Analysing Crop Loss in a Bean Rust Pathosystem: I. disease progress, crop growth, and yield loss

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Abstract

Progress of rust epidemics in one susceptible and one partially resistant haricot bean genotypes was manipulated by the application of a fungicide at five spray frequencies in a low external inputs production system. These resulted in differences in rust epidemics, crop growth and yield. Temporal progress of rust incidence, rust severity and crop growth indicated significant variations among treatments. Leaf area index increased with time and reached a maximum between 59 and 66 days after emergence, growth stages at which rust severity also reached its plateau. For all parameters, progress curves showed more variation for the susceptible than for the resistant genotype. For the susceptible genotype, '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 genotype, '6-R-395'. The loss depended on location, season and resistance level of the genotype.

Introduction

In Ethiopia, yields of dry haricot bean average 600-700 kg ha^{-1} (CSA 1995), far less than the attainable yield (Zadoks & Schein 1979) obtained under good management conditions (IAR 1991). The yield gap in beans results from yield limiting and yield reducing factors (Rabbinge & de Wit 1989) among which are diseases, insects, weeds, cultural practices, low soil fertility and drought (IAR 1991).

Rust, caused by *Uromyces appendiculatus* (Pers.) Unger, is one of the production constraints of beans in Ethiopia (IAR 1991) and in eastern and southern Africa (Howland & MacCartney 1966, Padwick 1956, Allen 1983). Progress of rust epidemics varies according to season, location (Habtu & Zadoks 1995), weather conditions (Imhoff et al. 1981) and resistance level of cultivars (Beebe & 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 (1995) described cross-sectional analyses 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 produced from experiments conducted at Ambo and Debre Zeit in 1990, 1991 and 1993. The experiments were conducted in a split plot arrangement in a randomized complete block design with six replications. Two genotypes, '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 fertilizer was applied. The experimental plots measured 4 m x 4 m. One seed per hole was planted at 40 cm distance between rows and 10 cm 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 plot was inoculated by spraying with a suspension of urediniospores (about 5 g urediniospore per 20 l of H_2O) of haricot 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 & 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 (treatment 1) days. A check (treatment 0) was left unsprayed to allow maximum development of bean rust.

Disease Assessment

Starting about 10 days after inoculation, assessment of incidence (number of infected leaves per plant) and severity (percent leaf area infected) were estimated at weekly intervals. Observations were made on 12 randomly selected and marked plants in the middle rows of each plot. 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.

Crop Assessment

Growth stages of the crop were determined at the dates of disease assessment (Fernandez et al. 1986). Plant density was determined by counting the total number of plants in the middle four rows of each plot at the first and last disease assessment dates. The leaf area of a plant selected for disease assessment was calculated using standard diagrams (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.

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 seeds pod^{-1} (SP) and number of pods $plant^{-1}$ (PP) were assessed. SY and SW were determined at 12% moisture after sun-drying the threshed seeds for 5 days. SP and PP were 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 growth and disease progress were calculated and subjected to analysis of variance. Differences between treatment means were tested at 5% probability level.

Results and Discussion

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

Disease and Crop Progress Curves

Rust incidence: In most cases, the incidence (IN) increased with time, but the curves varied with seasons and locations for SUS and RES (Fig. 2A-C). In Ambo, 1990 both SUS and RES produced curves with dips at 52-59 days from emergence (DFE), but no dips were observed at Debre Zeit in 1991 or at Ambo in 1993. Significant differences were found in the area under the rust incidence curve (Table 1) among treatments for SUS at Ambo in 1990 and 1993. For RES significant differences were mainly between treatments 0 and 3 or 4.

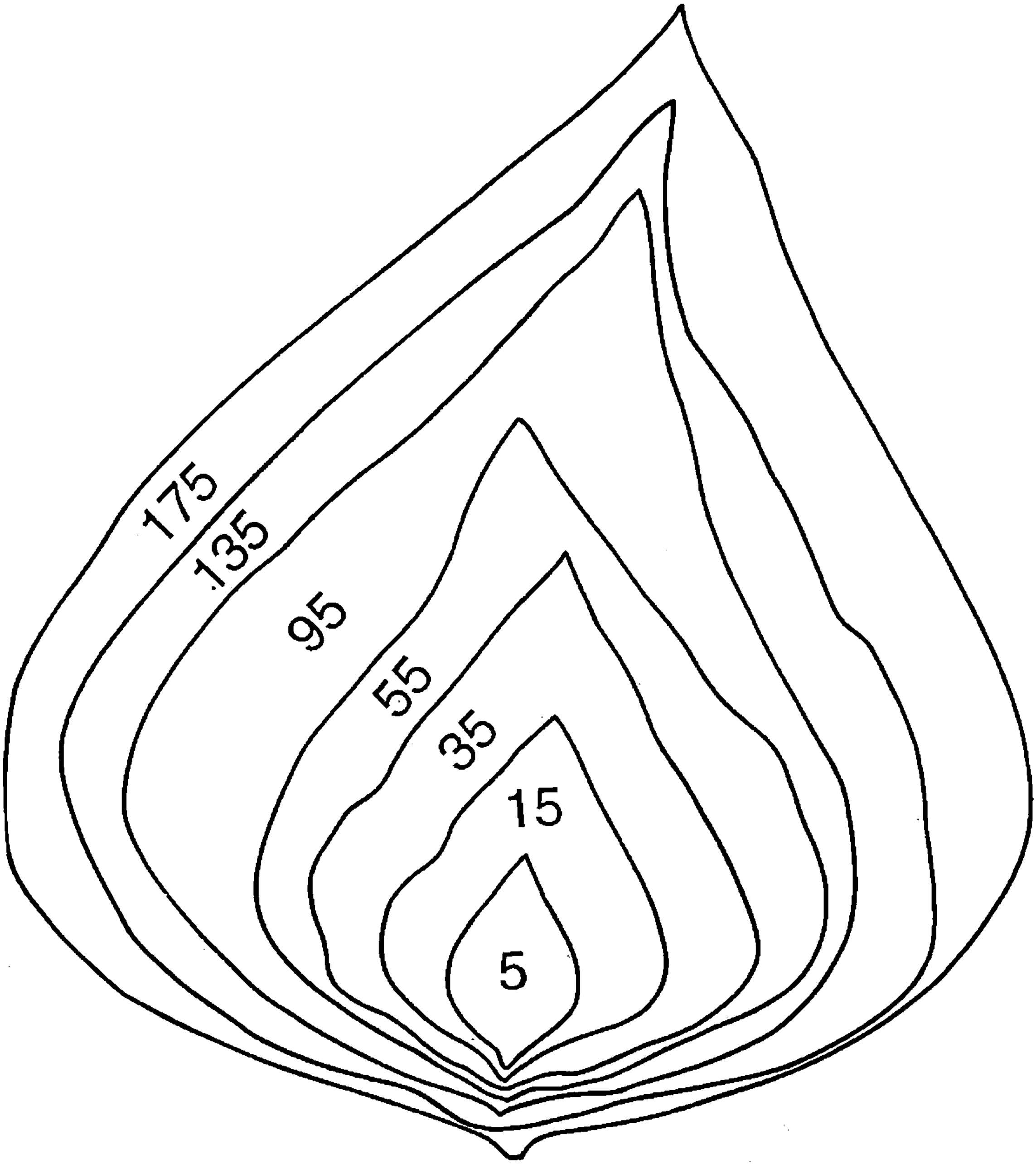

Fig 1. Pictorial key for the assessment of haricot bean leaf area, measured in cm^2

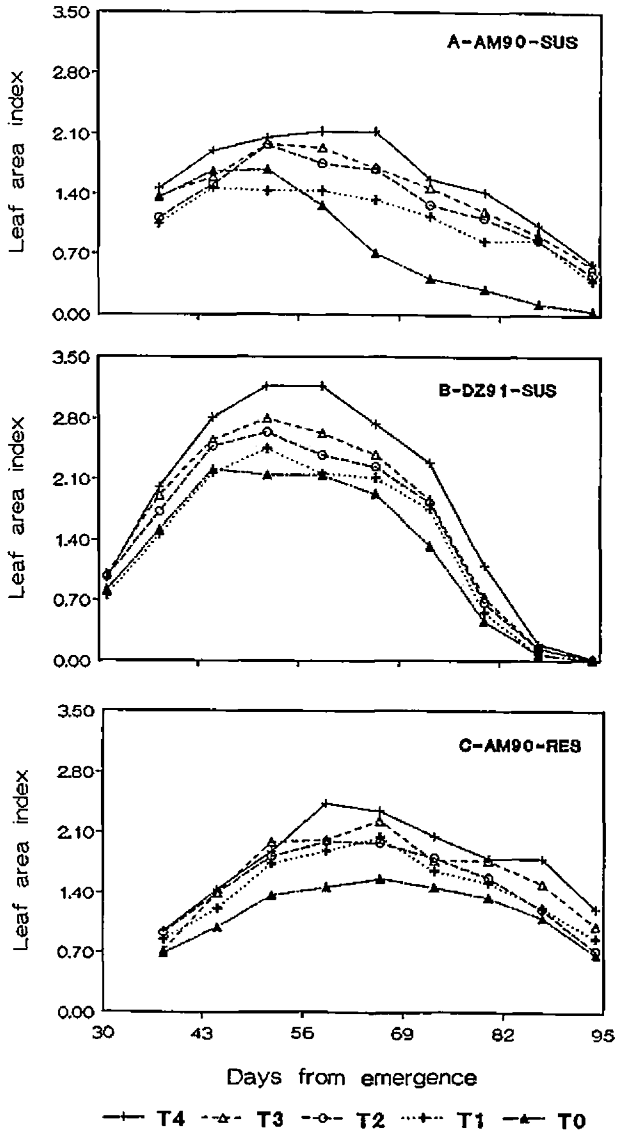

Fig 2. Crop growth curves, expressed as LAI against time in days from emergence. A = SUS, Ambo, 1990; B = RES, Ambo, 1990; C = SUS, Debre Zeit, 1991. T0 - T4 = spray frequencies (from zero to high).

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

Cultivar	Treatment	Leaf area index	Incidence	Severity		
				Upper canopy	Middle canopy	Lower canopy
Mexican 142	4**	114	771	24	59	20
	3	98	918	162	248	43
	2	88	1093	341	368	72
	1	77	1397	515	526	98
	0	65	2262	738	609	155
LSD 0.05		14	648	500	219	46
6-R-398	4	114	5	9	14	3
	3	103	116	48	56	8
	2	94	221	157	102	11
	1	92	230	181	284	37
	0	78	644	708	366	61
LSD 0.05		12	226	268	147	24

* *For Mexican 142, mean of 3 environments and for 6-R-395, mean of 2 environments*

** *Spray frequencies 5 days=reatment 4; 10 days=treatment 3; 15 days=treatment 2; 20 days=treatment 1; unsprayed check=treatment 1*

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 at Ambo in 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 the disease was early and severe and a flush of new leaves not yet sporulating may have resulted in the dips. Differences between treatments depended on rust intensity and resistance level. When the disease pressure was high, as at Ambo in 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 remained low and curves showed little variation with time.

Rust severity: 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, differences between treatments were greatest (Fig. 3A), especially between treatments 0 and 3 or 4.

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 were observed in all cases. Differences between treatments were greatest in SUS. 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. Significant differences were located mostly between treatment 0 or 1 and 3 or 4.

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 most of the treatments in AUC values (Fig. 3EF). 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.

The progress of rust severity 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. Thus, differences depended on cultivar resistance, canopy layer and treatment. The lower values in AUC for the lower canopy layer suggest removal of rust from the epidemic process through defoliation and subsequent reduction of severity in that layer. Lower values in treatments 3 and 4 reflect the impact of frequent spray on rust development.

Crop growth: Progress of LAI varied among spray frequencies (Fig. 4A-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 DFE at Ambo in 1990, and between 52 and 59 DFE at Debre Zeit in 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 treatments 0-3 and 59 DFE in treatment 4. LAI curves of SUS showed more variation than those of RES. For SUS, differences among treatments at Ambo were greater than at Debre Zeit.

LAI and leaf area index integrated over time are considered important determinants of yield (Waggoner& Berger 1987, Savary & Zadoks 1992). LAI curves of SUS differ significantly for all treatments with the greatest variation beginning at 59 DFE, when the disease severity was high, resulting in heavy defoliation and for all treatments with the 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 followed 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 coinciding with the initiation of pod production, stage R7. LAI integrated over time gave clear differences between treatments. These values were smaller under high disease pressure conditions such as at Ambo in 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 the leaves dropped off completely at 94 DFE while at Ambo plants continued to grow. The difference was due to the extended rainy season (about 138 days for Ambo and 120 days for Debre Zeit) and to cooler nights at Ambo.

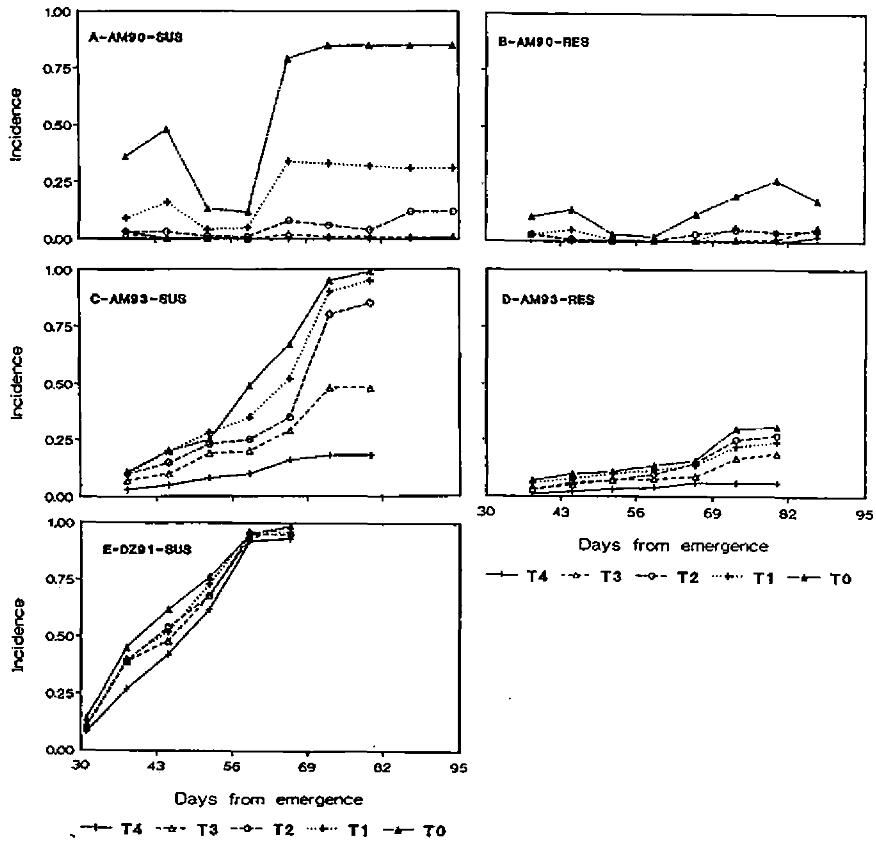

Fig 3. Disease progress curves expressed as rust incidence (1.00 = 100%) against time in days from emergence. A = SUS, Ambo, 1990; B = RES, Ambo, 1990; C = SUS, Ambo, 1993; D = RES, Ambe, 1993; E = SUS, Debre Zeit, 1991. T0 - T4 = Spray frequencies (from zero to high).

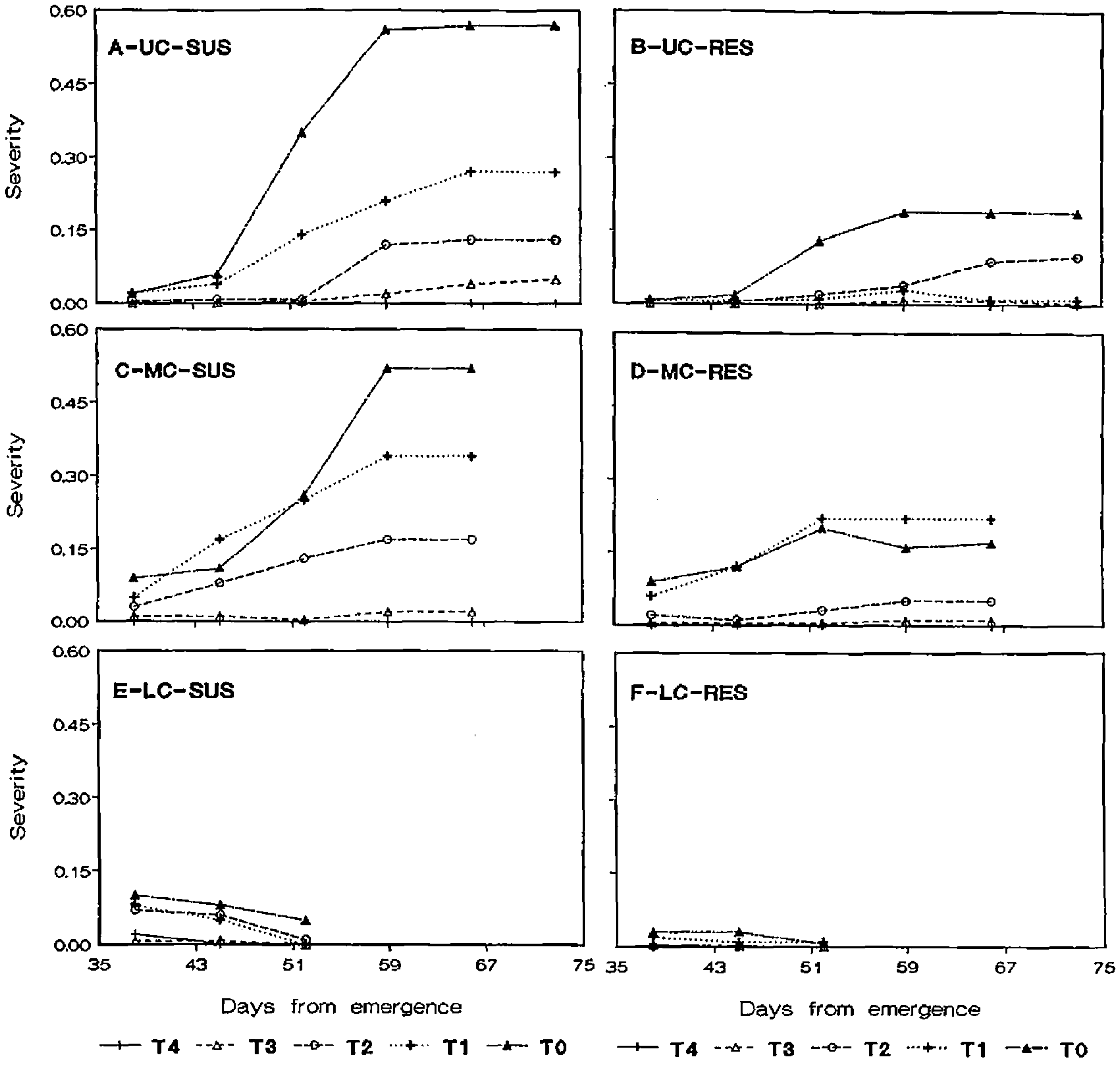

Fig 4. Disease progress curves expressed as rust severity (1.00 = 100%) against time in days from emergence, Ambo, 1990. A = SUS, upper canopy layer (UC); B = RES, upper canopy layer; C = SUS, middle canopy layer (MC); D = RES, middle canopy layor; E = SUS, lower canopy layer (LC); F = RES, lower canopy layer.

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. 5). Differences among treatments were observed in all experiments. The degree of variation in yield depended on the resistance level of the genotype and the disease severity. For SUS, maximum yield losses were 85, 43 and 60 % at Ambo in 1990, Debre Zeit in 1991, and Ambo in 1993, respectively. For RES, the maximum yield loss was 30% in both 1990 and 1993. In all cases, the yield loss increased with decreasing spray frequency.

The impact of bean rust on attainable yield of beans was large, even under the low external input conditions studied. The impact differed with genotype, intensity of rust, location and year. The greatest impact was at Ambo, where the disease pressure was high. When rust severity reached its highest level, the yield was reduced by 85%. In an environment with a moderate disease pressure, as at Debre Zeit, the highest yield reduction was 43%. In the partially resistant genotype the yield was reduced by 30% at most. The yield loss found in our trial was higher than that reported for Kenya (Singh & Musiyimi 1981) but less than indicated earlier for Ethiopia (IAR 1974). Yield loss in beans is mainly associated with reduction of pods per plant (Habtu & Zadoks 1995). The extent of yield loss caused by bean rust depends on the susceptibility of the genotype, plant growth stage at which infection occurs and rust intensity (Allen 1983, Pinstrup-Anderson et al. 1976).

In Ethiopia bean rust generally appeared at the vegetative stages (Habtu & Zadoks 1995). 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 & Musiyimi 1981).

Our experiment was conducted in research stations, with no external inputs but with relatively fertile soils. Farm operations are 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 genotypes (Parlevliet 1978) must be encouraged in any future rust management strategy.

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