Epidemiology of bean rust in Ethiopia

Promotor: Dr. J.C. Zadoks,
Hoogleraar in de ecologische fytopathologie

Habtu Assefa

Epidemiology of bean rust in Ethiopia

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Propositions (Stellingen)

1. Bean rust management in Ethiopia must be tailor-made to address the specific needs of each region. Each region has its own unique situation regarding cropping systems, altitude, rainfall, temperature, soil, production constraints and farmers' objectives.

   This thesis.

2. The magnitude of yield loss in beans due to bean rust under present low input conditions will depend in part on the amount of inoculum arriving prior to flowering. Reducing the amount of this incoming inoculum might provide a good control of bean rust.

   This thesis.

3. The use of partially resistant cultivars must be encouraged in any bean rust management strategy.

   This thesis.

4. Bean cultivar mixtures provide stability against bean rust.

   This thesis.

5. Comparative analysis yields insights into causes and effects of observed phenomena. Comparative epidemiology can point out alternatives.

   Kranz, 1978; Zadoks and Schein, 1978.

6. Every Ethiopian farmer produces something for the market. However, the mentality of subsistence farming still prevails and hampers development.

7. If we want to both feed the ever increasing Ethiopian population and develop a sustainable agriculture, then Dutch International Cooperation would be most productive if aimed at agricultural research and development.

8. Ethiopia is a complex country with different ethnic groups, languages, religions, modes of life and highly diversified geology and climate. Progress in development in Ethiopia requires three foundations: a well defined social purpose, freedom of expression and the rule of law.

9. Those who prescribe development projects for rural Ethiopia do so by totally ignoring the fact that their target populations is made up of human beings like themselves with feelings, aspirations and values of their own.
Mesfin Wolde-Mariam, 1991. Suffering under God's environment.
African Mountain Association, Geographica Bernensia.
Berne, Switzerland.

10. If famine is a function of human frailty, father god and mother nature, I believe the human frailty played a significant role in the Ethiopian situation.

11. In Wageningen they let you ask, ask and ask questions. I believe that is the road to acquire knowledge.

12. Knowledge can be acquired by direct experience, by reason or by authority. To this I wish to add Zadoks' red pen.

Propositions attached to the thesis 'Epidemiology of bean rust in Ethiopia', to be defended on Tuesday 13 September, 1994.

Habtu Assefa

AUTHOR'S ABSTRACT

Habtu, A., 1994. Epidemiology of bean rust in Ethiopia.
PhD Thesis. Wageningen Agricultural University, Department of Phytopathology, The Netherlands, 172 pp., 23 tables, 26 figures, English and Dutch summary.

Field and greenhouse experiments were conducted to study the epidemiology of rust (*Uromyces appendiculatus*) on beans (*Phaseolus vulgaris* L.) in Ethiopia. The experiments were conducted under low input conditions reflecting the traditional bean production practices. Surveys identified five major diseases. Bean rust, bacterial blight and anthracnose were widely distributed. Angular and floury leaf spots were prominent in the humid west. Disease severities depended on regions, cropping practices and seasons. Strong associations between sowing date and rust severity and between bacterial blight and weediness or plant density were found. Artificial differences in rust epidemics produced large differences in crop growth, yield and yield loss. Multiple regression models were developed to estimate yield and yield loss. Yield and yield loss were best estimated by leaf area index and rust severity during flowering and late pod setting stages. Differences were found in the velocity of focus expansion (3 to 16 cm day^{-1}) when susceptible and resistant bean cultivars were mixed at different proportions. The velocity of focus expansion increased linearly with the logarithm of the fraction of susceptible in the mixture. Five components of partial resistance were evaluated in a bean rust pathosystem. Differences between cultivars were largest for infection efficiency and sporulation capacity. Correlations existed between latency period and infection efficiency, infection efficiency and pustule size, and sporulation capacity and pustule size. Latency period, infection efficiency and pustule size can be used in screening for partial resistance.

Key words. Common beans, partial resistance, disease survey, cultivar mixtures, cultural practices, infection efficiency, infectious period, latency period, leaf area index, multiple regression analysis, *Phaseolus vulgaris*, plant density, pustule size, sowing date, sporulation capacity, *Uromyces appendiculatus*, weediness, yield, yield loss.

---and because I was amazed they said to me: honoured guest, do not be amazed, because in the years that we harvest little we gather enough for three year's plenty in the country; and if it were not for the multitude of locusts and the hail, which sometimes do great damage, we should not sow the half of what we saw, because the yield is incredibly great; so it is sowing wheat, or barley, lentils, pulse, or any other seed. And we saw so much with the hope that even if each of those said plagues should come, some would be spoiled, and some would remain, and if all is spoiled the year before has been so plentiful that we have no scarcity----.

Father Francisco Alvares. The Prestor John of the Indies. A true relation of the lands of the Prestor John, being the narrative of the Portuguese Embassy to Ethiopia in 1520, Edited by C.F. Beckingham and G.W.B. Huntingford, vol.1: p. 189 (1961, as quoted by Westphal, 1975).

This work is dedicated to Zewditu Adankew

PREFACE

This study began in April, 1989, to investigate the epidemiology of bean rust in the Ethiopian bean production system. Thanks to Dr. S. Slager, then head of the International Education Office of the Wageningen Agricultural University (WAU), my first contact with Professor J.C. Zadoks was arranged. Dr. Slager kindly facilitated a sandwich scholarship from the WAU. Later, Mr. C.M.M. van Heijst took over. He was a very kind and exceptionally helpful man. I am very grateful to both.

Professor J.C. Zadoks is my teacher, my advisor and my promotor. I am deeply pleased of his patience, guidance and support. He patiently guided me to this end. His red pen - the source of knowledge, encouragement and excitement - is memorable !! I thank him very much. I also like to express my appreciation to David Allen, Serge Savary, Ivan Sache, Richard Daamen and Theo Jacobs for critically reviewing parts of this thesis and to Gerrit Gort for providing statistical assistance.

I am indebted to the management of Nazareth Research Centre for providing all the necessary facilities and to the plant pathology section staff at Nazareth and Awassa for the many hours they spent in field preparation and data collection. Special thanks go to Abiye Tilahun who had to work for many weeks and several seasons at Ambo under sub-optimal conditions. I want to extend my appreciation to the management of Plant Pathology Research Centre at Ambo for providing field facilities, for their enthusiastic support and for providing accommodation for Abiye. Tesfaye Beshir and Zerihun Kasaye are my friends at heart. They were very helpful and their hospitality helped me 'survive' in that cold and busy period at Ambo. Tesfaye and Abyie, you remember those days when we collected data for the focus experiment!! I believe you both have recovered.

I like to express my gratitude to Piet Kostense not only for his assistance in preparing several graphs which form part of this thesis but also for his hospitality, Guido Pennings for his assistance in computer handling, Ivan Sache for his stimulating discussions in the field of epidemiology, Ankie Lamberts for facilitating accommodation, insurance and residence permits, Jan Eelco Jansma, Diana Uitdenbogerd, Marie-José Arts, Ernst van den

Ende, Wout Hoogkamer, Henk Schouten, Corrie Geerds, Arie de Wit and his parents - Loes and Arie - for their friendship, hospitality and moral support. Loes! many thanks for your letters and cards of encouragement.

Most of all I am indebted to my mother, Zewditu Adankew, who did not live to see her wishes fulfilled. Her memory, aspiration, encouragement, farsightedness and her desire to see me finish soon lived on. The support I received from my family - Lishan, Esete, Mahder and Abeba - and my brothers Mulugeta and Teklu helped me to concentrate on my studies. Their frequent letters provided the much needed moral support when at times life seemed difficult and accomplishment seemed distant.

The research was financed by the Wageningen Agricultural University, the Institute of Agricultural Research and CIAT Eastern Africa Regional Office.

CONTENTS

Chapter 1

GENERAL INTRODUCTION

Table 1. National estimates of area and production of cereals, food legumes and oil seeds in the 1989/1990 crop season (CSA, 1992).

Group	Crop	Area	Production	Yield
		'000 ha	'000 qu[a]	kg ha^{-1}
Cereals	Maize	1278	20556	1608
	Tef	1227	10461	853
	Barley	912	10630	1166
	Sorghum	738	9728	1318
	Wheat	605	7988	1320
	Millet	155	1526	984
	Oats	42	487	1160
	Rice	8	136	1700
	Total	4965	61512	1239
Legumes	Faba bean	228	2795	1226
	Chick pea	121	1013	837
	Common bean	110	829	754
	Field pea	88	966	1098
	Lentils	39	299	767
	Soybean	7	21	300
	Total	593	5923	999
Oil seeds	Neug	132	424	321
	Linseed	70	340	486
	Fenugreek	10	64	640
	Rape seed	13	78	600
	Sunflower	8	51	638
	Groundnut	2	12	600
	Sesame	2	4	200
	Total	237	973	410

[a] qu = quintals (1 qu = 100 kg)

Bean rust: A part of the system

Food legumes form an essential component of the Ethiopian diet. They are an important source of protein for a country where meat is expensive and also during the numerous fasting days. Of the more than 15 species of food legumes known in Ethiopia (Ohlander, 1980), five are grown extensively. These prominent food legumes are faba bean (*Vicia faba* L.), field pea (*Pisum sativum* L.), chick pea (*Cicer arietinum* L.), lentils (*Lens culinaris* Med. (*Lens esculenta* Moench)) and common bean (*Phaseolus vulgaris* L.). They rank second (CSA, 1992) after cereals and they comprise about 10-12% of the total crop production in the country (Table 1).

Faba bean, field pea, chick peas and lentils are of great importance in the Ethiopian highlands where they form an important rotation crop in the barley-oilseeds-tef-wheat production system, whereas common bean is generally prominent in the sorghum-maize-tef complex. Common beans are also intercropped with enset (*Ensete ventricosum* Welw.), chat (*Catha edulis* Forsk.), coffee (*Coffea arabica* L.) and vegetables in some parts of the country.

It is not clear when common beans were first introduced in to Ethiopia. Early reports suggest the presence of common beans (kidney beans) in the northern part of the country as early as 1520 (Alvares, 1540; Crawford, 1958; both quoted by Westphal, 1975). Current production of beans is much wider than these early observations, extending to different parts of the country (Imru, 1985; Ohlander, 1980; Westphal, 1974). Production estimates of beans are extremely variable. The Central Statistical Authority (CSA, 1992) figures gave an estimate of about 100,000 ha under common bean. Other estimates (IAR, 1991) suggest production to be at least twice this figure.

In Ethiopia, Common beans are grown from 1200-2000 meters above sea level (m) under diverse climatic conditions. They are extensively grown in at least four climatic regions (Table 2). These include the central Rift Valley and the Harerghe lowlands representing the semi-arid areas, Harerghe highlands, southern Ethiopia representing the mid altitude, cooler areas and western Ethiopia representing the sub-humid climates (Fig 1).

In the central Rift Valley the altitude ranges between 1500 and 1700 m, temperatures are high and rainfall is erratic. The main rainy season lasts for a

Table 2. Agro-ecological zonation of major common bean producing areas

Zone	Region	Altitude	Rainfall	Season	Cropping system	Other major crops	Use	Bean cultivar
Central Rift-Valley	East Shoa South Shoa	1500-1700	450-950	bimodal single season	monocrop	maize tef	cash	Mexican 142
Eastern	Hareghe highland	1700-2200	950-1500	unimodal single	Intercrop	maize sorghum chat	food cash	Varietal mixtures
Southern	Sidamo Gamo-Gofa	1500-1900	950-1500	bimodal	monocrop intercrop	maize coffee sweet potato enset tef	food	Red Wolaita
Western	Keffa Wollega Illubabur Gojjam	1500-1700	950-1500	unimodal	monocrop intercrop	maize sorghum coffee	food	Mexican 142 Varietal mixtures

period no longer than 3 months. There could be occasional rains between the months of February and April but these are not enough for crop production. Common beans are grown as a monocrop and production is based on single season cropping. Common beans are important cash earners to farmers in the central Rift Valley. Farmers here do not apply fertilizers and they do not weed their bean crop. There is a large variation in sowing date mainly depending on the arrival of the rain. In the eastern highlands common bean is the major food legume in the sorghum-maize-chat complex, mostly grown as intercrop. It is used both for food and cash. Here, cultivars are mixed in different sizes, shapes and colours. In the south (Sidamo), beans are grown either as a monocrop (Wolaita area) or as intercrop (Sidama area). In Sidama area they are grown in a crop mixture of several species including coffee, enset, vegetables of different kinds, and sometimes maize. In these areas (the south, Wolaita and Sidama) two harvests per year are possible. In the west, beans are either grown as monocrop or intercrop, and they are mostly used for food purposes. Beans are intercropped with maize, sorghum and coffee. Here, both bush and climbing types are found. Climbing beans are grown around the houses on fences as supports. In the west beans are grown once a year.

Common beans are accepted for a wide variety of preparations roasted or boiled and mixed with maize; boiled and spiced, eaten with 'kocho' prepared from 'enset'; as vegetable sauce or soup in urban areas (Senayit, personal communication). Common bean is also used for forage, fuel (cooking) and soil improvement (in rotation with cereals). Common beans have the advantage of early maturity and low moisture requirement making them a dependable alternate crop when staples such as maize fail during periods of early drought. This is especially true in the central Rift Valley where early drought occurs often.

Dry bean production under farmers' conditions is in the range of 600-700 kg ha^{-1}. Under good management conditions, beans can produce up to 2500-3000 kg ha^{-1} in Ethiopia (Amare, 1987). The wide gap in yield (Fig 2) is due to a wide range of production constraints (De Wit, 1982), among which are diseases (Ohlander, 1980; Habtu, 1987), pests (Ferede and Tsedeke, 1986; Tsedeke, 1991), weeds (Etagegnehu, 1987), improper cultural practices and poor soil fertility (Ohlander, 1980; Kidane and Kirkby, 1988), moisture stress (Kidane, 1987) and lack of pure seed (Ayele, 1991).

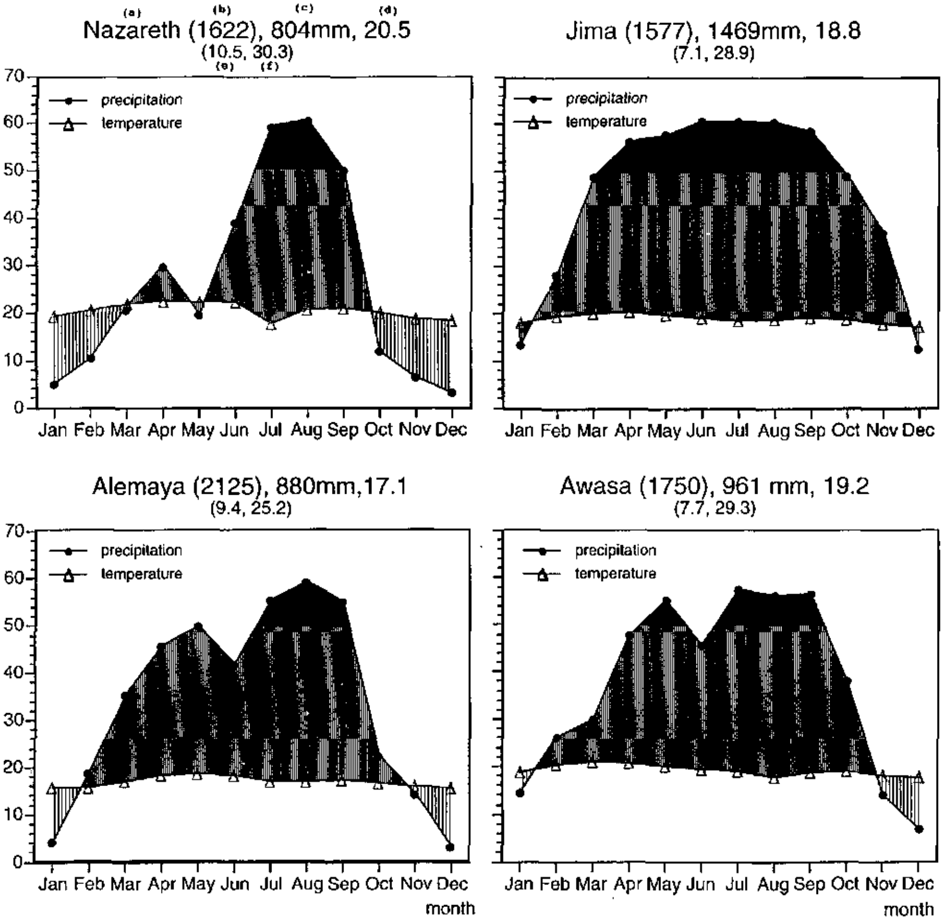

Fig 1. Climatic graphs (using Gaussen's classification) of Nazareth, Alemaya, Awassa and Jima representing four bean growing areas. The monthly mean of temperatures and of precipitation are drawn as curves. They have a fixed proportion: ten degrees centigrade corresponding to a precipitation of twenty mm. Precipitation above 100 mm is presented in scale of 1:10 and marked in black. a = location, b = altitude, masl, c = total annual rainfall, d = mean annual average temperature, e = mean annual minimum average temperature, f = mean annual maximum average temperature.

Due to differences in climatic conditions and cropping systems, production constraints vary from region to region. These constraints can be resolved by an understanding of the bean production practice in a system approach. In the Ethiopian bean production system, diseases play a significant role of which bean rust form an important part. Information on the relative importance, distribution, damage potential, and management of bean rust was urgently needed. Strategies for management needed to be devised in an integrated bean management scheme. To do this, knowledge of the epidemiology of bean rust is important. Thus, the present study was initiated to address part of these wider issues.

This thesis

This thesis is divided in to eight chapters. The geographic distribution, relative importance and relationships of bean rust and other major diseases with cropping practices and growing seasons is examined in chapter 2. The study focused in three important bean growing areas. In the second series of chapters the epidemiology of bean rust is studied. First, we try to uncover the crop-loss aspect of bean rust. We start by giving a quantitative analysis of the effects of spray schedules on rust intensities, crop growth and yield components in a cross-sectional (Chapter 3) and longitudinal (Chapter 4) analysis. Temporal progress of crop growth and disease epidemics were analyzed over time and differences at varying rust intensities were investigated (Chapter 5). The relationships between rust, crop growth and yield were studied in a multiple regression analysis. Then, regression models are developed for yield and yield loss for two cultivars in two climates. Chapters 6 and 7 deal with the rust control aspect. Chapter 6 shows the effect of cultivar mixtures on rust development. Bean rust has many physiologic races (Ballentyne, 1978; Mmbaga and Stavely, 1988; Stavely, 1984) which makes control of the disease by means of specific resistance genes difficult. Chapter 7 goes into *partial resistance* (Parlevliet, 1979), which hopefully is race non-specific. Several components of partial resistance can be used to compare cultivars. Chapter 8 provides discussion to tie results together and to suggest future research topics.

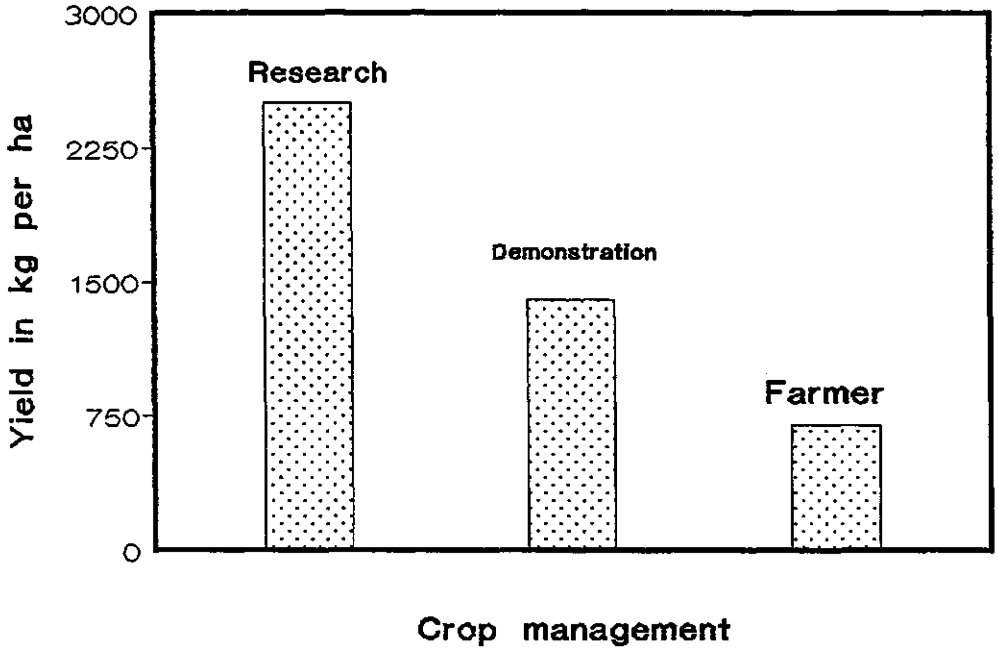

Fig 2. Comparison of seed yield of dry beans under three production situations. Research = Good management conditions, research centre; Demonstration = Recommended practice, farmer-researcher managed, farmers' fields; Farmer = National yield estimate from traditional farming practice. From IAR, 1991.

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Chapter 2

A SURVEY OF CROPPING PRACTICES AND FOLIAR DISEASES OF COMMON BEANS IN ETHIOPIA

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Abstract

Field surveys were conducted in three major bean growing areas of Ethiopia. Data collected include cropping systems and disease severities. We used correspondence analysis to characterize differences in disease severity between regions and seasons, and to determine associations between areas and cropping systems, areas and diseases, and cropping systems and diseases. The analyses suggested a high probability of high plant density, high weediness, high bacterial blight and high anthracnose being associated with area 1 (Rift Valley). In area 2 (Sidamo) there was a high probability of high rust intensity, low plant density and low weediness. Area 3 (Keffa) is characterized by a high probability of angular and floury leaf spots. In area 1 (Rift Valley) low rust intensity was closely associated with year 1 (1990) and high rust intensity with year 4 (1993). Anthracnose and bacterial blight showed no clear association with years. Some linkages between cropping systems and disease severities were indicated. In areas 1 and 2, there was a high probability of low rust at early sowing and a high probability of bacterial blight at high weediness and high plant density situations. The probability of observing high rust severity at high weediness was low. This study suggests that specific needs of areas, with their own production situations, must be considered in the process of developing strategies for the improvement of production and crop protection in beans.

Additional key words. Correspondence analyses, rust, anthracnose, bacterial blight, angular leaf spot, floury leaf spot, sowing date, plant density, weediness.

Introduction

In Ethiopia, common beans (*Phaseolus vulgaris* L.) are grown in rotation with cereals (Imru, 1985). They are grown for the export market and as a food legume in parts of the country (IAR, 1991). Common beans are grown from sea level to about 2800 m (Schwartz and Galvez, 1980). Under Ethiopian conditions they are well adapted to altitude ranges between 1200 m and 2000 m, and to rain-fed conditions (Ohlander, 1980). Common beans are grown in most parts of Ethiopia, but production is concentrated mainly in the east (Harerghe highlands), the south and the south west (Sidamo), the west (Keffa and Wollega) and in the Rift Valley. This wide geographical range is associated with a wide range of cultivars and diseases (Bos, 1974; Habtu, 1987; O'Bannon, 1975; Westphal, 1974).

Area under common bean production around 1990 was about 100,000 ha (CSA, 1992a,b). Farm surveys conducted in the major bean production regions suggested an area at least twice the official figures (IAR, 1991). Estimates of the national average bean yields were low, ca. 600 - 700 kg ha^{-1}. Diseases are a major factor in reducing bean yields. Of the more than 80 fungal, bacterial, viral, and nematode diseases reported in beans worldwide (Schwartz and Galvez, 1980; Allen, 1983), few were recorded in Ethiopia (Stewart and Dagnatchew, 1967). These older records gave little attention to geographic distribution and economic significance. Recently (Habtu, 1987), an attempt was made to determine the occurrence and importance of diseases of beans at various research and/or experiment stations. Disease epidemiology under farmers conditions is nearly unknown.

Survey data can help to describe the geographic distribution of diseases, their relative importance and their epidemiology (James, 1969; King, 1972; Savary, 1987; Zadoks, 1961, 1966). Hence, a survey of bean diseases was initiated to investigate the intensity of bean diseases, their relative importance, and their association with bean production practices (sowing date, growth condition, plant density, weediness, etc.) in Ethiopia.

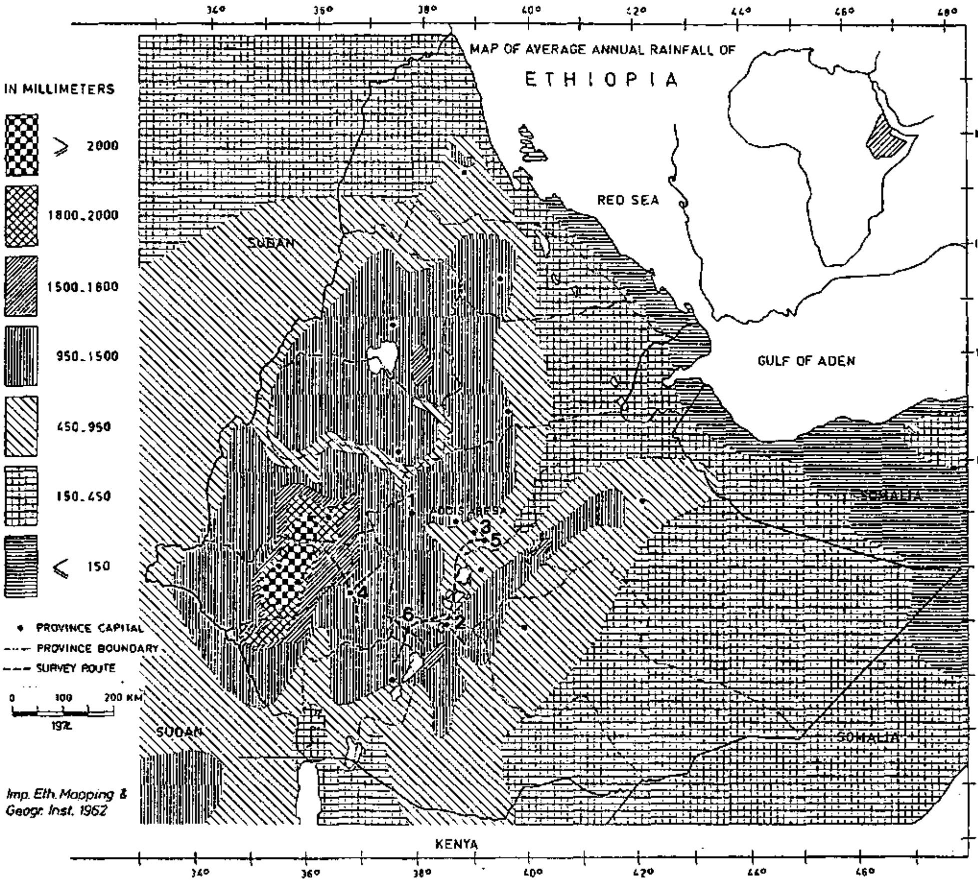

Fig 1. Map of Ethiopia showing average annual rainfall, representative locations and bean survey route. From Westphal, 1974.

Materials and methods

Sample regions. The surveys were conducted in three of the four major bean-growing areas of Ethiopia, the central Rift-Valley (East and South Shoa), south and south-west (Sidamo), and west (Keffa). Areas visited and the survey route is shown in Fig 1. Area 1, the central Rift-Valley (AR1), represents the hot, dry and erratic rainfall climate where beans are normally grown once in a year. Area 2, the south and south west (AR2), represents a major bean growing area where beans are planted at least twice a year either as intercrop or monocrop. Area 3, the west (AR3), is characterized by production of beans mainly as intercrops with maize or sorghum. Here beans are normally grown once in a year.

In area 1 the survey was conducted for 4 consecutive years (1990-1993) and information was gathered from 127 fields. In area 2, the survey was conducted in 1990 and 1993 and data was collected from 80 fields. In area 3 data was collected in 1990, 1992 and 1993 from 53 fields. In total, 262 fields were visited.

Sample fields. Fields were selected at random at intervals of 5 to 10 km along the main roads. When found necessary, the sample size (the number of observed fields per region) and the number of sample units (the randomly selected single plants) per field were adjusted to suit the field size and crop distribution as it became known. All sample fields belonged to small, private farmers. Each field was visited once only.

Sample units. Of each sample field, a general impression of the field was gained as to size, shape, and crop condition. Sample units were selected by making a specified number of equally spaced paces following an inverted "V" pattern. Having made the pre-set number of paces (according to the size of the field), the nearest plant to the right foot was taken as the sample unit. Per sample field, 10 sample units (plants) were taken for disease assessment. A sub-sample of 3 trifoliolate leaves per plant was selected, yielding a total of 30 leaves per field. The sub-sample was composed of one leaf from each of the upper, middle and bottom canopy layers of the main stem. Means of canopy layers were deter-

Table 1. Categorization of variables used in correspondence analyses

Variable	Acronym	Classes (boundaries)	Number of fields[3]		
			I	II	III
Area	AR	AR1 (central)	129	129	85
		AR2 (south)	80	80	80
		AR3 (west)	53	37	37
			262	246	202
Plant density	PD	PD1 (1-20)[1]			86
		PD2 (21-40)			38
		PD3 (41 and above)			78
					202
Sowing date	SD	SD1 (early)		48	
		SD2 (optimum)		130	
		SD3 (late)		68	
				246	
Weediness	WD	WD1 (light)		103	101
		WD2 (moderate)		105	78
		WD3 (high)		38	23
				246	202
Angular leaf spot	AL	AL0 (absent)	196		
		AL1 (present)	66		
			262		
Bacterial blight	BB	BB1 (0-2)[2]	124	112	106
		BB2 (2-5)	50	46	37
		BB3 (5 and above)	88	88	59
			262	246	202
Bean anthracnose	BA	BA1 (0-2)	140	129	105
		BA2 (2-5)	66	61	53
		BA3 (5 and above)	56	56	44
			262	246	202
Bean rust	BR	BR1 (0-2)	106	95	71
		BR2 (2-5)	97	92	80
		BR3 (5 and above)	59	59	51
			262	246	202
Floury leaf spot	FL	FL0 (absent)	214		
		FL1 (present)	48		
			262		

mined per plant and then averaged per field for data analysis.

Crop and disease assessment. Each field was represented by a set of variables (Table 1) on field characteristics, crop development and severity of the following diseases, angular leaf spot (*Phaeoisariopsis griseola* (Sacc.) Ferraris), bean anthracnose (*Colletotrichum lindemuthianum* (Sacc. and Magn.) Bri. and Cav.), bean rust (*Uromyces appendiculatus* (Pers.) Ung. (*U. phaseoli* (Pers.) Wint.), common bacterial blight (*Xanthomonas campestris* pv. *phaseoli* (Erw. Smith) Dowson) and floury leaf spot (*Mycovellosiella phaseoli* (Drummond) Deighton). Disease severity is the affected leaf area, including the lesion and associated chlorosis (i.e. the non-green area) in percent of total leaf area. Most data were collected around the pod filling stage (Fernandez et al., 1986) when diseases were conspicuous at all canopy layers.

Data categorization. Categorization (here the allocation of severities, recorded on a continuous scale from 0 to 100, to a few distinct class) is the transformation of quantitative data into coded, qualitative data. Class boundaries were chosen so that classes contained approximately equal totals (Table 1), 0 to 2 %, 2 - 5 %, and > 5 % severity. Thus, bean rust severities were coded as BR1, BR2, BR3. Three sowing dates (SD1 - SD3), three weed intensities (WD1 - WD3), three plant densities (PD1 -PD3), three areas (AR1 - AR3) and four years (Y1 - Y4) were considered.

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[1] PD = number of plants m^{-2}; SD2 = optimum sowing date as perceived by farmers, usually late June to early July for central, mid to late July for south and west, anything before is considered early and after late; WD1 = weeded at least once and absence of visible weeds, WD2 = weeds present but not in a strong competition with beans, WD3 = bean field not weeded at all and weed infestation greater than 10 m^{-2}.

[2] Disease intensity in percent severity (proportion of leaf area infected).

[3] Three analyses were performed due to inbalance of sample fields; I = all sample fields were included in the analysis, II = data missing for sowing date and weediness in area 3 (AR3), III = data missing for plant density in area 1 (AR1).

Table 2. Contingency tables for the analysis of data from four years (1990-1993) from three bean growing areas (central, south and west Ethiopia)

Area by disease

	BR1	BR2	BR3[1]	BA1	BA2	BA3	BB1	BB2	BB3	AL0	AL1	FL0	FL1
AR1	55	42	32	59	27	43	11	35	83	129	0	129	0
AR2	13	42	25	53	15	12	70	8	2	61	19	80	0
AR3	38	13	2	28	24	1	42	7	3	6	47	5	48

Year by disease [2]

	BR1	BR2	BR3	BA1	BA2	BA3	BB1	BB2	BB3
Y1	24	13	7	23	9	12	6	9	29
Y2	14	9	7	10	6	14	2	6	22
Y3	12	9	4	9	6	10	1	8	16
Y4	5	11	14	17	6	7	2	12	16

Cropping system by disease

	BR1	BR2	BR3	BA1	BA2	BA3	BB1	BB2	BB3
SD1	28	13	7	23	22	14	23	7	29
SD2	40	51	39	61	29	31	59	23	39
SD3	27	28	13	45	10	11	30	16	20

	BR1	BR2	BR3	BA1	BA2	BA3	BB1	BB2	BB3
WD1	36	42	25	66	30	19	81	19	15
WD2	37	38	30	47	24	23	25	19	50
WD3	22	12	4	16	7	14	6	8	23

	BR1	BR2	BR3	BA1	BA2	BA3	BB1	BB2	BB3
PD1	31	32	23	39	18	6	60	3	0
PD2	10	20	8	33	17	8	37	12	9
PD3	30	28	20	33	18	30	9	22	50

Area by cropping system

	PD1	PD2	PD3	WD1	WD2	WD3
AR1	0	8	77	22	46	17
AR2	52	28	0	57	19	4
AR3	34	2	1	22	13	2

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[1] For description of variables refer Table 1.

[2] Data from area 1 only

Contingency tables. All variables were encoded to build contingency tables (Tables 2), to represent the bivariate distribution of fields according to two classifications (say, sowing date and bean rust). An entry in a cell of a contingency table representes a frequency (ie., the number of fields falling into that cell). The independence of the frequency distributions of two variables was tested by chi-square (χ^2) tests. Several contingency tables can be combined into a single matrix, e.g. with disease severities as columns and other variables as rows.

Correspondence analysis. Because of the non-normal distribution of most variables and their low precision, a non-parametric method to analyse categorized information was used (Hill, 1974; Nutter et al., 1991; Savary et al.,1992, 1993). Correspondence analysis is a multivariate method that allows the pictorial representation of contingency tables in order to identify associations between two groups of variables. These two groups are the columns and the rows of Table 2. Disease severities in columns are variables to be explained while variables in the rows are explanatory variables.

A correspondence analysis was conducted for each bean growing area and across all three areas to characterize associations between cropping systems and disease severities. The method generated graphs where axes were used to plot categorized variables and examine their relationships. The resulting graphs use a χ^2 distance to represent relationships among categorized variables (Benzécri, 1973; Greenacre, 1984; Savary et al., 1993). The interpretation of the graphs is based on the proportion of variation accounted for by the axes, the classes that contribute most to each of them, the proximity of points representing classes, and the paths representing a succession of classes. Similarities in pattern or direction of paths indicate correspondences that can be tested further using the appropriate χ^2 tests (Savary et al., 1993). Analysis of data were performed using the NDMS computer program (Savary et al., 1988).

Results

A summary of the disease survey data over a 4-year period (Table 3) indicates

Table 3. Geographical distribution and severity of bean diseases in Ethiopia (1990-1993). Entry values in percent of leaf area infected.

Area	Year	BR[1]	BA	BB	AL	FL	DT
Central	1990	2.28	3.39	6.07	0.00	0.00	0.86
	1991	2.96	6.60	8.01	0.00	0.00	3.14
	1992	2.23	4.27	6.43	0.00	0.00	3.53
	1993	5.09	3.94	5.42	0.00	0.00	2.05
	Mean	3.14	4.30	6.48	0.00	0.00	2.39
South	1990	5.79	0.93	0.82	1.26	0.00	1.48
	1993	3.12	2.18	1.03	0.07	0.00	2.25
	Mean	4.45	1.55	0.92	0.66	0.00	1.86
West	1990	1.30	2.15	0.14	2.46	1.45	-
	1992	1.99	2.37	3.32	4.63	3.17	0.49
	1993	2.95	3.68	3.14	10.26	8.20	0.00
	Mean	2.08	2.73	2.20	5.78	4.27	0.24

[1] BR = bean rust; BA = anthracnose; BB = common bacterial blight; AL = angular leaf spot; FL = floury leaf spot; DT = Dead tissue

variation in disease severity with years and areas. Bean rust (BR), anthracnose (BA) and bacterial blight (BB) were more widely spread than angular leaf spot (AL) or floury leaf spot (FL) which were not found in some regions. In farmers' fields, disease severity was generally low and the overall mean did not exceed 7 %.

Analysis of the data using correspondence analysis suggests associations of years, areas and cropping practices with bean diseases. The axes generated by correspondence analysis accounted for > 90 % of the total inertia. These axes were used to draw graphs and interpret results.

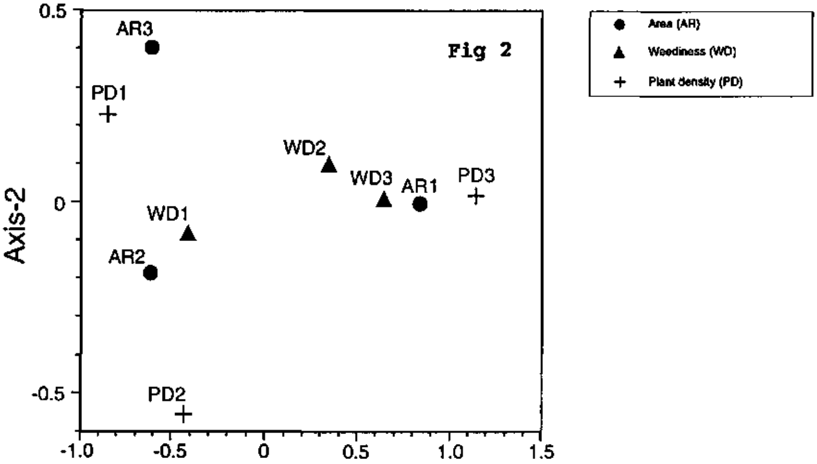
Area and cultural practices. Fig. 2 is produced with area, plant density and weediness as active variables. Most inertia is explained by Axis 1, roughly representing increases in plant density and weediness. The picture shows clear associations between area 1 (Rift Valley), high plant density and medium to high weediness. Area 2 (Sidamo) is associated with low weediness and low to medium medium plant densities, area 3 (Keffa) with low plant densities.

These associations are confirmed by χ^2 tests on two dimensional contingency tables. High plant density has a high probability in area 1, medium plant density in area 2, and low plant density in area 2 and 3, ($N = 202$, $\chi^2 = 188$, df = 4, $p << 0.001$). Low weediness has a low probability in area 1 (Rift Valley) and a high probability in area 2 (Sidamo). Area 1 has a high probability of medium and high weediness ($N = 246$, $\chi^2 = 37$, df = 4, $p << 0.001$). Plant density and weediness were also strongly associated ($N = 202$, $\chi^2 = 34$, df = 4, $p << 0.001$).

Year effects. The multivariate analysis of year effects on the major diseases, rust, anthracnose and bacterial blight is shown in Fig. 3, in which all variables mentioned are active. The two axes represent 94 % of total inertia. The horizontal axis is largely determined by rust and bacterial blight. The paths of rust and anthracnose cross at nearly right angles, indicating independence. The path from medium to high bacterial blight runs opposite to that of rust. Year 4 (1993) is associated with high and year 1 (1990) with low bean rust ($N = 129$, $\chi^2 = 15$,, df = 6, $p = 0.02$). Years 2 and 3 (1991,1992) were about average. No significant associations were found between years and anthracnose, though Fig 3 seems to suggest an association between years 2 and 3 and high anthracnose.

Cultural practices and diseases. In Fig. 4, the first axis ($\lambda = 0.095$) largely represents the trajectories of bacterial blight, weediness and anthracnose. The second axis ($\lambda = 0.013$) largely represents the lower parts of the plant density trajectory and the upper part of the rust trajectory, which run in opposite directions. The third axis ($\lambda = 0.01$) is largely dominated by the sowing date trajectory, paralled by the lower parts of the rust and anthracnose trajectories, the latter running in opposite directions.

In Fig 4A, the rust and plant density trajectories run nearly parallel. Early



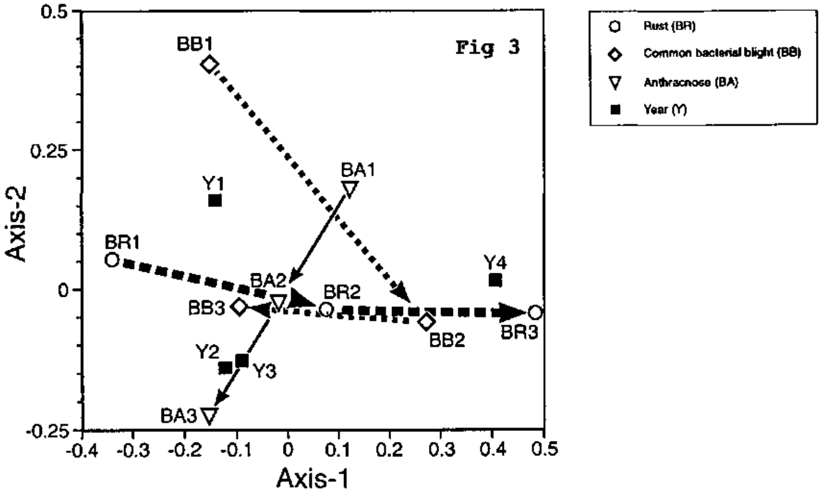


Fig 2. Ordination of six variables by correspondence analysis. The variables, all active, are area (AR1..AR3), plant density (PD1..PD3), and weediness (WD1..WD3), N = 202. The graph is largely dominated by Axis 1 (horizontal, $\lambda = 0.92$). Axis 2 (vertical, $\lambda = 0.08$) nicely separates areas but has little explanatory value.

Fig 3. Ordination of four variables by correspondence analysis. The active variables are years (Y1..Y4), and three major bean diseases , rust (BR1..BR3), anthracnose (BA1..BA3) and bacterial blight (BB1..BB3). λ_1 (horizontal) = 0.05, λ_2 (vertical) = 0.02. Total number of fields, N = 129.

sowing is associated with high values of weediness, bacterial blight and anthracnose. Low plant density (PD1) may be associated with high severities of rust. In Fig 4B, early sowing is associated with low rust intensities and intermediate sowing dates with intermediate to high rust values and low weediness. A low plant density is strongly associated with low weediness and low bacterial blight. High weediness and high plant densities are associated with high severities of bacterial blight and anthracnose.

Sowing date has a clear effect on diseases. Early sowing was associated with low bean rust whereas normal sowing date was associated with high rust intensities (Fig 4B). Normal and late sowing were associated with intermediate and fewer high bean rust intensities ($N = 246$, $\chi^2 = 13$, $df = 4$, $p = 0.011$). Early sowing was associated to some degree with intermediate anthracnose levels. Late sowing showed the inverse pattern. Normal sowing was rather neutral with some excess of high anthracnose levels ($N = 246$, $\chi^2 = 13$, $df = 4$, $p = 0.11$). Bacterial blight showed no significant associations with sowing date.

High weediness induced a higher probability of low bean rust levels whereas low and medium weediness were associated with medium and high rust levels, respectively ($N = 246$, $\chi^2 = 9$, $df = 4$, $p = 0.07$). Low weediness was highly associated with low bacterial blight, wheras medium and high weediness were strongly associated with high bacterial blight ($N = 246$, $\chi^2 = 62$, $df = 4$, $p << 0.001$). Intermediate bacterial blight was neutral as to weediness. The association between weediness and anthracnose was not significant.

High plant densities were associated with high levels of anthracnose, low plant density with low levels anthracnose ($N = 202$, $\chi^2 = 19$, $df = 4$, $p << 0.001$). Similarly, high plant density were strongly associated with high bacterial blight ($N = 202$, $\chi^2 = 111$, $df = 4$, $p << 0.001$). No significant association was found between plant density and bean rust intensities, despite strong graphical association of high levels of rust with low plant densities.

Areas and diseases. The two axis generated by the analysis accounted for nearly 100 % of total inertia. Area 1 (Rift Valley) was closely associated with high and intermediate level of bacterial blight and high level of anthracnose (Fig. 5). Area 2 (Sidamo) was closely associated with low level of anthracnose and

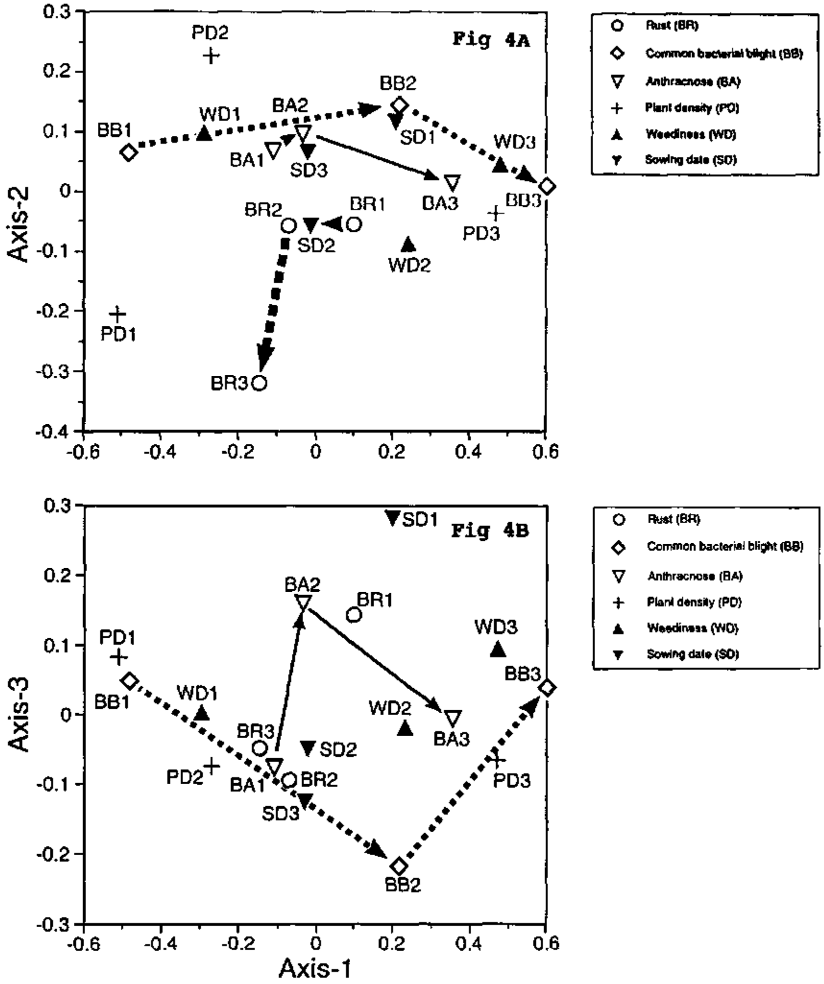


Fig 4. Ordination of six variables by correspondence analysis. The three major diseases (rust, anthracnose and bacterial blight are related to three variables representing cultural practices (sowing date, weediness, plant density). All six variables are active. Total number of fields, N = 202.

bacterial blight and intermediate to high level of rust. Area 3 (Keffa) was associated with a high presence of angular and floury leaf spot, low level of rust and intermediate level of anthracnose.

Whereas the three bean rust intensities are rather evenly distributed over area 1 (Rift Valley), low bean rust intensity has a very high probability in area 3 (Keffa) and a very low one in area 2 (Sidamo). Medium to high bean rust intensity have a high probability in area 2 (Sidamo) and a low one in area 3 (Keffa). The linkages are highly significant ($N = 262$, $\chi^2 = 44$, $df = 4$, $p << 0.001$).

High levels of anthracnose are overrepresented in area 1 (Rift Valley), low anthracnose intensities in area 2 (Sidamo), and intermediate intensities in area 3 (Keffa). The association was significant ($N = 262$, $\chi^2 = 34$, $df = 4$, $p << 0.001$).

Low levels of bacterial blight are strongly underrepresented in area 1 wheras medium and high values are underrepresented in areas 2 and 3. High intensities of bacterial blight are strongly overrepresented in area 1 and underrepresented in area 2 ($N = 262$, $\chi^2 = 161$, $df = 4$, $p << 0.001$).

Angular leaf spot shows a very high probability of low values in area 1 (Rift Valley) and of high vales in area 3 (Keffa), whereas area 2 (Sidamo) is about average ($N = 262$, $\chi^2 = 157$, $df = 2$, $p << 0.001$).

High levels of floury leaf spot are strongly overrepresented in area 3 (Keffa) and underepresented in area 2 (Sidamo) and especially in area 1 (Rift Valley) ($N = 262$, $\chi^2 = 232$, $df = 2$, $p = << 0.001$).

Discussion

Information on the geographical distribution of plant diseases is useful to understand disease spread into new areas and to set priorities for disease management. The understanding can be increased (Weltzien, 1972) by distinguishing degrees of intensity of the diseases within the area of its occurrence, distinguishing areas of main damage and marginal occurrence, and explaining the associations between cropping systems and disease intensities. Habtu (1987) considered the presence or absence of diseases within a given area of Ethiopia, emphasizing the situation in experiment stations. The present study revealed the wide distribution of some bean diseases, the limited occurrence of others and the association of disease intensities with cropping systems.

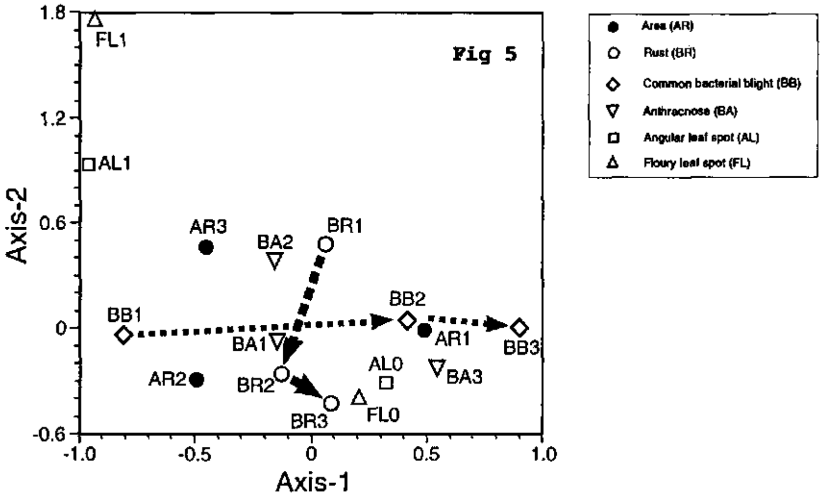


Fig 5. Ordination of six variables by correspondence analysis. The three areas (Rift Valley, Sidamo and Keffa) are related to five bean diseases (rust, anthracnose, bacterial blight, angular leaf spot and floury leaf spot). Areas, rust, anthracnose and bacterial blight were the active variables whereas angular and floury leaf spot were additional variables. Total number of fields, N = 262.

Cropping practices. Bean disease prevalence and severities vary with cropping practices. A general trend developed in correspondences between cropping practices and disease severities. In areas 1 and 2 low rust was associated to early sowing and high weediness. High levels of rust were associated with intermediate sowing date. The low presence of rust at early sowing dates may be due to several factors. First, early sowing dates might have lead to escape of crop from late rust inoculum, and second early in the cropping season temperatures near the canopy may be still high and rainfall low resulting in longer period of low leaf wetness for rust infection to take place. An increase in leaf wetness duration is an important factor for rust infection (Harter et al., 1935; Imhoff et al., 1981).

High severities of anthracnose and bacterial blight were associated to intermediate sowing dates. Early sowing and moderate weed density favoured anthracnose and bacterial blight, depicted by similarities of paths. In area 2, anthracnose and bacterial blight were nearly negligible during the survey period. Here the bean production practice is characterized by light weeding, low plant density, good crop rotation and possibly by the use of healthy seeds. The difference in weeding and plant density between areas 1 and 2 (Fig 2) was obvious.

Area and Year. The roles of environment and of human action in the development of plant diseases are depicted by the disease tetrahedron (Zadoks and Schein, 1979). The prevalence and severity of bean diseases in Ethiopia varied considerably with the environment, both by area and year. Within an area, disease intensities interacted with cropping practices. Beans produced under cool conditions at intermediate to high altitudes are often affected by rust, anthracnose and angular leaf spot, under hot and dry conditions by bean common mosaic virus, common bacterial blight and root rots, and under hot and moist climates by web blight (Allen, 1983).

The central Rift Valley, area 1, is characterized by high temperature and high variation in rainfall amount and intensity. Under such conditions the common bean diseases are bean common mosaic virus and common bacterial blight. In our study common bacterial blight was dominant, but rust and anthracnose were also observed. In area 1, angular and floury leaf spots were practically absent. The south, area 2, is cooler than central Rift Valley, and has dependable rains. Here, rust was prominent and, surprisingly, anthracnose was insignificant. In the south beans were carefully weeded, plant densities were rather low, perhaps adversely influencing the micro-environment required for the development of anthracnose. In the west, area 3, the situation is rather clear. Many diseases are present but the dominant ones are angular and floury leaf spots. The west is characterized by a humid climate, high temperature and high rainfall.

Though such is the general trend, disease intensity was affected by seasonal variation, primarily rainfall and temperature (Zadoks and Schein, 1979; Savary et al., 1987). In area 1, when temperatures are high and moisture is limiting common bacterial blight became dominant (Table 4, year 3). When there is a dependable rainfall resulting in a cooler temperature (year 2) anthracnose became the principal disease. Anthracnose became even more important when farmers used infected seed from their last harvest. A high anthracnose season, as in 1991, results in crop damage. In area 2 and 3 the

Table 4. Weather data from some representative locations

Weather variables	Location	Years 1990	1991[3]	1992	1993
Rainfall[1]	Nazareth	451.8	548.3	555.0	584.6
	Awassa	370.2	509.6	419.1	455.7
	Jima	1208.9	752.3	1156.1	1119.6
Min Temp.[2]	Nazareth	15.9	15.1	14.8	15.4
	Awassa	13.3	13.4	13.8	13.6
	Jima	12.4	12.9	12.4	12.6
Max temp.	Nazareth	27.7	27.9	30.7	27.0
	Awassa	26.3	25.9	25.8	25.2
	Jima	24.7	25.4	24.7	24.6

[1] Rainfall data total of five months (May-September).

[2] Temperature data averaged over five months.

[3] In 1991 data were available for only four months.

association of disease intensities with seasons is not very clear possibly due to the low variation of rainfall and temperatures between seasons in these two areas. It is difficult to find rainfall and temperature data to accurately describe these areas. Table 4 provides a general picture where data is provided for Nazareth (area 1), Awassa (area 2) and Jima (area 3).

Obviously, not all bean diseases occur everywhere, at the same intensity. Their prevalence and severity depends on area and season. Generally speaking, rust, common bacterial blight and anthracnose had wider distribution in Ethiopia than angular and floury leaf spot. Worldwide (Schwartz and Galvez, 1980) rust, anthracnose and angular leaf spot are reported to have wide distributions. Our results suggest priorities for strategies of control of angular and floury leaf spot in the west and rust in the south. In the central Rift Valley where rust, common bacterial blight and anthracnose occur simultaneously, at different degrees, any control strategy designed to reduce the impacts of diseases must concurrently deal with these three diseases.

Research implications. The variation among environments, crops and cropping regimens brings about concomitant variation in diseases and their intensities (Boudreau and Mundt, 1992; Zadoks and Schein, 1979). Management of diseases requires an understanding of these interrelated and interacting factors leading to epidemics.

The present study provided some clues to the understanding of the geographical distribution of bean diseases, the association of disease intensities with areas, seasonal variations of disease intensities and the interactions between cropping systems and disease intensities. Understanding the system will help to eventually achieve an economically sound and efficient crop and bean diseases management strategy. The Ethiopian national bean improvement program is trying to better focus its breeding activities by regionalization, recognising four major bean growing areas with different ecologies (differences in altitude, rainfall, temperature, soil, production system, production constraints and objectives). The present findings confirm that the approach is well justified. To address the specific needs of the different regions the program should, perhaps, integrate breeding and crop protection activities, in order to develop an overall strategy for the management of common beans.

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Chapter 3

YIELD LOSS STUDIES IN THE BEAN RUST PATHOSYSTEM OF ETHIOPIA: ANALYSIS OF CROP GROWTH, DISEASE AND YIELD COMPONENTS

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Abstract

Crop growth and disease epidemics in sprayed and non-sprayed bean plots, artificially infected three weeks after emergence with rust (Uromyces appendiculatus), were assessed weekly at the beginning of vegetative stage in two cultivars, at two locations for two seasons. Disease intensity was regulated by the application of a fungicide at 5 spray frequencies. Fungicide application influenced leaf area (LAI) and reduced rust intensity. The fungicide had no significant effect on other diseases and dead leaf area. Fungicide application increased seed yield (SY) by increased numbers of pods per plant (PP). Rust severity was strongly correlated with pustule density but the overall relationships among rust assessment parameters depended on cultivar and location. Seed yield and pods per plant were highly correlated with LAI. The relationships between LAI and seeds per pod or seed weight depended on cultivar and location. Overall rust assessment parameters (rust severity and pustule density) showed close, negative relationships with seed yield, seed weight and pods per plant but not with seeds per pod. The relationships obtained in the partially resistant line 6-R-395 were less definite than those in the susceptible line Mexican 142. The yield parameters seed yield and pods per plant showed strong positive relationships.

Additional key words: epidemiology, leaf area index, *Phaseolus vulgaris*, *Uromyces appendiculatus*.

Introduction

Rust caused by *Uromyces appendiculatus* Pers. (Unger) (syn. *U. phaseoli* (Reben) Wint.) is a wide-spread and important disease of beans (*Phaseolus vulgaris* L.) in eastern and southern Africa. In Ethiopia, severe outbreaks of bean rust were reported from the south and south-western parts and the mid altitude and cooler regions (IAR, 1974). A severe outbreak of bean rust resulted in nearly 100% yield loss in the popular and widely grown, but susceptible cultivar, Mexican 142. Howland and McCartney (1966) and Singh and Musiyimi (1981) suggested that a severe infection of rust may cause a 10% to 37% yield loss in East Africa.

These findings were mostly based on visual observation. Few quantitative data exist that show the impact of rust on crop growth, yield and yield components. Analysis of crop growth and yield components affected by rust should help to understand the relationship between the production situation (De Wit, 1982), yield and disease (Savary and Zadoks, 1992a,b). The tolerance of a crop to injury varies during the growing season (Zadoks, 1985), and so analysis of crop growth, disease development, yield components and their interrelationships at various constraint levels will help to understand the productivity of bean crops in Ethiopia.

Management of crop loss (Mackenzie, 1983; Zadoks and Schein, 1979) requires a good understanding of the relationships between crop growth and disease development. Savary and Zadoks (1992a,b) established relationships between production situations, injury and damage in a groundnut multiple pathosystem. In beans, no such relationships were studied. Experimental manipulation of epidemics is one way to influence crop growth, disease development and yield. This study reports on such experiments, addressing (1) the effect of fungicide spray frequencies on crop growth, disease and yield components, (2) relationships between different parameters for rust assessment, (3) relationships between yield components, and (4) relationships between crop growth and rust development at any particular time of crop growth stage and yield components.

Table 1. Descriptions of bean growth stages as used in this study, after Fernandez et al. (1986), with slight modifications

V4 = Third trifoliolate leaf
R5 = Pre-flowering, first floral bud
R6 = Flowering
R7 = Pod formation
    R7A - 1st week of pod formation
    R7B - 2nd week of pod formation
R8 = Pod filling
    R81 - 1st week of pod filling
    R82 - 2nd week of pod filling
    R83 - 3rd week of pod filling
R9 = Maturity (discoloration and drying of pods)

Materials and Methods

Field experiments. In Ethiopia, beans grow at altitudes from 1200 m to 2200 m, in a wide range of climates from hot and dry in the lowlands (1200 m - 1500 m) to cool and wet in the high lands (2000 m - 2200 m). Moreover, bean production prevails between 1500 m - 2100 m (Ohlander, 1976). The normal growing season for beans in Ethiopia is from June to October. Bean rust is common at the intermediate and higher altitudes. Field experiments were performed in 1990 and 1991, in experimental fields of the Institute of Agricultural Research at Debre Zeit and the Plant Protection Research Centre at Ambo. Debre Zeit represents the mid altitude (1850 m) and moderate rainfall (ca. 900 mm) regions while Ambo (2150 m) represents the higher altitude, moderate rainfall (ca. 960 mm) areas.

Experimental design. The experiments were conducted as a randomized complete block design with six replications with a split plot arrangement. Two varieties, Mexican 142, susceptible (SUS) and 6-R-395, partially resistant (RES), formed the main plots and five spray treatments the sub-plots. Seeds were sown in mid-June at Ambo and early July at Debre Zeit. The experimental data at Debre Zeit in 1991 for RES were excluded from the analysis due to a severe infection by Bean Common Mosaic Virus (BCMV).

Inoculation. Three weeks after emergence, each of the experimental plots was inoculated by spraying them with a urediniospore suspension (about 5 g urediniospore per 20 l of H_2O) containing a mixture of local isolates of bean rust collected from the respective locations.

Spray treatments. Fungicide spraying began one week after inoculation. To produce epidemics of varying intensity in each cultivar, plantvax 20 % (oxycarboxin, a systemic fungicide at the rate of 0.1 %) was applied at intervals of 5 (treatment 4), 10 (treatment 3), 15 (treatment 2) and 20 days (treatment 1). A check (treatment 0) was left unsprayed to allow maximum development of bean rust. Standard agronomic practices were followed and no fertilizers were applied. The experimental sub-plots measured 4 * 4 m^2. One seed per hole was sown at 40 cm distance between the rows and 10 cm distance within a row. Each plot was surrounded by 3.2 m guard rows of wheat to reduce interplot interference.

Crop assessment. Growth stages of the crop were determined at the dates of disease assessment, following Fernandez et al. (1986) with slight modifications (Table 1). At the first and last disease assessment dates, the total number of plants in the middle four rows of each plot were counted and the counts converted to plant density (theoretically 25 plants m^{-2}). The leaf area of each of the plants selected for disease assessment was calculated using a pictorial key (Fig 1). The leaf area index (LAI, the amount of leaf area per unit of soil area, $[L^2.L^{-2}] = [1]$) was determined at weekly intervals.

Disease assessment. From about 10 days after inoculation, assessment of incidence (number of infected leaves per plant), severity (percent leaf area infected), pustule density (number of pustules per leaf), and pustule size (1 = no visible symptoms, 2 = necrotic spots without sporulation, 3 = diameter of sporulating pustule $< 300\mu m$, 4 = $300\text{-}500\mu m$, 5 = $500\text{-}800\mu m$ and 6 = $> 800\mu m$) were estimated (Stavely et al., 1983) at weekly intervals. Observations

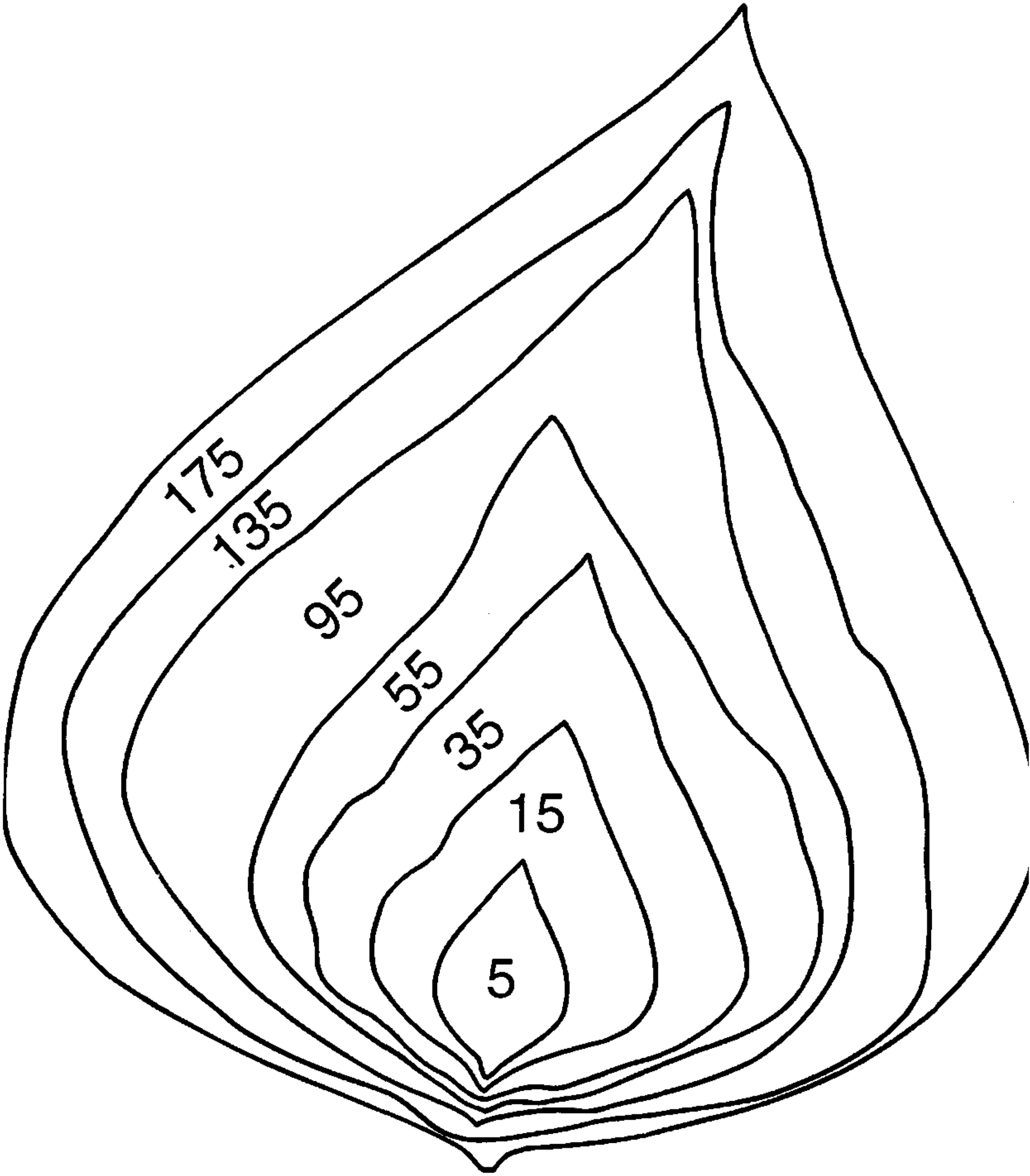

Fig 1. Pictorial key for the assessment of bean leaf area, measured in cm^2

were made on 12 randomly selected and marked plants per plot, avoiding plot borders. Well developed green leaves randomly selected from the 3rd, 5th, and the 9th canopy layers of main stems, representing the upper, middle and lower leaves, respectively, were used for disease assessment. The same tagged plants (non-destructive sampling) were used on each observation day.

Other diseases such as common bacterial blight (*Xanthomonas campestris* pv. *phaseoli* (Erw. Smith) Dowson) at Debre Zeit and anthracnose (*Colletotrichum lindemuthianum* (Sacc. and Magn.) Bri. and Cav. at Ambo, yellowing and dead tissue (mainly insect damage and slight necrosis) were assessed and recorded separately. At Ambo, seeds were treated with benomyl (Habtu and Awgechew, 1984) prior to planting because of the high incidence of anthracnose. It was not found necessary to apply foliar sprays for the protection of pods and leaves against anthracnose.

Yield assessment. At the end of the growing season, seed yield (SY) in g m^{-2}, seed weight (SW) in mg $seed^{-1}$, number of pods $plant^{-1}$ (PP), and number of seeds pod^{-1} (SP) of the four central rows were assessed. SY and SW were determined at 12 % moisture after sun-drying threshed seeds for 5 days. PP and SP were counted at harvest.

Computation. Cross-sectional analyses (Zadoks, 1978) were conducted to check the effects of treatments on LAI, disease intensity (rust incidence (IN), rust severity (RS), pustule density (PD), pustule size (PS)), severity of other diseases (OD) and dead tissue (DT) per canopy layer and per growth stage. The analysis tested for the effects of cultivar, treatment and interactions of cultivars by treatments (C*T). Coefficient of correlations of rust intensity parameters (IN, RS, PD, and PS) were calculated to determine mutual relationships. Further analyses were made to understand the nature of the relationships between LAI and yield parameters, rust intensities and yield parameters, and also between various yield parameters by correlation. Statistical analysis were performed using MSTAT (Freed et al., 1986). All tests for significance were performed at $P \leq 0.05$.

Table 2. Cross-sectional analysis of effects of treatments on LAI,incidence, severity, density, and pustule size, Ambo, 1990

Variables	Source of variation	Variance ratio values at GS=								
		V4	R5	R6	R7A	R7B	R81	R82	R83	R9
LAI	Cultivars	14.0[1]	ns	ns	ns	6.4	8.1	19.4	9.4	25.9
	Treatments	2.6	ns	5.0	19.4	16.0	19.0	21.8	23.3	19.7
	C*T	4.1	ns	ns	ns	ns	3.4	4.0	4.7	2.7
Incidence	Cultivars	23.7	35.3	156.7	67.1	82.7	98.7	198.0	68.4	10.1
	Treatments	38.4	31.2	137.1	74.3	77.5	104.6	64.3	20.3	6.6
	C*T	13.9	9.5	62.2	36.0	44.2	43.5	18.3	8.8	3.1
Severity-UC[2]	Cultivars	ns	8.0	117.3	15.7	19.7	20.0	13.9	-	-
	Treatments	ns	5.8	65.1	57.2	21.5	16.6	12.7	-	-
	C*T	ns	ns	16.2	14.1	6.6	7.9	6.7	-	-
-MC	Cultivars	ns	8.2	ns	19.5	10.6	-	-	-	-
	Treatments	17.4	16.0	11.6	16.5	7.4	-	-	-	-
	C*T	ns	ns	ns	3.9	ns	-	-	-	-
-LC	Cultivars	ns	ns	ns	-	-	-	-	-	-
	Treatments	6.0	4.0	4.9	-	-	-	-	-	-
	C*T	ns	ns	5.3	-	-	-	-	-	-
Density-UC	Cultivars	ns	ns	18.7	28.1	21.0	10.0	ns	-	-
	Treatments	ns	6.0	36.6	36.1	29.3	18.6	16.0	-	-
	C*T	ns	ns	9.4	9.8	10.1	6.0	5.0	-	-
-MC	Cultivars	ns	ns	10.3	9.2	9.6	-	-	-	-
	Treatments	20.5	17.2	16.0	10.7	7.1	-	-	-	-
	C*T	ns	ns	3.7	3.1	4.5	-	-	-	-
-LC	Cultivars	ns	ns	ns	-	-	-	-	-	-
	Treatments	13.8	2.7	5.7	-	-	-	-	-	-
	C*T	ns	ns	3.1	-	-	-	-	-	-
Size -UC	Cultivars	ns	ns	ns	ns	ns	ns	ns	-	-
	Treatments	ns	ns	14.2	39.8	17.3	13.9	13.8	16.4	-
	C*T	ns	3.4	4.4	ns	ns	ns	5.3	-	-
-MC	Cultivars	ns	ns	ns	ns	ns	-	-	-	-
	Treatments	20.0	38.1	39.7	13.0	8.2	-	-	-	-
	C*T	ns	ns	3.5	ns	ns	-	-	-	-
-LC	Cultivars	ns	ns	ns	-	-	-	-	-	-
	Treatments	ns	5.0	11.4	-	-	-	-	-	-
	C*T	3.2	ns	2.7	-	-	-	-	-	-

[1] ns = not significant; - = not determined; all others significant at $p \leq 0.05$.

[2] UC = Upper canopy layer; MC = middle canopy layer; LC = lower canopy layer

Results

Production situation

Ambo has more rainy days, more cloud cover, less radiation, cooler nights and higher rust pressure than Debre Zeit. Fertilizers were not applied. This production situation is reflected in the average maximum yield (yield of the rust free plot) of 1860 kg ha^{-1} and leaf area index, LAI (3.17) for SUS at Debre Zeit and maximum yield of 2180 kg ha^{-1} and LAI of 2.43 for RES at Ambo.

Effects of spray treatments

Leaf area index. Differences in LAI between spray treatments were significant from flowering (R6) onwards (Table 2), in 1990, and at all growth stages in 1991 (Table 3). In SUS, LAI reached a maximum of 2.25 at Ambo, 1990 (Ambo), and 2.81 at Debre Zeit, 1991 (Debre Zeit), both in treatment 4. For treatment 4 LAI reached the maximum at R7A. LAI increased till R6 for the other treatments, then declined. The decline was most prominent for treatment 0. Spray treatments resulted in significantly higher LAIs than the unsprayed check. RES also showed significant differences between spray treatments, but the differences were not large. The highest LAI was obtained in treatment 4 at R7A. Among treatments, there was a significant difference at all growth stages, the differences being largest at R7 and R8. The variation among treatments was much greater in SUS than RES.

Differences between cultivars were significant at V4 and at ≥ R7B. At two growth stages (R8 and R9) the interaction between cultivar and treatment (C*T) was significant, an indication of a difference in response to LAI between cultivars to treatments.

There was no block effect at Ambo, 1990. In Debre Zeit, 1991 the block effect being significant at all growth stages reflected the influence of waterlogging (which is common at Debre Zeit) that affected some treatments.

Incidence. In SUS at Ambo, 1990, rust incidence reached its highest level

Table 3. Cross-sectional analysis of effects of treatments on leaf area index, incidence, severity, density, and pustule size, Debre Zeit, 1991

Variables		Variance ratio values at GS=								
		V4	R5	R6	R7A	R7B	R81	R82	R83	R9
LAI		3.3[1]	5.7	11.1	16.8	20.8	15.0	10.6	11.9	3.4
Incidence		ns	9.2	11.0	7.2	ns	ns	-	-	-
Severity	-UC[2]	-	-	ns	ns	7.6	6.5	-	-	-
	-MC	-	ns	5.9	ns	17.9	27.0	-	-	-
	-LC	4.0	8.2	ns	ns	-	-	-	-	-
Density	-UC	-	-	ns	5.0	20.9	16.4	-	-	-
	-MC	-	ns	8.1	8.5	12.6	18.8	-	-	-
	-LC	5.2	6.1	11.9	ns	-	-	-	-	-
Size	-UC	-	-	ns	5.7	31.9	8.9	-	-	-
	-MC	-	ns	16.7	11.3	11.9	4.8	-	-	-
	-LC	ns	6.4	8.1	ns	-	-	-	-	-

[1] ns = not significant; - = not determined; all others significant at $p \leq 0.05$.
[2] UC = Upper canopy layer; MC = middle canopy layer; LC = lower canopy layer

(80%) in treatment 0. In treatment 4, no rust was found in any replication. Rust incidence increased from V4 to R5 and declined between R6 and R7A possibly due to the development of new flushes of leaves not yet infected at these stages. After R7 rust incidence increased until the bean crop reached R8. At maturity rust incidence declined. Differences between treatments remained significant at all stages of crop development (Table 2). Greatest significant differences were obtained at R7 or R8.

In RES at Ambo, 1990, rust incidence was low on average and never exceeded 25 %. The trend in RES was similar to that in SUS except for the magnitude of the differences between treatments. After R7, differences between treatments were significant (Table 2).

In Debre Zeit, 1991, differences between treatments of SUS were not quite as large as in Ambo, 1990. Significant differences were obtained between R5 and R7A. Differences between treatments were highest at R6 (Table 3).

At Ambo, 1990, block effects were not significant, but interaction effects between cultivar and treatment (C*T) were large and consistent. At Debre Zeit, 1991 the block effect, significant in 4 out of 8 cases, was largest at the earlier growth stages.

Rust severity

Upper canopy layer (UC): For SUS, rust severity reached a maximum of 55 at Ambo, 1990 and 15 at Debre Zeit, 1991 at R7B in treatment 0. In treatment 4, rust did not develop. In Ambo differences between treatments, significant from R5 onwards, were highest at R6 (Table 2).

For RES, rust development reached a maximum of 15 in treatment 0 at Ambo. Differences between treatments were not significant at V4 and R6. Slight but significant differences between the control and sprayed treatments were obtained at R7 and R8. At Ambo there was no block effect but a significant C*T interaction was found from R6 onwards.

At Debre Zeit (SUS), differences between treatments were significant at R7B and R81 (Table 3). Block effects were consistently significant, but interactions were not.

Middle canopy layer (MC). In SUS, rust severity reached a maximum of 50 at R7 for treatment 0, 30 for treatment 1, 15 for treatment 2, 5 for treatment 3 and 0 for treatment 4. In RES the highest rust level (18) was found at R6. Differences between treatments in RES remained significant from V4 to R7B. Significant differences between cultivars were observed at R5, R7A and R7B at Ambo. The only C*T interaction effect, observed at R7A, was highly significant. At Debre Zeit, treatment differences were significant at R6, R7B and R81. Block effects were more common in Debre Zeit than in Ambo.

Lower canopy layer (LC). Rust severity declined as the season progressed. For the control plots of SUS, rust severity decreased from 10 to 5. In Ambo, only three assessments were done on the lower canopy layer as leaves began to drop at R7A. Trends in SUS and RES were similar. Despite low disease values, differences between treatments remained significant at V4, R5 and R6. At R6 C*T interaction was significant (Table 2). In Debre Zeit significant differences between treatments were obtained at R5 and R6 (Table 3).

Pustule density

Upper canopy layer. Numbers of pustules reached a maximum of 230 pustules per leaf for treatment 0. Numbers of pustules were greatly reduced after chemical treatments. Treatment 4 resulted in the lowest pustule counts. In Ambo, differences between treatments were significant at R5 and variation increased and was highest at R6 and R7. The trend remained the same for both cultivars, but in SUS density was highest and variation between treatments was greatest. In SUS at Debre Zeit, despite significant differences between treatments, density was rather low, not exceeding 60 pustules per leaf. Significant differences between treatments were obtained at R7 and R8.

Middle canopy layer. In SUS at Ambo, the pustule density did not exceed 150 in middle canopy layer. At V4, pustule density was already 30 per leaf for treatment 0. For treatments 2, 3 and 4 initial density was zero. Later rust appeared in these treatments but remained significantly ($p \leq 0.05$) lower than the control. In RES pustule density was low throughout the season and differences among treatments were small but significant beginning at V4, and largest at V4, R5 and R6. Differences between cultivars were significant at R6 and R7. A significant C*T interaction was found at R6 and R7. In Debre Zeit, treatment effects remained significant after R6 with highest differences at R7B and R81. Pustule density was generally lower at the middle canopy than in the upper canopy layers.

Lower canopy layer. Rust was first observed in the lower canopy layer. As the crop developed leaves with pustules were removed from the infection process and mean pustule density was reduced. For SUS and RES in Ambo differences between treatments were significant at V4, R5 and R6, with significant C*T interaction at R6. In Debre Zeit, the results were similar and differences between treatments were significant at V4, R5, and R6.

Pustule Size

Upper canopy layer. Differences in size of pustules among the treatments began to show at R5. On average, pustule size increased with the development of the crop. For treatments 1, 2, and 3, pustule size peaked at R7 where maximum differences were attained (Fig 2A). For treatment 0 the maximum size was reached at R6 and remained constant till R9. Differences among treatments were strong at R6 to R8. The trend was similar for both varieties. Differences between treatments were larger in SUS than in RES. For SUS in Debre Zeit, differences between treatments were significant after R7.

Middle canopy layer. When bean crops were not sprayed with fungicides, pustule size continued to increase but because of leaf senescence and imminent defoliation, data could not be collected after R8 in Ambo.

In treatments 3 and 4, pustule size decreased and continued to decline after reaching a maximum of 2.0. Average pustule size peaked at R7A (Fig 2B) in treatments 1 and R6 in treatment 2. RES showed no consistent trend in relation to development stages, despite differences among treatments. In Ambo and Debre Zeit, differences between treatments were consistently significant from R5 onwards. In Ambo, significant cultivar differences and C*T interactions were found at R6 and R7.

Lower canopy layer. In most cases, the data were collected only three times due to fast defoliation within the lower canopy layer. All spray treatments resulted in a reduced pustule size. As the crop developed, reduction of pustule size was continuous for all spray treatments. The decline in pustule size is perhaps due to the early removal of the first appearing pustules and the subsequent appearance of new pustules which were rather smaller in size and more numerous. Treatment 0 resulted in a large pustule size, especially in SUS. In RES, pustule size decreased with time. Differences between treatments were significant at R6.

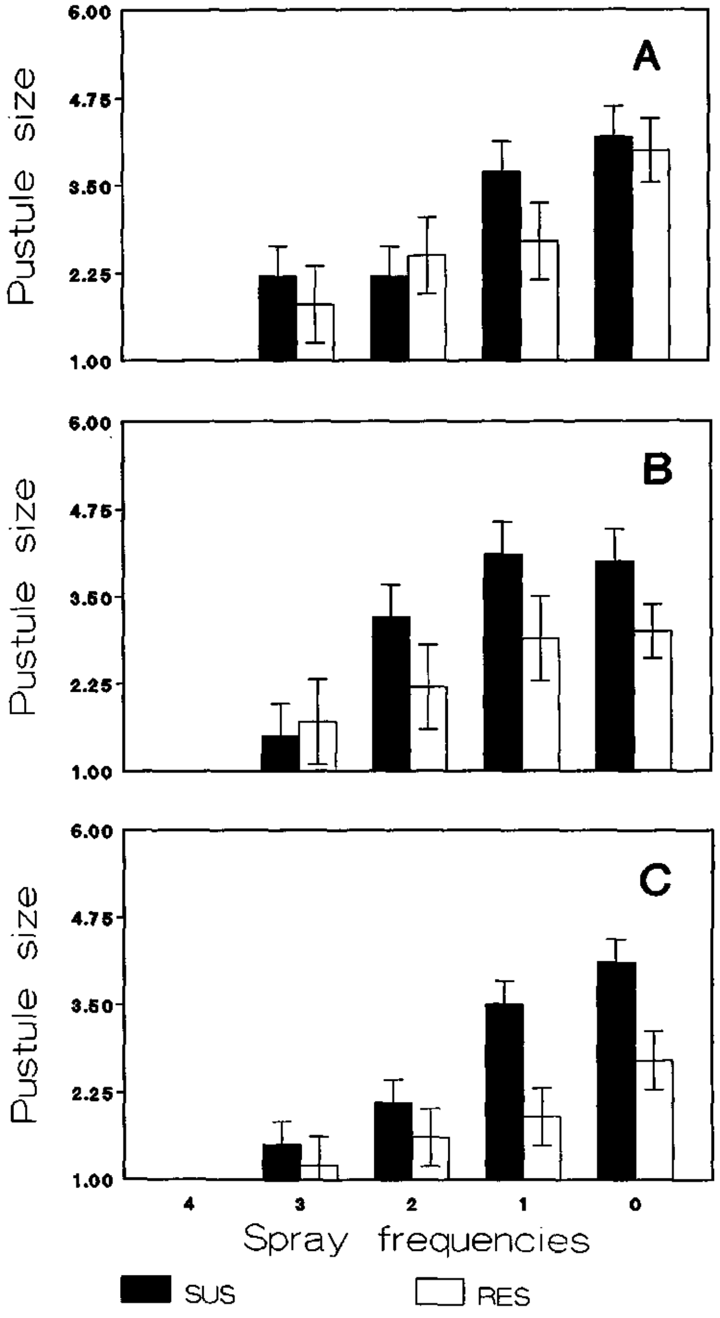

Fig 2. Effect of spray treatments on pustule size, Ambo, 1990, at R7A, A = upper canopy layer, B = middle canopy layer and C = mean. Black columns = SUS, white columns = RES. Each column is the mean of six replications

Other Diseases

Severity of other diseases, mainly common bacterial blight, anthracnose and ascochyta blight did not exceed 11 in any treatment. Differences between treatments were in most cases non-significant except at R6 and R7 in the upper canopy layer. All treatments produced more or less similar curves (Fig 3A,B,C). The trends were similar for the two varieties. In the lower canopy layer the rate of increase of other diseases was higher than in the upper canopy or middle canopy layers but due to defoliation at ≥ R6 the severity did not exceed 13 for treatment 0 and 8 for the spray treatments. Disease intensity increased from upper to lower canopies. If it had not been for the early defoliation at the lower canopy layer differences between the canopy layers would have been much greater.

Dead Tissue

In almost all cases (except the middle canopy layer at R5 in Ambo and the upper canopy layer at R8 and the middle canopy layer at R7B in Debre Zeit) differences between treatments were not-significant at $p \leq 0.05$ level (Fig 3D,E,F). In the upper canopy layer severity did not exceed 10 while in the middle canopy severity ranged between 10 and 15 for SUS and 12 to 24 for RES. In the lower canopy severity up to 30 was observed. Dead tissue including insect damage (leaf cuts and holes) and necrosis were relatively higher in the lower leaves where increase was fastest.

Effect of spray treatments on yield and yield components

Seed yield. Seed yield in g m^{-2} was calculated for SUS (Figures 4A, 5A) and RES (Fig 4A). In Ambo, seed yield varied from 24 g m^{-2} to 156 g m^{-2} in SUS and from 153 g m^{-2} to 218 g m^{-2} in RES. In Debre Zeit, the variation in yield ranged from 106 g m^{-2} to 186 g m^{-2}. The most frequently sprayed treatments produced the highest yields and the unprotected check gave the lowest yield. The ranges of yield values between the unprotected and highly protected plots were quite different for the two varieties. The range between the highest and lowest value was 132 g m^{-2} for SUS and 65 g m^{-2} for RES, suggesting an

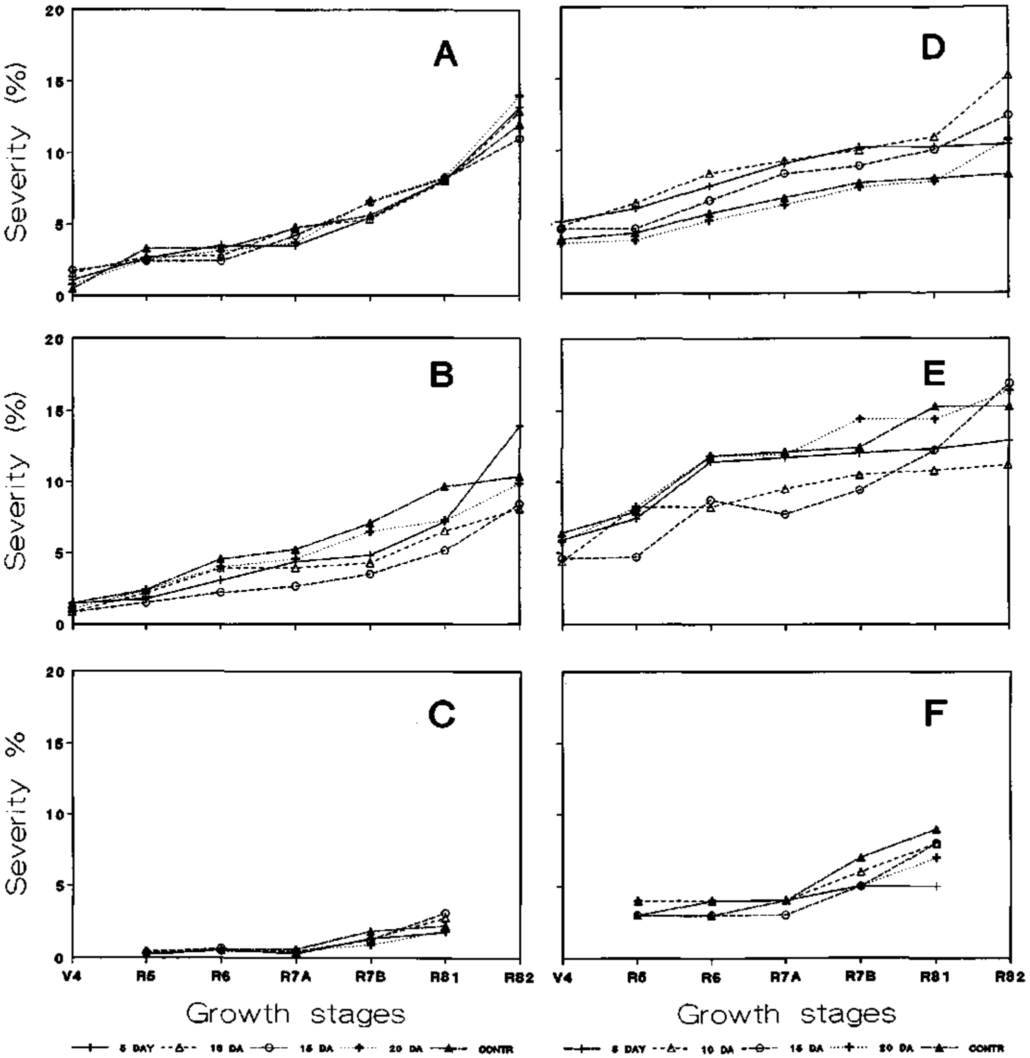

Fig 3. Effect of spray treatments on other diseases (A,B,C) and dead tissue (D,E,F). A,D = SUS Ambo, 1990; B,E = RES Ambo, 1990; C,F = SUS Debre Zeit, 1991; all at the same vertical scale 0 - 20

Table 4. Analysis of variance for yield parameters [1]

Year	Location	Source of variation	Variance ratio values for PP	SP	SW	SY
1990[2]	Ambo	Cultivars	37.0[3]	67.8	ns	31.4
		Treatments	45.2	3.8	12.1	42.4
		C*T	5.9	ns	ns	8.0
1991	Debre Zeit	Treatments	22.9	13.8	13.8	32.2

[1] PP = pods per plant; SP = seeds per pod; SW = seed weight; SY = seed yield

[2] SUS and RES in 1990 and SUS in 1991

[3] ns = not significant; all others significant at $p \leq 0.05$

interaction effect of spray treatments and cultivars. Close examination of the graph (Fig 4A, 5A) shows that the interaction effect is largely due to treatment 0 where no spray resulted in a significantly lower yield for SUS. When the disease pressure was low, as in Debre Zeit, the range in SUS was only 80 g m^{-2}. Differences between cultivars and treatments were significant. In Ambo, a significant C*T interaction was found (Table 4).

Seed weight. Spray treatments increased seed weight in both cultivars, but the effects were slight. Differences between treatments were significant. Seed weight ranged from 125 mg for treatment 0 to 150 mg for treatment 4 in SUS and from 130 mg to 147 mg in RES (Fig 4b). The range of variation for SUS (25 mg) was larger than for RES (17 mg). In Debre Zeit, seed weight of SUS ranged between 124 mg and 136 mg (Fig 5b).

Seeds per pod. Seeds per pod ranged between 3.3 to 4.0 for SUS and 4.1 to 4.7 for RES in Ambo, and 3.5 to 4.1 for SUS in Debre Zeit. In Ambo, there were significant differences between cultivars and treatments. Within the spray treatments the variation in seeds per pod was not significant in either cultivar

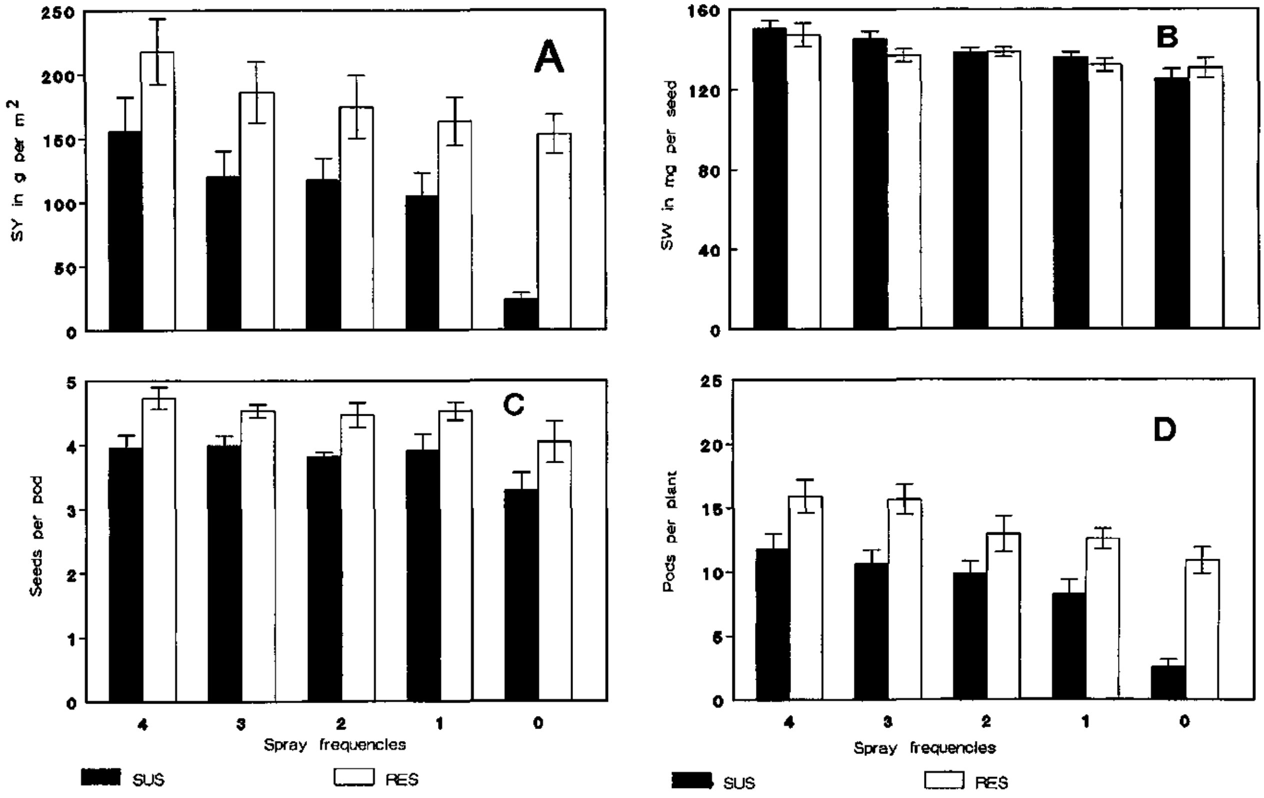

Fig 4. Effect of spray treatments on yield parameters, Ambo, 1990; A = Seed yield (SY) in g per m^{-2}, B = Seed weight (SW) in mg seed^{-1}, C = Number of seeds pod^{-1} (SP), D = Number of pods plant^{-1} (PP). Black columns = SUS, white columns = RES; bars indicate SD. Each column is the mean of six replications

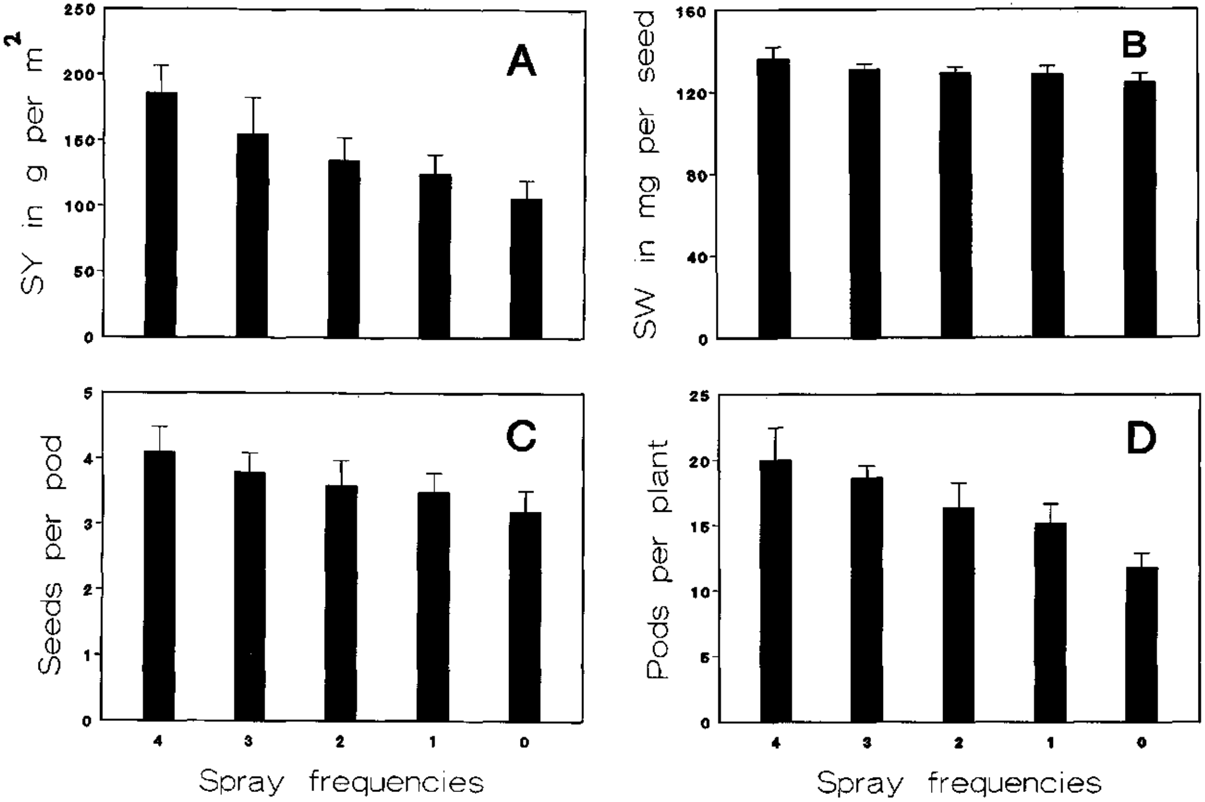

Fig 5. Effect of spray treatments on yield parameters, Debre Zeit, 1991; A = Seed yield (SY) in g per m^{-2}, B = Seed weight (SW) in mg seed^{-1}, C = Number of seeds pod^{-1} (SP), D = Number of pods plant^{-1} (PP). Black columns = SUS, RES failed because of virus attack; bars indicate SD. Each column is the mean of six replications

Table 5. Linear correlation coefficients *r* between rust parameters[1]

Growth Stage	Loc.	Year	Cul.	IN-RS[2]	IN-PD	IN-PS	RS-PD	RS-PS	PD-PS
V4	Ambo	1990	SUS	ns[3]	0.47	0.64	0.36	ns	0.51
R5				ns	0.39	0.70	0.69	0.47	0.59
R6				0.63	0.65	0.76	0.77	0.74	0.68
R7A				0.72	0.83	0.85	0.89	0.79	0.84
R7B				0.79	0.84	0.79	0.93	0.81	0.72
R81				0.76	0.82	0.76	0.88	0.82	0.75
V4			RES	ns	0.77	0.73	ns	0.46	0.63
R5				0.73	0.87	0.79	0.86	0.59	0.65
R6				ns	0.55	0.76	ns	0.55	0.63
R7A				0.56	0.42	0.68	ns	ns	ns
R7B				0.63	0.36	0.61	0.60	0.53	0.64
R81				ns	0.38	0.53	ns	ns	0.65
R5	DZ	1991	SUS	0.42	ns	0.45	0.63	0.56	0.52
R6				0.44	0.53	ns	0.59	0.38	ns
R7A				0.49	0.53	ns	0.81	0.37	ns
R7B				ns	ns	0.39	0.82	0.52	ns
R81				ns	ns	ns	0.63	ns	ns

[1] Number of plots to test correlation = 30 (5 treatments by 6 replications)

[2] IN = rust incidence; RS = rust severity; PD = pustule density; PS = pustule size; Loc = location; Cul = cultivar.

[3] ns = not significant; r values ≥ 0.36 significant at $p \leq 0.05$

(Figures 4C, 5C). Despite significant differences among treatments in both Ambo and Debre Zeit the differences between treatments are small except between the non-sprayed and sprayed treatments.

Pods per plant. In SUS, pods per plant ranged from 2.5 to 11.8 in Ambo and 11.8 to 20.0 in Debre Zeit (Fig 4d). In RES at Ambo the range was between

10.9 and 15.9 (Fig 5d). Differences between cultivars and treatments in pods per plant were large in Ambo. Significant C*T interactions were found, located mainly in the contrast between sprayed and unsprayed plots of the SUS.

Correlations between parameters for rust assessment

Table 5 provides correlation coefficients (*r*) for the relationships between the various bean rust parameters. For SUS in Ambo, the *r* values increased as the crop developed. They were low at V4 and R5. At R7 and R8 the relationships improved. Though all rust parameters are closely correlated, highest correlations (≥ 0.85) were found between rust severity and pustule density at R7A-R81. For RES the relationships were relatively low and unrelated to plant development. The *r* values were high at R5 with the highest values obtained between incidence and pustule density, and rust severity and pustule density.

In Debre Zeit, high r values were obtained between rust severity and pustule density at R7A-R81. In Debre Zeit, correlations between incidence and other parameters were poor compared to Ambo, especially after R7B. This is understandable since in Debre Zeit differences between treatments were not significant after R7B, as opposed to Ambo, where they remained significant at all growth stages.

Correlations between leaf area index and components of yield.

Leaf area index (LAI) and pods per plant. The correlations between LAI and pods per plant were found always to be positive (Table 6) and attained high levels between R7B and R9. For RES in Ambo and SUS in Debre Zeit, the relationships were lower than in SUS Ambo. The developmental trend remained the same since high *r* values were found almost always at ≥ R7B. The highest values were found at R8 in SUS and RES in Ambo, and SUS in Debre Zeit. For SUS in Debre Zeit results were significant from R7A onwards, with high *r* at the end of R8.

Leaf area index and seeds per pod. The correlations between LAI and seeds per pod were weak, especially between V4 and R7B, for SUS in Ambo, V4-R82

Table 6. Linear correlation coefficients between LAI and pods per plant (PP), seeds per pod (SP), seed weight (SW), and seed yield (SY)

Growth Stage	Ambo, 1990								Debre Zeit, 1991			
	SUS				RES				SUS			
	PP[1]	SP	SW	SY	PP	SP	SW	SY	PP	SP	SW	SY
V4	0.41[2]	ns	ns	0.49	0.41	0.41	ns	0.51	ns	ns	ns	0.41
R5	0.41	ns	ns	0.50	0.72	ns	ns	0.83	ns	ns	ns	0.56
R6	0.54	ns	ns	0.50	0.69	0.47	ns	0.71	ns	ns	ns	0.52
R7A	0.75	ns	0.42	0.73	0.80	ns	0.43	0.82	0.55	ns	ns	0.70
R7B	0.86	ns	0.41	0.82	0.76	ns	0.53	0.61	0.45	ns	ns	0.73
R8-1	0.86	0.42	0.50	0.93	0.65	ns	ns	0.61	0.68	ns	0.36	0.65
R8-2	0.91	0.46	0.56	0.93	0.80	ns	ns	0.87	0.67	ns	ns	0.71
R8-3	0.86	0.58	0.54	0.87	0.88	ns	0.48	0.85	0.72	0.52	0.66	0.81
R9	0.84	0.54	0.55	0.90	0.81	0.36	0.42	0.69	0.59	0.52	0.59	0.48

[1] Number of plots to test correlation = 30 (5 treatments by 6 replications)

[2] ns = not significant; r value ≥ 0.36 significant at $p \leq 0.05$

for SUS in Debre Zeit and lacked developmental trend for RES in Ambo. After R7B, and more specifically for SUS in Ambo, the relationship became slightly stronger but r did not exceed 0.58.

Leaf area index and seed weight. In SUS in Ambo, the correlation between LAI and seed weight became stronger as the crop developed with a maximum of $r = 0.56$ at R8 and R9. The r values were generally lower for RES than for SUS. Overall the relationship was weak though it improved after R7B for SUS in Ambo. In SUS in Debre Zeit and RES in Ambo the relationship did not follow any pattern of crop development.

Leaf area index and seed yield. The r values were generally high for the correlation between LAI and seed yield, increasing with developmental stage.

Table 7. Linear correlation coefficients between rust incidence and yield parameters

Growth Stage	Ambo, 1990								Debre Zeit, 1991			
	SUS				RES				SUS			
	SY[2]	SW	SP	PP	SY	SW	SP	PP	SY	SW	SP	PP
V4	-0.64[3]	-0.55	-0.50	-0.71	ns	ns	-0.38	ns	ns	ns	ns	ns
R5	-0.56	-0.61	ns	-0.68	ns	-0.42	-0.65	-0.43	-0.38	ns	ns	-0.42
R6	-0.65	-0.56	-0.42	-0.76	ns	-0.54	ns	-0.37	-0.47	ns	-0.40	-0.58
R7A	-0.63	-0.61	-0.46	-0.70	ns	ns	ns	ns	-0.65	-0.52	-0.45	-0.72
R7B	-0.71	-0.59	-0.50	-0.79	ns	-0.41	-0.39	-0.46	-0.71	-0.46	-0.36	-0.64
R81	-0.70	-0.65	-0.50	-0.79	-0.38	-0.41	-0.56	-0.59	ns	-0.41	ns	ns
R82	-0.69	-0.65	0.43	-0.76	ns	ns	-0.52	-0.44	ns	ns	ns	ns
R83	-0.61	-0.58	-0.48	-0.66	ns	ns	-0.39	-0.46	-	-	-	-
R9	-0.49	-0.45	ns	-0.53	ns	ns	ns	ns	-	-	-	-

[1] Yield parameters; Seed yield (SY), seed weight (SW), seeds per pod (SP) and pods per plant (PP)

[2] Number of plots to test correlation = 30 (5 treatments and 6 replications)

[3] ns = not significant; - = not determined; r value ≥ 0.36 significant at $p \leq 0.05$

The trend was the same in all experiments. The highest *r* values (≥ 0.85) were obtained at R8 for SUS and RES in Ambo.

Correlations between rust and components of yield

Rust incidence and yield components. For all parameters (Table 7) variation among cultivars, locations and growth stages was high. For rust incidence and seed yield, *r* values ranged between -0.38 and -0.71 for SUS in Ambo and Debre Zeit. With RES, the *r* value was significant ($p \leq 0.05$) only at R81. For SUS *r* peaked at R7B.

A similar and consistent result was obtained for incidence and seed weight for SUS in Ambo. The relationship was significant at all growth stages with

Table 8. Linear correlation coefficients[1] between rust severity and yield parameters

		Ambo, 1990								Debre Zeit, 1991			
		SUS				RES				SUS			
Leaf Layer	Growth Stage	SY[2]	SW	SP	PP	SY	SW	SP	PP	SY	SW	SP	PP
UC[3]	R5	ns[2]	ns	ns	ns	ns	ns	-0.48	ns	-	-	-	-
	R6	-0.54	-0.50	ns	-0.57	ns	ns	-0.64	-0.42	ns	ns	ns	ns
	R7A	-0.66	-0.64	ns	-0.73	-0.41	-0.39	-0.37	-0.52	ns	-0.39	-0.43	ns
	R7B	-0.64	-0.64	ns	-0.69	ns	ns	ns	ns	-0.39	-0.54	-0.55	-0.55
	R81	-0.60	-0.67	ns	-0.67	ns	ns	ns	ns	-0.45	-0.53	-0.46	-0.50
	R82	-0.61	-0.64	-0.36	-0.71	-0.41	ns	ns	-0.42	-	-	-	-
	R83	-0.52	-0.68	ns	-0.60	-0.41	ns	-0.59	-0.45	-	-	-	-
MC	R5	-0.62	-0.53	ns	-0.69	ns	-0.45	ns	-0.39	ns	ns	ns	ns
	R6	ns	-0.36	ns	-0.38	ns	-0.43	ns	-0.43	-0.42	ns	-0.40	ns
	R7A	-0.43	-0.39	ns	-0.54	ns	ns	ns	-0.37	-0.40	ns	-0.49	ns
	R7B	-0.65	-0.65	ns	-0.70	ns	ns	ns	-0.39	-0.75	-0.40	-0.54	-0.52
	R81	-0.51	-0.54	ns	-0.58	ns	ns	ns	ns	-0.81	-0.55	-0.63	-0.58
LC	R5	-0.53	-0.36	-0.44	-0.49	ns	-0.55	ns	ns	ns	ns	ns	ns
	R6	-0.42	ns	ns	-0.38	ns	ns	-0.65	-0.43	-0.40	ns	ns	ns
	R7A	-0.53	-0.43	ns	-0.62	ns	ns	ns	ns	-0.53	ns	ns	-0.52
	R7B	-	-	-	-	-	-	-	-	-0.45	ns	ns	-0.48

[1] number of plots to test correlation = 30 (5 treatments by 6 replications)

[2] ns = not significant; - = not determined; r value ≥ 0.36 significant at $p \leq 0.05$

[3] UC = upper canopy layer, MC = middle canopy layer, LC = lower canopy layer

high *r* values at R8. In SUS in Debre Zeit significance was found only at R7 and early R8. At both locations the *r* peaked at R7 and R8. For RES results lacked consistency, though significance was obtained at R5 to R8. The *r* values were generally lower for incidence and seeds per pod, ranging between -0.38 and -0.65. For RES in Ambo, *r* was higher for incidence and seeds per pod than for incidence and seed yield, and incidence and seed weight correlations, and *r* peaked at R7-R8.

High *r* values were obtained for the correlation of incidence and pods per plant, ranging between -0.37 and -0.79. In SUS in Ambo *r* was significant at all growth stages with little variation. In Debre Zeit the *r* values were significant at R5-R7. For RES generally the correlations of incidence with seeds per pod and pods per plant were better than with seed yield and seed weight. Differences in the relationships between location and/or year were common and variations were larger for RES in Ambo and SUS in Debre Zeit.

Rust severity and yield components. The correlation coefficients for rust severity and seed yield showed variation among cultivars, growth stages, locations, and canopy layers (Table 8). For SUS in Ambo *r* was significant at almost all growth stages, with peak values at R7. In Debre Zeit *r* was significant at R7B-R81 for the upper canopy layer at R6-R81 for the middle canopy layer and at R6-R7 for the lower canopy layer. For RES the relationship was weaker, with a significant *r* only in the upper canopy layer at R8.

The situation was similar for rust severity and seed weight relationships, except in the lower canopy at R6 for SUS in Ambo. In Debre Zeit the *r* values were stronger at R7B-R81 in the upper canopy and middle canopy layers. In RES significant *r* values were obtained only in upper canopy layer at R7A, middle canopy layer at R5 and R6, and lower canopy layer at R5.

As to the rust severity and seeds per pod correlations, except at upper canopy, R82 and lower canopy layer, R5, *r* was not significant in SUS in Ambo. In Debre Zeit, *r* was significant at most growth stages in the upper canopy and middle canopy layers. For RES no consistent trend was found though significance was attained at upper canopy layer at R5-R83, and in the upper canopy and lower canopy layers at R6.

The relationship was better and values higher for rust severity and pods per plant, especially in SUS in Ambo. Except At upper canopy layer at R5, *r* was significant in most cases. High *r* was obtained at R7 in all leaf layers. In Debre Zeit *r* was significant only at R7B-R81 in the upper canopy and middle canopy layers, and at R7 for the lower canopy layer. For RES, rust severity was significantly correlated with pods per plant in the middle canopy layer. In the

Table 9. Correlation matrices[1] of pods per plant (PP), seeds per pod (SP) seed weight (SW) and seed yield (SY).

	Year	Location	Cultivar	PP	SP	SW	SY
PP	1990	Ambo	SUS	1.00			
SP				0.51[2]	1.00		
SW				0.59	ns	1.00	
SY				0.90	0.54	0.58	1.00
PP			RES	1.00			
SP				ns	1.00		
SW				0.46	ns	1.00	
SY				0.81	ns	0.38	1.00
PP	1991	Debre Zeit	SUS	1.00			
SP				0.56	1.00		
SW				0.69	ns	1.00	
SY				0.71	0.48	0.51	1.00

[1] Number of plots to test correlation = 30 (5 treatments by 6 replications)

[2] ns = not significant; r value ≥ 0.36 significant at $p \leq 0.05$

upper canopy layer, results indicated lack of consistency with the development of the crop. Over all variations between growth stages, locations and cultivars were quite high.

Pustule density, pustule size and yield components. The correlations between pustule density and yield components or pustule size and yield components followed the general trend of rust severity and yield relationships and thus were not considered in detail.

Correlations among yield components

Significant relationships between the yield components were found (Table 9), except for seeds per pod and seed weight. *r* values were consistently higher for pods per plant and seed yield relationships. Bean yield is determined by its components,

$$SY = PP * SP * SW$$

where SY = seed yield, PP = pods per plant, SP = seed per pod and SW = seed weight. A simple linear regression of SY with the product of PP, SP and SW gave the following equations,

$$SY_{sus} = 0.49 + 0.96_{ppspsw}\ ; \qquad R^2 = 0.92$$

$$SY_{res} = 1.13 + 0.95_{ppspsw}\ ; \qquad R^2 = 0.90$$

In a multiple regression analysis where SY was regressed to the individual yield components plus two and three way interactions the following results were found,

$$SY_{sus} = -12.35 - 1.73_{pp} + 4.21_{sp} + 112.1_{sw} + 0.43_{ppsp} + 9.90_{ppsw} - 36.7_{spsw} - 1.43_{ppspsw}\ ; \qquad R^2 = 0.91$$

$$SY_{res} = +18.9 + 1.70_{pp} + 0.28_{sp} - 221.6_{sw} - 0.67_{ppsp} - 4.73_{ppsw} + 18.4_{spsw} + 4.06_{ppspsw}\ ; \qquad R^2 = 0.90$$

If the regressions were based on individual components without the interactions, the equations take the shape,

$$SY_{sus} = -5.5 + 0.48_{pp} + 1.03_{sp} + 16.3_{sw}\ ; \qquad R^2 = 0.90$$

$$SY_{res} = -9.88 + 0.58_{pp} + 0.89_{sp} + 47.7_{sw}\ ; \qquad R^2 = 0.88$$

Discussion

Analysis of crop growth, disease and yield parameters and their relationships

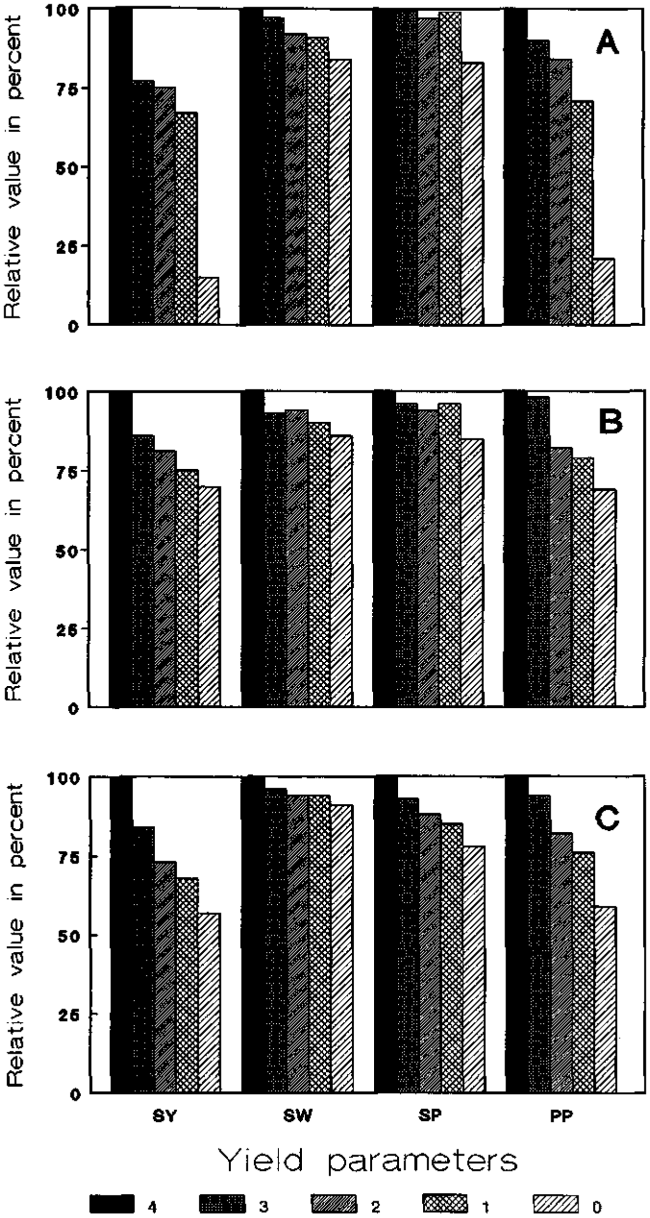

Fig 6. Yield components in relative values. Yield values as percent of the reference (rust free plot). A = Ambo, 1990 SUS; B = Ambo, 1990 RES; C = Debre Zeit, 1991 SUS. SY = seed yield; SW = seed weight; SP = number of seeds pod $^{-1}$; PP = number of pods plant $^{-1}$. Columns per item represent spray frequency from 0 (untreated control) to 4 treatments

provided some clues in understanding bean production in Ethiopia and gave some indications for future research.

Spray treatments

Crop growth and disease. The chemical was effective with a good control of rust at the highest spray frequency. Spray treatments influenced crop growth, rust intensity, other diseases and dead tissue. The magnitude of effects varied with location, cultivar, canopy layer and parameter.

Leaf area, measured by LAI, was most affected after pod formation. Rust, measured by either incidence, severity, pustule density or pustule size, varied with spray frequencies. Incidence was found most sensitive since differences were significant at all growth stages, whereas the impact of spraying on severity and pustule density was larger after flowering than in vegetative development. Rust severity, pustule density and pustule size showed differential responses to spray frequencies.

Differences between cultivars were common for LAI, incidence, severity, and pustule density but not for pustule size. Rust epidemics began at an early stage, and the bean crop continued to produce new leaves, hence it is not surprising to see great differences between treatments for incidence from an early developmental stage onward as opposed to rust severity and pustule density. Spray effects on other diseases and dead tissue were negligible. The chemical used to spray was hardly or not effective against common bacterial blight, bean anthracnose or insects, the main causes of dead tissue. Spray treatments produced the highest variations at pod initiation and seed filling, regardless of the parameters assessed.

In most cases (LAI, incidence, severity, pustule density), there appears to be a strong cultivar by treatment (C*T) interaction where the effects of treatments were stronger in SUS than in RES, suggesting a differential reaction to rust intensity at different levels of (partial) resistance. This is not uncommon as Lim and Gaunt (1986) suggested for the spring barley - leaf rust pathosystem. The result suggests in principle for the possibility of combining partial resistance with adequate fungicide management (Zadoks, 1989; 1993), but for bean production in Ethiopia one has to be cautious in recommending fungicides. The components of disease management beyond partial resistance are probably cultural (intercrops, cultivar mixtures, sowing dates, etc.)

Canopy layers. Distinction between leaf layers produced interesting results. The lower leaves died early. Treatment effects at lower canopy layer were not as strong as in the upper canopy and middle canopy layers, but remained significant in most cases. Cultivar by treatment interaction was absent mainly due to lack of differences between varieties at lower canopy layer. Rust began to develop on lower canopies and increased and moved upwards as the crop developed. Rust intensity seemed to decline at lower canopy because of removal (Zadoks and Schein, 1979) by death of primary pustules and subsequent appearance of many but significantly smaller pustules.

Moreover, leaves at lower canopy layer senesced and dropped early. Effects of early epidemics on lower leaves were reported by Rouse et al. (1980), Kolbe (1982) and by Lim and Gaunt (1986). In legumes, it is not always clear which nodes contribute more to yield (Debouck, 1991). Rust in *Phaseolus* beans, if it comes early, will most often affect the primary and the first trifoliolate leaves which in turn become the lower leaves. The fact that rust was first observed in the lower leaves make these leaves epidemiologically important, despite low incidence and early removal from the infection process. This is of particular importance to any rust control strategy. The loss of leaves in the lower canopy layer per se may or may not affect yield significantly but infection at this stage acts as a source of inoculum for the upper canopy layers, suggesting the appropriateness of managing bean rust at this stage.

Significant effects of treatments on LAI and most rust parameters from V4 onwards suggest the importance of a rust attack at an early stage of crop development. The loss of the primary leaves, when only primary leaves were present, reduced yield by about 65% (Wadill et al., 1984). This information is of particular significance if bean rust arrives early, at the primary leaf stage, and results in severe epidemics as happens often in some parts of southern Ethiopia. Thus, it is important to investigate to what degree a bean rust attack at each of the developmental stages affects the crop and its yield.

Fungicide. The use of different spray intervals produced good results. The fungicide was highly effective, and probably for this reason differences between treatments were not always as large as anticipated. In future trials one could consider varying the dosage, to use more and less effective fungicides and to inoculate repeatedly to obtain a range of epidemics of varying intensity.

Yield components. Yield depends on climate, production situation, cultivar, pathogen and disease severity (Zadoks and Schein, 1979; Daamen, 1989; Savary and Zadoks, 1992a,b). Analysis of disease effects on yield (Zadoks and Schein, 1979; Savary and Zadoks, 1992a,b) should include analysis of yield components to obtain a balanced view of their effects on final yield and their relationships. Some of these yield components were studied in the present report.

Spray treatments affected seed yield, seed weight, seeds per pod and pods per plant. There was variation in the degree of response (Fig 6), as seed yield and pods per plant were more affected than seeds per pod and seed weight. Obviously, variation in spray interval resulted in variations of disease pressure, which then resulted in differences in the (relative) magnitude of effects on yield components. SUS was always more sensitive to spray treatment than RES, suggesting a larger effect of sprays in susceptible cultivars.

Disease effects on legumes include reduction of attainable number of plants, pods per plant, seeds per pod, seed weight and seed yield. The effect on the yield components and seed yield depend on the pathosystem. Williams (1975, 1978) and Rapwood et al. (1984) showed that rust (*Uromyces vicia-fabae*) of faba bean mainly affected seed weight and chocolate spot (*Botrytis fabae*) mainly pods per plant. With rust (*Phakopsora pachyrhizi*) on soybean pods per plant was more affected than seeds per pod (Yang et al., 1991). In beans, pods per plant was greatly affected by Bean Yellow and Bean Common Mosaic Virus (Hampton, 1975). Van Bruggen and Arneson (1986) suggested two types of effects of *Rhizoctonia solani* on beans. The effect on plant development was a reduction of pods per plant and the effect on plant growth was a reduction of stem and root weight. In bean root rot and wilt combinations, *Fusarium solani* primarily reduced yields by reducing seed weight whereas *Pythium ultimum* affected pods per plant. *F. oxysporum* did not affect either seed weight or pods per plant (Sippell and Hall, 1982). In our study pods per plant was most affected.

The present report suggests the importance of rust in common bean, especially when a susceptible cultivar is attacked early. Rust is endemic in Ethiopia, especially in the Rift Valley and the southern provinces, where an outbreak of rust in combination with wide-spread cultivation of a susceptible cultivar can be devastating. The yield advantage obtained by applying fungicides frequently shows the damage potential of bean rust, but the experimental results also indicate that even one well-timed treatment could produce economic benefits, but the use of chemical spray to the Ethiopian condition is influenced by the value of the crop (cash or consumption), availability and cost of chemicals, availability of sprayer and water.

Relationships

Rust assessment parameters. Since disease assessment is laborious, bean breeders and extension specialists want a simple method suiting their needs. For beans in Ethiopia or elsewhere in East Africa a widely accepted method (compare Savary et al., 1988) to assess foliar diseases in beans is not available and the choice of a method is usually a compromise between the objectives and the available resources (Daamen, 1986a and 1986b; Zadoks and Schein, 1979). Correlations between rust parameters incidence, severity, pustule density and pustule size depended on cultivar, location and leaf layer. Higher correlation coefficients were obtained for susceptible than for partially resistant cultivars, and *r* values were better at Ambo than Debre Zeit. The two locations are quite different in terms of climate, altitude and soil factors, Ambo being more conducive to rust than Debre Zeit. The observed range of disease intensities are much greater at Ambo than Debre Zeit. Linear correlations become more significant with larger ranges of rust intensities. The correlations between rust severity and pustule density in SUS and rust incidence and pustule size in RES produced high *r* values regardless of canopy layers and growth stages.

There are conflicting reports on relationships of incidence and severity. The incidence-severity relationship may vary with season and leaf layer (James and Shih, 1973), with location but not with season (Chuang and Jeger, 1987) and with environmental factors (Imhoff et al., 1982). At high disease levels, the relationships between incidence and severity becomes uncertain (Zadoks, 1985).

Daamen (1986b) suggested that incidence-severity relations can be improved greatly by taking leaf size into account. We have not considered this, but a closer look at the data in the bean rust pathosystem suggests inconsistencies of the relationships at various growth stages (increase of leaf size with development of the crop). The relationships between rust assessment parameters are extremely variable and choices have to be made which one to use. Choices depend on the objectives. For bean breeders rust severity may be more attractive. For epidemiological purposes rust severity and pustule density are more appropriate. Extension specialists, who may have to deal with several crops, diseases and insects simultaneously, may wish to select the simplest (incidence), which may be less accurate for evaluating bean rust.

Leaf area index and yield components. LAI is an important determinant of seed yield in the common bean. Hence, the relationships of LAI and yield parameters were studied and the impact on yield components analyzed. LAI was more closely related with pods per plant than with seed weight and seeds per pod. The correlations between LAI-pods per plant and LAI-seed yield varied with growth stage rather than with cultivar and location. The *r* values were larger at the later stages of crop development. This is understandable as differences in LAI between treatments were greatest after pod formation. The *r* values for LAI-seeds per pod and LAI-seed weight depended on location and cultivar.

Rust and yield parameters. Correlations between rust and yield parameters were affected by cultivars, growth stages, canopy layers and locations. No clear trend was visible. Relationships between rust parameters and seed yield or pods per plant were always better than seed weight or seed per pod especially for SUS at Ambo, but the relationships were extremely variable for RES. The relationships were not greatly affected by the development of the crop but varied with location and cultivar. The strong relationship for seed yield and pods per plant at all growth stages and canopy layers regardless of the rust parameter used suggest the importance of all stages and canopy layers in any further epidemiological studies. This point will be elaborated in a subsequent paper.

Yield components. In dry beans the principal components of yield are pods per plant, seeds per pod, and seed weight (Adams, 1967). These components were subjected to correlation analysis.

Our data suggest a strong relationship between pods per plant and seed yield.

Early attack by rust may have affected the number of flowers. The numbers of flowers produced per axil and the rate of flower production in legumes is initially controlled by the ability of the plant to provide assimilates for these processes (Gaunt, 1987). This ability is, of course, influenced by a number of production constraints (insects, diseases). Bean rust at an early stage affects growth and development of leaves and thus the production of flowers and finally, pod number. Ogle et al. (1979) noted that rust infection reduces the production of photosynthate, alters its distribution within the plant and disrupts the internal water balance of the plant. The proportion of photosynthates retained in the leaves in which it is produced (Siddiqui and Manners, 1971), increase and changes in the water balance disrupt the functioning of the roots, the conductive elements, and the stomates. Non-stomatal transpiration increases by rupturing of the epidermis (Duniway, 1973). The effect of rust on abortion and pod filling could be partly due to the shortening of the pod filling period by defoliation. Stone and Pedigo (1972) suggested that the pod filling stage was the most sensitive to defoliation and subsequent loss of photosynthesis. Therewith, the strong relationship between pods per plant and seed yield becomes understandable. The strong relationships between pods per plant and seed yield under different conditions (location, cultivar and growth stages) illustrate the overriding importance of rust attack at an early stage and its subsequent influence on the number of flowers.

Generally speaking, seed yield and pods per plant show greater variation than seed weight and seeds per pod in response to various spray frequencies. How much of these changes in the yield components are associated with each of the crop and disease components in time and space will have to be investigated, probably using multiple regression analysis (Butt and Royle, 1974; Teng et al., 1979; Zadoks and Schein, 1979).

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Chapter 4

DISEASE PROGRESS, CROP GROWTH AND YIELD STUDIES IN A BEAN RUST PATHOSYSTEM OF ETHIOPIA

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Abstract

Progress of bean rust epidemics was manipulated by the application of a fungicide at 5 spray frequencies. These resulted in differences in rust epidemic, crop growth and yield in field experiments with two cultivars (one susceptible, one partially resistant) conducted in 1990, 1991 and 1993, at Ambo and Debre Zeit, Ethiopia, in a production situation with low external inputs. Progress curves of crop growth, rust incidence and rust severity showed significant variation among treatments. Leaf area index reached a maximum between 59 and 66 days from emergence at growth stages where rust severity also reached its plateau. For all parameters, progress curves showed more variation for the susceptible than for the resistant cultivar. For the susceptible cultivar, Mexican 142, differences between treatments were greatest during pod formation and under conditions of high disease pressure. Maximum yield loss was 85 % for the susceptible, Mexican 142, and 30 % for the partially resistant cultivar, 6-R-395. The loss depended on location, season and resistance level of cultivars.

Additional key words. Area under the curve, disease progress curves, haricot beans, infection rates, *Phaseolus vulgaris, Uromyces appendiculatus*.

Introduction

In Ethiopia, the yields of dry beans (*Phaseolus vulgaris* L.) averages 600 - 700 kg ha^{-1} (CSA, 1992), far less than the attainable yield (Zadoks and Schein, 1979) obtainable under good management conditions (IAR, 1991). The yield gap in beans results from yield limiting and yield reducing factors (Rabbinge and de Wit, 1989) among which are diseases, insects, weeds, cultural practices, low soil fertility and drought (IAR, 1991; Allen, 1983).

Rust, caused by *Uromyces appendiculatus* (Pers.) Unger, is one of the production constraints of beans in Ethiopia (IAR, 1991) and in East and Southern Africa (Howland and MacCartney, 1966; Padwick, 1956; Allen, 1983). Progress of rust epidemics varies according to season, location (Habtu and Zadoks, 1994), weather conditions (Imhoff et al., 1981) and resistance level of cultivars (Beebe and Pastor Corrales, 1991). These result in a concomitant variation in yield and yield loss. Experiments were conducted in different locations, seasons and cultivars to quantify such variation. Beans exhibit both determinate and indeterminate growth habits. They progressively produce new leaves in different canopy layers as they develop. The influence of different canopy layers on rust epidemics and its impact on yield is poorly documented.

Habtu and Zadoks (Chapter, 3) described cross-sectional analyses (Zadoks, 1978) of the effects of spray treatments on leaf area index and disease intensity per growth stage. In the present study we report on longitudinal analyses (Zadoks, 1978) of crop growth and disease progress and their influences on bean yields.

Materials and methods

Experimental design. A data base was provided by experiments conducted at Ambo and Debre Zeit in 1990, 1991 and 1993. The experiments were conducted as a randomized complete block design with six replications with a split plot arrangement. Two varieties, Mexican 142, susceptible (SUS) and 6-R-395, partially resistant (RES), formed the main plots and five spray treatments the sub-plots. Standard agronomic practices were followed and no fertilizers were applied. The experimental plots measured 4 * 4 m^2. One seed per hole was planted at 40 cm distance between the rows and 10 cm distance within a row. Each plot was surrounded by 3.2 m guard rows of wheat to reduce interplot interference.

Inoculation. Three weeks after emergence, each of the experimental plots was inoculated by spraying them with a urediniospore suspension (about 5 g urediniospore per 20 l of water) containing a mixture of local isolates of bean rust collected from the respective locations.

Spray treatments. Fungicide spraying began one week after inoculation. Rust epidemics of varying intensities were generated by adjusting the frequency of application of the systemic fungicide oxycarboxin (Bujulu and Lotasarwaki, 1986; Lamamoto et al., 1971) at a rate of 0.1% a.i. The fungicide was applied at intervals of 5 (treatment 4), 10 (treatment 3), 15 (treatment 2) and 20 days (treatment 1). A check (treatment 0) was left unsprayed to allow maximum development of bean rust.

Crop assessment. Growth stages of the crop were determined at the dates of disease assessment (Fernandez et al., 1986). At the first and last disease assessment dates, the total number of plants in the middle four rows of each plot were counted and converted to plant density. The leaf area of each of the plants selected for disease assessment was calculated using standard diagrams (Chapter 3). The leaf area index (LAI) was determined at weekly intervals.

Assessment for rust diseases. From about 10 days after inoculation, assessment of incidence (number of infected leaves per plant), severity (percent leaf area infected), pustule density (number of pustules per leaf), and pustule size (1 = no visible symptoms, 2 = necrotic spots without sporulation, 3 = diameter of sporulating pustule $< 300\mu m$, 4 = 300-500mμ, 5 = 500-800mμ and 6 = $>$ 800μm) were estimated at weekly intervals. Observations were made on 12 randomly selected and marked plants per plot, avoiding plot borders. Well developed green leaves randomly selected from the 3rd, 5th, and the 9th canopy layers of main stems, representing the upper (UC), middle (MC) and lower

(LC) canopy layers, respectively, were used for disease assessment. The same tagged plants (non-destructive sampling) were used at all observation days.

Yield assessment. At the end of the growing season seed yield (SY) in g m^{-2} and number of pods $plant^{-1}$ (PP) were assessed. SY was determined at 12 % moisture after sun-drying threshed seeds for 5 days. PP was counted at harvest.

Computation. Longitudinal analyses, applied to leaf growth and rust intensity, tested for differences in crop growth and disease development with time. Areas under the curve (AUC) for crop and disease were calculated and subjected to analysis of variance. Apparent infection rates (Van der Plank, 1963) were calculated to determine differences in disease progress. Differences between treatment means were tested at $p \leq 0.05$.

Results

Different frequencies of fungicide application resulted in pronounced differences of crop growth curves, diseases progress curves and yields at two sites in three years. No specific effect of oxycarboxin on treated plots versus non-treated plots was observed, but the experimental design does not allow to exclude such an effect.

Crop and disease progress curves

Crop growth. Progress of LAI varied among spray frequencies (Fig 1A-C). When progress was integrated over time, significant differences were found in the area under the LAI curve between the treatments (Table 1). LAI reached a maximum between 52 and 66 days from emergence (DFE) at Ambo, 1990, and between 52 and 59 DFE at Debre Zeit, 1991. Differences between treatments became apparent at 52 DFE and continued till plant maturity. For SUS, in treatments 0-3, LAI reached maxima at 52 DFE. In treatment 4 leaf area continued to increase, with maxima at 66 DFE in 1990 and 59 DFE in 1991. For RES, LAI increased till 66 DFE in treatment 0 - 3 and till 59 DFE in

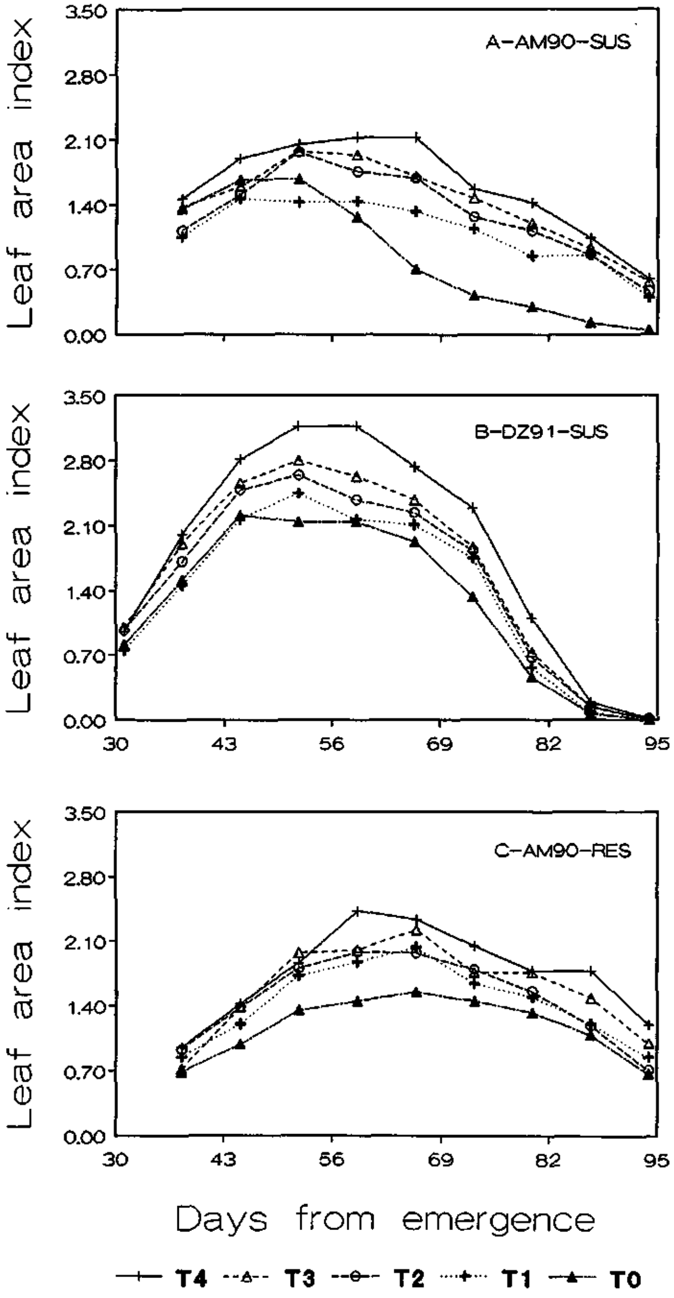


Fig 1. Crop growth curves, expressed as LAI against time in days from emergence. A = SUS, Ambo, 1990; B = SUS, Debre Zeit, 1991; C = RES, Ambo 1990. T0 - T4 = spray frequencies (from zero to high)

treatment 4. LAI curves of SUS (Fig 1AB) showed more variation than those of RES (Fig 1C). For SUS, differences among treatments at Ambo were greater than at Debre Zeit.

Rust incidence. In most cases, incidence (IN) increased with time, but the curves vary with seasons and locations for SUS and RES (Fig 2). In Ambo, 1990 both SUS and RES produced curves with dips at 52-59 DFE, but no dips were observed in Debre Zeit, 1991 or Ambo, 1993. Significant differences were found in the area under the rust incidence curve (Table 1) among treatments for SUS at Ambo, 1990 and Ambo, 1993 (Fig 2AC). For RES significant differences were mainly between treatments 0 and 3 or 4. Apparent infection rates for IN 'r_I' showed significant differences for all experiments (Table 2). Mean r_I was larger for SUS in 1993 than SUS 1990, both in Ambo, mainly due to the interruption of progress (the dip) observed in SUS in 1990. For RES, r_I were lower than for SUS both in 1990 and 1993.

Rust severity, upper canopy layer. Progress curves of rust severity (RS) in the upper canopy layer (Fig 3AB) showed significant differences between treatments. Differences between treatments began to show at 45 to 66 DFE and reached maxima at about 59 DFE when disease progress stopped.

Area under the curve for RS in the upper canopy layer produced significant differences between treatments. The magnitude of the differences depended on cultivar, location and year. When the disease severity was high as in Ambo, 1990, differences between treatments were greatest (Fig 3A), especially between treatments 0 and 3 or 4.

The apparent infection rate calculated from RS, r_S, showed significant differences between treatments. High values were observed in SUS (Ambo 1990 and 1993, Fig 3), where differences between treatments were greatest (Table 2). Epidemics in SUS for Debre Zeit, 1991 (not shown), RES in Ambo, 1990 (Fig 3B) and RES in Ambo, 1993 (not shown) were slower than in SUS in Ambo, 1990. In SUS in Ambo (1990), r_S for treatment 0 was about 10 times higher than for treatment 4. For RES, sprayed treatments did not provide consistent trends, though indications for differences between treatments were noticed. Spray treatments provided variation in epidemic development of rust

Table 1. Areas under the curve, AUC, of crop growth and rust progress in beans

Cul	Loc	Treat.	LAI[1]	IN	RSUC	RSMC	RSLC	PDUC	PDMC	PDLC	PSUC	PSMC	PSLC
SUS	AM90	4	93	13	0	1	8	0	1	16	42	32	23
		3	83	47	101	152	8	56	5	21	65	38	19
		2	77	332	325	352	51	244	354	66	85	89	31
		1	65	1350	786	719	79	1948	1060	124	132	102	32
		0	47	3318	1454	833	183	5852	2265	223	167	105	50
	$LSD_{0.05}$		16	1305	557	361	67	2332	893	80	47	33	11
SUS	DZ91	4	130	2049	50	157	50	180	434	87	70	89	81
		3	113	2180	84	283	72	328	932	156	81	95	86
		2	106	2212	98	278	66	442	1076	272	88	100	90
		1	95	1917	117	327	81	538	1235	416	93	103	98
		0	89	2439	176	461	147	764	1418	527	95	111	103
	$LSD_{0.05}$		5	348	21	55	23	101	186	70	6	4	5
SUS	AM93	4	119	251	23	18	1						
		3	98	527	302	308	50						
		2	80	734	600	473	100						
		1	72	923	642	532	106						
		0	58	1030	768	700	135						
	$LSD_{0.05}$		22	292	281	241	49						
RES	AM90	4	103	20	0	0	5	0	0	6	42	28	21
		3	95	40	28	5	7	34	22	26	66	36	32
		2	88	176	195	84	9	266	206	54	97	66	22
		1	85	186	209	427	59	530	257	76	93	73	38
		0	70	972	1194	514	108	2679	935	228	140	113	42
	$LSD_{0.05}$		12	369	462	230	43	1050	355	82	34	32	9
RES	AM93	4	124	90	18	28	1						
		3	111	191	68	106	10						
		2	100	266	119	119	13						
		1	99	273	153	142	15						
		0	87	316	222	219	14						
	$LSD_{0.05}$		13	83	73	64	5						

[1] LAI = Leaf area index; IN = rust incidence; RS = rust severity; PD = pustule density; PS = pustule size; UC = upper canopy layer; MC = middle canopy layer; LC = lower canopy layer; areas under the curve for IN and RS are in percent days; for LAI in days, for PD in number days and for PS in micron days, Cul = cultivar and Loc = location. SUS = susceptible cultivar, Mexican 142; RES = partially resistant cultivar, 6-R-395; AM90 = Amho, 1990; AM93 = Amho, 1993; DZ91 = Debre Zeit, 1991.

but r_S depended also on cultivar, location and year.

Rust severity, middle canopy layer. Severity progress curves of the middle canopy layer (Fig 3CD) generally followed the pattern described for the upper canopy layer. Significant differences among treatments in AUC and r_S were observed in all cases. Differences between treatments were greatest in SUS in Ambo, 1990 and SUS in Ambo, 1993 (Table 1 and Table 2, column RSML). Treatments 0, 1 and 2 in RES did not result in significant differences. Similarly, treatments 3 and 4 did not reveal significant differences for AUC or r_S. Significant differences were located mostly between treatment 0 or 1 and 3 or 4. For RES r_S was lower than for SUS in both 1990 and 1993.

Rust severity, lower canopy layer. Rust epidemics in the lower canopy layer were cut short by early defoliation, resulting in the absence of epidemic trends and lack of significant variation between treatments in AUC and r_S values (Fig 3EF; Table 1 and Table 2). At the earliest date of disease assessment rust was present at the lower canopy layer but because of high rust some leaves dropped early resulting in apparent reduction of rust severity.

Pustule density and pustule size. Progress of rust epidemic as measured by pustule density and pustule size in 1990 and 1991 followed patterns similar to that of rust severity (Fig 4,5; Table 1 and Table 2). However, it may be interesting to note that terminal pustule sizes in Fig 5AB do not differ much for SUS and RES in treatments 0, 1 and 3.

Yield loss

Yield variation was analyzed per cultivar across a range of environments. The reference yield was that of the most frequently treated plots (treatment 4), set to 100 % (Fig 6). Differences among treatments were observed in all experiments. The degree of variation in yield depended on the resistance level of cultivars and the disease severity. For the susceptible cultivar, Mexican 142 (SUS), maximum yield losses were 85, 43 and 60 % at Ambo, 1990; Debre Zeit, 1991; and Ambo, 1993, respectively. For the partially resistant cultivar,

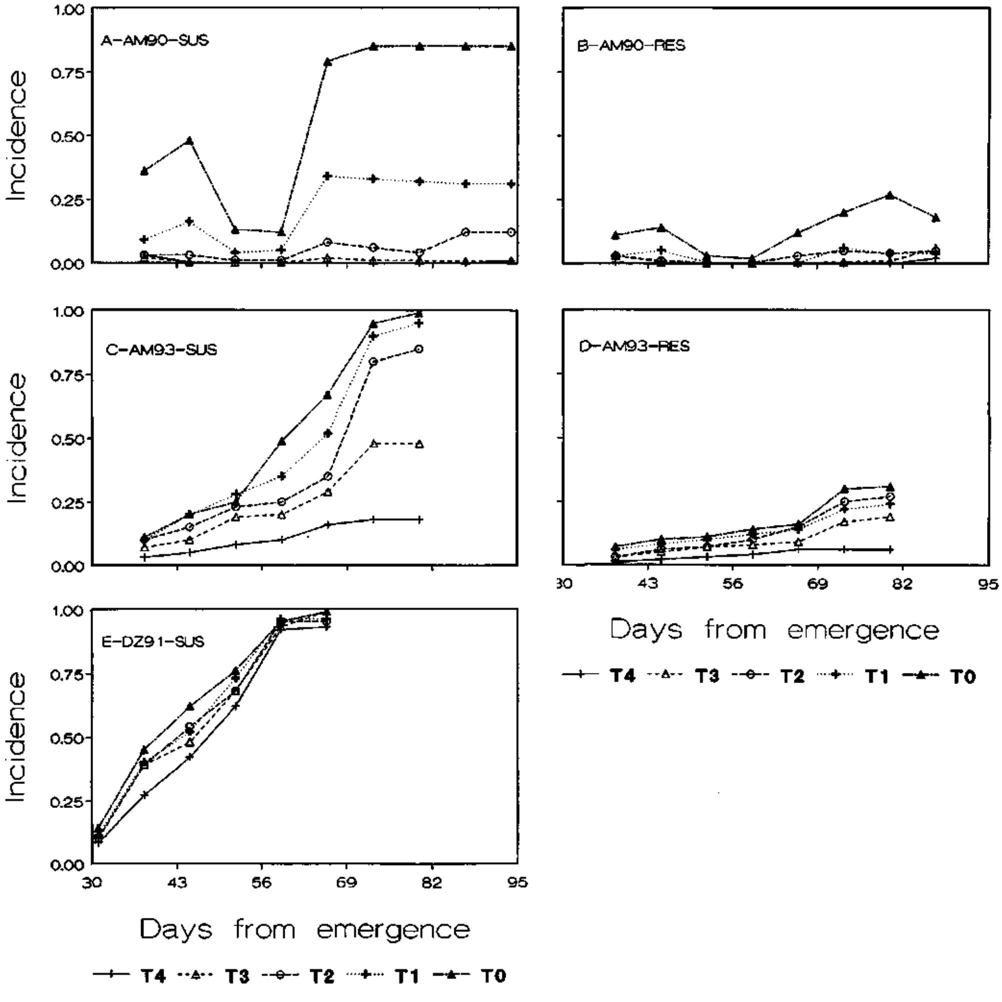


Fig 2. Disease progress curves expressed as rust incidence against time in days from emergence. A = SUS, Ambo, 1990; B = RES, Ambo, 1990; C = SUS, Ambo, 1993; D = RES, Ambo, 1993; E = SUS, Debre Zeit, 1991. T0 - T4 = Spray frequencies (from zero to high)

Table 2. Relative rates of rust development, *r* in beans

Cul	Loc	Treat.	IN	RSUC	RSMC	RSLC	PDUC	PDMC	PDLC	PSUC	PSMC	PSLC
SUS	AM90	4	-0.036	0.000	0.000	-0.133	0.000	0.001	-0.027	0.000	-0.011	-0.034
		3	-0.004	0.043	0.008	-0.096	0.006	0.001	-0.008	0.008	-0.003	-0.024
		2	0.007	0.066	0.049	-0.065	0.008	0.021	-0.007	0.008	0.001	-0.020
		1	0.012	0.086	0.053	-0.038	0.040	0.021	-0.007	0.010	0.002	-0.011
		0	0.016	0.096	0.058	0.012	0.063	0.028	-0.005	0.015	0.005	0.001
	LSD$_{0.05}$		0.020	0.042	0.042	0.054	0.013	0.010	0.019	0.010	0.008	0.015
SUS	DZ91	4	0.024	0.051	0.044	-0.017	0.017	0.001	0.003	0.023	0.027	-0.004
		3	0.024	0.058	0.069	-0.014	0.031	0.017	0.016	0.026	0.028	-0.002
		2	0.024	0.062	0.070	-0.013	0.033	0.019	0.024	0.029	0.028	0.003
		1	0.025	0.068	0.074	-0.016	0.034	0.025	0.031	0.031	0.026	0.001
		0	0.029	0.069	0.077	-0.039	0.041	0.027	0.032	0.031	0.020	0.002
	LSD$_{0.05}$		0.004	0.006	0.013	0.040	0.006	0.008	0.010	0.000	0.065	0.002
SUS	AM93	4	0.019	0.012	0.005	0.002						
		3	0.046	0.026	0.038	-0.049						
		2	0.048	0.032	0.043	-0.089						
		1	0.051	0.040	0.047	-0.055						
		0	0.052	0.042	0.053	-0.069						
	LSD$_{0.05}$		0.018	0.021	0.008	-0.027						
RES	AM90	4	-0.024	0.000	-0.019	-0.076	0.000	0.000	-0.040	0.000	-0.009	-0.041
		3	-0.008	0.010	-0.007	-0.070	0.001	0.002	-0.019	0.008	-0.003	-0.019
		2	0.001	0.027	0.003	-0.053	0.013	0.005	-0.015	0.008	-0.001	-0.018
		1	0.002	0.061	0.000	-0.042	0.013	0.005	-0.006	0.017	0.000	0.016
		0	0.003	0.090	0.002	-0.012	0.035	0.005	-0.002	0.017	0.004	0.014
	LSD$_{0.05}$		0.002	0.035	0.048	0.067	0.013	0.003	0.015	0.013	-0.010	0.019
RES	AM93	4	-0.006	0.026	0.026	-0.007						
		3	0.036	0.037	0.032	-0.051						
		2	0.036	0.041	0.037	-0.046						
		1	0.038	0.045	0.039	-0.027						
		0	0.038	0.048	0.042	0.026						
	LSD$_{0.05}$		0.026	0.010	0.017	0.029						

[1] LAI = Leaf area index; IN = rust incidence, proportion of number of leaves infected; RS = rust severity, proportion of leaf area infected; PD = pustule density, number of pustules per leaf; PS = pustule size, microns; UC = upper leaf layer; MC = middle leaf layer; LC = lower leaf layer. Entries are relative rates of development, for RS these equal the apparent infection rates.
SUS = susceptible cultivar, Mexican 142; RES = partially resistant cultivar, 6-R-395; AM90 = Ambo, 1990; AM93 = Ambo, 1993; DZ91 = Debre Zeit, 1991.

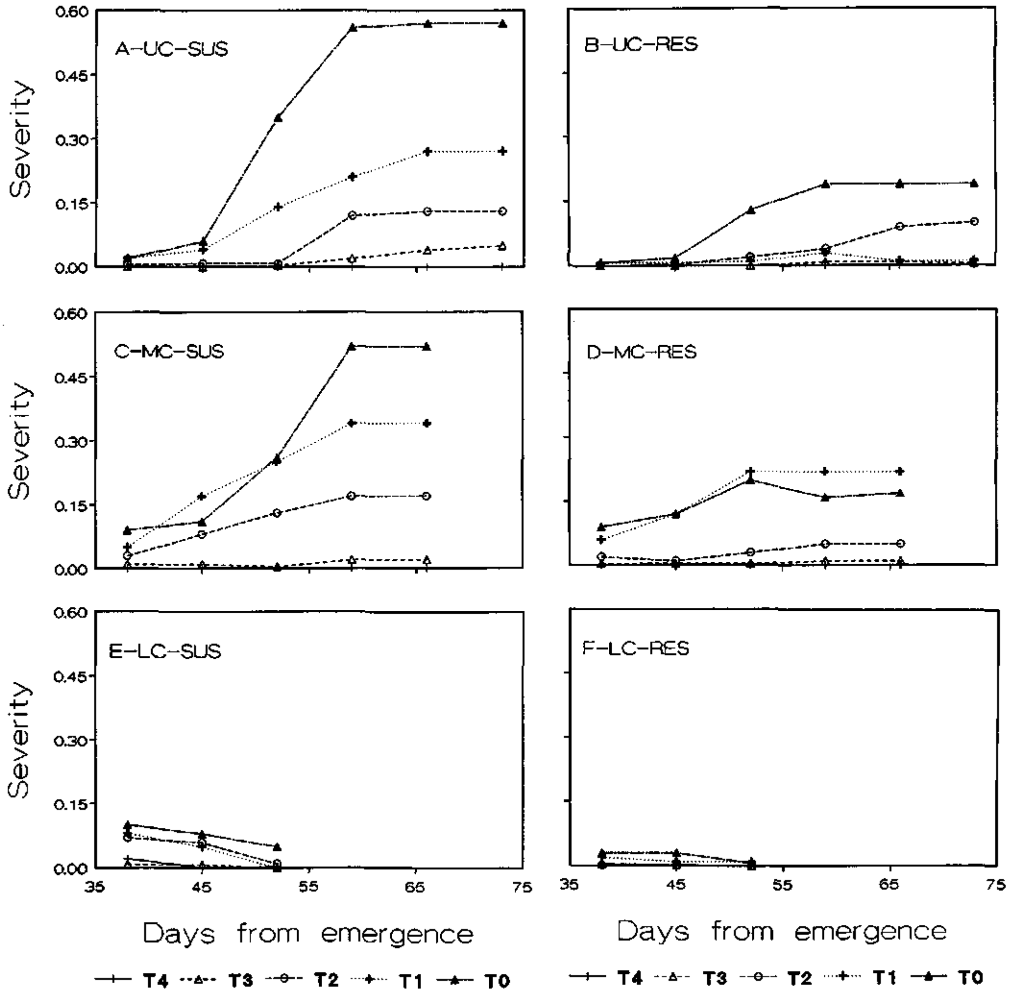
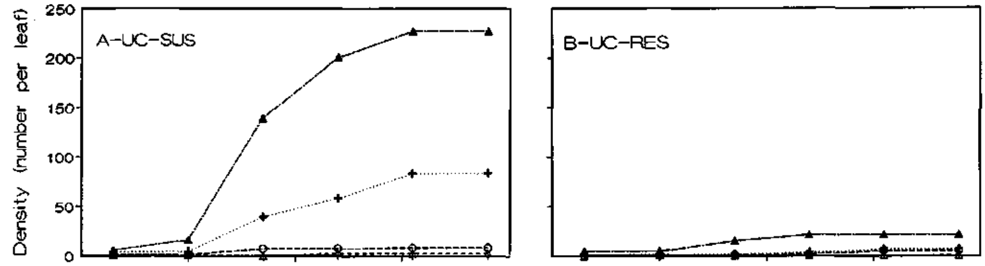


Fig 3. Disease progress curves expressed as rust severity against time in days from emergence, Ambo, 1990. A = SUS, upper canopy layer (UC); B = RES, upper canopy layer; C = SUS, middle canopy layer (MC); D = RES, middle canopy layer; E = SUS, lower canopy layer (LC); F = RES, lower canopy layer



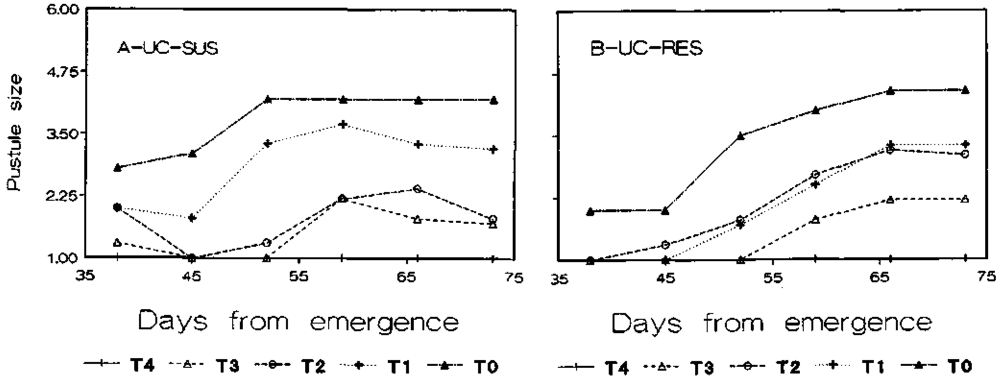


Fig 4 (above). Disease progress curves expressed as pustule density (number of pustules per leaf) against time in days from emergence in the upper canopy (UC). A = SUS; B = RES. Ambo, 1990

Fig 5 (below). Disease progress curves expressed as pustule size (in microns) against time in days from emergence in the upper canopy (UC). A = SUS; B = RES. Ambo, 1990

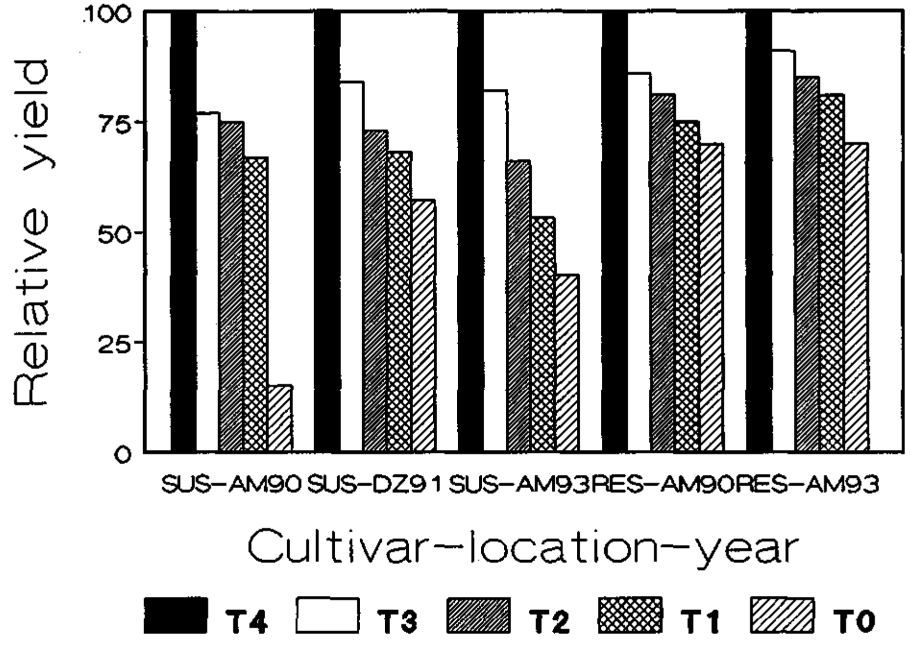


Fig 6. Seed yield, relative to the most frequently sprayed treatment, T4. SUS = susceptible cultivar, Mexican 142; RES = partially resistant cultivar, 6-R-395; AM90 = Ambo, 1990; DZ91 = Debre Zeit, 1991; AM93 = Ambo, 1993; T0 - T4 = Spray frequencies, T0 = check; T1 = 20 days; T2 = 15 days; T3 = 10 days; T4 = 5 days

6-R-395 (RES), maximum yield loss was 30 % in both 1990 and 1993. In all cases, yield loss increased with decreasing spray frequency.

Discussion

Progress curves

LAI. LAI and leaf area duration (LAD) are considered important determinants of yield (Waggoner and Berger, 1987; Savary and Zadoks, 1992). LAI curves of SUS differ significantly for all treatments with greatest variation beginning at 59 DFE, when the disease severity was high, resulting in heavy defoliation and reduction in size of young leaves. The curves follow a general trend, peaking at 52-59 DFE for SUS and 59-66 DFE for RES. The impact of rust on LAI was thus felt after 59 DFE, roughly coincident with the initiation of pod production, stage R7. LAD, LAI integrated over time, gave clear differences between treatments. LAD values were smaller under high disease pressure conditions such as in Ambo, 1990. At low disease severity or in the case of a partially resistant cultivar the values are larger.

The bean growing season is longer in Ambo than in Debre Zeit. At Debre Zeit leaves had completely dropped at 94 DFE while at Ambo plants continued to grow. The difference is due to the extended rainy season (about 138 days for Ambo and 120 days for Debre Zeit) and to the cooler nights at Ambo.

Rust incidence. The increase of rust incidence with time produced differently shaped curves according to location and, perhaps, disease pressure. Under conditions of early and high disease pressure typical dips were observed in the curves, as in Ambo, 1990, both for SUS and RES. In the succeeding years such dips did not occur and incidence values reached their maxima between 66-73 DFE, coinciding with pod initiation. Differences between treatments varied with location and season. In 1990 disease was early and severe and a flush of new leaves not yet sporulating may have resulted in the dips. Consequently, infection rates (averaged over the season) were low. Differences between treatments depended on rust intensity and resistance level. When the disease pressure was high (as in Ambo, 1990), the progress curves showed wide variation resulting in significant differences between epidemics as measured by AUC and progress rate. Differences were greatest from 52 DFE onwards. For SUS in 1991 at Debre Zeit and SUS in 1993 at Ambo, differences in AUC and r_1 remained low and curves showed little variation with time.

Rust severity. The progress of rust severity (RS) generally followed a sigmoid curve, increasing with time and reaching a plateau at 59 DFE (Fig 3). Integration of progress curves over time resulted in significant differences in AUCs between treatments, according to rust pressure, resistance level and canopy layers. Differences were largest for the susceptible cultivar. Maximum differences were obtained in the upper canopy layer. Likewise, differences in apparent infection rate, r_S, depended on cultivar resistance, canopy layer and treatment. The negative values for the lower canopy layer suggest removal of rust from the epidemic process through defoliation and subsequent reduction of severity in that layer. Negative values in treatment 3 and 4 reflect the impact of frequent spray on rust development.

Yield loss

The impact of bean rust on potential yield of beans was large, even under the low external input conditions studied. The impact differed with cultivar, intensity of rust, location and year. The greatest impact was at Ambo, where disease pressure is high. When rust severity reached its highest level yield was reduced by 85 %. In an environment with a moderate disease pressure as in Debre Zeit the highest yield reduction was less (43 %). In the partially resistant cultivar yield was reduced by 30 % at most. The yield loss found in our trial was higher than reported for Kenya (Singh and Musiyimi, 1981) but less than indicated for Ethiopia (IAR, 1974). The yield loss by bean rust was comparable to that reported for bean anthracnose (Shao and Teri, 1985) or soybean rust (Hartman et al., 1991). Yield loss in beans is mainly associated with reduction of pods per plant (Chapter 3). The extent of yield loss caused by bean rust depends on the susceptibility of the cultivar, plant growth stage at which infection occurs and rust intensity (Allen, 1983; Pinstrup-Anderson et al., 1976). Rust intensity was manipulated by varying spray frequencies. Manipulation of epidemics by varying spray frequencies and rate of application was also studied for other diseases, with reasonable success (James, 1974; Shao and Teri, 1985; Williams, 1978).

In Ethiopia bean rust generally appeared at the vegetative stages (Chapter 3). When the environment is conducive to rust development, outbreaks early in the growing season may cause premature defoliation and subsequent severe yield loss (IAR, 1974; Singh and Musiyimi, 1981). Similarly, in a susceptible soybean cultivar, Ogle et al. (1979) found a 95 % yield loss when rust was inoculated prior to flowering.

Our experiment was conducted in research stations, with no external inputs but with relatively fertile soils. Farm operation is dynamic, cropping practices and use of external inputs may change over time. Such dynamic changes will have an effect on the epidemics of diseases and subsequent impact on the damage to beans. To avoid serious losses, the use of partially resistant varieties (Parlevliet, 1978) must be encouraged in any future rust management strategy.

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Chapter 5

REGRESSION MODELS TO ESTIMATE RUST SEVERITY, CROP GROWTH, YIELD AND YIELD LOSS OF BEANS IN ETHIOPIA

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Abstract

Field experiments were conducted in 1990, 1991 and 1993, at Ambo and Debre Zeit, Ethiopia, to determine relationships of damage to crop growth and rust intensity in a bean rust pathosystem. A systemic fungicide was applied at 5 spray frequencies to create differences in rust epidemic. The experiment was carried out in a production situation with low external inputs. Regression models were developed for yield and yield loss by attempting to incorporate leaf area index, and rust incidence and severity in three canopy layers at one or more growth stages. Multiple regression models based on leaf area index and rust severity at growth stages R6 (flowering) and R7B (pod formation) fitted the data with R^2 *values of* ≥ 0.85*. Addition of an incidence parameter did not improve the goodness of fit. Single point models developed at pod formation showed better fit than those developed at or prior to flowering. Models based on crop and disease assessments of the upper canopy layer produced good fit, but the goodness of fit was improved by including data from the middle canopy. For rust management purposes, crop and disease assessments from before flowering up to seed filling stages can be used. For survey purposes models based on assessments at the pod filling stage will be satisfactory.*

Additional key words: haricot beans, leaf area index, multiple regression analysis, *Phaseolus vulgaris,* single point model, multiple point model, *Uromyces appendiculatus*.

Introduction

An economically sound disease control strategy requires an understanding of the relationships between production constraints and damage (Zadoks, 1985). Several damage functions were proposed to estimate yield loss from disease intensity for cereals (James, 1974; Burleigh et al., 1972; King, 1976; Romig and Calpouzos, 1970; Teng et al., 1979). In legumes, which often exhibit another mechanism of yield build-up (Gaunt, 1987), information on such relationships is sparse. Yang et al. (1991) and Schneider et al. (1976) developed yield loss models for soybean rust (*Phakopsora pachyrhizi* Syd.) and cercospora leaf spot (*Cercospora cruenta* Sacc.) of cowpea (*Vigna unguiculata* L.). Savary and Zadoks (1992) developed a model of production constraints for varying production situations in groundnut. The latter model incorporated interaction between production situations (De Wit, 1982) and damage. In bean rust, such information is absent.

Habtu and Zadoks (1994, Chapters 3,4) described cross-sectional and longitudinal analyses (Zadoks, 1978) of the effects of spray treatments on leaf area index and disease intensity per growth stage, and progress of crop growth and disease. In the present paper regression models for the relationships of damage with crop growth and disease intensity in a production situation with low external inputs (as these are considered likely to be relevant in eastern African conditions) are described.

Materials and methods

A data base was provided by experiments conducted at Ambo and Debre Zeit in 1990, 1991 and 1993. Rust epidemics of varying intensities were generated by adjusting the frequency of application of the systemic fungicide oxycarboxin (Bujulu and Lotasarwaki, 1986; Lamamoto et al., 1971) at a rate of 0.1% a.i. The experimental design and the assessment methods for crop growth, disease development and yield components for 1990 and 1991 were reported (Chapter 3). Investigations in 1993 were confined to Ambo. Data collected included leaf

Table 1. Multiple regression equations and coefficients of determination (R^2) values for pods per plant (PP) and seed yield (SY)[1] in bean rust

Independent variables					Dependent variables			
		Severity			PP		SY	
LAI	IN	UC	MC	LC	SUS	RES	SUS	RES
R6	R6	R6	R6	R6	0.91	0.92	0.87	0.89
R6	R6		R6	R6	0.91	0.92	0.85	0.89
R6	R6				0.90	0.92	0.85	0.89
R6		R6	R6	R6	0.91	0.92	0.87	0.89
R6			R6	R6	0.91	0.92	0.85	0.89
R7B	R7B	R7B	R7B		0.92	0.93	0.89	0.89
R7B	R7B				0.92	0.93	0.88	0.89
R7B		R7B	R7B		0.92	0.92	0.89	0.89
R6-R7B	R6-R7B				0.92	0.93	0.89	0.89
R6-R7B		R6-R7B	R6-R7B	R6	0.92	0.93	0.90	0.89
R6-R7B		R6-R7B	R6-R7B		0.92	0.93	0.89	0.89
R6-R7B	R6-R7B	R6-R7B			0.92	0.93	0.89	0.89
R6-R7B	R6-R7B	R6-R7B	R6-R7B		0.92	0.93	0.89	0.89
R6-R7B	R6-R7B	R6-R7B	R6-R7B	R6	0.92	0.94	0.90	0.89

[1] LAI = leaf area index; IN = rust incidence; RS = rust severity; UC = upper canopy layer, MC = middle canopy layer, LC = lower canopy layer; PP = pods plant^{-1}; SY = seed yield in g m^{-2}; SUS = susceptible, Mexican 142; RES = partially resistant, 6-R-395.

area index (LAI), rust incidence (IN), rust severity (RS) in the upper (UC), middle (MC) and lower (LC) canopy layers, number of pods plant^{-1} (PP) and seed yield (SY). Losses in pods plant^{-1} (PL) and seed yield (YL) were estimated using the most frequently sprayed plots as references.

Regression analysis. Stepwise multiple regression analyses (Butt and Royle, 1974; Teng, 1980) were performed using yield and loss parameters as dependent variables and sets of crop and disease parameters as independent variables. Four variables were chosen to represent yield, pods per plant, seeds per pod, seed weight and seed yield. The independent variables were leaf area index, rust incidence, rust severity, pustule density, pustule size, the severity of other diseases and dead tissue, each assessed per canopy layer and at different growth stages (dates). A large number of combinations of independent variables was tested. Any independent variable that was not associated significantly with the dependent variable was discarded. The independent variables that accounted for the greatest amount of variation (high R^2) were retained. The remaining variables were regressed again and those with practical implications retained for analysis, interpretation of data and selection of models for future application. Analysis of variance and multiple regression analysis were performed using the SAS (1985).

Results

Regression models

Multiple regression analyses (MRA) were conducted for several independent variables among which LAI, rust intensity, severity of rust and other diseases, and dead tissue present during different growth stages and at different canopy layers. A number of equations were tested by combining several independent variables. The independent variables selected and the equations computed are given in Tables 1-4. Because of high cultivar by treatment interaction (Chapter 3), models in this paper are presented separately for susceptible (SUS) and partially resistant (RES) cultivars.

Pods per plant (PP). To develop the model we used the combined results of three years for SUS and two years for RES. For SUS we tested 14 combinations of which models using data of growth stage R7B or a combination of R6 and R7B were slightly better than models based on stage R6 (Table 1). Models

Table 2. Multiple regression equations, partial regression coefficients and Coefficients of determination (R^2) for pods per plant (PP) and seed yield (SY)[1] in bean rust

							RS					
			LAI		IN		UC		MC		LC	
Model	Y	a^2	R6	R7B	R6	R7B	R6	R7B	R6	R7B	R6	R2
1.1	PPsus	19.6	0.13	-	-	-	-	-	0.01	-	0.001	0.91
1.2	PPsus	14.8	-	1.86	-	-	-	-0.01	-	-0.02	-	0.92
1.3	PPsus	15.5	-0.47	2.03	-	-	0.05	-0.02	0.01	-0.01	-0.09	0.92
1.4	PPsus	15.8	-0.47	1.97	-0.01	-0.003	0.06	-0.02	-0.01	-0.008	-0.10	0.90
2.1	PPres	24.8	0.75	-	-	-	-0.07	-	-0.01	-	0.04	0.92
2.2	PPres	25.7	-	0.26	-	-	-	0.01	-	0.01	-	0.93
2.3	PPres	24.3	0.64	0.24	-	-	-0.07	0.01	-0.03	0.04	0.06	0.93
2.4	PPres	23.9	0.37	0.52	0.004	-0.07	-0.05	0.03	-0.04	0.04	0.06	0.94
3.1	SYsus	245	3.1	-	-	-	-1.30	-	0.28	-	0.93	0.85
3.2	SYsus	177	-	25.4	-	-	-	-0.51	-	0.06	-	0.89
3.3	SYsus	185	-4.69	27.9	-	-	-0.58	-0.50	0.44	0.003	1.43	0.92
3.4	SYsus	190	-5.24	27.3	0.49	-0.20	-0.28	-0.48	0.56	0.02	1.27	0.90
4.1	SYres	300	-5.37	-	-	-	0.81	-	-0.09	-	1.14	0.89
4.2	SYres	305	-	7.37	-	-	-	-0.26	-	0.36	-	0.89
4.3	SYres	307	3.79	-5.12	-	-	1.39	-0.51	-0.43	0.69	1.49	0.89
4.4	SYres	309	-5.88	-4.27	-0.69	0.15	1.36	-0.54	-0.43	0.67	1.51	0.89

[1] LAI = leaf area index; IN = rust incidence; RS = rust severity; UC = upper canopy, MC = middle canopy, LC = lower canopy; PP = number of pods plant^{-1}; SY = seed yield in g m^{-2} ; SUS = susceptible, Mexican 142; RES = partially resistant, 6-R-395.

[2] a = intercept, other entries are partial regression coefficients, - = not relevant

[3] R6 = flowering stage, R7B = pod setting stage, second week, R^2 = coefficient of determination, significant at $p \leq 0.05$

with LAI and severity of rust were slightly better than those with LAI and rust incidence. All models resulted in R^2 values explaining ≥ 90 % of the variation in PP. The best equations for PP contained two or three input variables at both R6 and R7B. When R6 and R7B were taken both, the combined use of LAI, rust incidence and severity of rust did not improve the R^2 value. For PP, middle and lower canopy layers were determinant since removal of the upper canopy layer did not change R^2. Generally, R^2 values were highest at stage R7B. For SUS the best models were models 1.1 - 1.4 (Table 2).

For RES, at R6 the use of incidence or severity variables did hardly affect R^2 values. When R6 and R7B were combined, models based on LAI and incidence showed a slight improvement. Models 2.1 - 2.4 (Table 2) were selected. Models 1.1, 1.2, 2.1 and 2.2 are single point models, with either R6 or R7B, while models 1.3, 1.4, 2.3, and 2.4 are two-point models.

Seed Yield (SY). For yield of SUS the best models were based on LAI and severity at two growth stages (Table 1), with R^2 values $\geq$ 85 % of the variation. Generally, models based on R7B or on a combination of R6 and R7B resulted in R^2 value $\geq$ 89 % of the variation (models 3.2 - 3.4; Table 2). Inclusion of incidence did not affect the relationship, but exclusion of severity at upper canopy reduced R^2 by 1-3 %. For SUS a combination of LAI and severity at growth stage R6 gave an acceptable model explaining 85 % of the variation (model 3.1). For a similar combination at R7B R^2 increased by 4 % (model 3.2). In these two cases addition of incidence variable did not improve the model. For RES the 14 models did not show substantial differences. For all practical purposes models 4.1 - 4.4 were considered satisfactory.

Pod loss (PL). With SUS the best equations for PL were models 5.1 - 5.4 (Table 4) explaining $\geq$ 83% of the variation. Models using R6 (models 5.1 and 6.1) showed a 1 - 2 % improvement over R7B models (models 5.2 and 6.2). For both SUS and RES exclusion of incidence did not change R^2 but exclusion of severity in the upper canopy resulted in lower R^2 values. For SUS, severity at R6 was more important than incidence. For RES inclusion of rust severity at lower canopy did not improve R^2 (Table 3).

Yield loss (YL). For SUS, YL was best estimated by models including variables at both stages R6 and R7B (Table 3). Addition of incidence or subtraction of severity at lower canopy did not affect the outcome. The best models explained

Table 3. Multiple regression equations and coefficients of determination (R^2) values for pod loss (PL) and seed loss (YL)[1] in bean rust

Independent variables					Dependent variables			
		Severity			PL		YL	
LAI	IN	UC	MC	LC	SUS	RES	SUS	RES
R6	R6	R6	R6	R6	0.83	0.80	0.83	0.75
R6	R6		R6	R6	0.83	0.79	0.80	0.74
R6	R6				0.82	0.79	0.80	0.73
R6		R6	R6	R6	0.83	0.80	0.83	0.74
R6			R6	R6	0.83	0.79	0.80	0.73
R7B	R7B	R7B	R7B		0.85	0.82	0.85	0.73
R7B	R7B				0.85	0.82	0.85	0.72
R7B		R7B	R7B		0.85	0.79	0.85	0.73
R6-R7B	R6-R7B				0.86	0.82	0.85	0.73
R6-R7B		R6-R7B	R6-R7B	R6	0.86	0.80	0.86	0.76
R6-R7B		R6-R7B	R6-R7B		0.86	0.80	0.85	0.74
R6-R7B	R6-R7B	R6-R7B			0.86	0.83	0.85	0.74
R6-R7B	R6-R7B	R6-R7B	R6-R7B		0.86	0.83	0.86	0.76
R6-R7B	R6-R7B	R6-R7B	R6-R7B	R6	0.86	0.84	0.87	0.77

[1] LAI = leaf area index; IN = rust incidence; RS = rust severity; UC = upper canopy layer, MC = middle canopy layer, LC = lower canopy layer; PL = loss in pods plant^{-1}; YL = loss in seed yield in g m^{-2}; SUS = susceptible, Mexican 142; RES = partially resistant, 6-R-395.

86 % of the variation (models 7.3 and 7.4, Table 4). These models showed a 1 - 4 % improvement in R^2 over models for either R6 or R7B (models 7.1 and 7.3). Again, addition of incidence gave no improvement.

For RES the trend was similar to SUS. Models 8.1 and 8.2, which consider variables at either R6 or R7B, explained 73 and 74 % of the variation. No information was lost by excluding incidence. Models 8.3 and 8.4, which consider R6 and R7B simultaneously, were marginally better. For RES the percent variation in yield loss explained by all 14 models was relatively low, in the range of 72 % to 77 %.

Discussion

Multiple regression models

Models linking disease intensity (rust incidence or severity of rust) and crop growth (LAI) seem to be a realistic approach to crop loss studies (Mackenzie and King, 1980). The relation between severity and yield is often disappointing (Waggoner and Berger, 1987) because the effect of severity is different for early and late observations, or because defoliation is not included in severity assessment. In our model we tried to incorporate LAI, rust incidence and rust severity in three canopy layers at one or more growth stages in a multiple regression analysis. Two - point equations based on LAI and severity explained the relationship better than single point equations based on LAI and incidence or severity. Equations at later growth stages showed better fit than at earlier growth stages. For bean cultivars with indeterminate growth habit, the growth stages R5 or R6 might be a bit early to estimate yield or yield loss but for cultivars with determinate growth R6 could be used. At Ambo the inoculum arrived early and the onset of an epidemic can be at the vegetative stage. Here, it is believed that equations at growth stage R6 will give a better estimate of yield or yield loss.

The results obtained here confirm those of others (Teng et al., 1979). An assessment at one critical growth stage may be adequate but a better fit can be obtained by using assessments at more growth stages. Although models based on the upper canopy layer were satisfactory, they were improved by including data from the middle canopy layer. The dynamics of yield build-up in legumes is unclear and it is not known which nodes contribute most to the final yield (Debouck, 1991). The ability of a model to estimate yield and yield loss accurately is judged by its applicability under different environments (Zadoks and Schein, 1979). Our models incorporated data covering a fairly wide range

Table 4. Multiple regression equations, partial regression coefficients and Coefficients of determination (R^2) for pod loss (PL) and seed loss (YL)[1] in beans

							RS					
			LAI		IN		UC		MC		LC	
Model	Y	a[2]	R6	R7B	R6	R7B	R6	R7B	R6	R7B	R6	R2
5.1	PPLsus	5.9	-0.12	-	-	-	-0.004	-	-0.005	-	0.11	0.83
5.2	PPLsus	11.0	-	-1.94	-	-	-	0.01	-	-0.003	-	0.85
5.3	PPLsus	10.2	0.48	-2.11	-	-	0.04	0.02	-0.02	0.002	0.08	0.86
5.4	PPLsus	9.8	0.49	-2.03	0.01	0.01	-0.05	0.02	-0.02	0.001	0.08	0.86
6.1	PPLres	0.61	-0.75	-	-	-	0.07	-	0.01	-	-0.04	0.80
6.2	PPLres	0.28	-	-0.26	-	-	-	-0.01	-	-0.01	-	0.79
6.3	PPLres	1.07	-0.64	-0.24	-	-	0.07	-0.01	0.03	-0.03	-0.06	0.80
6.4	PPLres	1.48	-0.37	-0.52	-0.004	0.07	0.05	-0.03	0.04	-0.04	-0.06	0.84
7.1	SYLsus	54	-3.09	-	-	-	1.30	-	-0.28	-	-0.93	0.83
7.2	SYLsus	122	-	-25.3	-	-	-	0.51	-	-0.06	-	0.85
7.3	SYLsus	114	4.70	-27.9	-	-	0.58	0.50	-0.43	-0.00	-1.43	0.86
7.4	SYLsus	109	5.24	-27.3	-0.49	0.20	0.28	0.48	-0.56	-0.02	-1.27	0.87
8.1	SYLres	-10.3	7.21	-	-	-	-1.64	-	0.06	-	-1.13	0.74
8.2	SYLres	-1.2	-	3.29	-	-	-	0.07	-	-0.45	-	0.73
8.3	SYLres	-9.4	7.35	0.31	-	-	-2.15	0.40	0.53	-0.85	-1.66	0.76
8.4	SYLres	-10.5	11.4	-2.12	1.29	0.09	-2.18	0.37	0.56	-0.83	-1.68	0.77

[1] LAI = leaf area index; IN = rust incidence; RS = rust severity; UC = upper canopy layer, MC = middle canopy layer, LC = lower canopy layer; PL = loss in number of pods plant^{-1}; YL = loss in seed yield in g m^{-2} ; SUS = susceptible, Mexican 142; RES = partially resistant, 6-R-395.

[2] a = intercept, other entries are partial regression coefficients, - = not relevant

[3] R6 = flowering stage, R7B = pod setting stage, second week, R^2 = coefficient of determination, significant at $p \leq 0.05$,

of growing conditions.

Farmers in Ethiopia use different cultivars to suit their needs. The cultivars vary not only in their susceptibility to bean rust but also in their growth habit and use. In view of the large differences between cultivars, separate regression models should be developed for cultivars representing defined resistance classes (categories). More information is needed in this area.

Applications. Yield loss models could have several applications be it in the area of planning, market development or rust management (Zadoks, 1985). Under current Ethiopian conditions an important issue is when to assess crop and disease parameters to accurately estimate yield or yield loss. Yield and yield loss equations established at growth stages R6 and R7B are acceptable for application in practice. For extension specialists a fair estimate of yield or yield loss can be achieved by a single assessment at R7 (Models 3.2 and 4.2 for SY). For policy decisions, where yield loss estimates may be the objective, models 7.2 and 8.2 may be applied. For rust management purposes, crop and disease assessments starting at or before flowering (R5 and R6) will give a realistic estimate. The dates of field operations, especially sowing, vary from field to field even within one region. It is thus recommended that field visits coincide with the growth stages (R6-R7B) described above, where possible.

The magnitude of yield loss depend in part on the amount of inoculum arriving during the vegetative stage. A model which covers this aspect of epidemiology would explain yield and yield loss fairly accurately, and thus help in the management of rust. Generally the equations accounted for a fairly high proportion (74 - 92 %) of the variation. Part of the unexplained variance could be due to variables and interactions not included. Other diseases such as common bacterial blight (*Xanthomonas campestris* pv *phaseoli* (Erw. Smith) Dowson, anthracnose (*Colletotrichum lindemuthianum* (Sacc. and Magn) Bri. and Cav.) and ascochyta blight (*Phoma exigua* (Desm)), insect pests and dead tissue (necrosis by unknown causes) occur simultaneously with rust (Chapter 3). Knowledge of the role of these diseases either independently or in a multiple pathosystem will further improve the accuracy of estimation of bean yield and yield loss. An understanding of this dynamic relationship will help us develop an acceptable disease management strategy. The study reported here emphasised seed yield and gave little attention to the effect of diseases on seed quality and straw weight which are important to the Ethiopian farmer, especially in areas where seed is produced for cash and straw for fodder. Understandably, there is lack of information on the quantitative relationship of these factors. An overall crop management strategy necessitates a better knowledge of these relationships.

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Chapter 6

FOCUS EXPANSION OF BEAN RUST IN CULTIVAR MIXTURES

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Abstract

Radial expansion of foci in mixtures of susceptible and resistant bean cultivars was studied at two sites in Ethiopia. The foci expanded in a wave-like fashion. At Ambo (1990), radial expansion velocity ranged from 6 cm per day, in mixtures with 20 % susceptible plants, to 15 cm per day, in plots with the susceptible plants only. At Debre Zeit, the velocity ranged from 3 cm per day, in a mixture with 20% susceptible plants to 16 cm per day in plots with 100 % susceptible plants. At both sites the radial expansion velocity of foci correlated linearly with the logarithm of the fraction susceptible plants in the mixture. Velocities of focus expansion at Ambo and Debre Zeit were approximately equal in plots consisting of susceptibles only. At lower proportions of susceptible plants the velocities at Debre Zeit were smaller than at Ambo. Indications were given as to the environmental factors responsible for the observed difference between sites. At each site, variation between plots showed a clear spatial pattern. Environmental factors probably responsible for these spatial patterns are discussed.

Additional key words. Crop growth, common bean, erosion, *Phaseolus vulgaris* L., *Uromyces appendiculatus*, velocity of focus expansion, water logging, wetting period, wind direction.

Introduction

Modernization of agricultural practice resulted in a drastic decline in inter- and intra-specific diversity, which led to an increase in the frequency and intensity of epidemics (Mundt, 1989; Zadoks and Schein, 1979). The widespread use of single resistance genes over large areas aggravated the problem. Alternative approaches for better management of diseases and disease resistance genes, such as mixed populations (Borlaug, 1958), intercropping (Van Rheenen et al., 1981), and inter- and intra-specific diversity (Groenewegen and Zadoks, 1979; Jensen, 1952; Wolfe, 1985; Zadoks, 1958 and 1959), were suggested.

In small-grain cereals, the use of varietal mixtures and their potential to control diseases and stabilize yield was extensively studied. The effectiveness of varietal mixtures in reducing the rate of disease progress was established both experimentally (Barrett, 1978; Jeger et al., 1983; Zadoks, 1958) and by computer simulation (Mundt and Leonard, 1986; Mundt et al., 1986; Kampmeijer and Zadoks, 1977). The rate of disease progress can be measured by the velocity of focus expansion (Minogue and Fry, 1983a,b; Van den Bosch et al., 1988a,b,c). Focal expansion reaches a constant velocity, after an initial phase of focus build up (Kampmeijer and Zadoks, 1977). Factors such as level of resistance, genetic heterogeneity, plant density, temperature, wind and stochasticity of spore dispersal can influence the velocity of focus expansion, as was illustrated experimentally (Buiel et el., 1989), analytically (Minogue and Fry, 1983a,b; Van den Bosch, 1993; Van den Bosch et al., 1990), and by computer simulation (Zadoks and Kampmeijer, 1977; Zawolek, 1989; Zawolek and Zadoks, 1992).

Van den Bosch et al. (1988c) developed a model to describe the relationship between the velocity of focus expansion, c, and the proportion of susceptibles in a mixture, f. They showed that

$$c = \mathrm{A} + \mathrm{B} \ln (f) \qquad 1$$

The velocity of focus expansion, c, increases linearly with the logarithm of the proportion of susceptible plants in a mixture, *f*. The purpose of the present study is to examine this relationship for bean rust (*Uromyces appendiculatus*), in mixtures of resistant and susceptible common bean (*Phaseolus vulgaris* L.) cultivars, in two different environments.

Materials and methods

The experiment was conducted during the main crop growing seasons (June-October) in the research stations of the Institute of Agricultural Research at Debre Zeit (1991) and the Phytopathological Laboratory at Ambo (1990), Ethiopia.

Experimental design. The experiment was carried out in a 5 * 5 latin square design. The plot size was 4 m * 4 m. Each plot was surrounded by a 2.4 m broad strip planted with wheat. There were five treatments with the mixing proportions of 1:0 (twice, one treatment as a check without a focus and the other one with focus), 1:1, 1:2 and 1:4 susceptible (Mexican 142) to resistant (Negro Mecentral) plants. Seeds of the susceptible and resistant cultivars were mixed manually. From this mixture one seed at a time was drawn randomly and placed along the row at a distance of 10 cm between seeds. Each plot consisted of 10 rows of bean plants, planted at 40 cm between rows. One row of resistant beans was planted around each plot to reduce interplot interference.

Establishment of infected plants. Four seeds of the susceptible bean cultivar were sown along with the test seeds at the centre of each plot. At about three weeks after sowing, in four of the five treatments, two of the four plants were removed and the remaining plants were inoculated with rust suspensions to establish the foci. Inoculated plants were covered with plastics for 24 hours to ensure high humidity for infection. The check plot, planted with only the susceptible cultivar, was left uninoculated to serve as a control.

Observations. Observation grids (made of plastic string) with grid cells of 0.40 m * 0.40 m were placed over the plots, with the inoculated plants in the central cell. Thus, each plot was divided into 100 cells. The development of the foci was monitored weekly by counting the number of open pustules per grid cell. The numbers of pustules were counted on three trifoliolate leaves at the third, fifth and ninth leaf positions (from the top) representing the top, middle and bottom canopy layers, respectively. When the number of pustules per leaf exceeded 50, the numbers were estimated in intervals of ten. To prevent cross-infection between plots during observation, boots and hands of observers were cleaned before entering the next experimental plot. The observations continued until the bean plants reached full maturity though leaves were still green. Data were expressed as the mean number of pustules per leaf and per grid cell for each plot, after averaging over the three canopy layers.

Velocity of focus expansion. The rate of focus expansion was large compared to the plot size used. This implies that the area within which disease severity exceeded a chosen value increased from zero to more than the plot area within one to one-and-a-half weeks. In such situations the area method of Van den Bosch et al. (1990) cannot be used. Therefore we applied the gradient method described by Buiel et al. (1989). Using the observation grid, the average number of pustules was calculated at distances of 20, 60, 100, 140 cm and 180 cm from the focal centre. These averages were based on a variable number of grid cells. Theoretically, the tail of the disease profile is exponential. For each plot the logarithm of the number of pustules was plotted as a function of the distance from the focal centre (Fig 1). Parallel straight lines were fitted using the program STATGRAPHICS. From these lines the horizontal distance travelled by the disease profile was measured relative to the first observation date. Plotting these distances as a function of time (Fig 2), a straight line resulted from which the velocity of focus expansion can be calculated.

Results

Beans at Debre Zeit grew more vigorously and matured earlier than at Ambo. The bean rust epidemics originating from the point sources, established by inoculation, continued to intensify and expand throughout the growing season

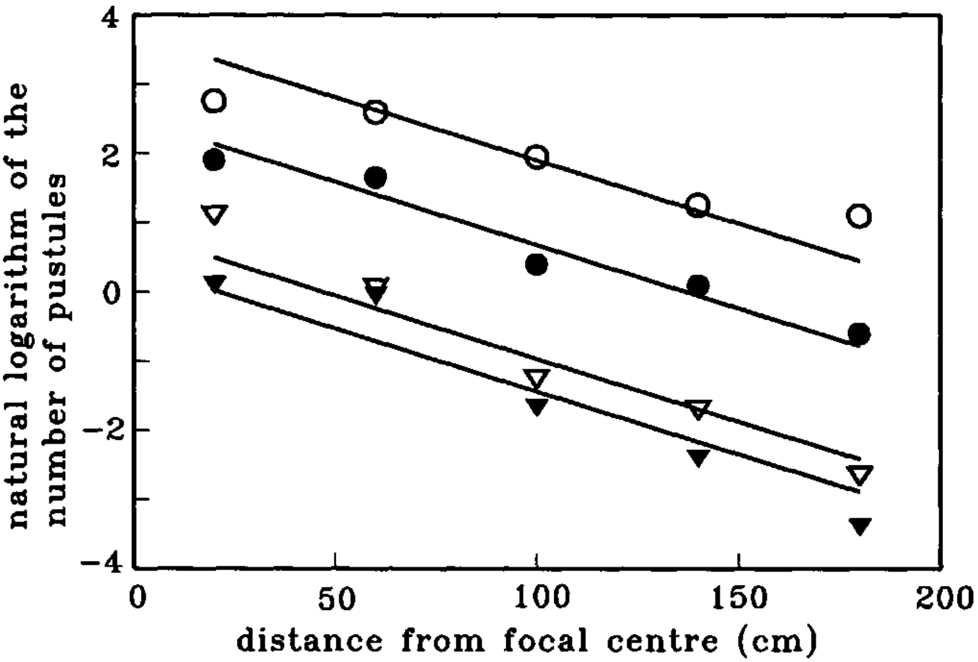

Fig 1. Focus development of bean rust in cultivar mixtures. The natural logarithm of the number of pustules is plotted against distance from the focal centre in cm. Parallel lines are fitted at four successive dates. (▼) = 10 days after inoculation (DAI), day 0; (▽) = 17 DAI, day 7; (●) = 24 DAI, day 14; (○) = 31 DAI, day 21

at both locations. Disease intensity at and near the focal centres was higher at Ambo than at Debre Zeit. At Debre Zeit, due to waterlogging of some plots in one of the replications, only 4 replications were used in the analysis. The rust infection in the control plots was negligible, and therefore we did not adjust the data for interference by inoculum from outside sources.

Velocity of focus expansion was plotted as a function of the natural logarithm of the fraction of susceptible plants (Fig 3). The velocity of focus expansion at Ambo ranged from 6 cm to 15 cm day^{-1} and for Debre Zeit from 3 cm to 16 cm day^{-1}. The velocity of focus expansion, *c*, showed variation between plots (wide scattering of dots) and within plots (high standard deviations). The fitted line for Debre Zeit was steeper than for Ambo. The probability that the two lines have the same slope is $p = 0.08$. In plots with susceptible plants only ($f = 1$), the velocities, *c*, did not differ between

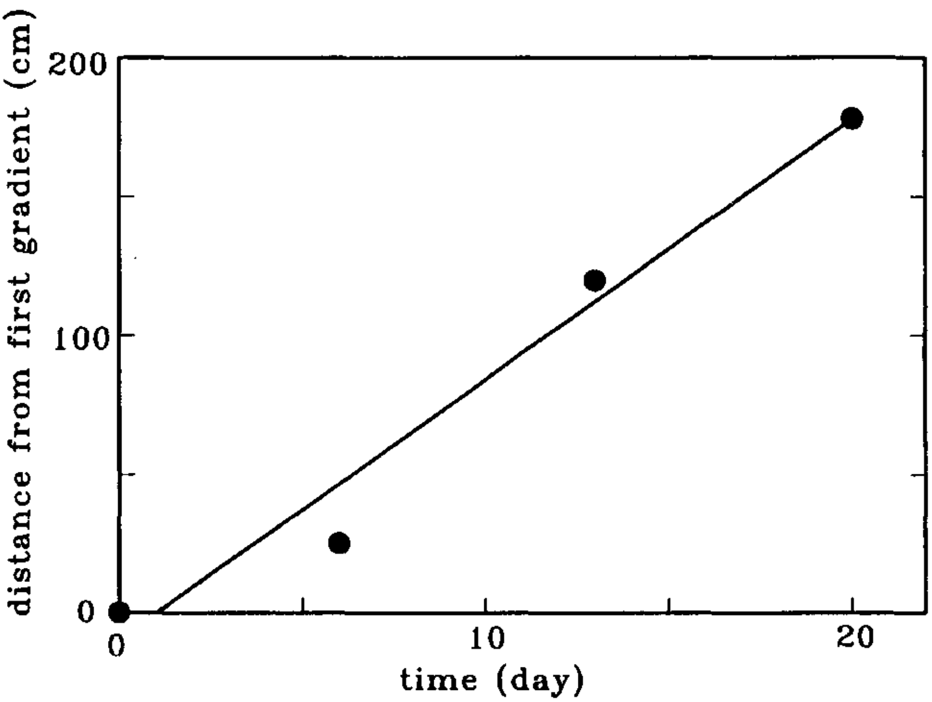

Fig 2. Focus development of bean rust in cultivar mixtures. The distance in cm of a disease gradient in Fig 1 from the first disease gradient is plotted against time in days. The radial velocity of focus expansion per plot was calculated from the straight line. Dots represent successive observations

locations. When the fraction of susceptible plants was low ($f = 0.2$), the velocity, c, at Debre Zeit was smaller than at Ambo. The agreement between the observed data and the model was fair to good for both locations.

The spatial arrangement of the plots is shown in Fig 4. The signs indicate whether the observed velocity is larger (+) or smaller (-) than the velocity calculated from the fitted lines. The clustering of positive and negative signs in the field is noticeable. At Ambo (1990) most of the negative signs are clustered in the West of the field as indicated by the broken curve. At Debre Zeit (1991), six of the 7 positive signs are located in the north western section of the field.

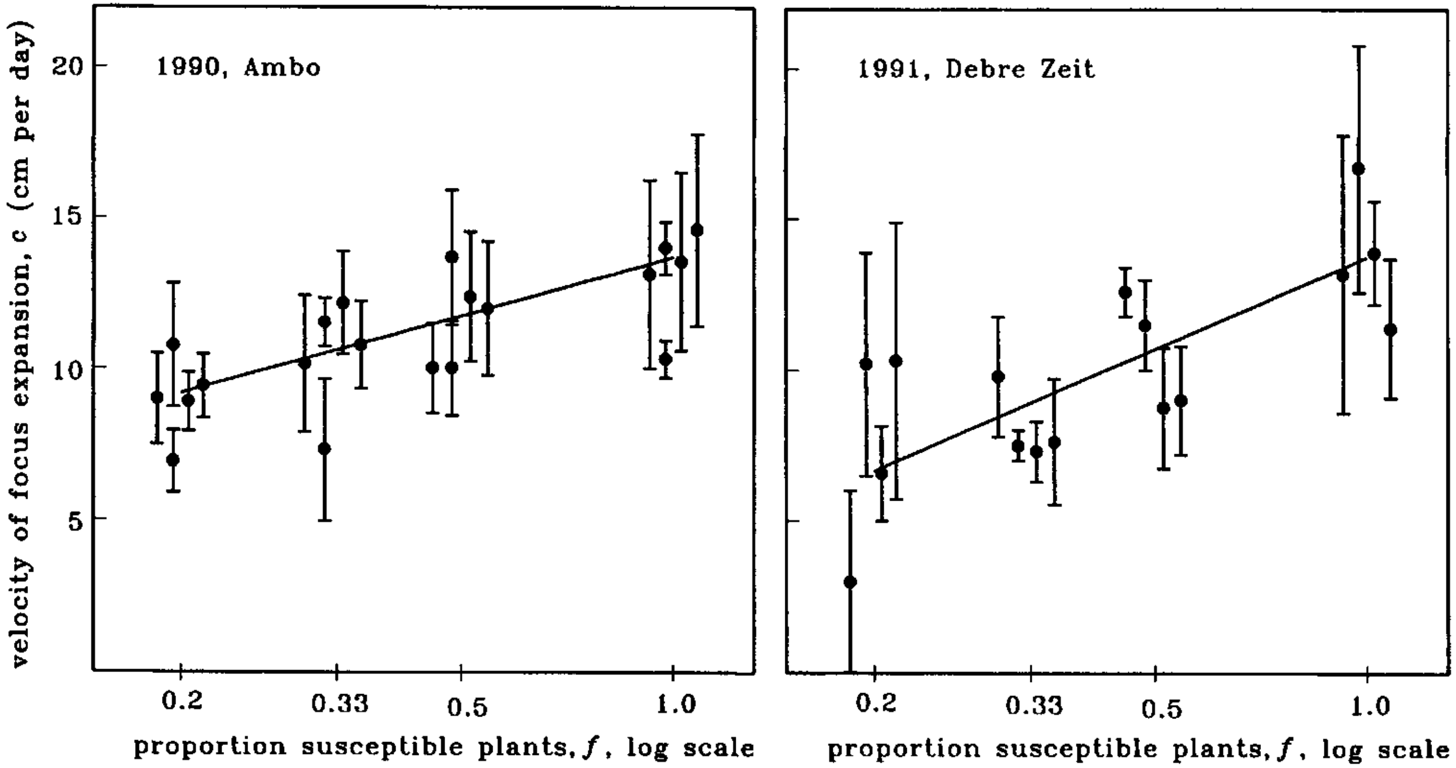

Fig 3. The velocity of focus expansion, *c*, as a function of the proportion of susceptible plants, *f*, in the experimental plots. Dots represent observed *c* values (means per plot), vertical bars their standard deviations. Data points are scattered slightly in the horizontal direction to avoid obscuring data points in similar positions. The drawn line is fitted according to equation 1

Discussion

In this paper we showed the velocity of focus expansion, c, to be proportional to the logarithm of the fraction of susceptible plants in the mixture, f, as predicted by the model of van den Bosch et al. (1988c). There are, however, clear variations between and within experiments. In this discussion we suggest possible explanations of these variations.

There were *within plot variations*. The sequential observations as plotted in Fig 2 show variation around the regression line which can be expressed in terms of a standard deviation. Fig 3 shows that these within plot standard deviations are relatively high, suggesting high variability of c in time. In calculating the focus expansion velocity, c, two methods, the area method (van den Bosch et al., 1990) and the gradient method (Buiel, et al., 1989), can be used. Studies made on cereal rusts indicated that standard deviations in the gradient method, which was rather sensitive to the presence of daughter foci and background noise, were much larger than in the area method. The area method is generally recommended for calculating c but for relatively small plot sizes, as in this study, it was not applicable.

Variability between plots of similar experiments was evident, suggesting systematic differences between plots. Differences between plots can be caused by several factors including wind speed and direction, experimental position relative to ditches, water logging, and presence or absence of trees in the surrounding areas, and so on. Wind influences the speed and shape of epidemics (Gregory, 1973; Okubo, 1980; Zawolek, 1993). During the crop growing season (June-October) the prevailing wind direction was south west. Fig 4 shows no obvious relationship between the wind direction and the + or - signs. The differences in velocity of focus expansion between plots within locations did not depend on wind direction. The experiment at Ambo was surrounded by tall trees (west) on one side and up-hills (south) on the other. The experiment at Debre Zeit was in an open field. Environment of the fields does not explain the spatial variation observed at the two locations. Both fields had a light slope and the spatial distribution of the signs rather corresponded with the direction of the slope of the fields.

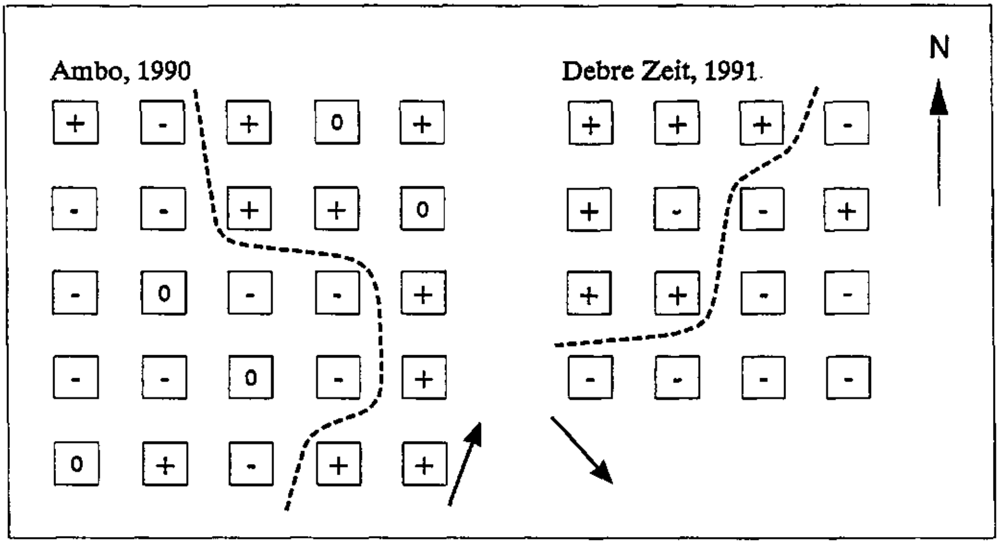

Fig 4. Positions of bean plots. The signs with each plot indicate whether the numerical values of the observed velocity of focus expansion, *c*, are larger (+) or smaller (-) than the values calculated by equation 1. (0) = non-inoculated control

The most likely explanation of the sign clusters was a gradient in the experimental field created by either water logging (Debre Zeit) or erosion (Ambo) due to water. Both could result in low availablility of nutrients, mainly N, to the plant, in Debre Zeit at the lower end of the field, in Ambo at the upper end. Several studies suggest an increase of rust and mildew diseases with increasing application of nitrogen fertilizers (Leich et al., 1987; Jenkyn et al., 1983; Nazim et al., 1982). At low N biotrophic fungi such as rust develop poorly (Zadoks and Schein, 1979), which would result in lower values of *c*. Systematic differences between plots resulting in a varying *c* were also observed in other studies (van den Bosch et al., 1990).

The difference in slope between the regression lines of Fig 3 may be explained by variation in environmental conditions. Differences of velocity between location could arise from variations in crop growth, wind speed, turbulance, periods of leaf wetness and so on. At low *f* the velocity *c* is higher at Ambo than at Debre Zeit but at high *f* the velocity is about equal.

Van den Bosch et al. (1988c) showed that the velocity of focus expansion is proportional to the logarithm of the fraction of susceptible plants. The formula does not give insight in the dependence of the velocity on parameters other than net reproductive rate, relative rate of spore production (time kernel) and spatial distribution of infection (primary gradient). The difference between the two experiments in the slope of the regression lines relating focus expansion velocity to the logarithm of the fraction of susceptible plants can only be attributed to the effect of other parameters. Thus, the formula of van den Bosch et al. (1988c) must be extended.

Consider a line source parallel to the front of the focus. The number of pustules produced by this line source at a distance x from this source is:

$$N(x) = \gamma S_0 f \frac{1}{\sqrt{2}} \frac{1}{\sigma} \exp[-\sqrt{2}\frac{1}{\sigma}|x|] \qquad 2$$

where σ is the standard deviation of the distance of daughter lesions from the line source, *f* is the proportion of susceptible plants in the mixture and γS_0 is the net reproductive value of the disease. This net reproductive value is the total number of daughter lesions produced by one mother lesion during the whole course of its life if it is continuously surrounded by susceptible only. Define the effective distance, X_{eff}, as the distance beyond which N(x) decreases below a certain number, κ. Then

$$X_{eff} = \frac{\sigma}{\sqrt{2}} \ln[\frac{\gamma S_0 f}{\kappa \sigma \sqrt{2}}] \qquad 3$$

The effective distance is a measure of the distance travelled by the focal front in one generation. Therefore the velocity of focus expansion is proportional to the effective distance. Rearrangement of equation 3 leads to

$$C = B + A\sigma \ln(\frac{\gamma S_0}{\sigma}) + A\sigma \ln(f) \qquad 4$$

For plots consisting of susceptibles only, $f = 1$, this implies:

$$c = B + A\sigma \ln (\frac{\gamma S_0}{\sigma}) \qquad 5$$

Using these formulae we can find an explanation for the observed differences in the slope of the regression lines in Fig 3. Weather conditions are much better for infection and sporulation at Ambo than at Debre Zeit. Favourable temperature and dependable rain resulting in long wetness periods lead to a higher net reproduction rate, γS_0, for Ambo than for Debre Zeit. Increasing wetness periods may increase germinability of rust spores (Imhoff, 1981). Prolonged periods of rain can also reduce the dispersion of the urediniospores, essentially dependent on wind (Amorim et al., 1994). The experimental field at Ambo was partly bordered by high earth walls and tall trees, which reduced the effect of wind and turbulence and thus reduced σ in Ambo more than in Debre Zeit. Such interacting conditions could result in almost equal velocities for $f = 1$ at the two locations (equation 5), yet at the same time resulting in different slopes of the regression lines in Fig 3AB. The standard deviation of the distance travelled by spores at Ambo is smaller than at Debre Zeit,

$\sigma_A < \sigma_{DZ}$, as argued above.

Low σ results in small slopes and high σ results in large slopes (equation 4). We conclude that differences in slopes at the two sites might be explained by differences in the environmental factors.

The potential of cultivar mixtures to reduce foliar fungal disease is extensively studied (Buiel et al., 1989; Jeger et al., 1983; Mundt and Leonard, 1986; van den Bosch et al., 1990) in cereals. Based on the results obtained from replicated focal epidemics in two locations, we conclude that cultivar mixtures have potential for reducing foliar fungal diseases in beans too. This disease suppressive potential may be one reason why farmers in Ethiopia used varietal mixtures (Westphal, 1974; IAR, 1991). We also conclude that both at Ambo and Debre Zeit radial expansion of bean rust epidemics in bean cultivar mixtures originating from a point source was proportional to the logarithm of the proportion of susceptibles in the mixture as described by Van den Bosch et al. (1988c). We believe that more can be gained by incorporating other parameters such as wind, canopy (LAI or LAD), leaf wetness duration or a measure of partial resistance in the model.

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Chapter 7

STUDIES ON COMPONENTS OF PARTIAL RESISTANCE IN BEAN RUST

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Abstract

Common bean cultivars, obtained from the Ethiopian national breeding program, and cultivars widely grown in the country, 15 in total, were tested in a greenhouse for five components of partial resistance to an Ambo isolate of bean rust. The components examined include latent period (LP_{50}), infection efficiency (IE), sporulation capacity (SC), infectious period (IP) and pustule size (PS). Differences in cultivar responses were found for all PR components. Differences were largest, however, for infection efficiency and sporulation capacity. Cultivars Exrico 23, A 176, Veracruz 10 and BAT 1198 had a high level of PR to the Ambo isolate. Mexican 142, widely grown cultivar in Ethiopia was intermediate whereas Red Wolaita, an important cultivar in the south, showed a low level of PR. Linear correlations between LP_{50} and IE, and between SC and PS were high. Linear correlations between IE, SC, or PS with IP were not significant. Though differences in cultivar response were found for all components, any one parameter may not suffice to explain the PR potential of a particular cultivar. The study suggests to use latent period, infection efficiency and pustule size in the selection for PR. For the evaluation of large numbers of bean cultivars in the greenhouse, IE and PS are preferable to minimize labour requirements.

Additional key words: cultivars, infection efficiency, infectious period, latent period, *Phaseolus vulgaris*, pustule size, sporulation capacity, *Uromyces appendiculatus*.

Introduction

Beans (*Phaseolus vulgaris* L.) differ widely in their susceptibility to bean rust (Ballentyne, 1978; Coyne and Schusten, 1975). Genetic studies in beans have suggested most rust resistance to be monogenic (Christ and Groth, 1982; Grafton et al., 1985; Stavely, 1984, Webster and Ainsworth, 1988; Zaumeyer and Harter, 1941). Because of the ability of the bean rust fungus to adapt to new bean cultivars with monogenic resistance (high variability in terms of pathogenicity), the effectiveness of race-specific resistance is only temporary (Beebe and Pastor Corrales, 1991). Attention therefore shifted to a race non-specific type of resistance, partial resistance. Partial resistance (PR), a resistance that causes a reduced epidemic build-up of a pathogen despite a susceptible infection type (Parlevliet, 1981), can be expressed at different phases during the life cycle of a pathogen (Zadoks and Schein, 1979).

Simulated epidemics and experimental investigations suggest latent period to be the most important component of partial resistance in determining the rate of epidemic build-up (Parlevliet and van Ommeren, 1975; Zadoks, 1972). Infection frequency, sporulation capacity, pustule size and sporulation period were also used as estimates of partial resistance in several patho-systems (Mehta and Zadoks, 1970; Parlevliet, 1975; Parlevliet and Kuiper, 1977; Shaner and Hess, 1978; Statler and Parlevliet, 1987). In the bean-rust pathosystem (Statler and McVey, 1987), no differences in latent period between cultivars were found, but the number of pustules per unit area and the number of spores per pustule were associated with levels of partial resistance.

For a variable pathogen, in terms of pathogenicity, such as rust of beans, selection for higher levels of PR is a good alternative than selection for specific resistance. Selection for PR is not always easy because the expression of PR varies according to environmental factors (Zadoks and Schein, 1979). For a better understanding of the interactions between host and pathogen it is essential to evaluate components of PR. For application in a breeding program one or two of the components have to be selected. In the bean-rust pathosystem this paper addresses the following: which components shall be used for disease screening programs and can we detect differences in the level of resistance in bean cultivars found in the advanced stages of the breeding program with respect to the components of partial resistance, and if so, which component(s) is (are) the most effective and reliable in determining PR of rust in beans?

Materials and methods

Experimental design. The fifteen bean cultivars used for this experiment originate from the bean improvement program of the Institute of Agricultural Research, Nazareth, Ethiopia of which Red Wolaita and Mexican 142 are widely grown cultivars, Exrico 23 (Awash) and A 176 (Roba) are recently released and Brown Speckled is a standard check in the large kidney bean trial. Bean plants were grown in a sterilized soil (Sandy loam soil representing the soil type in the Rift Valley) in 15 cm diameter pots at the greenhouse of Nazareth Agricultural Research Centre. The plants were grown at about 23 ± 3°c during day time and 15 ± 3°c at night. As the experiment was conducted in the dry season, light was not a limiting factor. No fertilizer was applied. The experiment was replicated in four blocks and repeated three times. Per block, each cultivar was represented by one pot, four plants per pot, and pots were randomized within blocks. Assessments were made on two of the four plants, two leaves per plant. Two separate experiments were carried out, one for determining latent period, infection efficiency and pustule size, and the other for determining sporulation capacity and infectious period.

Inoculation. All cultivars were inoculated with urediniospores of an Ambo single-pustule isolate at the primary leaf stage, 10-12 days after sowing. Inoculation was carried out by spraying suspensions with about $2 * 10^4$ urediniospores ml^{-1} over both sides of the primary bean leaves. Microscope slides greased slightly with vaseline were placed horizontally near the plants to check the resulting spore density (spores cm^{-2}). After inoculation, all plants were placed in a near-saturated atmosphere. Twenty four hours after the deposition of spores plants were returned to a bench in the greenhouse where they remained for the duration of the experiment.

Progress curve. Numbers of pustules per cultivar were counted daily once white flecks had been observed. The change in number of pustules with time was plotted to see variation between cultivars.

Latent period and infection efficiency. The latent periods were calculated by counting the number of visible pustules every day until no more pustules appeared (Parlevliet, 1975). Latent period, LP_{50}, was calculated as the time in days between inoculation and the moment at which 50 % pustules were open. The infection efficiency (IE), the ratio between the number of resulting pustules and the number of spores applied, both per unit area (Zadoks and Schein, 1979) was determined by counting the number of pustules per unit leaf area (sum of the upper and lower surfaces) of the leaves about 15 days after inoculation. For both parameters counts were made on 2 * 2 cm^2 area.

Sporulation capacity and infectious period. Sporulation capacity (SC, weight of spores produced per unit area) and infectious period (IP, period in days from the appearance of the first open pustule until the end of sporulation) were determined per cultivar. Spores were collected every 3 days (until no more sporulation occurred) by means of a spore collector beginning the first day of sporulation. Spores were collected from two areas of 4 cm^2, one at either side of the leaf. The data were converted to mg spores cm^{-2}.

Pustule size. Pustule size (PS) was assessed when it reached its maximum, at about 14 days after inoculation for most of the cultivars, according to the scale of Stavely et al., 1983 (1 = no visible symptoms, 2 = necrotic spots without sporulation, 3 = diameter of sporulating pustule < 300 μm, 4 = 300-500 μm, 5 = 500-800 μm and 6 = > 800 μm).

Statistical analysis. All data were subjected to ANOVA and mean values were separated by LSD at $p \leq 0.05$.

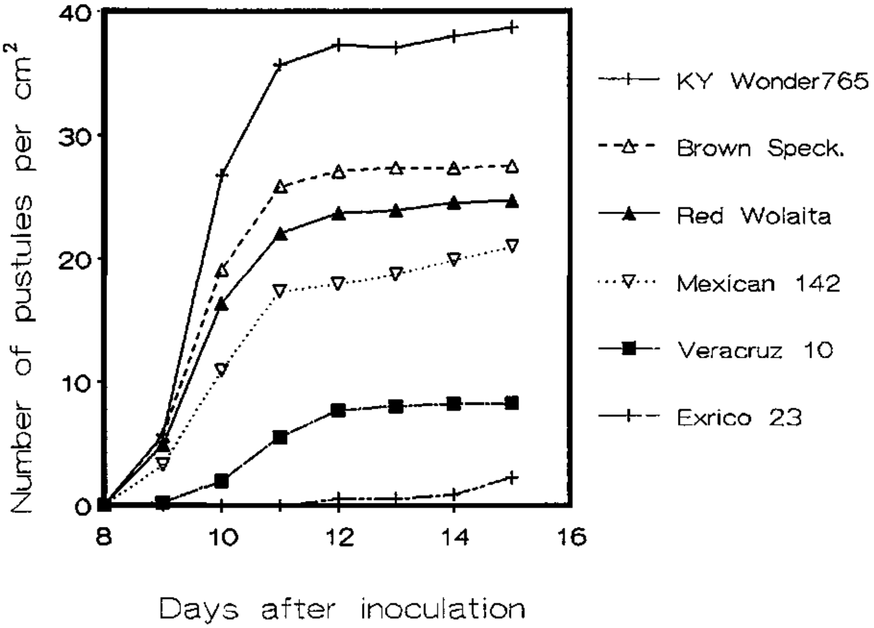

Fig 1. Progress curves of number of pustules cm^{-2} with time in days for 6 representative cultivars, primary leaves

Results

Progress curves. In some cultivars minute, raised, white flecks appeared on both sides of the leaves about 7 to 8 days after inoculation. A day or two later the epidermis ruptured and a reddish brown coloured sporulating pustules appeared. Except BAT 338-1c which was found immune to an Ambo isolate, all cultivars showed asymptotically sigmoidal curves (Fig 1). In most cultivars a maximum was reached asymptotically 15 days after inoculation but for Exrico 23 and A 176, about 24 days. The cultivars can be grouped into at least four classes. In group 1 is found KY Wonder 765 and in group 2, Brown speckled, CSW, Red Wolaita, US # 3, Mexican 142 and Diacol Calima, and in group 3 are BAT 1198 and Veracruz 10, and in group 4, A 176 and Exrico 23.

Table 1. Latent period (LP_{50}), infection efficiency (IE), sporulation capacity (SC), infectious period (IP) and pustule size (PS) of primary leaves of 14 cultivars, inoculated with a bean rust isolate from Ambo

Cultivars	LP_{50}	IE	SC	IP	PS
ICA 15441	9.4a	2.5d	0.34ef	27.6a	4.0c
Jalisco 33	9.6a	3.1bcd	1.12a	14.6d	6.0a
Red Wolaita	9.6a	3.5bc	0.76cd	15.2d	5.0b
Brown Speckled	9.7a	3.9b	0.38ef	15.2d	5.0b
KY Wonder 765	9.7a	5.4a	0.44de	24.3b	5.0b
Diacol Calima	9.9ab	2.4d	0.58cd	27.3a	4.0c
Mexican 142	9.9ab	2.9cd	0.53de	23.6b	3.5cd
US # 3	9.9ab	3.4bc	0.50de	21.5bc	3.5cd
Mexico 6	10.1ab	2.4d	0.51de	21.5bc	4.0c
CSW	10.2ab	3.6bc	0.47de	15.5d	3.5cd
BAT 1198	10.7ab	0.8ef	0.04g	19.6c	2.5e
Veracruz 10	11.4b	1.2e	0.19fg	22.4b	3.0de
Exrico 23 (Awash)	17.0c	0.2f	0.04g	14.4d	2.5e
A 176 (Roba)	18.6c	0.1f	0.04g	15.0d	2.5e

Cultivar means within each component followed by the same letter are not significantly different at $p \leq 0.05$.

Latent period. LP_{50}, varied between 9.4 days for ICA 15441 and 18.6 days for A 176 (Table 1). The cultivars can be grouped into 3 LP_{50} classes (Fig 2). Most cultivars are in group 1 with latent periods ranging from 9.4 to 9.9 days. In group 2 are Mexico 6, CSW, BAT 1198 and Veracruz 10 with an LP_{50} between 10.1 and 11.4 days. In group 3 are A 176 and Exrico 23 with an LP_{50} of 17.0 or more days.

Infection efficiency. IE varied between 0.1 % for A 176 to 5.4 % for KY Wonder 765 (Table 1). IE was below 1 % for A 176, BAT 1198 and Exrico 23, between 1 and 2 % for Veracruz 10, 2-3 % for 4 cultivars and greater than 3 % for the remaining cultivars. Differences in IE were mainly due to the small numbers of pustules observed in A 176, BAT 1198 and Exrico 23.

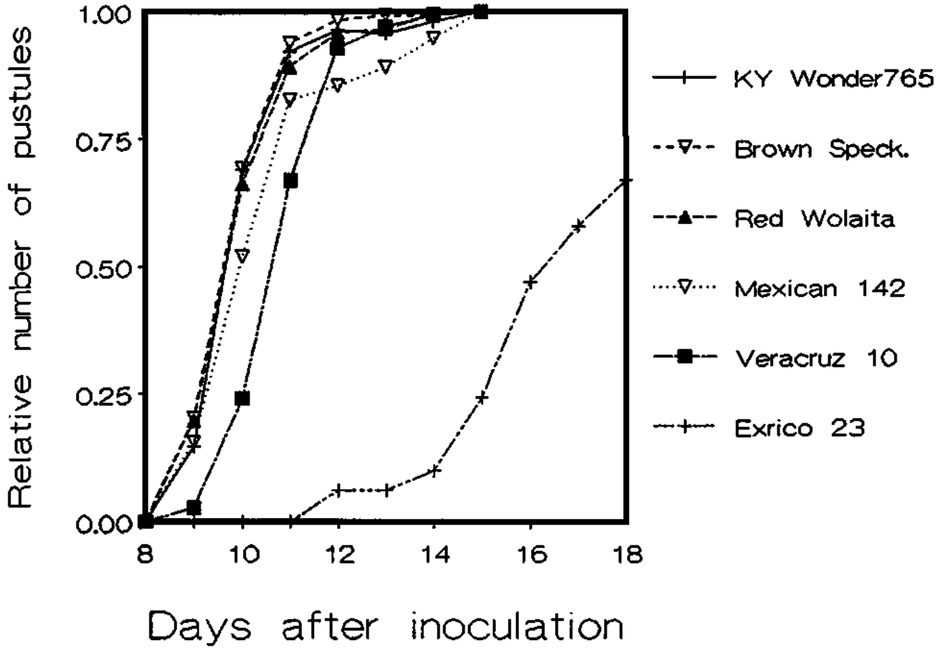

Fig 2. Relative number of pustules per cultivar plotted with time in days for determination of latent period (LP_{50}); graph showing six representative cultivars

Sporulation capacity. Total amount of spores produced during one infection cycle varied between 0.04 mg cm^{-2} for A 176 to 1.12 mg cm^{-2} for Jalisco 33 (Table 1). Total amount of spores produced was high for Jalisco 33 and Red Wolaita, moderate for Mexican 142, Diacol Calima and Mexico 6, and low for A 176, Exrico 23 and BAT 1198.

Infectious period. Infectious period varied considerably (Table 1). The 14 cultivars can be grouped into roughly 3 categories. Cultivars with a short infectious period were A 176, Brown Speckled, CSW, Exrico 23, Jalisco 33 and Red Wolaita. In the intermediate category are BAT 1198, KY Wonder 765, Mexican 142, Mexico 6 and US # 3. ICA 15441 and Diacol Calima had a long infectious period.

Pustule size. Pustule size, classified in micro meters, shows variation between cultivars (Table 1). Pustule sizes were small (< 3 μm) for cultivars A 176, BAT 1198 and Exrico 23, small - medium (3-4 μm) for ICA 15441, CSW, Mexican 142, Mexico 6, US # 3 and Veracruz 10, large (5 μm) for Brown speckled, KY 765 and Red Wolaita, and very large (> 5 μm) for Jalisco 33.

Relationships between the PR components. Linear correlations between latent period and infection efficiency, and between pustule size and sporulation capacity were high (Table 2). Linear correlations between infection efficiency, sporulating capacity or pustule size with infectious period were not significant. Significant linear correlations exist between latent period and sporulation capacity, latent period and infectious period and infection efficiency and sporulation capacity, but *r* values were generally lower (Table 2).

Table 2. Correlation matrix of latent period (LP_{50}), infection efficiency (IE), sporulation capacity (SC), infectious period (IP) and pustule size (PS). Number of observations (Table 1) = 14. $p \leq 0.05$. Entries are linear correlation coefficients

	LP_{50}	IE	SC	IP
IE	-0.74			
SC	-0.62	0.62		
IP	-0.43	ns	ns	
PS	-0.62	0.77	0.85	ns

Discussion

The experiment was designed to represent Ethiopian conditions. An array of varieties, used in the breeding program and representing the three bean types as classified by breeders in Ethiopia, was tested. The widely grown cultivars Mexican 142 and Red Wolaita were included for comparison. No fertilizer was applied as it is not recommended for beans. The soil type (sandy loam) used represents the soils of the bean growing area in the Rift Valley. The bean program selected Ambo as testing site for bean germplasm, thus a rust isolate from Ambo was used.

Variations in components. Latent period, infection efficiency, sporulation capacity, infectious period and pustule size are important components of partial resistance. Zadoks (1972) demonstrated the importance of latent period by means of dynamic simulation. In experiments, latent period was found to be an important component in some pathosystems (Parlevliet, 1975; Neervoort and Parlevliet, 1978; Savary et al., 1988) but not in others (Statler and McVey, 1987; Roumen, 1993). However, in the 15 cultivars of beans studied here, important differences in latent period were found. The differences were largely due to two cultivars, A 176 and Exrico 23, with latent periods exceeding 16 days. The difference between group 1 and 2 is roughly one day. If the bean season is 90 days and the rust season is 80 days (primary leaf infected), the rust can complete 8 cycles in group 1 and 7 cycles in group 2, with multiplications up to 10^8 and 10^7, respectively. The use of a partially resistant cultivar in an area of origin could play an important role in reducing the amount of rust inoculum travelling to other part of the country. Exrico 23 and A 176, in group 3, are newly released cultivars tested under a wide range of environmental conditions in Ethiopia. Despite their susceptibility to anthracnose (Habtu, unpublished), limiting wider acceptance, they showed high level of partial resistance to bean rust at all test sites. Collaborative activities, either in the area of regional rust nurseries or bean yield regional trials, currently ongoing in Eastern Africa, should help to determine the performance of these cultivars under varying climatic conditions.

Differences in infection efficiency between cultivars were found in most pathosystems studied (Groth and Urs, 1982; Ahn and Ou, 1982; Parlevliet and Kuiper, 1976; Statler and McVey, 1987; Roumen, 1993). Our study also supports such findings. Sporulation capacity was highly correlated with partial resistance in the field (Aust et al., 1984; Neervoort and Parlevliet, 1977). Small pustule size was associated with slow rusting of wheat (Ohm and Shaner, 1976) and high partial resistance in beans (Statler and McVey, 1987). In our study cultivars A 176 and Exrico 23, with long latent periods, low infection efficiencies and low sporulation capacities had small pustules.

This study has indicated wide differences between cultivars in five components of partial resistance. Ideally, a high degree of resistance implies long latent period, low infection efficiency, low sporulating capacity, short infectious period and small pustule size. Exrico 23 and A 176 seem to possess such ideal characteristics. Conversely, a highly susceptible cultivar will have a short latent period, high infection efficiency, high sporulation capacity, long infectious period and large pustule size. Of the 15 cultivars tested none showed such characteristics. Mexican 142, the widely grown cultivar, showed a moderate infection efficiency. Red Wolaita, the most dominant cultivar in southern Ethiopia, showed a high infection efficiency. Note that Mexican 142 is in the higher intermediate category if all components are considered. In the crop loss study (Chapters 3, 4), where Mexican 142 was used as a susceptible check, a seed yield loss of up to 85% was obtained. This difference could be due to a high damage potential expressed by Mexican 142. One cultivar could be more susceptible to damage than the other.

Correlation of components. The relationships between the components is not considered to be high, 0.85 being the highest r obtained). This is probably due to mutual compensation (Yarwood, 1961; Zadoks and Schein, 1979) of PR components. The cultivars appear to differ from one another for all components of PR. Clustering of cultivars provides a good picture of associations between cultivars with respect to the components studied (Fig 3). Except for A 176 and Exrico 23, all cultivars differ to some degree from one another in the response of their components. Determination of PR is laborious and also sensitive to environmental conditions. The expression of partial resistance is complex and so is its measurement (Zadoks, 1972; Roumen, 1993), depending on environmental factors (Imhoff et al., 1982). The differences between cultivars for the various components may point to a race-non-specific type of resistance (Shaik, 1985), which is believed to be durable (Parlevliet and Zadoks, 1977; Parlevliet, 1993).

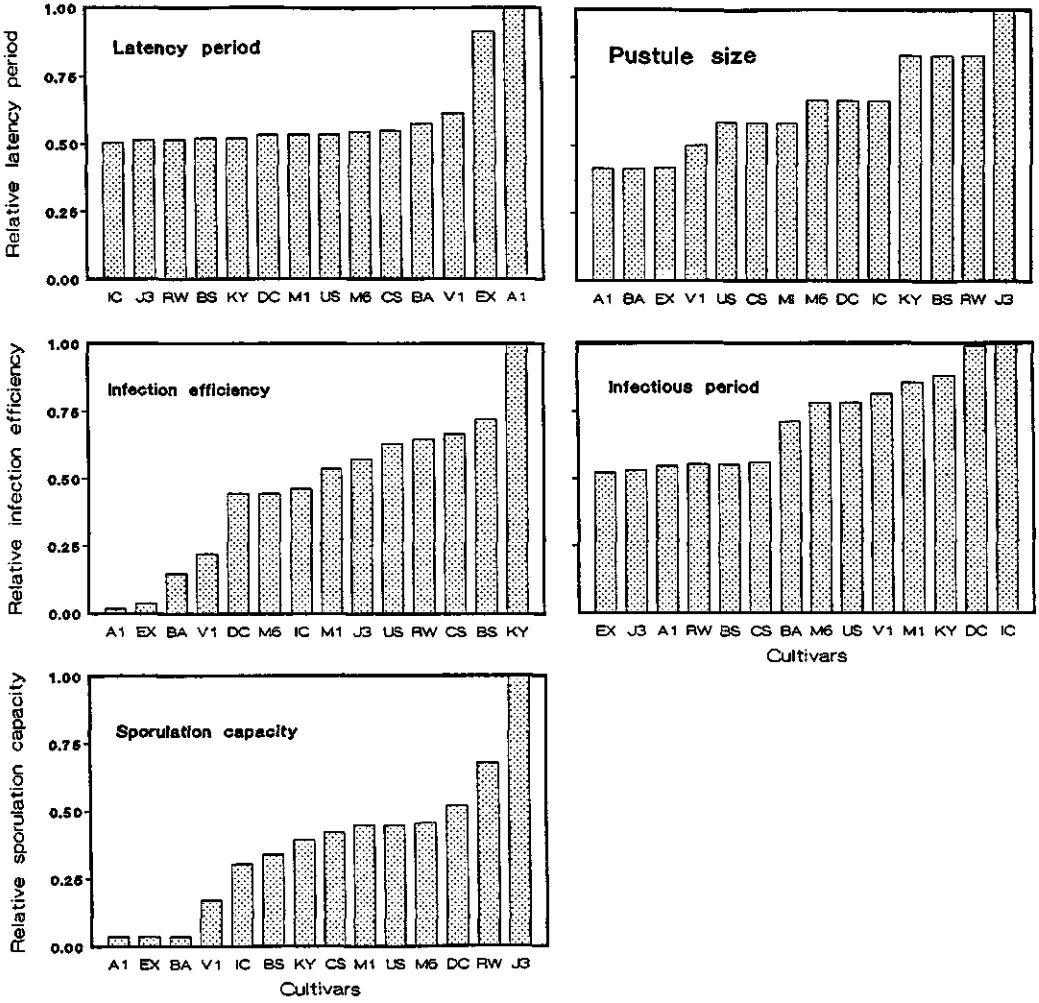

Fig 3. Ranking of cultivars for each of the partial resistance components (relative values). A = latency period, B = infection efficiency, C = pustule size, D = sporulation capacity, E = infectious period

Relative importance of components. Any one parameter may not suffice to explain the PR potential of a particular cultivar. Our result suggests the inclusion of latent period, infection efficiency and pustule size in the selection for partial resistance. Determination of latent period is time consuming. For the evaluation of large numbers of bean cultivars in the greenhouse, infection efficiency and pustule size are preferable to minimize labour. As pustule size and sporulation capacity are strongly correlated there is no need to include the latter for screening purposes. Infectious period showed poor correlation with other components and should thus be handled with care. Severely infected leaves dropped early, before spore production came to end. Small pustules can continue to produce spores for a long period and nonetheless have low sporulation. These results underline the importance of testing for PR components at low infection density for a better expression of PR, as suggested earlier (Parlevliet, 1976).

Research implications. Because of the different responses of cultivars for the different parameters it is unlikely to find one measure representative for all components. The result suggest differences, however small, in all the components studied. For polycyclic diseases such as rust (Parlevliet, 1975; Zadoks and Schein, 1979), even small differences as found here may benefit integrated bean rust management. The existence of such differences in all parameters provides possibilities to identify PR cultivars at an early stage in the Ethiopian national bean breeding scheme. Before drawing far reaching conclusions, studies need to be made (*i*) on the relationship between component response in a monocyclic study on seedling leaves and polycyclic disease progress in the field on adult plants, (*ii*) correlation between component response at seedling and adult plant stages, (*iii*) correlation between component response and disease progress in the field, and (*iv*) testing a range of PR cultivars with various rust genotypes (Habtu and Girma, unpublished) prevalent in Ethiopia and, eventually, in East Africa.

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Chapter 8

GENERAL DISCUSSION

Disease and crop management

In Ethiopia, bean rust management forms an essential part of the overall crop management scheme. Disease management is part of crop management (Zadoks and Schein, 1979). Development of a rust management program depends a.o. on a good understanding of the many interrelated factors which contribute to the system. The study reported here is intended to help and understand the geographic distribution of bean rust, its relative importance, its association with traditional cropping practices, its damage potential, and its management. The main findings, and some implications thereof for immediate use or for further research are discussed briefly.

Regional differences within Ethiopia

A crop and disease survey should help to understand the epidemiology of bean diseases in farmers fields (Zadoks, 1961; King, 1972; Savary, 1987; James, 1969). A better understanding of the disease in the field under farmer conditions is a prerequisite to effective disease management. It includes knowledge of the distribution, intensity and seasonal variation of disease and its association with the prevailing cropping systems. The results could help to develop research priorities and disease management schemes.

A survey of farmers' fields provided information on the relative importance of rust in a multiple pathosystem situation where other foliar diseases co-exist with rust. Differences among regions in terms of cropping practice, disease prevalence and disease severity were common. In the central Rift Valley beans are grown as monocrops, sown densely, never weeded, with highly variable sowing dates. Seeds are normally broadcasted. Under such conditions the most prevalent diseases were common bacterial blight, anthracnose and rust. Their severities depended on seasons and cropping practices. Rust severity was associated with sowing date and probably with weediness but not with plant density. Seasonal differences were considerable in rust severity. Rust severity was closely associated with the rainfall pattern. When there was a well distributed rain (resulting in cooler temperatures and extended wetting periods), as in 1993, rust severity was high. Severities of anthracnose and bacterial blight were associated with plant density and weediness, and probably with sowing date. During the study period the severity of anthracnose was not influenced by seasonal variation. Anthracnose is a seed-borne disease. The high weediness and high plant density conditions common in the Rift Valley may have created the right micro-environment for the development of this disease. In areas where farmers were provided with relatively clean seed there seems to be a reduction in the severity of anthracnose (Habtu, unpublished). Bacterial blight is rather wide-spread in the central Rift Valley.

In the south beans are grown twice a year (July to October and February to May). Beans are either grown as a monocrop (Wolaita) or as an intercrop (Sidama) in association with enset, maize, coffee and sweet potato. Row planting is practised to a large degree, beans are weeded and sometimes fertilizers are applied. Plant density of beans is rather low. As in the Rift Valley sowing dates are variable as they depend on the harvest time of the preceding crop. Here, rust is wide-spread and dominant. Other diseases are found generally but their severity was slight. Severity of rust varied with cropping practice, mainly sowing date, but not so much with season.

In the west beans are grown as monocrops and intercrops. Many diseases are found in beans. Angular and floury leaf spots were the most important and wide-spread diseases. The west has a humid, warm climate.

The large variation in climates and cropping practices within Ethiopia affected types and levels of diseases in the regions. Of the five diseases surveyed rust, anthracnose and bacterial blight were most wide-spread whereas floury and angular leaf spots had limited distribution. There was also variation within regions according to season and cropping system. Disease management strategy in Ethiopia thus needs to be designed on a regional basis emphasizing bacterial blight and anthracnose in the centre, rust in the south, and angular and floury leaf spots in the west.

Because of the clear association between cropping practices and disease severities there is a need to investigate the role of these practices in the development of epidemics under farmer conditions. The strong association of rust with sowing date in the south and central regions and of high severities of bacterial blight with weediness and high plant density in the centre demand further research, as does the absence of anthracnose in the south, despite favourable weather conditions. Integrated rust management strategy demands good knowledge of associations between cultural practices and disease severities. With the recent development of the Global Positioning System (GPS) it is possible to obtain rapid and accurate geographical information in field surveys, which could help to better understand the epidemiology of plant diseases under farmer conditions.

Disease assessment and prediction

Bean rust is endemic in Ethiopia. Quantified information was lacking to determine relationships between rust severities and crop yield or damage. For a better management of rust it is essential to have adequate information on the influence of rust on crop growth and development, yield and yield loss.

The yield advantage obtained by fungicide treatment demonstrated the damage potential of bean rust (Chapter 3). The results in chapter 3 and 4 suggest that under conditions of early attack by rust, as in the experiment, the loss due to rust could be high, up to 85%. Rust affected the leaf area index. Of the yield components, pods per plant were most affected. The number of pods per plant is closely related to seed yield. The effect of rust on cultivars with different levels of partial resistance is quite different. The cultivar with a low level of partial resistance was affected most severely.

Partial resistance, even modest, might reduce total amount of inoculum in source areas considerably. If so, deployment of a partially resistant cultivar in the south, which is generally believed to act as a source of inoculum to the central part of Ethiopia, could play an important role in bean rust management. In the south, farmers grow beans twice a year allowing for seasonal inoculum transfer. A reduction of this inoculum even by a small amount could be beneficial. The use of a partially resistant cultivar in the south would thus not only minimize yield loss in the region but also reduce damage elsewhere in the country by limiting the total amount of inoculum travelling to other areas. The yield loss obtained even by the partially resistant cultivar, up to 30%, emphasizes the need to combine such partial resistance with cultural methods of rust management.

For a better management of rust the relationship between rust severity and damage needs to be known. Rust usually arrives in a field at the primary leaf stage. Using multiple regression analysis, current understanding of the effect of rust severity on growth and yield of beans was improved (Chapter 5). Yield and damage can be estimated using two variables, leaf area index and rust severity. Multiple regression analysis also suggest two points in time to estimate damage - severity relationships. Data collected at both flowering and pod filling stages will give a better estimate than a single stage assessment, but when costs and logistics limit field visits, assessment at the pod filling stage suffices. Because sowing dates are variable under farmer conditions (Chapter 2), we provided equations to use either one of the two stages, with little loss of information. Whatever stage is chosen we recommend that both leaf area index and rust severity (assessed at the upper and middle canopy layers) be considered.

Rust management

Integrated control of rust must use several control strategies. For Ethiopia, and for East Africa at large, components of control strategies are (partial) resistance and cultural practices.

Despite an effective control of rust by a once only chemical treatment (Chapters 3,4), the use of chemicals in traditional African bean production is definitely a last resort, to say the least, as cost, unavailability, lack of safety, lack of equipment and unavailability of water all combine to limit its use.

In the traditional bean production systems of tropical Africa, cultivar mixtures are extensively used for various reasons. Common beans are mixed in different sizes, shapes and colours. Chapter 6 demonstrates the ability of mixtures to reduce the spread of rust. The potential of cultivar mixtures in reducing foliar fungal diseases is well documented (Wolfe, 1985; Luo and Zadoks, 1992). Cultivar mixtures could thus form a classical as well as a modern component in a rust management strategy.

Bean rust is a highly variable pathogen (Allen, 1983; Beebe and Pastor

Corrales, 1991; MmBaga and Stavely, 1988). Worldwide close to 200 bean rust races have been identified (Stavely et al., 1989). In Ethiopia, there are indications for the presence of several races (Habtu and Girma, unpublished).

So, it is unlikely that race-specific resistance will play an important role in rust control. It is believed that the most likely option is partial resistance, hopefully of a non-race specific type (Edington et al., 1994; Parlevliet, 1979). Chapter 7 analyzed various components of partial resistance. It is suggested that latent period, infection efficiency and pustule size together provide a good measure of partial resistance in the case of bean rust. Time and labour requirements may further limit the number of parameters.

Small differences in cultivar response existed in all the components assessed. These small differences may be exploited to control polycyclic diseases such as bean rust. Breeders and pathologists need to work together to make maximum use of these inherent differences.

Conclusions and recommendations

The results reported in this study enabled us to enrich our understanding in the geographic distribution of rust, its relative importance viz-a-viz other diseases, the effect of cropping systems on disease epidemics, damage potential of rust and prediction of yield and damage, the effects of cultivar mixtures and of components of partial resistance on rust development. Still, many questions remain to be addressed. We know very little on the immigration of rust into Ethiopia and its migration within Ethiopia.

Rust epidemics usually begin as small foci (≤ 1m diameter), as observed during field surveys (Habtu and Zadoks, unpublished), which suggests that the rust comes from afar. We need better understanding of source-target trajectories of rust in Ethiopia. A collaborative action with neighbouring countries, where rust is also prominent, is suggested. Items to be addressed are the sources of rust at any particular time and its trajectories. An answer to these questions could probably lead to a management issues, gene deployment and gene rotation (Zadoks and Schein, 1979). A collaborative effort of breeders, meteorologists and pathologists is needed to address these issues. In Ethiopia, breeders are now proposing to regionalize their breeding program. Such an approach should help to focus on specific regional constraints, and to develop cultivars resistant to a local population of rust isolates.

In tropical Africa cultural practices, among which species mixtures, play important role in disease management. Partial resistance and combinations of cultural aspects should be components in the overall disease management strategy, recognizing regional needs. Crop protection must be tailor-made (Zadoks, 1994), which for bean rust in Ethiopia implies to deal with the specific needs of each region within an integrated concept. Thus, we recommend that future bean rust research needs to focus on the following items.

1. Breeding for *partial resistance*. Bean cultivars show great deal of variation in response to rust infection. However small, there are differences between cultivars. Good screening methods are needed to identify such small differences in order to exploit them in breeding programs. Partial resistance could be durable and well suited to Ethiopia.

2. *Cultivar mixtures*. We have been led to believe that cultivar mixtures are primitive and old-fashioned. Now, we realize that they have their own value in crop production and crop protection, and thus merit renewed interest. Research in cultivar mixtures should address issues such as optimum combinations of resistances, similarities in growth habit, maturity, yield potential and other agronomic characteristics, and aspects of cooking quality and nutritional value.

3. *Species mixtures*. Intercropping of beans with one or more other crops is a common feature in most East African bean production systems. It is an important practice in the eastern highlands of Ethiopia and in some parts in the west. Little work has been done on this rather important and traditionally widely used practice. We believe that more can be gained by understanding this practice in relation to disease development.

4. *Cropping practices*. Research needs to focus on the effects of sowing dates, plant densities, weediness, and available nutrients in the soil on development of the bean crop and its diseases.

5. *Physiologic races*. Preliminary information points to the existence of several races in Ethiopia, but accurate race identification still needs to be done. Knowledge of races will help to understand bean genotype * rust genotype * environment interactions under Ethiopian conditions.

6. *Migration of rust*. For a better management of rust, for addressing the issue of gene deployment and gene rotation a good knowledge of rust migration is essential.

A combined use of partial resistance and cultural methods is expected to provide the key for future success in the context of integrated disease and crop management.

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SUMMARY

Chapter 1. Common beans are one of the five prominent food legumes in Ethiopia. They form an important component in the lowland crop production system. They are an important source of protein and cash. They are used for forage, fuel for cooking, and soil amendment in rotation with cereals. They are either grown as monocrop or intercropped with various other crops including sorghum, maize, coffee, *'chat'* and at times vegetables.

Under farmer conditions the yield of common beans is low (600-700 kg ha^{-1}). This is due to several production constraints, among which are diseases. Rust is one of the major diseases of beans. Information on the epidemiology of this disease in Ethiopia was scanty. The present study was undertaken to address issues such as geographical distribution of bean rust, importance of rust relative to other diseases, effect of rust on crop growth, disease development, yield and yield loss, rust development in cultivar mixtures, and components of partial resistance of beans against rust.

Field and greenhouse experiments were performed to study the epidemiology of bean rust in Ethiopia. The studies were made under low input conditions reflecting the traditional bean production practice in Ethiopia and elsewhere in tropical East Africa.

Chapter 2. Field surveys were conducted in three major bean growing areas of Ethiopia. Using correspondence analysis differences in disease severity between regions and seasons, associations between areas and cropping systems, areas and diseases, and cropping systems and diseases were characterized. The analysis suggested a significant association between high plant density, high weediness, high bacterial blight and high anthracnose in the Rift Valley. In Sidamo, the south, there was a strong association between high rust intensity, low plant density and low weediness. In Keffa there was a significant association of angular and floury leaf spots. In the Rift Valley rust severity was closely associated with season. Anthracnose and bacterial blight provided no clear trends. Cropping systems were associated with disease severities. In the Rift Valley and the south, there was a high probability of low rust severity in early sown crops and a high probability of bacterial blight in crops with high

weediness and high plant densities. The probability to find high rust severity at high weediness was low. To formulate strategies for bean improvement the specific needs of the regions with their unique farming systems need to be addressed.

Chapter 3. Crop growth and disease epidemics in sprayed and non-sprayed bean plots, artificially infected with rust, were assessed weekly from the beginning of the vegetative stage in two cultivars, at two locations for two seasons. Disease intensity was regulated by the application of a fungicide, oxycarboxin. Fungicide application reduced rust intensity, influenced leaf area (LAI), and increased seed yield by increased numbers of pods per plant. Rust severity was strongly correlated with pustule density. The overall relationships among rust assessment parameters depended on cultivar, location and season. Seed yield and pods per plant were highly correlated with LAI. The relationships between LAI and seeds per pod or seed weight depended on cultivar, location and season. Rust severity and pustule density showed close, negative relationships with seed yield, seed weight and pods per plant but not with seeds per pod. The relationships obtained in the partially resistant cultivar 6-R-395 were less definite than those in the susceptible cultivar Mexican 142. The yield parameters seed yield and pods per plant showed strong positive relationships.

Chapter 4. Bean rust epidemics, manipulated by the application of a fungicide, resulted in differences in rust development, crop growth and yield. Progress curves of crop growth, rust incidence and rust severity show significant variation among treatments. LAI reached a maximum between 59 and 66 days from emergence at growth stages where rust severity also reached its plateau. For all parameters, progress curves showed more variation for the susceptible than for the resistant cultivar. For the susceptible cultivar, Mexican 142, differences between treatments were greatest during pod formation and under conditions of high disease pressure. Maximum yield loss was 85 % for the susceptible cultivar, Mexican 142, and 30 % for the partially resistant cultivar, 6-R-395. The loss depended on the resistance level of cultivars, location and season.

Chapter 5. Field experiments were conducted to determine relationships of damage to crop growth and rust intensity. Regression models were developed for yield and yield loss by incorporating LAI, rust incidence and severity of three canopy layers at one or more growth stages. Multiple regression models based on LAI and rust severity at growth stages R6 (flowering) and R7B (pod formation) fitted the data with R^2 values of ≥ 0.85. Addition of an incidence parameter did not improve the goodness of fit. Single point models developed at pod formation showed better fit than those developed at or prior to flowering. Models based on crop and disease assessments of the upper canopy layer produced good fit, but the goodness of fit was improved by including data from the middle canopy. For rust management purposes, crop and disease assessments from before flowering up to seed filling stages can be used. For survey purposes models based on assessments at the pod filling stage will be satisfactory.

Chapter 6. Field experiments were conducted to study the radial expansion of rust foci in mixtures of susceptible and resistant bean cultivars at two sites. At Ambo, radial expansion velocity ranged from 6 cm per day, in mixtures with 20 % susceptible plants, to 15 cm per day in completely susceptible plots. At Debre Zeit, the velocity ranged from 3 cm, in mixtures with 20% susceptible plants, to 16 cm per day in completely susceptible plots. At both sites the velocity of radial expansion depended linearly on the logarithm of the fraction susceptible plants in the mixture.

Chapter 7. Bean cultivars, obtained from the Ethiopian national breeding program, and cultivars widely grown in the country were studied for components of partial resistance to an Ambo isolate of bean rust. The components included latent period (LP_{50}), infection efficiency (IE), sporulation capacity (SC), infectious period (IP) and pustule size (PS). Differences in cultivar responses were found for all components. Differences were largest for infection efficiency and sporulation capacity. Cultivars Exrico 23, A 176, Veracruz 10 and BAT 1198 had a high level of PR to the Ambo isolate. Mexican 142, widely grown in Ethiopia, was intermediate whereas Red Wolaita, an important cultivar in the south, showed a low level of PR. Linear correlations between LP_{50} and IE, and between SC and PS were high. Linear correlations between IE, SC, or PS with IP were not significant. Though differences in cultivar response were found for all components, any one parameter may not suffice to explain the PR potential of a particular cultivar. The study suggests to use at least LP_{50}, IE and PS in the selection for PR. For the evaluation of large numbers of bean cultivars in the greenhouse, IE and PS are preferable to minimize labour requirements.

Further studies need to be made on relationships between component response at primary leaf and adult plant stages, component response and disease progress in the field, and comparison of rust genotypes for a range of partially resistant cultivars.

Chapter 8. Achievements of this study were discussed, comparisons with other studies were made and suggestions on future bean rust control strategy were forwarded. Areas requiring further research were identified. Priority areas are:

1. Breeding aimed at partial resistance.
2. Evaluation of cultivar mixtures.
3. Evaluation of mixed cultivation (intercropping).
4. Evaluation of cropping practices (with emphasis on sowing date, weediness and plant density).
5. Studies on rust migration.
6. Analysis of physiologic races.

Hoofdstuk 1. De phaseolus boon is één van de vijf voor de voedselproduktie van Ethiopië belangrijke vlinderbloemige gewassen. Bonen hebben een groot aandeel in het produktie-systeem van het laaglaand. Zij zijn een belangrijke bron van eiwit en zij genereren contante inkomsten. Zij worden gebruikt als veevoer, brandstof in de keuken en bodemverbeteraar in rotatie met granen. Zij worden geteeld als onvermengd gewas ("monocrop") of in mengteelt met verscheidene andere gewassen zoals sorgum, mais, koffie, 'chat', en soms groenten.

Bij een normale bedrijfsvoering is de opbrengst van bonen laag (600-700 kg ha^{-1}). Dit is het gevolg van een aantal produktie-beperkende faktoren, waaronder ziekten. Roest is één van de belangrijkste ziekten van boon. Informatie over de epidemiologie van deze ziekte in Ethiopië was schaars. Het hier gerapporteerde onderzoek werd verricht om vragen te beantwoorden inzake de geografische verbreiding van boneroest, het belang van roest ten opzichte van andere boneziekten en het effekt van roest op gewasgroei, ziekteverloop, opbrengst en schade. Het ziekteverloop in rassenmengsels en enige componenten van partiële resistentie tegen boneroest werden bestudeerd.

De epidemiologie van de boneroest in Ethiopië werd bestudeerd in veld- en kasproeven. De proeven werden verricht bij lage inputs om de gebruikelijke praktijk van de boneteelt in Ethiopië en elders in tropisch Oost-Afrika te weerspiegelen.

Hoofdstuk 2. In de drie voornaamste produktie-gebieden van bonen in Ethiopië werden "surveys" verricht. Verschillen in aantastingsniveau tussen gebieden en seizoenen, associaties tussen gebieden en teeltsystemen, gebieden en ziekten, en teeltsystemen en ziekten werden gekenschetst met behulp van correspondentie-analyse. Het resultaat suggereerde een significante associatie tussen hoge plantdichtheid, hoge onkruidbezetting, hoge bacteriële aantasting en hoge anthracnose aantasting in de Rift Vallei. In Sidamo, het zuiden, werd een sterke associatie gevonden tussen hoge roest-intensiteit, lage plantdichtheid en lage onkruidbezetting. In Keffa bestond een significante associatie van de schimmelziekten "angular leaf spot" en "floury leaf spot". In de Rift Vallei was roest-intensiteit sterk geässocieerd met seizoen. Teeltsystemen waren geässocieerd met intensiteiten van ziekten. In de Rift Vallei en in het zuiden werd een hoge waarschijnlijkheid gevonden van lage roest intensiteit in vroeg gezaaide gewassen en een hoge waarschijnlijkheid van bacterievlekkenziekte in gewassen met hoge onkruidbezetting en hoge plantdichtheden. De kans om hoge roest aantasting te vinden bij hoge onkruidbezetting was klein. On strategieën uit te zetten voor de verbetering van de boneteelt moeten de specifieke behoeften van de gebieden met hun teeltsystemen bezien worden.

Hoofdstuk 3. Vanaf het vegetatieve stadium werden wekelijks metingen gedaan over gewasgroei en ziekte-ontwikkeling in bespoten en onbespoten veldjes, kunstmatig geïnfecteerd met roest, op twee plaatsen, in twee seizoenen. De ziektegraad werd aangestuurd met behulp van een fungicide, oxycaboxin. Toepassing verlaagde de roest-intensiteit, beïnvloedde het bladoppervlak (LAI), en verhoogde de zaadopbrengst door verhoging van het aantal peulen per plant. De aantastingsgraad van de roest was sterk gecorreleerd met de dichtheid van de sporenhoopjes. De algemene relaties tussen de meetvariabelen van de roest hingen af van cultivar, plaats en seizoen. Zaadopbrengst en aantal peulen per plant waren sterk gecorreleerd met LAI. De betrekkingen tussen LAI en zaden per peul of zaadgewicht hingen af van cultivar, plaats en seizoen. Aantastingsgraad en dichtheid van sporenhoopjes vertoonde sterke, negatieve correlaties met zaadopbrengst, zaadgewicht en aantal peulen per plant, maar niet met aantal zaden per peul. De relaties bij de partieel resistente lijn 6-R-395 waren minder duidelijk dan bij de vatbare cultivar Mexican 142. The opbrengstparameters zaadopbrengst en aantal peulen per plant lieten krachtige, positieve correlaties zien.

Hoofdstuk 4. Epidemieën van boneroest, gemanipuleerd met behulp van een fungicide, vertoonden verschillen in roest-ontwikkeling, gewasgroei en opbrengst. Significante verschillen tussen behandelingen werden aangetoond bij groeicurven van gewasgroei, roest-incidentie en -aantastingsgraad. LAI bereikte een maximum 59 tot 66 dagen na opkomst, bij ontwikkelinsstadia waar ook de aantastingsgraad van de roest een plateau bereikte. Bij de vatbare cultivar, Mexican 142, waren de verschillen het grootst tijdens de peulvorming, bij hoge ziektedruk. De grootste opbrengstderving was 85 % voor de vatbare cultivar Mexican 142 en 30 % voor de partieel resistente lijn 6-R-395. Het verlies hing mede af van resistentie-niveau van de cultivars, plaats en seizoen.

Hoofdstuk 5. Veldproeven werden gedaan om de relaties tussen schade aan de gewasgroei en roestintensiteit te bepalen. Regressiemodellen werden opgesteld voor opbrengst en opbrengstderving door LAI, roest-incidentie en -aantastingsgraad van drie gewas-lagen bij één of meer ontwikkelingsstadia op te nemen. Multipele regressie modellen gebaseerd op LAI en aantastingsgraad bij de ontwikkelingsstadia R6 (bloei) en R7B (peulvorming) hadden R^2 waarden $\geq$ 0.85. Toevoeging van een incidentie-parameter verbeterde deze waarden niet. Een-puntsmodellen voor het stadium van peulvulling hadden hogere R^2 waarden dan modellen voor stadia tot en met de bloei. Modellen die gebruik maakten van gegevens van de bovenste gewas-laag waren goed, maar werden beter door gegevens van de middelste gewas-laag mee te nemen. Voor het doel "roest-beheersing" kunnen gewas- en ziekte-waarnemingen gebruikt worden uit een periode van vlak voor de bloei tot en met de zaadvulling. Voor het doel "survey" zijn modellen met waarnemingen tijdens de peulvulling geschikt.

Hoofdstuk 6. Op twee plaatsen werden veldproeven gedaan om de radiale uitbreiding van roesthaarden in mengsels van vatbare en resistente bonerassen te bestuderen. In Ambo varieerde de radiale haarduitbreidingssnelheid van 6 cm per dag, in mengsels met 20 % vatbare planten, tot 15 cm per dag in veldjes met alleen vatbare planten. In Debre Zeit varieerden deze snelheden van 3 tot 16 cm per dag. Op beide plaatsen was de radiale uitbreidingssnelheid evenredig met de logarithme van de fractie vatbare planten in het mengsel.

Hoofdstuk 7. Componenten van partiële resistentie (PR) werden bestudeerd in bonerassen uit het nationale Ethiopische veredelingsprogramma en algemeen in het land geteelde cultivars. De componenten waren latente periode (LP_{50}), infectie-efficiëntie (IE), sporulatie-capaciteit (SC), infectieuze periode

(IP) en sporenhoopjesgrootte (PS). Voor alle componenten werden verschillen tussen cultivars gevonden. Zij waren het grootst voor infectieeffciëntie en sporulatie-capaciteit. De cultivars Exrico 23, A 176, Veracruz 10 and BAT 1198 hadden een hoog niveau van partiële resistentie tegen het roest-isolaat uit Ambo. Mexican 142, algemeen verbouwd in Ethiopië, was intermediair terwijl Red Wolaita, een belangrijk ras in het zuiden, een laag niveau van partiële resistentie had. Lineaire correlaties tussen (LP_{50}) en IE, en tussen SC en PS waren hoog. Die tussen IE en SC, of PS en IP waren niet significant. Hoewel alle componenten verschillen tussen cultivars lieten zien, kon één enkele parameter niet alle verschillen tussen cultivars verklaren. Gesuggereerd wordt tenminste LP_{50}, IE en PS te gebruiken bij de selectie op PR. Als grote aantallen lijnen doorgemeten moeten worden in de kas, zijn IE en PS te verkiezen om de hoeveelehid werk te beperken.

Voortgezet onderzoek is nodig om de relaties te bepalen tussen componenten gemeten aan het eerste blad en aan volwassen planten, tussen responsies van componenten en ziekteverloop te velde, en om de reacties te vergelijken van een reeks van partieëel resistente lijnen op verschillende genotypen van de roest.

Hoofdtuk 8. De resultaten van deze studie werden besproken, vergelijkingen gemaakt met andere onderzoekingen en suggesties gedaan voor een strategie van boneroest-beheersing in de toekomst. Prioriteitsgebieden zijn:

1. Onderzoek naar fysiologische rassen van de roest.
2. Veredeling op partiële resistentie.
3. Evaluatie van teeltsystemen (met nadruk op zaaidatum, onkruidbezetting en plantdichtheid).
4. Evaluatie van rassenmengsels.
5. Evaluatie van gemengde teelten ("intercropping").
6. Onderzoek naar migratie van de roest.

PUBLICATIONS

Submitted papers (from this thesis)

1. Habtu, A., Sache, I. and Zadoks, J.C. A survey of cropping practices and foliar diseases of common beans in Ethiopia. Chapter 2.

2. Habtu, A. and Zadoks, J.C. Yield loss studies in the bean rust pathosystem of Ethiopia: Analysis of crop growth, disease and yield components. Chapter 3.

3. Habtu, A. and Zadoks, J.C. Disease progress, crop growth and yield studies in a bean rust pathosystem of Ethiopia. Chapter 4.

4. Habtu, A., Verdooren, L.R. and Zadoks, J.C. Regression models to estimate rust severity, crop growth, yield and yield loss of beans in Ethiopia. Chapter 5.

5. Habtu, A., van den Bosch, F. and Zadoks, J.C. Focus expansion of bean rust in cultivar mixtures. Chapter 6.

6. Habtu, A. and Zadoks, J.C. Studies on components of partial resistance in bean rust. Chapter 7.

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CURRICULUM VITAE

The author was born on 2 February, 1952, Shoa, Ethiopia. His elementary education began at Atse Lebne Dengel School in Debre Zeit, Ethiopia. He finished high school at Debre Zeit Comprehensive High School, in 1970. He began his university studies at the Alemaya College of Agriculture, Dire Dawa, Ethiopia. From 1974-1976 he participated in the Ethiopian University Service (EUS) and the 'National Campaign' program. He obtained his B.Sc. (1977) in Plant Science and his M.Sc. (1979) in Plant Pathology at the University of Florida, Gainesville, U.S.A. Since then, he was a researcher at the Institute of Agricultural Research, Ethiopia. He worked as a plant pathologist and team member, first in the food legumes improvement program, and later in the lowlands pulse improvement program based at Nazareth. In 1989, he was awarded a fellowship to undertake a Ph.D. study at the Wageningen Agricultural University, Department of Phytopathology, under the supervision of Professor J.C. Zadoks. In 1989 he spent six months in Wageningen for preliminary studies and to prepare a project proposal. October, 1989, he returned to Ethiopia to do his field experiments which took him up to the middle of 1993. Due to disturbances during the transition period in 1991 many data and most of the materials and equipment were lost. In November, 1993, he returned to Wageningen to finalize his thesis. He is married to Lishan. They have two daughters, Mahder and Abeba.