4 scenarios. A low soil pH, helminthosporium and nematodes were probably the most important yield-limiting factors (Zam-Can, 1979).

Heads from scenarios 6 and 7 with very shrivelled kernels or many kernels with black points were eliminated. The numbers of selections retained differed significantly between the scenarios 6 and 7 (Table 8.9). 2 and 6 plant selections remained, respectively. Head selections produced by scenarios 8 and 9 were threshed, the largest seeds were sifted out; kernels with black points were eliminated. The weight of the remaining seed was 70 and 139 g, respectively.

The combine-harvested seed was sifted. The percentages for the weight of the largest kernels remaining after sifting expressed as a percentage of the weight of all kernels for scenarios 6 to 9 were 3, 11, 5 and 8, respectively. Selections by sifting and by eye had the selection of well-filled kernels in common. Accordingly, seed produced by scenario 7, with a relatively high percentage of large seeds, also had a relatively large number of remaining head selections.

8.3.3. 1979 Irrigation season

The remaining MB entries were sown in drills (2.5 x 0.3 m) in SB3 at NIRS on 22 June. Selection criteria for rows were: relatively thick stand, relatively high shoot production, mildew severities < 10 on the lower leaves and < 1 on the flag leaves (compared to 10 to 20 and 0.1 to 1, respectively, for JUP), and a TSS $< 5\%$ (compared to 4 to 7% for JUP). Some row selections had mildew severities which surpassed the selection threshold, e.g. Selection 6.PLS4.14. Good agronomic performance was given higher priority than low susceptibility to mildew, as mildew tended to be rare during RS.

Table 8.9. Number of selections produced by scenarios 6 and 7, and selected from JUP. X2 is the Chi-square corrected for continuity.

	1978-79 RS		1979 IS		1979-80 RS
Days after sowing	59	103	111	115	120
Selection sequence	1	2	3	4	5
Scenario 6	1000	60	5	1	0
Scenario 7	1000	100	26	10	4
Jupateco 73	-	80	7	4	1
Comparisons	1/2		2/3		
X2 for Scenario 6 and 7	10.3**		6.4*		
X2 for Jup and Scenario 7	-		7.7**		
X2 for Jup and Scenario 6	-		ns		

Rows with many virus-infected plants or with many aphids were discarded. Rows were selected with a yield > 200 g, this being the yield of JUP. The best entry produced by scenario 6 was retained though, it had a yield of 140 g only.

The number of row selections at day 111 differed significantly between scenarios 7 and 6, and between scenario 7 and JUP (Table 8.9). The number of row selections did not differ between JUP and scenario 6. Scenarios 7 and 6 differed in the number of remaining head and row selections; most selections were produced by scenario 7.

8.3.4. 1979-80 Rainy season

General. Thirty entries were grown rainfed at MB and, partly irrigated, in SB1 at NIRS. At MB, the 2 plots per entry were adjacent. Only the means per entry were used for data analysis. At NIRS, the randomized block design made it possible to apply to each variable a two-way ANOVA for entry and block. RRES was calculated using Equation (4.5). UMN had the highest mean severity.

Grain yield. ZAM was the REFCV with the highest yield over 2 locations (Table 8.10). Eleven entries, including plant selections (PLS), head selections (HS), and mixtures, had a higher ranking yield over 2 locations. Several selections differed distinctly in yields from ZAM and TOK, so that selection was effective. One Selection (7.HS20.8) was close of producing the target yield. At NIRS, yields of most of the better yielding lines and of the better yielding REFCVs did not differ significantly. At MB, variation in yield among better yielding selections and better yielding REFCVs was small.

Table 8.10. Performance of some selections produced by scenarios 6 to 9, at NIRS and MB, 1979-80 RS. Sowing dates were 29 February and 26 February 1980, respectively. Harvest dates were 10 July and 17 June 1980, respectively. The mean was calculated for 4 replications per entry at NIRS, and 2 at MB. For further explanation see text and List of abbreviations and symbols.

Code		Y(mt/ha)		ANOH2(m-2)		ANOK(-)		TKWh(g)		HAI(-)	PSS(-)	TSS(-)
		NIRS	MB	NIRS	MB	NIRS	MB	NIRS	MB	NIRS	NIRS	NIRS
	DAY	152	110	118	104	132	104	153	119	-	73	91
Selections												
6 HS 23	20	0.8	1.1	289	250	27	17	24	33	0.13	16	44
PLS 3	3	1.7	1.1	211	415	26	21	33	27	0.31	7	19
PLS 4	14	1.5	1.2	283	300	30	18	29	30	0.28	8	25
7 HS 15	10	1.4	1.3	250	325	34	29	31	23	0.27	12	39
HS 20	8	1.9	1.7	250	280	25	21	41	29	0.34	15	28
HS 38	11	1.4	1.1	239	330	35	16	28	29	0.30	13	34
HS 60	9	1.4	1.0	311	445	30	23	31	22	0.23	9	15
HS 95	12	1.3	0.2	211	275	40	16	30	27	0.26	7	21
JUP HS 36	19	1.3	1.1	261	255	34	21	29	27	0.25	6	30
Reference cultivars												
JUP	22	0.5	0.7	244	250	32	20	16	23	0.10	26	39
ZAM	21	1.1	0.9	256	260	34	13	24	21	0.26	15	31
TOK	23	0.9	0.6	294	270	26	22	21	25	0.20	14	21
UMN	24	0.1	1.1	217	245	19	19	20	27	0.03	33	50
Mean 32 entries		1.0	1.0	250	300	32	20	27	25	0.22	-	-
LSD 5%		0.6	-	65	-	10	-	11	-	-	15	18

Yield and stem rust severity in some JUP-selections differed significantly from JUP, confirming that the commercial cultivar JUP consisted of lines as suggested in Subsection 8.1.3.

Differences between means (Table 8.11) for yield were mostly smaller than 2 x SE, despite differences in number of crossing generations, in number of selfing generations, or differences in selection. Only row selections from a population produced by scenario 7 (Group 4) differed from Group 1 mixtures by > 2 x SE.

Yields of population mixtures produced by scenarios 8 and 9 were lower than yields of the best row selections. All relative yields of Groups 2 and 3 were > 100% if the relative yield is the yield expressed as a percentage of the yield of the corresponding population of Group 1. Sifting during 1979 IS appeared to give a small increase in relative yield. As it was not associated with reduction in stem rust severities, sifting is not a useful method of selection in Zambia.

Crop performance. The baking quality of the highest yielding Selection 7.HS20.8 was good (Meppelink, 1981).

Table 8.11. Grain yield (mt/ha), relative yield (%) and relative resistance at day 91 (-) for populations of scenarios 6 to 9, JUP and ZAM at NIRS after different treatments (selfing, selection). Sowing date 29 February, harvesting date 10 July 1980.
SD = pooled standard deviation with as sources of variation scenario and replicate (block). SE = standard error of the difference between means.
Number of cases (N) between brackets.

Scenario	Selfing and selection: 1979 IS No		Yes					
	Selection group: 1979-80 RS Sifted group 1		Not sifted group 2		Sifted group 3		Selections group 4	
	Yield							
6	0.9	(4)	-	(0)	-	(0)	0.8	(4)
7	0.8	(4)	-	(0)	-	(0)	1.3	(56)
8	0.8	(4)	0.9	(4)	1.0	(4)	-	(0)
9	1.1	(4)	1.2	(4)	1.2	(4)	-	(0)
JUP	-	(0)	0.5	(4)	-	(0)	0.7	(16)
ZAM	-	(0)	1.1	(4)	-	(0)	-	(0)
	Relative yield							
8	100	(4)	113	(4)	125	(4)	-	(0)
9	100	(4)	110	(4)	110	(4)	-	(0)
	Relative resistance							
6	0.14	(4)	-	(0)	-	(0)	0.12	(4)
7	0.08	(4)	-	(0)	-	(0)	0.41	(56)
8	0.20	(4)	0.12	(4)	0.04	(4)	-	(0)
9	0.24	(4)	0.28	(4)	0.10	(4)	-	(0)
JUP	-	(0)	0.22	(4)	-	(0)	0.34	(16)
ZAM	-	(0)	0.38	(4)	-	(0)	-	(0)

SD = 0.49 mt/ha	N	4	8	12	16	56	60
	SE	0.35	0.25	0.20	0.17	0.09	0.09

At MB, rainfall distribution and a low pH in the sub-soil (Zam-Can, 1980 a) were the most important constraints to yield. The early termination of rains (mid-April), and several dry periods each lasting several weeks (Zam-Can, 1980 a) kept helminthosporium at a low level. Because of liming, the pH (CaCl2) on the top 7.5 cm was > 5, but in the 7.5 to 22.5 cm layer it was < 4.4 (Zam-Can, 1980 a). Root development was almost entirely restricted to the top 7.5 cm layer. Stress symptoms occurred in the middle rows of some entries. For these entries, plant height differences between rows were up to 20 cm; kernel setting and filling differed between rows and were poorer in the middle rows.

At NIRS, entries with a high mean Y had a high mean TKWh (Table 8.12) but not necessarily a high mean ANOH2 or ANOK. Kernel filling was particularly important for yield. Entries with a high mean Y also tended to have a high mean shoot weight (SHW, which as also observed in Subsection 8.1.4. Apparantly, SHW could be used to select for Y.

Entries with early crop development tended to have higher yields than late ones, both at NIRS, where stem rust occurred, and at MB where adverse conditions existed for root development. Early development limited yield loss due to adverse conditions and stem rust and was an advantage, as helminthosporium severities remained low.

For yield, yield components and ANOS, the correlations of NIRS with MB were not significant. Probably, entries performed differently at the 2 locations. Selection at NIRS is not likely to produce suitable lines for MB, and vice versa. However, the correlations of DVS and APHT between NIRS and MB were highly significant. Selection at NIRS for a specific APHT or DVS may be effective for MB.

Mean APHT of JUP was 55 cm in unlimed soils and 77 cm in soils with 2.5 mt lime/ha. Liming significantly influenced APHT and yield (Zam-Can, 1980 a). In the HRBP-trial, mean APHT of JUP was 76 cm, which indicates that liming had influenced crop performance. The trial therefore was a test for performance in improved soils and not a test for performance in a soil with a low pH. Early-heading entries did not suffer as much as late-heading entries, and may have escaped adverse conditions to some extent.

Stem rust. Stem rust severities differed significantly between entries. Several selections had the same severities as TOK, the REFCV with the lowest TSS. All entries had a TSS > 10%, which is high. Stem rust significantly reduced yield. Correlations of TSS with ANOH2 and ANOK were not significant. Correlation of TSS with TKWh was significant (r = -0.38*, 29 df). In this trial, stem rust limited yield mainly by limiting kernel filling, which explains that the highest mean yields were relatively high even at a TSS > 10.

Selection for stem rust in 1979 IS, when the severities remained < 10%, had some effect on the 1979-80 RS, because the correlation of TSS for 1979 IS on TSS for 1979-80 RS was significant (r = 0.49*, 17 df).

Scenario 9, with 3 crossing generations, produced mixtures with high stem rust severities. Furthermore, G5 populations were not available within 5 years. Scenario 9 therefore appears to be an inefficient scenario.

Table 8.12. Pearson's r for correlations between grain yield (Y) and various variables (see List of abbreviations and symbols) at NIRS, 1979-80 RS, one-tailed test. Mean values per entry, 31 pairs.

	SHW	ANOH2	ANOK	TKWh	DVS	PSS	TSS
Y	0.69***	ns	ns	0.74**	0.59***	-0.54***	-0.56***

Contrary to expectation, RRES of the mixture of Selection group 3 was not higher than that of the corresponding mixture of Selection group 2, despite sifting after a stem rust attack (Table 8.11). Apparently, large sized kernels were not produced by stem rust resistant plants only. Stem rust severities were high in all entries, resulting in low RRES values. Possibly, the drastic selection at MB reduced the genetic diversity. Sifting before sowing in 1979 IS further reduced the genetic diversity of the mixtures; only highly susceptible plants remained.

8.3.5. Following seasons

Grain yield and crop performance. Three lines (Selections 7.HS20.8, 7.HS15.10 and 6.PLS4.14) were sown by the Research Branch at MB, on 10 February 1981. Yields of the HRBP selections and the commercial cultivars JUP did not differ significantly, and were approximately 0.5 mt/ha. TKWh was relatively low, approximately 25 g (Zam-Can, 1981). Selection 7.HS20.8, the entry with the highest yield in 1979-80 RS, had the lowest yield of the 3 lines tested in 1980-81 RS. The change in ranking order of this entry is possibly due to poor tolerance to low pH. This change indicates that to obtain stable yield at MB genotypes have to be tested for more than 2 seasons. After crossing of genotypes poorly adapted to rainfed conditions (Table 7.1), selections were obtained which did not differ in yield from the best commercial cultivars during RS. However, yields remained below the target yield.

In April 1981 there were 26 rainfree days and 4 "rainy" days and the monthly precipitation was 39 mm. In May the monthly precipitation was 20 mm. This low rainfall subjected plants to stress during anthesis and kernel filling. As a result, a selection for deep rooting and tolerance to acid soils was expected (Zam-Can, 1981). Mean APHT of JUP was low, 55 cm, growth had probably been influenced by the low pH of the sub-soil.

Leaf rust. In 1982 and 1983, the resistance of 3 lines and a Jupateco 73 selection were tested in the Netherlands against 5 Dutch leaf rust isolates. Only one line showed a uniform resistance, but with a resistant reaction type. Apparently, the selection procedure did not eliminate differential resistance to leaf rust. In Zambia, selection for leaf rust resistance received little attention because only low severities occurred. The low severity levels may have contributed to the fact that differential resistance was not eliminated.

8.3.6. Summary

- The scenarios 6 and 7 produced lines with the following properties:
  - a. yields which did not differ from the highest yielding commercial cultivar at MB during the rainy season,
  - b. incomplete and inadequate resistance to stem rust,
  - c. differential incomplete but adequate resistance to leaf rust,
  - d. inadequate resistance to helminthosporium,
  - e. incomplete but adequate resistance to various parasites, and
  - f. good baking quality (only tested for one line).
- Lines did not produce the target yield during the rainy season.
- By means of scenarios 6 and 7 lines were produced acceptable to the Research Branch for pre-registration trials.
- The number of remaining G5 lines differed significantly between scenario 6, with one crossing generation, and scenario 7, with 2 crossing generations. Scenario 7 produced more selections.
- G5 selections were produced in 5 years.

- Scenario 9, with 3 crossing generations, was inefficient as it did not produce G5 populations in 5 years; resulting populations had high stem rust severities.
- NIRS was not an appropriate location for selection of rainfed wheat.
- Multilocational testing was essential to eliminate narrowly adapted genotypes.
- Sifting in segregating populations was not a useful selection method in Zambia, as the populations thus obtained were highly susceptible to stem rust.
- During the rainy season, early development limited yield loss due to stem rust, provided that helminthosporium severities were low.

8.4. Material handled in 1980 and 1981

In 1980 and 1981, there was some segregating material with 2, 3 or 4 crossing generations, for further selfing and selection (Table 8.13). The entries in the trials were G4 and subsequent generations.

With a group of 5 labourers as many as 180 entries per trial could be tested at one location in one season. The number of entries can be increased by reducing the number of drills per plot. However, for reasons of uniformity only one plot size (3 m2) was used in HRBP trials.

In 1980, 9 lines were admitted to the National Test. One HRBP line and a line selection made by HRBP in the cultivar Lee from the 1976 European Yellow Rust Trap Nursery were tested during both seasons. Three lines were discarded because of segregation and one because of susceptibility to helminthosporium, so that 5 lines remained for testing in 1981, including that from Lee.

In 1981, in total 19 lines were admitted to the National Test. Three new lines and the line from Lee participated in trials during both seasons. All 19 lines as well as 4 other promising lines were multiplied and some were submitted to the Field Test. Several lines with a good yield under partly irrigated conditions, moderate to low stem rust and leaf rust susceptibilities, and early heading were tested in the field on seepage soils, and some performed well.

Table 8.13. Number of entries of wheat in various breeding stages. Figures within brackets indicate the number of locations at which entries were grown.

Breeding stage	Rainy season 1979-80	Rainy season 1980-81	Irrigation season 1980	Irrigation season 1981
Segregating material + head selections	200(3)	3150(2)	1500(1)	1600(1)
First HRBP trial	78(3)	133(3)	126(1)	44(2)
Second HRBP trial	1(2)	45(3)	28(1)	72(2)
National Test	2(2)	9(3)	9(4)	14(4)
Field Test	0(0)	0(0)	6(4)	9(4)
Multiplications	0(0)	0(0)	2(2)	23(1)

8.5. Discussion

The primary breeding objective, a good yield, was realized by HRBP. The results seemed to depend on the characteristics of the parent genotypes. Most parent genotypes had moderate to high yields under irrigated conditions with high inputs. Under favourable irrigated conditions, the highest mean yields of parent genotypes were between 6.0 and 7.0 mt/ha and these yields were also obtained by HRBP lines at various locations (Figure 8.2 and Table 8.7). High yielding lines were produced by various scenarios, including scenarios with one (scenario 1) and 2 crossing generations (scenario 3). Selection in Jupateco 73 indicated that yield improvements could be realized without performing a cross.

Under rainfed conditions, parent genotypes had very low yields. HRBP lines did not surpass yield from the highest yielding commercial cultivars in Zambia (JUP, Tai), but had higher yields than the commercial cultivars ZAM and TOK. ZAM and TOK had yields close to the mean over all parent genotypes (Figures 6.7 and 6.8). These results indicate that crossing and selection improved yield. In view of the results during the IS, improving yields of rainfed wheat may be possible by making use of parent genotypes with moderate to high yields under rainfed conditions.

Parent genotypes were moderately to extremely susceptible to stem rust. HRBP lines had a moderately resistant to susceptible reaction type in Zambia, depending on plant organ and genotype. Incomplete resistance levels of the HRBP lines varied little among years (= stable incomplete resistance); RRES was > 0.80. The high yielding REFCV, Jupateco 73, had distinctly different levels of infection in various seasons (Table 8.3). Lines with stable incomplete resistance were produced by a number of scenarios, including scenarios with one (scenario 1) and 2 crossing generations (scenario 3).

Uniform and incomplete resistance to leaf rust appeared to be more common in lines produced by scenario 1, with one crossing generation, than for lines produced by other scenarios (3 and 7) with 2 crossing generations. Possibly, genes responsible for differential resistance occurred in some parent genotypes and they may also have occurred in their progenies.

The method used by HRBP to test the type of resistance is indicative only (Section 7.2). Whether the resistance will be durable is not known. The testing method of the Research Branch; micro-plots with different genotypes inoculated with populations of races, is primarily a test for resistance to allo-infection with high interplot interference. It gives little information about race specificity of the resistance and resistance to auto-infection. The expensive method, which uses isolated 'race nurseries' inoculated with isolates from various races (Zadoks, 1972), could be used to test whether the resistance is differential. Trials with 'microfields' could be used to test the resistance to auto-infection (Parlevliet, 1976; Zadoks and Schein, 1979).

Little attention was paid to a number of potentially important diseases (helminthosporium and mildew) and pests (aphids and armyworm), as high severities or incidence levels did not develop during the trials. In future tests of HRBP lines under conditions differing from those described, high severities or incidences may occur, as little selection against these parasites was done. Severe mildew infection occurred in some lines in Zambia (Little, 1982, 1983) and in the Netherlands in 1983.

Scenarios 1, 3 and 7 produced lines with a good capacity to adapt. These lines gave high yields at different locations during different seasons. The scenarios with 2 crossing generations (scenarios 3 and 7) tended to produce more lines than scenarios with one crossing generation only (scenarios 2, 4, 5 or 6).

If selection was based on only a limited number of criteria, e.g. high yield at different locations, adequate lines could be produced by almost all scenarios (Table 7.5). However, lines with high yield, stable incomplete resistance to rusts, and comparatively wide adaptation were rare. Lines which produced the target yield during the rainy season were not found. Screening of large populations (> 10,000) at several locations, during several years, is necessary to obtain lines with all of these characteristics.

There are distinct differences in requirements for rainfed wheat (ability to grow on ferrallitic soils with a low pH, resistance to helminthosporium and stem rust) and for irrigated wheat (yields over 5 mt/ha, resistance to stem rust but not necessarily resistance to helminthosporium). In view of the low chances to find selections for rainfed conditions or selections which combine all these characteristics, it appears necessary to use different parent genotypes for breeding of irrigated wheat and rainfed wheat. Virtually all scenarios produced acceptable G5 lines (Table 7.5). Thus production of lines may become less energy demanding.

Scenario 5, with only 12 parent genotypes, did not produce a line acceptable for the National Test. Cross-fertilization was very low in most genotypes. Possibly too little diversity was created to obtain sufficient G5 lines. If the number of parent genotypes to be crossed is limited, it is important to test the response of the genotypes to Ethrel and to eliminate those genotypes which have a low percentage of cross-fertilization. If time restrictions do not permit preliminary tests, crossing by hand may be preferred to application of Ethrel as it is more reliable.

Scenario 9 with 3 crossing generations had no distinct advantages concerning yield or resistance over other scenarios (6 to 8). It was, however, more time-consuming and therefore it appears to be of little practical use.

By multiplication of G1 and G2 in the late IS and the following RS, three generations can be produced in one year as done in the scenario by McBean (1981) (Table 2.5). In view of the good results from scenario 7, multiplication under adverse climate conditions appears to have practical possibilities.

HRBP had a low budget with very little external financial contributions. Personnel was trained locally. The programme operated with the facilities available to the Research Branch. Within 5 years good wheat lines were made available. Due to training and practice, the HRBP personnel acquired sufficient professional experience and competence to perform breeding activities for the Research Branch. Several promising scenarios were identified. HRBP demonstrated that Ethrel can be used to perform large numbers of crossings in Zambia. Thus a method became available to Zambia whereby many crossings can be performed at low costs. HRBP also contributed to making documentation available on wheat production, breeding and epidemiology of rusts in Zambia. Lines with the target yield during the rainy season were not found.

8.6. Conclusions

Most breeding objectives were realized, with locally trained personnel, with a low budget, and within a short period. Good yielding lines with a wide adaptability and incomplete but adequate resistance to several parasites (aphids, stem borers, virus) were developed. Stable incomplete resistance to stem rust and uniform incomplete resistance to leaf rust may have occurred, however, neither race non-specificity nor durability of rust resistances have been proven conclusively. HRBP lines are not suitable to stimulate rainfed wheat production, as they did not normally produce target yields during the rainy season.

9. FUTURE WHEAT GROWING IN ZAMBIA

Zambia produces only a very small percentage of its wheat demand and is faced with an increasing demand. Wheat is imported using much needed foreign currency. Increased wheat production, therefore, has a high priority. Further increases, however, depend on research. This Chapter discusses some of the possibilities and constraints of increasing wheat production, in view of results presented in the previous chapters.

9.1. Research capacity

Prices of copper and oil have a strong influence on the balance of trade and costs of living in Zambia. Decreased copper prices and increased oil prices during the 1970s had a significant impact on all government expenses. The budget of the Research Branch was reduced on several occasions and budgetary increases in the 1980s are dubious.

Personnel, including foreign experts, to undertake research and stimulate production of wheat is not lacking. Wheat research is stimulated energetically by Mount Makulu staff as well as by the Department of Agriculture. Bilateral and multilateral programmes aim at increasing wheat production. CIMMYT provides genotypes and advice. A bilateral programme with Belgium is giving significant contributions to the development of rainfed wheat with resistance to diseases, in particular helminthosporium. The largest programme is that with Canada, called Zam-Can, which was started to increase rainfed wheat production. Zam-Can is active in Zambia since 1974. Zam-Can had a large scale scheme near Livingstone, aimed at production. A current idea was, that all necessary knowledge on wheat was already available, and needed only to be applied. The scheme was abandoned in 1978 because rainfed wheat production was not profitable. A new scheme was opened at Mbala, which operated from 1978 to 1982. Here, some research was carried out. Between 1978 and 1982, Zam-Can provided assistance to national trials, and trained local staff. Its experts shared their knowledge about wheat with other members of the Research Branch in Zambia. At Mbala, Zam-Can also tried to interest farmers in highly mechanized large scale production (wheat farms > 50 ha) with relatively high inputs (Subsection 2.3.1). The production scheme at Mbala was abandoned because, there too, rainfed wheat production was not profitable. Presently, Zam-Can's activities are limited to research (Times of Zambia, December 30, 1982).

The Zam-Can story illustrates the degree of complexity the Zambian government is facing in attempting to increase wheat production.

9.2. Regions and wheat production

In Chapters 2, 6 and 8 it is shown that wheat can be grown in Zambia and that wheat production can be increased. Break-even yields cannot be obtained in all parts of the country. Soil, climate, relief, infrastructure, oil prices, and also diseases and pests affect production. Reducing variation in yields due to diseases and pests is only one of the requirements to increase wheat production. Chapters 4 and 8 demonstrate that resistance to stem rust, leaf rust, and helminthosporium is important to guarantee stable yields. HRBP activities have shown that improvement of yield, adaptability, and resistance to stem rust is possible. HRBP lines combine high yielding ability, wide adaptability (Figure 8.2) and stable incomplete resistance to stem rust (Chapter 8).
HRBP demonstrated that opportunities exist to realize improvements using locally available discarded cultivars in a breeding programme (Chapter 8).

Opportunities for continued increase of wheat production seem to exist (Chapter 2). The various regions of Zambia have different potentials. The number of farmers per region and the categories of farmers must be considered in plans. Distinct regional differences in infrastructure and population densities (Subsection 2.1.1) exist between:

a) the regions where the railway was first introduced, including Copperbelt, Central, Lusaka and Southern Provinces, and
b) outlying regions.

9.3. Copperbelt, Central, Lusaka and Southern Provinces

These regions produce approximately 60% of the total agricultural production (including subsistence production). A high percentage of the large scale farmers and emergent farmers (Section 2.2) live in this region. Production costs tend to be lower in these regions than in outlying regions, as infrastructure is better.

Rainfed wheat as yet rarely yields 2 mt/ha or more (Subsection 2.3.1, Chapter 8). Consequently, production is not yet economically interesting. Helminthosporium resistance needs to be improved. Tolerance to low pH is required in certain areas. In various areas, temperatures are too high and rainfall is not suitable, as at NIRS (Chapter 8) and Livingstone (Section 9.1).

Irrigated high input wheat production is possible and can be profitable. In 1975, break-even yields were below 3 mt/ha (Table 2.3), while actual yields tended to be above 4 mt/ha. Presently, few farmers can afford this type of production (Table 2.2), and their number will probably increase by at most a few hundreds. It is questionable whether a sufficient number of large scale farmers will emerge soon to make the country self-supporting in wheat. By means of large scale projects and parastatal farms, a significant contribution could be made to increase wheat production, but at great costs. Experiences in neighbouring countries Tanzania (Fuggles-Couchman, 1951; Northwood, 1970; Toogood, 1981), Mozambique (Viana, 1937; Mota, 1971; Croon, 1976; Rodrigues et al., 1976), and Angola (Ribeiro, 1949; Barradas et al., 1974), insofar as comparison is justified, indicate that long term production is not easily guaranteed, and that the benefit/cost ratio does not give rise to great expectations. Sufficient knowledge is presently available to optimize irrigated wheat production. HRBP lines could contribute to stabilization of this production because of their comparatively wide adaptability and their stable resistance to stem rust.

Dambo and seepage wheat production is not yet practised. Possibly, these types of production are feasible for emergent farmers, and possibly thus the number of farmers involved may be increased by thousands. This type of production, therefore, deserves attention from research. Yield levels and management practices need to be investigated. Crop production in dambos and on seepage soils may lead to destruction of the organic matter in the soil. This would be 'capital destruction' which can only be avoided by means of specific, 'on site' research and extension. HRBP lines have been successfully tested on dambo and seepage soils. Dambo and seepage wheat production are not expected to drastically increase wheat production in the near future.

9.4. Outlying regions

Areas. Outlying regions are divided into areas according to abiotic criteria:

a) north (Luapula and Northern Provinces),
b) east (Eastern Province) and south-east (Kariba area in the Southern Province),
c) west (Western Province) and north-west (North-Western Province).

North. Results of HRBP (Subsection 2.3.1 and results at MB in Chapter 8) and Zam-Can (Section 9.1) indicate that rainfed wheat is not yet profitable. Farmers need to be trained as they have no experience with wheat. This will require extension. Possibly, settlement schemes for farmers are required as there is a limited number of local farmers. Furthermore, cultivars adapted to ferrallitic soils as well as resistant to helminthosporium and possibly to American bollworm and armyworm are required. Meeting all of these conditions will require considerable amounts of time and effort.

In many areas the high altitude assures a temperature regime suitable for wheat. High yields may be expected on suitable soils because of favourable temperatures during the irrigation season (Van Keulen and De Milliano, 1984). Rust epidemics are expected to be of relatively little importance, because:
- spores are assumed to arrive late in the season (Section 4.3),
- distances from the sources are large (Section 5.2),
- lines are available with stable incomplete resistance to stem rust (Chapter 8) as well as lines with complete resistance (Little, 1982),
- fields will be small to medium sized and scattered,
- wheat growing areas will be small and scattered.

East and south-east. At present, rainfed wheat is not economically interesting. In the east, temperatures are too high. In the south-east, rainfall is not suitable. Therefore, rainfed wheat is not likely to become of importance.

Irrigated wheat may have potentials but requires high inputs. Because of fluctuating temperatures during the irrigation season, the date of sowing will be as important or even more important than at NIRS (Chapter 6, Van Keulen and De Milliano, 1984). Widely adapted lines of HRBP, with tolerance to high temperatures (Section 8.1), may useful in these areas.

West and north-west. Rainfed wheat is not economically interesting. Possibly, there are areas in North-Western Province where rainfed wheat can be produced. This should be examined. Seepage and dambo wheat production have definite possibilities, as was demonstrated in Mongu and Kalabo (Offergelt and De Milliano, 1979). Specific research 'on the spot' is needed to explore these possibilities. Large areas are in principle available. Nevertheless, their contribution will probably not make Zambia self-sufficient in the near future. HRBP lines with good results in Mongu and Kalabo area are available.

Apart from the technical possibilities and constraints, a major constraint is the infrastructure.

9.5. Conclusions

Zambia is not likely to become self-sufficient in wheat in the near future. However, possibilities to increase wheat production, and thus reduce imports, exist. HRBP lines have qualities needed for this increase of wheat production. Because of these qualities they may contribute to further increase and improvement of wheat production. HRBP lines can be used in irrigated, dambo and seepage wheat production, but they are not suitable for rainfed production. Presently, there is little hope for an economically attractive rainfed wheat production. Regional projects at selected sites with suitable soils, temperatures and water supplies seem to offer some prospect. Such regional projects could help to alleviate some of Zambia's foreign currency problems, but only at the expense of large investments in infrastructure.

SUMMARY

Wheat is of importance to Zambia (2.3). The Zambian government has expressed a great interest in the development of wheat with resistance to locally important pests and diseases (1.1). At the initiative of FAO, a programme of wheat improvement was developed making use of incomplete resistance (1.2) to rusts. The programme used local facilities (finance, personnel, infrastructure); the budget was low; there were few personnel.

The abiotic conditions (2.1), the socio-economic status of the farmers (2.2), the cropping methods (2.3), the economic aims of wheat production (2.3) and the status of research (2.4) are described. The location of the research stations, and soils and weather at these stations are described (2.5). Stem rust, helminthosporium, and various other diseases and pests can cause yield losses. Possible yield losses in wheat in Zambia due to diseases and pests are estimated (Table 2.4). Wheat can be produced by all categories of farmers (2.2), in most of Zambia, but break-even yields cannot be obtained throughout the country. Soils, climate and relief affect yield levels. Actual and maximum yields have been increasing for all major cropping methods since the 1950s (2.3.1). Further increase of wheat production in both the rainy season and the irrigation season seems feasible. Because of the 3 principal airstreams (2.1.4), Zambia may receive inoculum from virtually all wheat-growing neighbour countries.

The materials and methods applied (3) are to some extent the results of a developmental process, based on local conditions and local requirements (farmers, input levels). Only limited efforts were made to improve so-called poor working conditions. Crop protection is described (3.3). Pests and diseases are discussed including some which are yet of minor importance to Zambia (3.3). Sophistication of statistical analysis in Zambia was kept at the level of the pocket calculator. To process the large quantity of data collected, and to obtain additional information, use was made of a DEC10 computer. Card types were designed (Table 3.2) and programmes were written for data processing.

Recent literature on stem rust in Zambia and in neighbouring wheat growing countries is reviewed (4.2 and 4.3). Occurrence of stem rust in Zambia and HRBP (Table 4.2), its development after inoculation at different locations during rainy and irrigation seasons (Figures 4.1 and 4.2), its development for different sowing dates of wheat (Tables 4.3 and 4.4; 4.3.5), the effect of overlapping vegetation periods of wheat (4.3.6), and possibilities for perennation are discussed. Possible effects due to an increase in the Zambian wheat area are considered. Races (Table 4.1) and race shifts are studied (4.2 and 4.4). Stem rust developed during both rainy and irrigation seasons. Terminal severities were higher during the rainy season than during the irrigation season, except for very susceptible genotypes. High severities can occur especially at lower altitudes (4.3.9), and might occur more frequently with an increase of the wheat hectareage. Resistance to stem rust might be of importance to reduce yield loss during both rainy and irrigation seasons and to reduce chances for perennation. Postponement of sowing to May may result in an escape from high severities during the irrigation season (4.3.5 and 4.3.6). Stem rust influenced yield of all genotypes tested (Table 4.15); the mean yield loss was 15% for a terminal severity of 10% (James' Scale). All yield components appeared to be influenced. Tolerance had no practical importance (Table 4.16). A good estimate of yield loss could be made by various approaches including simple regression (4.5). Race shifts occur in Zambia and in neighbouring wheat growing countries. Race shifts were infrequent in Zambia and Zimbabwe (4.4) but frequent in Kenya (4.2.2). The relatively stable stem rust situation may lead to ineffective selection; selections exhibiting a stable incomplete resistance may have a

differential resistance (Figure 4.6). The great distance between sources and target, the relatively small area of the sources and the vagaries of the weather during spore transportation may explain the variablity in stem rust occurrence. Differences in source-target relations are expected between areas in the central and southern part of Zambia and the areas in the northern part. At present, the target with a relatively small hectareage of rainfed wheat is reached in February, and that with irrigated wheat in June. As a small target is reached by inoculum, a larger target would certainly be reached, perhaps even at an earlier date. Considering the frequency of occurrence of stem rust and yield loss, selection criteria suggested for Zambia are: a terminal severity on the stem (exludig leaf blades) of less than 5% and a relative resistance larger than 0.80.

The importance of leaf rust in Zambia and surrounding countries is reviewed (5.1). It is demonstrated (Table 5.1) that genetic uniformity of wheat was not avoided in Africa south of the Sahara; this may pose a threat to stable wheat production. Inoculum production and dispersal are discussed (5.2). Results of recent investigations concerning host resistance, rust races and yield loss are presented (5.3 to 5.5). Leaf rust occurred more frequently in Zambia than stem rust but few genotypes were very susceptible; most genotypes had a reduction in the thousand kernel weight of less than 5%. Spontaneous epidemics can begin in February. Severities > 10% can occur in late April on rainfed wheat and in late June on irrigated wheat. Kernel weight was the only yield component to be significantly influenced, after an early onset of the epidemic (Table 5.5). With an increase of the wheat hectareage, resistance to leaf rust might be of importance to reduce yield loss during both the rainy and irrigation seasons and to reduce chances for perennation, especially at lower altitudes. Postponement of sowing to May might serve as a method to escape from high leaf rust severities during the irrigation season (Figure 5.1). Different races are present in neighbouring countries, which could reach Zambia because of the 3 principal airstreams. Most genotypes tested had differential resistance (Figure 5.2, Table 5.3); only some may have had uniform resistance. Selection criteria suggested for Zambia were a terminal severity on the lower leaves of less than 10% and a relative resistance of more than 0.80.

Qualitative characteristics of the parent genotypes were studied (6.2). Trials were performed during various irrigation seasons to obtain information about variations between trials, groups of genotypes and genotypes for various quantitative plant characteristics: plant height (6.2.2), number of spikelets per head (6.2.3), emergence (6.3), development (6.4), stand (6.5), yield components (6.6), and grain yield (6.7). Main factors influencing quantitative variables were: water stress, temperature and stem rust (6.8). Some genotypes with incomplete resistance to rusts had relatively high yields during rust years. Genotypes suitable for the rainy season were not necessarily suitable for the irrigation season. Suggestion were made for selection in Zambia (6.9). Selection for a high ranking mean yield over trials was effective provided that stem rust was present and had mean severities over genotypes of at least 8%. Selection for high yield under favourable conditions did not lead to a 'stable yield'. The yield of the reference cultivars is discussed and compared with that of parent genotypes (Figure 6.8).

Activities performed in the attempt to realize breeding objectives (7.1) included: avoidance of differential resistance (7.2), selection of parent genotypes (7.3), the performance of crosses and the development of crossing methods (7.4 and 7.5), the design and tests of breeding scenarios (7.7), the implementation of selection, and the management of trials (7.6). Differential resistance to certain pests and diseases, including rusts, may inadvertently have been included in the parent genotypes. The 34 parent genotypes all had incomplete resistance to stem rust and leaf rust. After application of the male gametocide Ethrel (7.5), cross-fertilization occurred in several genotypes by open pollination and large quantities of cross-fertilized seed were produced. Crossing by means of Ethrel was useful during the cooler irrigation season, but was inefficient during the warm rainy season.

Suitable lines for irrigated production were produced within 5 years by means of different scenarios, described in detail (8). Nine HRBP lines were admitted to the National Test (pre-registration trials) in 1980 and 19 HRBP lines in 1981. HRBP lines combined relatively high yield with comparatively wide adaptability (Figure 8.2) and good baking quality. Lines did not differ in yield from the best commercial cultivars when grown under rainfed conditions. Yields remained below the target yield of 2 mt/ha (Tables 8.1, 8.7 and 8.10). Resistance to helminthosporium and tolerance to low pH need improvement (8.1.4, 8.2.6 and 8.3). Thus the HRBP lines could not be used to stimulate rainfed wheat production. The lines had a stable and incomplete resistance to stem rust while the highest yielding reference cultivar had an unstable resistance (Table 8.3). The lines possibly had uniform and incomplete resistance or differential and incomplete resistance to leaf rust (8.1.5, 8.2.6 and 8.3.5) and incomplete but adequate resistance to various pests and diseases. NIRS was an appropriate location for selection of irrigated wheat but not for rainfed wheat. Multilocational testing was essential for rainfed and irrigated wheat to eliminate narrowly adapted genotypes (8.1.5). As there are distinct differences in requirements for rainfed and for irrigated wheat, breeding and selection in separate populations may be more efficient than using one population only (8.5). During the rainy season, early developing genotypes tended to have low yield loss due to stem rust, had a good chance to get sufficient moisture, but tended to have high helminthosporium severities (Table 8.4.b). Sifting was not a useful method of selection (8.3.4). Scenarios with 2 crossing generations tended to produce a higher number of acceptable lines for pre-registration than scenarios with one crossing generation.

Opportunities for increasing wheat production in Zambia are discussed (9). There is a limited scope for improvement when well-designed research efforts are made. The costs of the necessary infrastructural investments have to be weighted against the benefits of regionally improved wheat production. It is indicated where and how HRBP lines can be used in Zambia.

SAMENVATTING

Tarwe is van belang voor Zambia (2.3). De Zambiaanse regering heeft belangstelling getoond voor de ontwikkeling van tarwe met duurzame resistentie tegen ter plaatse belangrijke ziekten en plagen (1.1). Op initiatief van de Voedsel en Landbouw Organisatie van de Verenigde Naties (FAO) werd een programma uitgevoerd voor de verbetering van tarwe, gebruik makend van onvolledige resistentie (1.2) tegen roesten. Er werd gewerkt met plaatselijke faciliteiten (financiën, infrastructuur), een laag budget en weinig personeel.

De abiotische omstandigheden (2.1), de sociaal-economische positie van de boeren (2.2), de teeltmethoden (2.3), de financiële aspekten van de tarweteelt (2.3) en de status van het onderzoek (2.4) worden beschreven. Ook de proefbedrijven, hun bodems en het weer worden beschreven (2.5). Zwarte roest, *helminthosporium* en verschillende andere ziekten en plagen kunnen opbrengstverliezen veroorzaken in tarwe in Zambia; mogelijke verliezen als gevolg van ziekten en plagen worden geschat (Tabel 2.4). Tarwe kan in vrijwel geheel Zambia verbouwd worden door boeren van verschillende categorieën (2.2), maar de teelt is niet overal kostendekkend. Bodem, klimaat en hoogteverschillen beinvloeden de opbrengstniveaus. Sinds de vijftiger jaren zijn de doorsnee en maximum opbrengsten gestegen voor alle belangrijke teeltmethoden (2.3.1). Een verdere toename van de tarweproduktie is mogelijk, zowel voor het natte als het droge seizoen. Als gevolg van de 3 belangrijke windstromingen (2.1.4) kan Zambia roest-inoculum ontvangen uit bijna alle naburige landen met tarwe.

Materialen en methoden (3) werden grotendeels plaatselijk ontwikkeld, rekening houdend met plaatselijke behoeften (boeren, 'input' niveaus). Gewasbeschermingsmaatregelen worden beschreven (3.3). Ziekten en plagen worden besproken, met inbegrip van voor Zambia nog van gering belang zijnde ziekten en plagen (3.3). De statistische verwerking van waarnemingen in Zambia werd uitgevoerd met een zak-rekenmachine. Verdere verwerking van de grote hoeveelheid gegevens vond plaats met een DEC10 computer. Er werden kaarttypes ontworpen (Tabel 3.2) en programma's geschreven voor de gegevensverwerking.

Een overzicht wordt gegeven van de recente literatuur over zwarte roest in Zambia en naburige landen (4.2 en 4.3). De aanwezigheid wordt besproken van zwarte roest in Zambia en in het horizontale resistentie programma (HRBP) (Tabel 4.2), de ontwikkeling van de roest na inoculatie op verschillende plaatsen gedurende het natte en het droge seizoen (Figuren 4.1 en 4.2), de ontwikkeling van zwarte roest in tarwe gezaaid op verschillende data (Tabellen 4.3 en 4.4; 4.3.5), het effect van het overlappen van vegetatieperiodes van tarwe (4.3.6) en de mogelijkheden voor het overblijven van de roest in Zambia. De mogelijke gevolgen van het uitbreiden van het Zambiaanse tarwe-areaal worden in beschouwing genomen. Fysio's (Tabel 4.1) en veranderingen in de fysiosamenstelling worden bestudeerd (4.2 en 4.4). Zwarte roest ontwikkelde gedurende het natte en droge seizoen. Terminale aantastingen waren hoger tijdens het natte seizoen, uitgezonderd voor zeer vatbare genotypes. Hoge aantastingen kunnen vooral aanwezig zijn in gebieden met relatief geringe hoogte boven zeeniveau (4.3.9), en kunnen mogelijk vaker optreden als het tarweareaal groter is. Resistentie tegen zwarte roest kan van belang zijn om opbrengstverlies te beperken gedurende het natte en het droge seizoen en om de kansen van overblijven van de roest te reduceren. Door het zaaien uit te stellen tot in mei kunnen hoge aantastingen mogelijk voorkomen worden (4.3.5 en 4.3.6). Zwarte roest beinvloedde de opbrengst van alle getoetste genotypen (Tabel 4.15); het gemiddelde opbrengstverlies bij een terminale aantasting van 10%, waargenomen volgens de schaal van James, was 15%. Alle opbrengstkomponenten werden beinvloed door zwarte roest. Tolerantie had geen praktisch belang (Tabel 4.16).

Opbrengstverlies kon goed geschat worden met verschillende schattingsmethoden, inclusief enkelvoudige regressie (4.5). De fysiosamenstelling veranderde in Zambia en ook in naburige landen. Veranderingen kwamen niet vaak voor in Zambia en Zimbabwe (4.4), maar wel in Kenya (4.2.2). Selekties met een stabiele onvolledige resistentie kunnen een differentiële resistentie hebben (Figuur 4.6). De grote afstand tussen tarwe-arealen in naburige landen en Zambia, de relatief kleine tarwe-arealen in naburige landen en de grilligheid van het weer tijdens sporentransport kunnen een verklaring zijn voor de onregelmatige verschijning van zwarte roest. Momenteel kan zwarte roest in februari aanwezig zijn in tarwe tijdens het natte seizoen en in juni tijdens het droge seizoen. Als een klein gebied bereikt wordt door inoculum, zal een groot gebied beslist ook bereikt worden en mogelijk nog vroeger. Gezien de frequentie van de aanwezigheid van zwarte roest en het opbrengstverlies werden de volgende selektiecriteria voorgesteld voor Zambia: een terminale aantasting van de halm (exclusief bladschijf) van minder dan 5% en een relatieve resistentie (Formule 4.5) van ten minste 0.80.

Het belang van bruine roest in Zambia wordt opnieuw bezien (5.1). Aangetoond wordt (Tabel 5.1) dat er genetische uniformiteit is in tarwe in Afrika ten zuiden van de Sahara. Mogelijk kan dit de stabiliteit van tarweproduktie in gevaar brengen. De produktie en verspreiding van sporen worden besproken (5.2), alsmede nieuwe onderzoeksresultaten over waardplantresistentie, bruine-roestfysio's en opbrengstverlies (5.3, 5.4 en 5.5). Bruine roest kwam vaker voor in Zambia dan zwarte roest maar slechts weinig genotypen zijn erg vatbaar. De meeste genotypen hadden minder dan 5% verlies aan korrelgewicht. Bij een 'vroege' epidemie beinvloedde bruine roest alleen het korrelgewicht (Tabel 5.5). Spontane epidemieën kunnen beginnen in februari. Aantastingen van meer dan 10% kunnen eind april aanwezig zijn op tarwe verbouwd in het natte seizoen en eind juni in geirrigeerde tarwe. Bij in gebruik nemen van grote tarwe-arealen kan bruine-roestresistentie van belang zijn om opbrengstverliezen te beperken tijdens het natte en het droge seizoen en om de kansen van overblijven van de roest te reduceren, vooral in gebieden met relatief geringe hoogte boven zeeniveau. Door het zaaien uit te stellen tot in mei kunnen hoge aantastingen voorkomen worden in het droge seizoen (Figuur 5.1). Fysio's uit naburige landen kunnen Zambia bereiken met de 3 voornaamste winden. Vrijwel alle getoetste genotypen hadden een differentiële resistentie (Figuur 5.2, Tabel 5.3), enkele genotypen hadden een mogelijk uniforme resistentie. Voorgestelde selektiecriteria voor Zambia waren: een aantasting op de lagere bladeren van minder dan 10% en een relatieve resistentie van ten minste 0.80.

Een aantal kwalitatieve eigenschappen van de oudergenotypen werden bestudeerd (6.2). Uit proeven uitgevoerd tijdens het droge seizoen werd informatie verkregen over variaties tussen proeven, groepen van genotypen en individuele genotypen voor verschillende kwantitatieve eigenschappen, namelijk plant hoogte (6.2.2) aantal kafjes per aar (6.2.3), opkomst (6.3), ontwikkeling (6.4), standdichtheid (6.5), opbrengstkomponenten (6.6) en opbrengst (6.7). De voornaamste factoren van invloed op kwantitatieve variabelen waren water, temperatuur en zwarte roest (6.8). Sommige genotypen met onvolledige resistentie tegen roesten hadden relatief hoge opbrengsten in roestjaren. Geschikte genotypen voor het natte seizoen waren veelal niet geschikt voor het droge seizoen. Suggesties worden gegeven voor selektie van tarwe in Zambia (6.9). Selektie op een hoge opbrengst over proeven was effectief bij aanwezigheid van zwarte-roestaantastingen op de stengel van tenminste 8% gemiddeld over alle genotypen . Hoge opbrengst onder gunstige groeiomstandigheden was niet geassocieerd met een stabiele opbrengst. De opbrengsten van de referentie cultivars worden vergeleken met die van de oudergenotypen (Figuur 6.8).

Aktiviteiten om de veredelingsdoelstellingen (7.1) te realizeren omvatten:

het vermijden van differentiële resistentie (7.2), het selekteren van oudergenotypen (7.3), het uitvoeren van kruisingen en het uitwerken van methoden (7.4 en 7.5), het ontwerpen en uitvoeren van veredelingsscenario's (7.7), het uitvoeren van selekties en het verrichten van proeven (7.5 en 7.6). Differentiële resistentie tegen bepaalde ziekten en plagen, inclusief roesten, was mogelijk ongewild aanwezig in de oudergenotypen. De 34 oudergenotypen hadden wel allen een onvolledige resistentie tegen zwarte en bruine roest. Na behandeling met Ethrel (7.5) vond kruisbevruchting plaats in vele genotypen met vrije bestuiving en grote hoeveelheden kruisbevrucht zaad werd geproduceerd. Ethrel was bruikbaar voor het maken van kruisingen in het koele droge seizoen, maar was inefficient in het warme natte seizoen.

Bruikbare lijnen werden geproduceerd voor de geirrigeerde tarweteelt met verschillende in detail beschreven scenario's (8). Negen HRBP lijnen werden toegelaten tot de Nationale Toets (proeven voor toelating tot registratie) in 1980 en 19 lijnen in 1981. HRBP lijnen combineerden een relatief hoge opbrengst met een relatief brede aanpassing (Figuur 8.2) en goede bakkwaliteit. Tijdens het natte seizoen hadden de HRBP lijnen opbrengsten ongeveer gelijk aan de beste commerciële cultivars, maar de opbrengsten waren beneden het economisch wenselijke opbrengstniveau van ongeveer 2 ton per ha (Tabellen 8.1, 8.7 en 8.10). De resistentie tegen helminthosporium en de tolerantie voor een lage pH waren ontoereikend (8.1.4, 8.2.6 en 8.3). Daardoor konden HRBP lijnen niet gebruikt worden om de tarweteelt in het natte seizoen te bevorderen. De lijnen hadden een stabiele en onvolledige resistentie tegen zwarte roest terwijl de hoogst opbrengende referentiecultivar een instabiele resistentie had (Tabel 8.3). De lijnen hadden een mogelijk uniforme en onvolledige of een differentiële resistentie tegen bruine roest (8.1.5, 8.2.6 en 8.3.5) en onvolledige maar toereikende resistentie tegen verschillende ziekten en plagen. NIRS was een geschikte plaats voor selektie van geirrigeerde tarwe maar niet voor selektie van tarwe voor het regenseizoen. Voor een goede selektie was het noodzakelijk om lijnen te toetsen op meer plaatsen, zowel tijdens het droge als het natte seizoen (8.1.5). Aangezien er geheel verschillende eisen gesteld worden aan lijnen voor het droge en het natte seizoen, is het mogelijk efficienter om verschillende populaties te gebruiken voor veredeling in plaats van èèn (8.5). Gedurende het natte seizoen hadden vroege genotypen de neiging tot een laag opbrengstverlies door zwarte roest, ze maakten een goede kans om voldoende vocht te krijgen, maar ze hadden de neiging tot een hoge helminthosporium-aantasting (Tabel 8.4.b). Zeven was geen goede selektiemethode in Zambia (8.3.4). Scenario's met 2 kruisingsgeneraties (scenario's 3 en 7) produceerden meer lijnen geschikt voor de Nationale Toets dan scenario's met èèn kruisingsgeneratie.

De mogelijkheden voor een verhoging van tarweproduktie in Zambia worden besproken (9). Er zijn beperkte mogelijkheden voor verhoging met behulp van goed opgezet onderzoek. De kosten nodig voor de verbetering van de infrastruktuur moeten worden afgewogen tegen de baten van een regionale toename in tarweproduktie. Er wordt aangegeven waar en hoe HRBP lijnen gebruikt kunnen worden in Zambia.

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CURRICULUM VITAE

Walter Alphonsus Johannes de Milliano werd op 21 augustus 1950 geboren te Oostburg. In 1968 behaalde hij het einddiploma HBS-B aan de Katholieke HBS en MMS voor West Zeeuwsch Vlaanderen 'Sint Eloy' te Oostburg. Hetzelfde jaar begon hij zijn studie aan de Landbouwhogeschool te Wageningen. In september 1975 behaalde hij het ingenieurs-examen richting Planteziektenkunde, met als hoofdvakken Fytopathologie en Entomologie en als bijvak Theoretische Teeltkunde. Ingenieursonderzoek is verricht aan de 'Kansas State University' in de VSA (met een studiebeurs van Rotary International), aan het Phytopathologisch Laboratorium 'Willie Commelin Scholten' te Baarn, en op de Proefboerderij 'de Eest' in de Noordoostpolder. Een le graads bevoegdheid Biologie werd behaald in Wageningen in 1975; de aantekening voor de vakken pedagogiek, puberteitspsychologie en algemene didactiek werd behaald in Utrecht in 1974. Hij was studentencoördinator van de Studentenvereniging voor Planteziektenkunde en voorzitter van het studentendispuut 'Kongsi'.

Van januari 1976 tot januari 1979 heeft hij gewerkt als assistent-deskundige op het 'National Irrigation Research Station' te Mazabuka, Zambia, in een project voor de verbetering van tarwe in Zambia. De werkgever was de Voedsel en Landbouw Organisatie van de Verenigde Naties (FAO). Vanaf januari 1979 tot juli 1982 heeft hij gewerkt als teamleider in hetzelfde project uitgezonden via het Directoraat Generaal Internationale Samenwerking van het Ministerie van Ontwikkelingssamenwerking. Sinds augustus 1981 heeft hij gastvrijheid genoten bij de Vakgroep Fytopathologie van de Landbouwhogeschool. In de periode augustus 1981 tot juli 1982 werden gegevens voor dit proefschrift uitgewerkt; het proefschrift werd geschreven in de periode augustus 1982 tot augustus 1983.