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The impact of pathogens and arthropod pests on common bean production in Rwanda

(*Keywords* production constraints on farm diagnostic research *Phaseolus vulgaris* Rwanda)

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Abstract. The economic importance of diseases and pests on common bean production in Rwanda was investigated using on farm diagnostic trials multiregression models and national production information Disease and arthropod pest control resulted respectively in yield increases of 447–497 kg ha^{-1} and 158–233 kg ha^{-1} Nationally annual dry bean losses from diseases were estimated to be 219 300 tonnes or US$89 9 million and from arthropod pests 79 800 tonnes or US$32 7 million Major losses using multiregression models were attributed to angular leaf spot (56 656 tonnes) anthracnose (35 925 tonnes) floury leaf spot (30 264 tonnes) phoma blight (27 513 tonnes) rust (15 667 tonnes) and root rots (14 690 tonnes) Multiregression models were less useful in explaining losses from pests possibly due to the quality of data With results from national endosulfan seed treatment trials it was conservatively estimated that beanflies principally *Ophiomyia spencerella* reduced bean yields nationally by 18 000 tonnes The results have relevance for research and policy priorities for bean research not only in Rwanda but also in agroecologically similar regions in the Great Lakes region of Africa

1 Introduction

Projects to increase production of subsistence crops in developing countries are generally justified using the best available information on production constraints Unfortunately often the information is descriptive or not on farm based but rather biased towards problems found on research stations (Allen *et al* 1989) To set effective priorities for national and international research on subsistence food crops it is essential to obtain information of constraints under farmers conditions

Phaseolus vulgaris L is the primary source of protein and an important source of carbohydrates in the highly populated highlands of the Great Lakes region encompassing Burundi Rwanda the Kivu region of Zaire and southwestern Uganda For example in Rwanda beans provide a third of the total protein intake and an eighth of the carbohydrate consumption (Pachico 1989) Numerous diseases and pests as well as fertility were thought to be important bean production constraints in the Great Lakes region but empirical data were not available (CIAT 1981) When the Centro Internacional de Agricultura Tropical (CIAT) established a regional bean programme systematic on farm diagnostic research with national research institutes of Rwanda Burundi and Zaire and development projects became a major priority in efforts to develop technologies to increase bean production in the region

Various methods to quantify constraints are available (James 1974 Pinstrup Andersen *et al* 1976 Hildebrand and Poey 1985 Teng 1987) We used on farm diagnostic trials to determine yield gains by removal of a constraint (Hildebrand and Poey 1985) together with individual disease and arthropod pest evaluations linear empirical models using the multivariate regression technique to measure the functional relationship between yield and individual independent variables (Teng 1987) and reliable national data on area cultivated to beans (Anon 1984) In this paper we discuss principally the importance of pathogens and arthropod pests as constraints to bean production We believe the paper should be read in conjunction with two other papers which diagnose farmer perception and management of diseases (Trutmann *et al* 1993a b)

2 Materials and methods

A total of 45 replicated on farm diagnostic trials were installed in six different agroecological regions of Rwanda over three seasons in collaboration with various development projects Due to the small average size of farms of 0 5 ha the trials used were plus one and minus one exploratory designs (De Datta *et al* 1980 Hildebrand and Poey 1985) rather than a complete factorial design In plus one trials the effect of a factor is evaluated by adding a treatment to a farmer base treatment whereas in minus one trials the effect of a factor is deduced by eliminating treatments from a complete treatment in this case a disease and arthropod control and full nutrition base treatment In the first two seasons plus one trials were used followed by a further two seasons using minus one trials Plus one design trials used 9 m plots in which half the border row was sprayed in order to allow complete harvesting of the plots Minus one design trials used 16 m plots in which the inner 12 2 m was harvested Plots were separated by 1 m For plus one design trials plot treatments were as follows (1) farmer method (2) farmer

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method and fungal and bacterial control (3) farmer method and insect control and (4) soil fertilization In minus one design trials the above treatments were used as follows (1) disease and insect control and fertilization (2) disease and insect control (3) disease control and fertilization (4) insect control and fertilization (5) farmer treatment The farmer method consisted of sowing on a well prepared bed the traditional farmer bean mixture with small hoes in an evenly spaced fashion The whole field including the trial area was sown in this manner The beans were weeded and managed in the local tradition except no pods and leaves were consumed during the season Diseases were controlled with a pre sowing soil treatment with 50 kg ha benomyl 50% a i and 5 kg ha metalaxyl 80% a i in 3000 litres and from the first leaf stage a weekly foliar treatment with 1 kg ha benomyl 50% a i when necessary together with 4 5 kg ha copper oxychloride (or copper hydroxide 2 kg ha) in 3000 litres To control arthropod pests plots were treated with a pre sowing treatment of carbonyl at 10 kg ha in 3000 litres and each week after emergence with dimethoate 40% a i 2 litres ha in 3000 litres water Other plots were treated with water before sowing To optimize plant nutrition plots were treated with 30 tonnes ha and at the first compound leaf stage with 110 kg ha of diammonium phosphate Three trials were sown per season in each of six agroecological zones Treatments were replicated twice per farm per season with a randomized block design using three or four farms per region The trials were continued for three seasons except in the Bugesera (two seasons) The trials were harvested by farmers dried on farm and weighed using a balance accurate to the nearest gram

Evaluations were made of mean disease or arthropod severity per plot during the season Disease evaluations of foliar non systemic pathogens were based on percentage surface area of plants affected in each plot at the late podfill to late grainfill stage (Fernandez *et al* 1986) as it was regarded as the most critical time when photosynthate production would affect yield Soil borne pathogens bean common mosaic virus (BCMV) and beanfly were evaluated at the pre flowering stage They and other insects were evaluated using a 1–9 scale to indicate severity 1 = no symptoms 3 = slight 5 = moderate 7 = severe 9 = very severe or 50% or more of plants wilted Other less common pests were noted only for presence or absence

Yield disease and insect severity data were analysed using an analysis of variance and Duncan s multiple range test The effect of diseases arthropod pest control and improved plant nutrition on bean yield was calculated using De Datta *et al* (1980) and Hildebrand and Poey (1985) The data were also used in a linear multi regression analysis over agroecological regions using yield augmentation as the dependent variable and individual diseases and arthropod pests as independent variables To correlate observed yield increases with relative importance of either diseases or pests yield gains per repetition per region from either fungicide or insecticide treatments and controls of diagnostic trials were used in multi regression analyses As disease and insect severity data were not available for all trials model means were not necessarily the same as the means obtained for diagnostic trials over three seasons General national bean yield loss estimations due to diseases pests and suboptimal plant nutrition were made using diagnostic trial data over seasons which were extrapolated to all agroecological regions using the assumption that the Imbo and Eastern Savanna were similar to the Bugesera the Shores of Lake Kivu and the Eastern Plateau similar to the Mayaga Impara and Granitic Spur similar to the Central Plateau and the Volcanic Region similar to the Bubaruka Highlands These data were used together with reliable data of surface area under bean cultivation in various regions in Rwanda (Anon 1984) The season 1984b was a severe drought season where the mean yield estimate for the national survey was 412 kg ha which was not regarded as representative Monetary losses were calculated using the national assumptions of 35 Rwandan francs (FRW) kg and converted to US dollars using the exchange rate of 84 FRW dollar (US$ 0 41 kg) in December 1986

3 Results

The relative yield attributed to each limiting factor over agroecological regions is given in Table 1 Control of arthropods using minus or plus one design trials increased mean bean yield overall trials 17–30% disease control 52–59% and soil fertilization increased yield 22–60% Yield increases from arthropod control were lower in either trial design than those obtained from disease control or improved fertility The importance of diseases as a production limiting factor was noted both in plus and minus one design trials Soil fertility was numerically the greatest yield limiting factor in minus one designs trials but not in the plus one design trials Mean on farm bean yields were between 764 and 949 kg ha but could be improved to 2000 kg ha by removal of the three limiting factors

Table 1 Mean yield of dry beans through control of diseases arthropod pests and fertility 45 replicated on farm diagnostic trials Rwanda between 1985 and 1987

Trial design	Mean yield augmentation (kg ha)			Farm yield (kg ha)	Yield after elimination of limiting factors
	Disease control	Insect control	Plant fertility		
Plus	447	233	166	764	
Minus	497	158	566	949	1995

Table 2. The yield increase through control of diseases and arthropod pests in diagnostic trials (n = 90) in agroecological regions of Rwanda

Region	Altitude (metres above sea level)	Mean yield increase (kg ha^{-1}) Disease control	Mean yield increase (kg ha^{-1}) Insect control	Farm (kg ha^{-1})
Zaire-Nile Divide	1800–2200	440	315	820
Buberuka Highland	1800–2200	453	0	1050
Central Plateau	1600–1800	657	193	1049
Mayaga	1400–1600	367	166	789
Bugesera	1300–1400	38	168	517

Number of seasons that result was significantly different (P < 0.05) from farm control using Duncan's multiple range test.

Table 3. Severity of bean diseases in agroecological regions of Rwanda from 1985 to 1987

Disease	Disease severity (percentage of leaf area infected or 1–9 scale†) Buberuka highland	Zaire-Nile divide	Central Plateau	Mayaga	Bugesera
Phoma blight (%)	9.9	8.0ab	6.8 b	1.0c	3.2b
Anthracnose (%)	3.5b	10.2	4.6b	0.4c	2.7b
Angular leaf spot (%)	8.0bc	11.3b	9.4bc	10.3b	10.5bc
Floury leaf spot (%)	1.2d	0.2b	2.8bcd	4.7b	3.5bc
Rust (%)	0.6b	0.2b	1.1b	0.6b	5.3
Common blight (%)	0.9b	0.8bc	0.6bc	3.9a	3.4
Halo blight (%)	0.6	0.7b	0.0b	0.0b	0.0b
BCMV†	2	2d	2bcd	3 b	3
Root rots†	4b	5b	3	2	1d
Macrophomina†	1b	1b	1b	1b	3a
Root knot nematode†	1b	1b	1b	1b	3

Values in a row followed by the same letter do not differ significantly at P = 0.05 using Duncan's multiple range test.
†1 = no symptoms, 9 = very severe or 50% or more plants wilted.

Table 4. Estimated production losses of common bean in Rwanda due to diseases and arthropod pests

Agroecological region	Hectares of beans† grown	Estimated yield (tonnes)	Estimated loss (tonnes) Disease	Estimated loss (tonnes) Pest	Estimated loss (1000 US$) Disease	Estimated loss (1000 US$) Pest
Imbo	9501	4912	361	1596	148	654
Impara	25 475	26 723	16 737	4916	6862	2015
Lake Kivu Shoreline	23 800	26 496	8735	3950	3581	1619
Volcanic region	35 327	37 093	16 003	0	6561	0
Zaire–Nile Divide	43 978	36 061	19 350	13 853	7933	5679
Buberuka	35 995	37 794	16 305	0	6685	0
Central Plateau	99 286	104 151	65 230	19 162	26 744	7856
Granitic Spine	44 583	46 767	29 291	8604	12 009	3527
Mayaga	25 598	20 196	9394	4249	3851	1742
Bugesera	22 149	11 451	841	3721	344	1525
Eastern Plateau	99 143	78 223	36 385	16 457	14 917	6747
East Savanna	19 559	10 112	743	3285	304	1346
Total	483 790	439 979	219 375	79 793	89 939	32 710

†1984 M g q êt g l d t (Anon 1984)

Lowest increases from disease control were obtained in the lowest lying regions, but highest yield increase from the disease control was obtained in the mid altitudes (1600–1800 m), not the highest altitudes (Table 2). The severity of diseases and pests was often agroecological region rather than altitude dependent (Table 3). The greatest yield increases from beanfly control were actually recorded at high altitudes. Using national production survey data (Anon 1984), diseases were estimated to reduce yields by 219 375 tonnes per year, valued at 89.9 million dollars (Table 4). Arthropod pests were estimated to reduce yields by 79 793 tonnes valued at 32.7 million dollars

Table 5 Relative importance of pests and other problems in natural regions of Rwanda from 1985 to 1986

Region	Beanfly severity†	Aphid severity†	Observed pests and problems ‡
Buberuka highlands	2d	3	b p
Zaire Nile Divide	4bcd	3	b p q
Central Plateau	4bc	2b	f k l m
Mayaga	5ab		c d f g h j m
Bugesera	6a		b c d e h q s

Values in a column followed by the same letter do not differ significantly at
P = 0 05 using Duncan multiple range test
†On a 1 9 scale (1 = no symptoms 9 = very severe)
‡ *Altheca* sp b leaf hoppers *Medythia* q t m d *Maruca testulalis* Mealy bugs ts f w e l g *Alcidodes leucogramma* h grasshoppers *Ophiomyia spencerella* j *Ophiomyia phaseoli* k *Heliothis* spp l be w b w rm m *Zonocerus elegans* *Trichoplusia* pp o ats p h l q weeds *Mylabris* spp *Aphis fabae*

Highest disease severity ratings were obtained for angular leaf spot caused by *Phaeoisariopsis griseola* (Sacc) Ferraris anthracnose caused by *Colletotrichum lindemuthianum* (Sacc & Magnus) Briosi & Ferraris phoma (ascochyta) blight caused by *Phoma exigua* var *diversispora* (Desm) Boerema floury leaf spot caused by *Mycovellosiella phaseoli* (Drummond) Deighton and root rots associated with *Fusarium oxysporum* f sp *phaseoli* Kendrick & Snyder (Table 3) Phoma blight anthracnose and root rots were most severe in the medium to high altitudes and floury leaf spot in the medium to low regions Angular leaf spot was severe in all agroecological regions Beanfly predominantly *Ophiomyia spencerella* Greathead was the most severe pest in all agroecological regions except the Buberuka highlands Aphids predominantly *Aphis fabae* Scopoli were relatively less severe (Table 5) Other pests were found but were not commonly found at high populations levels Only for phoma blight aphids and beanfly did season significantly influence severity (Table 6)

Highly significant regression models (*P* = 0 000 to *P* = 0 009) were obtained to describe the influence of diseases on yield in all agroecological regions except in the Zaire Nile Divide (*P* = 0 132) and Mayaga (*P* = 0 330) (Table 5) All models had R^2 values between 0 41 and 0 95 Highly significant regressions were used in the general analysis over all agroecological regions to describe the correlations of angular leaf spot phoma blight floury leaf spot root rots and rust severity with yield Lower confidence levels were frequently observed in multi regressions of regional data but trends were similar to those expected from severity ratings Angular leaf spot was associated with the highest yield and monetary losses followed by anthracnose floury leaf spot phoma blight rust caused by *Uromyces appendiculatus* (Pers) Unger var *appendiculatus* and root rots (Table 6) Total yield estimations from the models of losses due to diseases correlated well with those of the actual values from diagnostic trials used to calculate national losses (Tables 4 and 8)

Significant overall relationships were obtained with the multivariate regression models (*P* = 0 000 to *P* = 0 05) between yield and arthropod pests severity in all agroecological regions except the Bubaruka highlands and significant correlations were obtained for beanfly in all regions but not for aphids (Table 7) However R^2 values of models were too low (0 04–0 39) to meaningfully estimate the contribution of beanfly or aphids to yield loss

Table 6 Disease and pest severity o e te on beans in the first and second growing season

Disease or pest	Disease severity	
	September to January	March to June
Phoma blight†	3 4	8 8b
Anthracnose†	5 0	5 3
Angular leaf spot†	9 1	10 9
Floury leaf spot†	2 4	2 4a
Rust†	0 6	1 1a
Common blight†	1 4a	1 2
Halo blight†	0 2a	0 2
BCMV‡	1 8	1 8
Root rots‡	2 6b	4 4b
Aphids‡	2 2	1 1b

Numbers in each row followed by the same letter do not differ (*P* = 0 05) using analysis of

†Percentage of surface infected
‡1 = no symptoms 9 = very

4 Discussion

Diseases were the most important agronomic yield limiting factor in Rwanda using plus one trials and the second most important agronomic factor after plant nutrition using minus one trials The differences in the results from the two trials are due to a masking effect in the plus one trials where potential yield grains through improved fertility were not realized due to losses from diseases (Graf and Trutmann unpublished) Conservative estimates indicate that disease control could contribute nationally to additional production of 219 300 tonnes of dry beans (50 / of

Table 7 Multiple regression models correlating bean yield with disease in agroecological regions of Rwanda

Disease	Buberuka highland	Zaire-Nile divide	Central Plateau	Mayaga	Bugesera	Global
	Coef *P*	Coef *P*	Coef *P*	Coef *P*	Coef *P*	Coef *P*
Phoma blight	−0 45(0 15)	−0 34(0 15)	−0 30(0 70)	0 08(0 31)	−0 17(0 26)	−0 27(0 05)
Anthracnose	−0 37(0 94)	−0 31(0 19)	−0 38(0 16)	−0 20(0 34)	−0 23(0 00)	−0 29(0 19)
Angular leaf spot	−0 50(0 14)	−0 45(0 95)	−0 53(0 00)	−0 49(0 04)	−0 25(0 78)	−0 46(0 00)
Floury leaf spot	−0 22(0 22)	−0 23(0 71)	−0 36(0 01)	−0 18(0 09)	−0 17(0 00)	−0 22(0 05)
Common blight	−0 25(0 06)	−0 23(0 26)	0 27(0 08)	0 07(0 97)	−0 32(0 39)	−0 04(0 93)
Halo blight	−0 18(0 43)	−0 14(0 90)				−0 09(0 32)
BCMV	0 15(0 51)	−0 11(0 04)	−0 14(0 62)	−0 01(0 08)	−0 08(0 02)	
Rust	−0 10(0 49)	−0 17(0 07)	−0 06(0 17)	−0 27(0 10)	−0 17(0 95)	−0 15(0 75)
Root rot	−0 29(0 06)	−0 27(0 21)	−0 08(0 35)	−0 07(0 55)	0 34(0 00)	−0 13(0 04)
Macrophomina					−0 46(0 90)	
Nematode					−0 07(0 00)	
R model	0 563	0 407	0 540	0 442	0 953	0 343
Model *P* =	0 007	0 132	0 000	0 330	0 009	0 000
Yield (kg ha)	574	398	526	502	44	512

Table 8 Estimated production losses of common bean per disease in Rwanda

Disease	Estimated yield loss (thousand tonnes)	Estimated economic loss (million US$)
Phoma blight	27 5136	11 2806
Anthracnose	35 9252	14 7293
Angular leaf spot	56 6565	23 2292
Floury leaf spot	30 2642	12 4083
Rust	15 6635	6 4220
Common blight	7 7821	3 1907
Halo blight	5 1482	2 1108
Bean common mosaic virus	9 8544	4 0403
Macrophomina stem blight	0 9724	0 3987
Root rot	14 6909	6 0233
Nematodes	0 1537	0 0630
Total	204 6247	83 8962

Table 9 Multiple regression models correlating yield with arthropod pests on beans in agricultural regions of Rwanda

Disease	Buberuka highland	Zaire-Nile divide	Central Plateau	Mayaga	Bugesera	Global
	Coef *P*	Coef *P*	Coef *P*	Coef *P*	Coef *P*	Coef *P*
Bean fly	−0 10(0 51)	−0 42(0 06)	−0 44(0 01)	−0 47(0 00)	−0 62(0 01)	−0 31(0 00)
Aphid	−0 16(0 34)	−0 30(0 33)	0 10(0 76)		−0 14(0 68)	−0 15(0 11)
R model	0 04	0 200	0 20	0 22	0 39	0 11
Model *P* =	0 544	0 049	0 035	0 008	0 042	0 000
Yield (kg ha)	19	492	126	151	152	183

actual production) or 89 9 million dollars per annum Control of pests was estimated to contribute 79 800 tonnes of dry beans (18% of actual production) or 32 7 million dollars per annum Results from Burundi (van Durme *et al* 1983 Perreaux 1986 Autrique 1987) and the Kivu region of Zaire (Pyndyi 1987 Trutmann unpublished) and observations from southwestern Uganda (Trutmann unpublished) suggest disease and pest problems and losses are similar to those in Rwanda suggesting this study could be useful to obtain rough estimates of the importance of major diseases and arthropod pests in other countries of the region

The results suggest the greatest impact on bean yield through disease management in Rwanda would come from control of angular leaf spot which alone accounts for annual production losses of 56 700 tonnes or 12% of the national bean production Other priority diseases are anthracnose (7% of national production) floury leaf spot phoma blight (each 6% of national production) rust and root rots (each 3% of national production) Control of these six diseases accounts for 82% of total production grains due to disease control

The regression models used to correlate individual diseases with yield appear to be relatively accurate National yield losses for individual diseases calculated with the linear multi regression model closely approximated those directly obtained from diagnostic trials (Tables 3 and 8) The relative importance of individual diseases using the model also correlates well with severity ratings except for floury leaf spot and rust which account for more yield loss in the models than suggested by severity ratings alone

Although diagnostic trial results showed arthropod pest control to increase bean yield multi regression models were not useful in calculating losses due beanfly or aphids According to the models control of beanflies predominantly *O spencerella* and aphids explained only 11% of observed national yield increases from pest control The R^2 of models was low although the importance of beanfly as a pest is suggested as it explained much of the variability in the models in all agroecological regions except the Buberuka highlands where little beanfly was found during the time of the trials More recent results from regional seed treatment trials provide an estimate of the importance of beanfly control on national production (Trutmann *et al* 1992) It is estimated that beanfly control would annually increase national yields in Rwanda by 18000 tonnes or 4% of total national bean production equivalent to US$ 7 4 million This suggests beanfly causes about 25% of the total losses attributed to arthropod pests in Rwanda Larger yield increases from beanfly control have been obtained in seed treatment trials in Burundi (Autrique 1987) which suggest beanfly could be a greater production constraint there than in Rwanda

This study represents the first in depth analysis of disease and pest constraints of common bean in the Great Lakes region of Africa However the results are based on a number of assumptions and extrapolations which the user should be aware of Most of the assumptions are evident from tables and information presented For example results from diagnostic trials were extrapolated to an entire agroecological region and to agroecologically similar regions where no diagnostic trials had been conducted Multi seasonal on farm data were used We assume the seasons were representative and indicative of future trends Teng (1987) discusses some of the assumptions and limitations of the multi regression models In this study correlations for individual diseases on the regional level were often above $P = 0\ 05$ and the regional model for the Mayaga was only significant at $P = 0\ 33$ Nevertheless we consider the assumptions and extrapolations made are justifiable considering the logistical difficulty of the work and similar assumptions by most other investigators working on crop loss assessment

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Management of common bean diseases by farmers in the Central African Highlands

(*Keywords* Indigenous farmer knowledge IPM bean diseases system diagnostics African Great Lakes)

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Abstract. Farmers management of bean diseases in the Great Lakes region of Africa was investigated from both phytopathological and anthropological perspectives Local crop protection strategies were based on microclimate regulation genetic diversity and sanitation Microclimate management involved selectively integrating numerous agronomic practices depending on the site and conditions The strategies included manipulating sowing density and time of sowing choice of soil use of varieties variety and species mixtures for specific conditions foliage reduction staking and selective weeding Decision making flexibility was essential to the effectiveness of local microclimate management strategies Resistant varieties were available in local mixtures and were managed by farmers through intervention and natural selection in the field A number of sanitation methods were used such as removal of debris from fields at harvest but the value by farmers of crop protection was less recognized Improvements to local plant protection should be possible through the development of technologies which reduce losses in plant density improve crop resistance to rain while maintaining genetic variability and improve seed health and by educating farmers in the basic principles of plant pathology while ensuring the participation of farmers in the development of technologies destined for these agroecosystems The authors emphasize the importance of developing technologies for farmers which do not decrease existing management flexibility

1 Introduction

Around 70% of the world poor engage in subsistence agriculture (Todaro 1977) That such farmers have rarely benefited from available technological advances is a major concern for national and international agricultural research institutes (Moreno 1985) Technologies intended for these farmers have often not been adopted or have failed mostly because the research was conducted without adequate consideration of farmers own knowledge and practices Recently a realization has emerged of the importance of using indigenous knowledge as a foundation for change (Rau 1991)

Considerable knowledge has been collected in agriculture by anthropologists about farmer knowledge Farmers appear to know much about their crops (Bentley 1989) animals (Hunn 1977) soil (Conklin 1954) flora (Conklin 1954 Berlin *et al* 1974) less about insects (Wynman and Bailey 1964 Altieri 1984 Bentley 1989) and little of plant diseases (Bentley 1989 1990 1991) A major resource on information of disease management in traditional systems has recently been published which illustrates the existence of similar technologies in different ages cultures and geography (Thurston 1992) Curiously few detailed studies are available about plant disease management by subsistence farmers

As part of a regional research effort in the Great Lakes region of Africa to find technologies to increase productivity of beans (*Phaseolus vulgaris* L) this study aimed to understand local disease management in the context of a parallel study on farmer perceptions of plant disease to determine likely areas where improvements could be made to local systems of plant protection Although we emphasize phytopathological issues general aspects of crop protection important to farmers are also discussed

1 1 Context

Beans are the most important protein source in the Great Lakes region which encompasses Burundi Rwanda the Kivu region of Zaire the West Lake district of Tanzania and the Kigezi district of Uganda Average per capita consumption is over 40 kg per year (ISAR 1987) which is the highest in the world Farmers overwhelmingly grow beans as varietal mixtures Women are responsible for the majority of food crop cultivation tasks especially of beans (Voss 1992) Bean yields average between 700 and 900 kg/ha Diseases and pests are important production constraints in the region Disease control in diagnostic trials increased yields by 300–450 kg/ha (ISABU 1986 Trutmann and Graf 1993 Pyndji 1987) The most important diseases on farm were angular leaf spot (*Phaeoisariopsis griseola* (Sacc) Ferraris) phoma blight (*Phoma exigua* var *diversispora* (Desm) Boerema) anthracnose (*Colletotrichum lindemuthianum* (Sacc & Magnus) Briosi & Ferraris) floury leaf spot (*Mycovellosiella phaseoli* (Drummond) Deighton) and root rots associated mainly with *Fusarium oxysporum* f sp *phaseoli* Kendrick & Snyder Insects especially beanfly (*Ophiomyia spencerella* Greathead) limited production on average by 150–250 kg/ha

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2 Materials and methods

2 1 *Farmer interviews*

In 1984–5 a formal agricultural production survey was conducted around Ruhengeri in the volcanic region of northern Rwanda and backed by a smaller informal survey around Butare in the central plateau Using a standard questionnaire 120 Ruhengeri farmers selected at random were asked what characters they considered most important in selecting a new variety their reasons for using varietal mixtures and methods used to test new varieties for their mixtures

In 1987 a 20 month study was conducted in Bwisha a Zairian village near the Rwandan border These farmers were considered to have the same cultural base as those in Rwanda Burundi and the Kigezi district of Uganda Information on farmer management practices to protect crops from the effects of rain was obtained using participant observation and was complemented by structured interviews and group discussions in the village once local themes in crop protection had been assessed Regular feedback between the phytopathologist and the anthropologist enabled the latter to probe farmers techniques comprehensively Two months of repeated structured group discussions were also conducted in six different villages in the vicinity of the study village at altitudes between 1000 and 2000 m The groups consisted of six people (three women and three men) who were locally regarded as good farmers

2 2 *Experimental*

2 2 1 Relation of plant density to plant disease and insect damage On the Zaire–Nile divide station of Gasenyi (2000 m) on low fertility acidic soils pH 4 10 m^2 plots were sown in an equally spaced non linear pattern as practised by farmers at a rate of 5 × 10 plants ha The plots were replicated five times using a randomized block design Plant losses during the September to January and April to July seasons were measured using four measurements with a 0 25 m quadrant At harvest total plant number per plot was counted

2 2 2 Effect of staking climbing beans on foliar disease severity To measure the effectiveness of staking on disease development 2 5 m plots were sown with five rows of the climbing variety Gisenyi 2 bis at 2 × 10 plants ha Beans were grown with or without support Treatments were replicated five times using a random block design The inner three rows were evaluated for disease at grainfill The trial data were analysed using a two way analysis of variance (ANOVA)

2 2 3 Determination of anthracnose resistance in local mixtures Twenty varietal mixtures were collected from farmers in each of two regions of Rwanda the Mayaga (1400–1500 m) and the Zaire Nile watershed (1800–2000 m) To estimate the composition of the mixtures of the different regions equal quantities of mixtures from each region were mixed In the resulting mixture the different varieties as measured by colour seed shape and size were separated and noted Three seeds of each variety (Adams and Martin 1988) were sown in a screen house in 20 cm clay pots filled with forest soil Control pots consisting of two anthracnose susceptible varieties (Shikashike and Rubona 5) were placed after every five treatment pots to measure the evenness of infection To evaluate the varieties for resistance anthracnose suspensions of 1 × 10 spores ml ^{1} of a mixture of local *C lindemuthianum* strains obtained from heavily infected pods collected on farm in each region were sprayed on varieties from the same region at the primary leaf stage of growth In this manner components of each mixture were exposed only to *C lindemuthianum* races from the agro ecological region of collection After inoculation plants were covered with plastic bags for 7 days Varieties were evaluated for anthracnose after 14 days using percentage surface area infected adapted from CIAT (1987)

2 2 4 Farmer seed selection practices Mixtures of bean seed from 50 farms across three agro ecological zones the Zaire–Nile Crest Central Plateau and Mayaga were collected while farmers were sowing Farmers were asked to classify the field according to fertility Five kinds of mixtures were selected (1) unsorted beans directly from storage (2) seed sorted for sowing on fertile ground (3) seed sorted for infertile soil and (4) seed rejected for sowing On station seed was visually evaluated for dark lesions which were used as indicators of the presence of seed borne infection (Trutmann and Kayitare 1991) To measure what changes had occurred during seed sorting seed for sowing was compared with stored and rejected seed Grain size was evaluated by passing seed through a sieve which retained large grained seed Seed was also evaluated for less preferred black and preferred yellow grain colour In addition in an informal survey women were asked how they selected seed for sowing

2 2 5 Field sanitation at harvest This information was obtained informally through on farm observation of farmers during the harvest and pre harvest periods in Rwanda Burundi and the Kivu region of Zaire

3 Results

3 1 *Microclimate*

Farmers purposefully regulated the crop microclimate in fields of varying fertility soil type slope and field aspect depending on the moisture risk by managing the plant architecture crop associations weeding sowing density sowing dates and staking density Farmers mentioned they usually sowed a field at a uniform density each season and if there was too much rain picked off the leaves of the beans to enable light to penetrate between plants The options available to farmers and the dynamic nature of decisions for microclimate management are presented in Figure 1 Flexibility was central to the farmers crop protection and risk reduction strategy

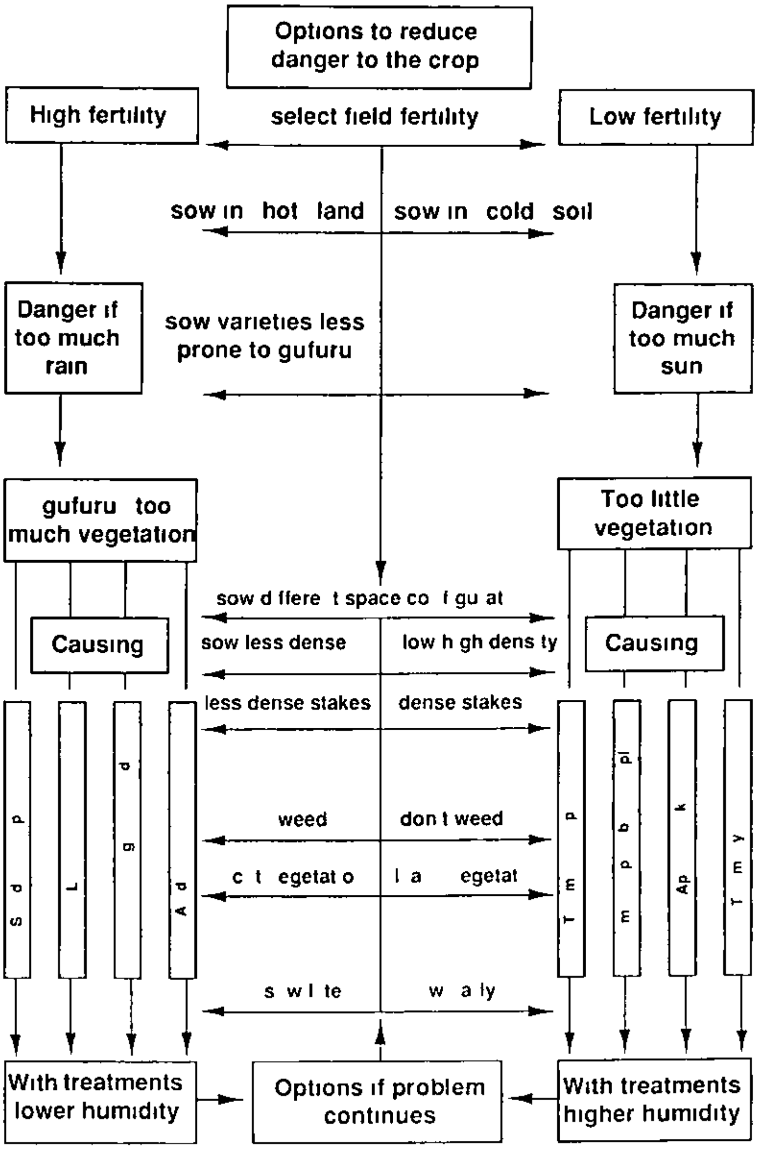


Fig 1 F rm rop m ocl m t m g me t ho es n fert l nd f rt le soil

3 1 1 Sowing density and configuration A generally held principle derived from local concepts of plant health was that bush beans not sown in the same hole should not touch each other Similarly climbing beans on one stake should not touch plants on other stakes In conditions where plants were likely to do well and grow larger they were either sown further apart or other conditions were altered such as sowing the crop later

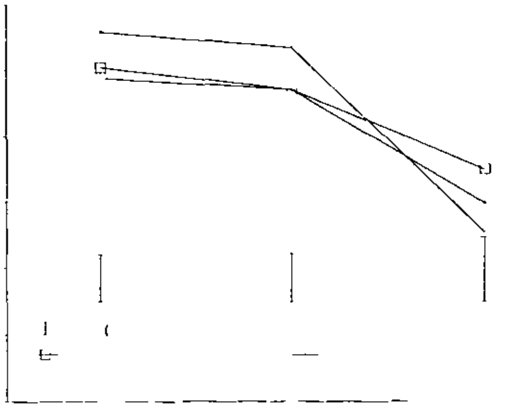
Seed was sown not in line but in an equidistant pattern The seeds were placed either singly or in pairs within the same hole Apart from saving time this sowing configuration maximized the distance between the plant units in different holes Sowing similar densities in rows which was promoted by the local extension services caused greater contact of the plants within rows

Preventing plants from touching was considered most important in damp and fertile conditions when each plant tended to grow larger and required more individual space If conditions were less fertile it was considered wrong to reduce the plant density due to reductions in yield Plant numbers could be established by changing the sowing configuration Two seeds were sown per hole but the holes were wider apart Thus two plants became a unit Farmers also varied the configuration of staking to change the sowing density for climbing beans to manage the danger of gufura a condition when plants are in danger of touching due to excess vigour For example where the crop was vigorous fewer and taller stakes were used

The strategies used by farmers are pertinent as many pathogens infect hosts more readily through wounds derived from physical contact and leaf contact promotes pathogen spread From a scientific standpoint practices which minimize infection sites through wounding are accepted disease avoidance practices (Palti 1981) and those which maximize distance between susceptible tissue are believed to encourage wastage of pathogen inoculum (Wolfe 1985)

Farmers used sowing density flexibly They sowed more densely in less fertile soil where each plant took up less space and if seed quality was poor Within a given field farmers sowed more densely the greater the estimated weed pressure More seed was sown in badly prepared fields or was likely to provide a hostile environment to the growing plants (e g beanfly pressure) Great importance was attached to decisions concerning sowing density and conformation hence sowing was often a specialist s task given to the few people who were regarded as good judges of the relationship between fields and varieties and climates

Observations of on farm plant densities supported comments made by farmers in the study village Differential sowing rates were used in different regions and seasons On the poor soils of the Zaire–Nile divide farmers sowed 3–3 5 × 10 and 4 5–6 × 10 plants ha in the September and April season respectively (Trutmann and Graf unpublished) In the fertile northern Rwandan highlands densities of 3 5–4 5 × 10 plants ha were found in both seasons (Paul 1987) Similar densities were the rule in the volcanic Goma region of Kivu in Zaire Significant reductions were observed over the growing season in plant density of beans in the Zaire–Nile divide ranging between 33 / and 55 / (Figure 2) Substantial reductions in plant density were also observed in other agro ecological zones (Trutmann *et al* 1992) Protection of plants by seed treatments against beanfly and seed borne diseases increased plant survival significantly (Trutmann *et al* 1992) Root rots were severe in a number of regions in Rwanda including the Zaire–Nile divide and were associated with reduced plant densities and with significant yield losses (Trutmann and Graf 1993) It was evident that high sowing density used by the farmer was in part a response to severe pathogen and arthropod pest pressure



Fg 2 O f rm pl t de ty h g f mm b d g th so th Z Nl d d

3 1 2 Mounding and ridging Technologies which reduced beanfly damage were used in some regions Farmers mounded soil around the base of stems at first weeding and mulched the soil leaving the roots in a humid environment which protected infected roots from desiccation The effectiveness of local methods was supported by results from a trial which showed that mounding soil did not significantly reduce the beanfly severity but increased (*P* = 0 05) plant survival by 41 / (Table 1)

Raised beds were used in high lying more fertile volcanic regions They prevented roots from becoming waterlogged during frequent heavy rains and may have served to reduce the incidence of root rots particularly those caused by Oomycetes (Lozano and Terry 1976) and *Rhizoctonia* (Pieczarka and Lorbeer 1974)

3 1 3 Defoliation Climbing bean leaves were removed to regulate the effects of rain Leaves which did not protect flowers from rain or touch neighbouring plants and lush green mature leaves were taken from the middle level of the plant at flowering and during weeding Farmers believed leaf removal reduced shade at the mid level of the crop which promoted flower production not only on the upper plant levels which increased yield and reduced pod rot Leaf removal also prevented leaves touching other plants and climbing up neighbouring stakes

A recurring theme was the importance farmers placed on the control of flowersetting and development Protecting flowers was basic to crop protection from the farmer s point of view Flowers were considered to be an indicator through which a multitude of divergent influences on plant growth could be related to yield

3 1 4 Staking A feature of climbing beans was that they are cultivated predominantly on fertile soils in the highlands where disease pressure is high Staked climbing beans usually suffered less from disease than bush beans even though there was no evidence that they were innately less susceptible to foliar diseases The effectiveness of staking as a disease escape mechanism was illustrated in a trial where staking significantly (*P* = 0 05) reduced levels of the important diseases anthracnose and phoma blight in comparison to unstaked plants (Table 2)

3 1 5 Weeding Patterns of weeding varied according to altitude and region In Bwisha at lower altitudes where bush beans predominated one weeding was essential and a second one nearer harvest was optional

T bl 1 Th ffect f t k g be th d f g l le f pot th d ph m blight

	P t ge rf f ted		
C lt t m thod	A g la le f pot	A th a	Ph m bl ght
No t k g	13 8	8 2	6 2
St k g	10 8	3 0b	3 4b

F g s l m w th the m l tt d ot d ffe g f tly t *P* = 0 05 g lys f

Table 2 Effect of mounding soil around seedling stems on beanfly severity and plant survival

Treatment	Beanfly severity	Plant survival (plants ha)
Not mounded	7.2	108670
Mounded	6.8	153330b

Figures in columns with the same letter do not differ significantly at $P = 0.05$ using analysis of

Each weeding had specific objectives The first around flowering was considered to reduce weed competition and to provide a mulch of decaying vegetation whose rapid decomposition was believed to provide a source of nutrients to the crop and prevented the soil from drying should the season end early Weeding also opened up the crop facilitating more rapid drying during wet weather and the mulch prevented soil splash However the only concern for soil splash was when plants turned yellow and developed holes It was believed rainfall splashed soil onto the plants which then died There was no clear association by farmers between rain splash and spread of rotting tissue

When the crop began to ripen farmers recognized two alternative courses of events The first was the steady timely and good drying out of the crop as the crop matured The second was a rapid putrefaction if the crop matured poorly The latter was common if ripening was delayed when the crop was over vigorous The second weeding at pod fill encouraged ripening by promoting air circulation and according to farmers prevented dew from promoting decay

There was a reluctance by farmers to pull out plants although farmers in certain regions did remove wilted seedlings which suffered from root rots or beanfly These wilted plants were left on the ground along with primary leaves of the rest of the crop and weeds which were removed during weeding

3.1.6 Timing In Bwisha beanfly was seen to be a problem in later sowings Beanfly was termed the worm in the root and it was considered especially a problem of late planted bush beans The increased severity of beanfly attack on beans in late planted beans was confirmed by Gasana (1988)

Farmers changed varieties according to the season In Bwisha during the long rainy season rain resistant varieties were sown and those with gufura were sown later During the shorter rainy season more vigorous and higher yielding varieties were used Because of the different seasonal requirements or possibilities farmers often preferred different varieties for each season

3.2 Host resistance and crop diversity

3.2.1 Associations Although beans are often grown in monoculture of mixed varieties association of species is a common practice in the Great Lakes region (Jones and Egli 1984) The major associations with beans include maize sweet potatoes and banana However farmers made little reference to the use of associations in crop protection with exception of banana–bean associations to protect beans against drought

3.2.2 Varietal mixtures In northern Rwanda 96% of farmers preferred growing mixtures over single varieties and 67% did so for yield stability and 61% exclusively or also for higher yield Farmers also considered rain tolerance to be one of the most important criteria for varietal selection (Table 3) Clearly a major element in the overall plant protection strategy was the use of plant genetic diversity in the form of varietal mixtures

Just as farmers were aware of the importance of regulating the crop microclimate through cultural techniques the same was true for their understanding and description of selection of architectural traits which enabled plants to better resist the effects of rain However farmers were unable to express the methods used in selection of varieties with physiological resistance to disease It was unclear whether farmers selected for resistance to major diseases Consequently to obtain this information we relied on direct evaluation of local germplasm to obtain information Similarly to obtain information on methods used by farmers to select germplasm resistant to local diseases we relied on direct observation of the way farmers manipulated mixture components in newly colonized areas

Farmers consciously selected varieties for rain tolerance using principally plant architecture and plants which tolerated the effects of rain Mixtures of climbing beans were selected to include varieties which climbed vigorously to protect like umbrellas the flowers of less precocious varieties For bush varieties resistance to heavy rainfall was partially understood according to the plant s growth pattern One variety *Simama* was considered very resistant to rain its name meant stand up which reflected its growth habit The plant continued to remain erect rather than lodge even when laden with pods Varieties which weakened in the stem or lodged before ripening were less resistant to rain as they touched the ground and if they were harvested late rotted in the field much faster

Table 3 Bean variety characteristics important to farmers when selecting varieties for mixture

Attribute	Importance score (maximum 100)
Yield	92
Rain tolerance	85
Drought tolerance	76
Eating quality	60
Standing upright	48
Stability	36
Fast cooking	31
Green bean quality	29
Leaf quality	20
Grain colour	6

Farmers also selected varieties for their mixtures with physiological resistance to diseases. However, the selection of physiological resistance was not consciously separated by farmers from other characters which enabled plants to tolerate or escape the effects of rain. It became clear from a study that farmers in different regions selected physiologically resistant varieties. Local mixtures from both high and medium altitudes had substantial proportions of varieties completely resistant to local pathotypes of *C. lindemuthianum* (Table 4). In both agro-ecological regions 35–40% of mixture components were completely resistant (no symptoms) to local strains of *C. lindemuthianum*. However, in regions less favourable to anthracnose development completely resistant varieties occupied only 16% of the mixtures, whereas in higher altitudes which were more conducive to the disease they made up 25% of the bean mixtures, a 56% increase. These results suggest that a relatively high proportion of varieties in mixtures were resistant to local races of *C. lindemuthianum* and that farmers selected mixtures with higher proportions of resistant varieties in regions where conditions were highly favourable to *Colletotrichum* activity.

Observations between 1984 and 1988 showed that mixtures were selected by farmers in two basic ways. In established areas, as in northern Rwanda, the composition of most mixtures was generally finely tuned and farmer preference was more evident. Most farmers were reluctant to add new varieties to their established mixtures and 78% first tested new varieties in different parts of the farm to see where they could best fit before they were added to a mixture. In new areas of settlement such as the Bugasera (Cishabayo, personal communication) and the Zaire–Nile divide, farmers were not particular about varieties. Farmers repeatedly added any available variety or mixture to their mixtures and harvested seed from the survivors. In this way, using a process of natural selection, farmers appeared to select the fittest plants and mixtures for their specific environment.

3.3 *Sanitation*

3.3.1 Seed selection and management. Farmers selected seed principally immediately before sowing, although some farmers selected seed for sowing gradually up to the time of sowing while preparing beans for cooking. In a survey of farmers' seed stock before and after sorting, seed with lesions represented 19.5% of the initial

Table 4. Susceptibility of local bean mixture components from two altitudes in Rwanda to local pathotypes of C. lindemuthianum

Seed type			Surface area of bean plants from Mayaga and the Zaire-Nile Divide affected by anthracnose†					
Primary colour	Secondary colour		Mayaga (1500 m)			Zaire–Nile Divide (200 m)		
			0%	1–5%‡	10%	0%	1–5%‡	10%
White 1	red	large				0.0	2.6	0.0
White 2	red	large				1.8	0.0	0.0
White 3	black	medium				1.0	3.1	0.0
White 4	black	medium				0.0	0.9	0.4
White 5	black	medium				0.0	1.3	0.0
White 6	black	small				1.3	1.3	0.0
Yellow 1	(dark)	large	3.7	7.4	0.0	0.0	4.4	0.0
Yellow 2	black	large	0.0	6.7	0.0	0.0	10.9	0.0
Yellow 3	(light)	medium	2.3	2.3	0.0	4.0	0.0	0.0
Yellow 4	(light)	medium	0.0	26.7	0.0	0.0	1.3	0.0
Yellow 5	black	medium	0.0	17.8	0.0			
Brown 1		large	6.5	13.2	0.0	0.0	3.5	0.0
Brown 2		medium				0.0	1.8	0.0
Brown 3	(dark)	medium				0.0	1.8	0.0
Pink 1		medium				0.0	5.8	0.0
Red 1		medium	0.0	1.7	0.0			
M 1		large	0.0	1.7	0.0	5.7	11.4	0.0
Black 1		medium	3.9	0.0	0.0	10.6	0.0	0.0
Gray 1	black	large				0.0	1.8	1.8
Gray 2		medium				0.0	10.1	0.0
Gray 3		medium				0.4	0.9	0.0
Mixed 1		med/l	0.0	6.2	0.0	0.0	9.6	0.0
Sum of mixture components			16.4	83.7	0.0	24.8	72.5	2.2
Sum of controls			0.0	100.0	0.0	0.0	92.2	7.8

†Mixture components f ch eg w p sed ly t *C l d m th m* collected th m g

‡NB 1–5% f rf a ea fected by *C l dem th n m* (g e ally l f s pet l t m) lly ca se ll p of la g a ea f t s ppl ed by th ffected l system d eg ded q t se f t

stock 12 5 / of sowing seed and 25 5 / of rejected seed It suggested farmers reduced seed borne pathogen inoculum by managing the seed To select seed farmers scrutinized the hilum area of the beans which was not allowed to be blemished Less attention was given to other areas of the seed Blemished small or imperfect seed was used for sowing only when insufficient seed was available

In many areas different varietal mixtures were preferred for each of the two seasons For the longer wet season varieties had to be more resistant to rain than those used during the shorter wet season In highland areas harvested seed from the September season could be stored throughout the March season and planted during next season and vice versa Farmers stated that seed stored for a season was more productive In lowland areas such long term storage was impossible because of higher temperatures which promoted bruchids and reduced seed viability Seed would be stored in the ground a small amount of seed from the September season was sown in March and its harvest was seed for September once more Many farmers could not maintain these preferred systems The agricultural survey in the Ruhengeri area showed that in the highland area 43 / of farmers stored seed 1–3 months 30 / for 4–6 months and 27 / longer Only half the farmers stored seed between growing seasons

3 3 2 Rotations The advantages of alternating crops or crop varieties were clear to farmers The benefits in the study village were largely seen in terms of fertility However fertility was recognized from the yield and an important influence on the yield was disease After a poor crop of beans farmers would say that the ground was poor for beans Soil poverty was related to specific crops Thus although poor for beans the field might well have been good for sorghum or even millet Or it may have been good for a different variety or mixture of beans in which case bean varieties could be rotated Crop rotations in the strict sense were rare as associated cropping was the rule It was often the dominance of crops in a field that shifted In many areas beans were rarely absent from a field

3 3 3 Field sanitation and selection at harvest Farmers preferred early maturing varieties and harvested early In doing so they removed plants from the field to homesteads Bean debris in Zaire was burned but recently by law in Rwanda it now has to be composted which is often done inefficiently Fields were left until the onset of the next rainy season and were prepared twice by hoeing when available compost was added

4 Discussion

Farmers in the central African highlands had a holistic view of crop protection They used an elaborate array of methods to manage plant disease which often were not possible to separate from general plant protection strategies These included management of moisture vigour genetic diversity disease resistance and sanitation The disease management strategies were preventative in nature rather than curative and reflect local perceptions of disease (Trutmann Voss and Fairhead unpublished) Collectively these strategies form a powerful and integrated crop protection strategy

Management of microclimate and fertility was an essential element in farmer crop protection and risk avoidance strategies Farmers combined strategies in different soil types fertility and field aspects and climatic conditions through a dynamic and flexible use of sowing configuration plant density mounding and ridging defoliation staking weeding time of sowing and harvest and plant architecture These were combined with physiological resistance to diseases inter and intra specific diversity and sanitary practices Clearly flexibility in disease management choices was critical to farmers and new technologies should not restrict these

The importance to farmers of genetic diversity was evident Many crop associations have been reported in the region (Jones and Egli 1984) Various associations are known to influence disease severity For example bean–maize associations reduced the severity of a number of bean diseases (Moreno 1977 van Rheenen *et al* 1981) In addition varietal mixtures were preferred by farmers because they provided better yield and better stability than individual varieties In a region where control of diseases on average increased bean yield by 50 / (Trutmann and Graf 1993) farmer preference for varietal mixtures can be attributed in part to the unique effect of varietal mixtures which reduces disease spread considerably relative to the mean of the mixture components provided the components differ in their susceptibility (Wolfe 1985) Firstly trials in Tanzania have shown that less disease developed in varietal mixtures than in pure varieties (Lyimo and Teri 1984) Secondly resistance and variability in resistance to diseases was found in local mixtures as a proportion of bean mixture components tested were completely resistant to local strains of *C lindemuthianum*

The proportion of the mixture which resistant varieties occupied was greater where conditions for anthracnose were more favourable This suggests farmers passively manipulated the proportion which resistant varieties occupy in mixtures in any given environment We found farmers principally used natural selection to obtain higher levels of resistance in mixtures by initially adding any variety available to a field and harvesting the seed of survivors They also actively selected against blemished seed In established areas farmers were more conservative about changing the composition but tested new germplasm in different locations on farm to determine its adaptation before adding it to a mixture Interestingly some of these methods reflect recent thinking about selection practices to obtain broad based resistance to diseases

Farmers used a number of sanitation practices which have been associated with disease control These included rejection of seed blemished around the hilum area rotations (becoming less common) removal of plants from the field early harvest and composting of field debris The area of post harvest practices would benefit from further study to elaborate farmer knowledge It is evident improvements could be made to the local sanitation practices For example better phytosanitary considerations could reduce the severity of seed borne diseases (Trutmann and Kayitare 1991 Trutmann *et al* 1992) better composting techniques could ensure more thorough elimination of pathogen inoculum and innovative uses of composts and their products to control could be used by farmers to prophylactically control many diseases (Hoitink and Fahy 1986 Weltzien 1990)

Although clearly much yield was still lost from diseases using traditional crop protection strategies (Trutmann and Graf 1993) and improvements are needed to reduce yield losses there is a need for serious consideration of the ways new technologies would impact relatively functional management systems Research and extension strategies should take into account that high levels of resistance were available on farm at least for anthracnose and probably for other diseases that there was local preference for mixtures that there is mounting evidence of advantages of mixtures for yield stability and disease control and that presently available management options to farmers should not be reduced Mechanical application of strategies which displace local varietal mixtures with single varieties by national programmes and International Agricultural Research Centres should be discouraged Germplasm displacement strategies if continued are likely to lead to more erosion of local genetic diversity of beans as in Kenya Tanzania and Uganda and will probably result in decreased yield stability

The farmers focus of attention on the environment as the cause of plant death and their conscious manipulation of the environment to protect their crops have served them well Nevertheless it is evident that they would benefit from many improvements to reduce the impact of disease on crop production A number of potential improvements have been mentioned in passing Possibly the greatest impact of all would be made by education The empowerment of farmers with knowledge about plant diseases pathogen ecology and epidemiology alone would enable farmers to consider other approaches to crop protection complementary to those which they already use Because crop management and body management is seen in similar or identical idioms such education could usefully be linked to human health education programmes or vice versa

It is difficult to obtain precise knowledge about farmers practices On farm experimentation is costly and provides only limited insight into farmers practices Like all strangers researchers inevitably plug into the polite social idioms when discussing agriculture with local farmers Although there is much that can be derived from discussing in these socially easy terms much is missed Part of the problem is that local knowledge is relatively unformulated and for this reason it is difficult to access It is also a farmer s problem There is no forum no institutionalization that could lead to the pooling exchange and local assessment of this knowledge Consequently farmers are forced to be inquisitive and innovative but beneficial ideas of one farmer are often not extended to other farms Improving farming does not just involve offering farmers new information but it can also involve giving farmers more confidence to follow their own initiatives and involving them in the research process

We have demonstrated the use by local farmers in the central African highlands of various disease management strategies It is noteworthy that many methods described here have also been described in other traditional societies (Thurston 1992) For example manipulation of plant density was common in ancient Aztec societies (Clavigero 1974) and is used in southeast Asia (Harwood 1979) sowing time is used by Mexican farmers (Wilken 1987) seed selection is practised by North Dakota Indians (Wilson 1987) raised beds occur in Africa (Harwood and Plucknett 1981) multiple cropping is also commonly used in south America (Kirkby *et al* 1980) and varietal mixtures are used in Africa and America (Clawson 1985) Evidently many local plant protection methods are not site specific or unique to farmers in the central African highlands but part of a host of practices that are or were used in communities dependent on traditional methods of agriculture What may be unique is the specific context or dynamic way in which local plant protection methods are used and in this case the interrelationship of plant protection strategies with local perceptions of human health Hence although there appear to be some general similarities between regions and cultures in methods used to protect crops the results presented here cannot be seen as a substitute for working and communicating with farmers

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Local Knowledge and Farmer Perceptions of Bean Diseases in the Central African Highlands

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ABSTRACT Central African highland farmers perceptions of common bean disease were investigated using both phytopathology and anthropological techniques Farmers rarely mentioned diseases as production constraints in formal questionnaires More participatory research showed farmers often related disease symptoms to the effects of rain and soil depletion for fungal diseases or to varietal traits for bean common mosaic virus Rain or moisture is divided into numerous forms through which it can damage plants both physically and through putrefaction Most conditions associated with putrefaction appear to be linked to pathogens Farmers have an understanding of plant health closely related to their concept of human health In plants this understanding is based on the prior state of plant health Conceptually local disease management strategies are based on prevention by managing the conditions that promote good plant health rather than by treating disease symptoms Intervention strategies that build on local knowledge are encouraged

Introduction

Around 40% of agricultural land is cultivated by farmers who use techniques broadly characterized as *traditional* (Wellhausen 1970) Most of these farmers have benefited little from available technological advances The failure to reach such farmers represents a major concern for national and international agricultural research institutes (Moreno 1985) Technologies developed for these farmers frequently have not been adopted or have failed with negative social consequences mostly because the research was conducted without adequate participation of farmers and with little consideration of farmers own knowledge practices needs and desires

The purpose of this study was to investigate farmer knowledge and management of bean diseases as part of a regional research effort in the Great Lakes region of Africa to find ways to increase productivity of beans (*Phaseolus vulgaris* L) The objective was to incorporate farmer knowledge into the research process and thereby promote development of appropriate technologies and strategies to improve local systems of plant protection The study was carried out by Centro Internacional de Agricultural Tropical (CIAT) as part of its global mandate to improve the productivity and quality of beans for resource poor farmers The study was supported by the national agricultural research programs of Rwanda and Zaire

Farmer knowledge

A number of social anthropologists have described the logic and complexity of various systems of indigenous agricultural knowledge and have argued for its incorporation into agricultural research and development programs (Brokensha *et al* 1980 Richards 1985) Research approaches are evolving that better integrate farmers needs skills and perceptions with those of researchers by actively working with farmers both in setting the research agenda and developing appropriate technologies (Ashby *et al* 1987 Sperling 1992) As a result of this process researchers begin to understand farmers ways of thinking and crop management and thus better appreciate the skills and complexities of local agriculture (Goodell *et al* 1990)

Curiously little research has been conducted into indigenous plant disease knowledge although plant pathologists such as Thurston (1992) have noted traditional farmer knowledge is often impressively broad and comprehensive Farmers should be able to provide substantial information about local diseases and perhaps about ways of improving disease management A few studies have documented farmer s perceptions of disease (Huapaya *et al* 1982 Bentley 1989 1991) However to date no systematic information is available that explicitly describes indigenous plant disease knowledge in Africa and its role in improving plant protection and crop yields

Interest in indigenous knowledge has recently undergone a major revival Several centers for research on indigenous knowledge have been established in both developed and developing countries and at least one journal is dedicated explicitly to the subject (*The Indigenous Knowledge Monitor*) At least in the African context this is not entirely new *The African Husbandman* (Allan 1965) for example is based on interdisciplinary field research carried out by ecologists agronomists soil scientists and anthropologists in Zimbabwe in the 1940s In spite of its regrettable absence of gender analysis this work long ago played an important role in debunking the myth of primitiveness in African agriculture through its detailed description of the complexity and ingenuity of problem solving found in African farming systems Where it fell short was in not recognizing the importance of women s knowledge and broader gender in this regard

In the contemporary context at least two major issues have added considerable passion to the debate The first has to do with the relationship between farmer knowledge and scientific research (Eyzaguirre 1992) Much of this relates to examining the validity and utility of local knowledge as a basis for development At its best, the reverse question i e that of the validity and utility of scientific knowledge in the local context is also part of the problematic The orientation of this paper is primarily in these terms

The second set of issues is concerned with the political economy of indigenous knowledge They deal primarily with appropriation of knowledge by the more powerful scientific orthodoxy for its own hegemonic ends (Cashman 1991 O Brien and Flora 1992) and its expropriation by commercial interests through northern biased systems of intellectual property rights (Belcher and Hawtin 1991 Nair and Kumar 1993) This is an especially important issue when dealing with areas of knowledge with considerable profit potential such as medicinal plants and genetic resources Although this is a crucial issue for developing country farmers it is not very germane to this particular study because 1) the CIAT Bean Program had an explicit low agricultural input philosophy in its research for farmers who generally could not afford external inputs such as fertilizer and pesticides (Nickel 1987) 2) for a variety of reasons including the fact that beans are self pollinating there is little commercial interest in bean seed and 3) the focus of the research was on disease management and farmer produced seed

The principal approach taken in the on farm research part of the project may best be described as Participatory Rural Experimentation (PRE) This was complemented by diagnostic surveys and informal discussions There is no doubt that when farmers and researchers conduct joint experiments and enter into extended and repeated discussions about them the power and wealth rests disproportionately with researchers The question thus becomes toward what ends researchers employ their means — to the benefit of the farmers with whom they work or to their own or other external agencies gain? It is also clear that local farmers are far from powerless As James Scott and Theodor Shanin have convincingly shown (Scott 1985 Shanin 1971) they have local knowledge numbers experience language and most importantly the refusal to cooperate on their side[1] It is rather ironic that many of the same authors who extol the virtues of peasant knowledge do not credit them with the capacity to deal effectively with intrusive obnoxious or exploitative outsiders In our experience working successfully with farmers requires both respect and reciprocity which includes a fair exchange of information In such an exchange it is important to recognize that both local and scientific knowledge have their strengths and weaknesses and that the relationship is most fruitful when both learn from each other Ultimately a tendency to over romanticize either indigenous knowledge or world science by its proponents would be self defeating because critics and experience will always find gaps and errors in any knowledge system The history of Western science is a case in point

Context

The general characteristics of African bean crop ping systems have been recently reviewed by Allen *et al* (1989) Beans are the most important protein source in the Great Lakes region Average consumption per capita is over 40 kg per year (ISAR 1987) which is the highest in the world Beans constitute 50% of Rwanda s protein and 25% of its carbohydrate production (CIAT 1984) Farmers predominantly grow beans as varietal mixtures which nationally yield between 700 and 900 kgha ^{1} According to Voss (1992) 96% of farmers in Rwanda prefer to grow varietal mixtures Women are responsible for the majority of food crop cultivation tasks especially of beans

Diseases are an important production constraint Disease control in national on farm diagnostic trials increased yields by 450 500 kgha ^{1} (Trutmann and Graf 1993) The most important diseases were angular leaf spot (*Phaeoisariopsis griseola* (Sacc) Ferraris) phoma blight (*Phoma exigua var exigua* (Desm) Boerema) anthracnose (*Colletotrichum lindemuthianum* (Sacc & Magnus) Briosi & Ferraris) floury leaf spot (*Mycovellosiella phaseoli* (Drummond) Deighton) and root rots associated mainly with *Fusarium oxysporum f sp phaseoli* Kendrick & Snyder Insects especially beanfly (*Ophiomyia spencerella* Greathead) limited production on average by 150 250 kgha ^{1}

Materials And Methods

In 1984 85 an agricultural production survey was conducted around Ruhengeri in the volcanic region of northern Rwanda and backed by a smaller informal survey around Butare in the central plateau The aim was to focus scientist attention on problems identified as priorities by farmers and to discern farmer preferences in bean types in order to orient the bean breeding program Using a standard questionnaire 120 Ruhengeri farmers selected at random were asked to rank their major production constraints and varietal selection criteria in order of importance The formal survey also asked farmers whether they tried new varieties and whether they first tried new varieties alone or directly in their mixture

In 1986 a survey was conducted around Butare in the central plateau The aim was to determine if farmers recognized common bean diseases and their causes A random sample of ten women farmers was shown pictures of some local bean diseases asked whether they had seen the phenomenon and asked to describe the cause The pictures of diseases used were those of angular leaf spot phoma (Ascochyta) blight and bean common mosaic virus (BCMV)

In 1987 a twenty months *in situ* study was conducted by a social anthropologist trained in agriculture and local languages in Bwisha a Kinyarwanda speaking village in the Kivu region of Zaire near the Rwandan border The aim was based on information obtained in earlier studies to explore farmer perception and management of bean diseases in more depth These farmers are considered to have the same cultural base as those in Rwanda Burundi and the Kigezi district of Uganda Information was obtained using participant observation and was complemented by structured interviews and group discussions in the village once local themes in crop protection had been assessed Regular feedback between the phytopathologist and anthropologist enabled the latter to probe farmers techniques comprehensively Later two months of repeated structured group discussions were also conducted in 6 different villages in the vicinity of the study village at altitudes between 1000 and 2000 m Each group consisted of 6 key informants — 3 women and 3 men — who were locally regarded as particularly knowledgeable farmers

Results

In the 1984 85 study that evaluated bean production constraints insects drought and excess rain were the major constraints listed by farmers (Table 1) Almost no farmer mentioned diseases as an important constraint When asked if you see a dead plant what caused it 65% of farmers answered sun 37% rain 40% insects 7% poor soil and only 2% mentioned disease The presence of a drought during the survey is likely to have influenced farmers responses since this led to an plague of aphids However it also showed that problems such as excess rain that were prevalent in other seasons were not forgotten There is virtually no use of pesticides or fungicides on beans with the exception of a very few farmers who use pesticides provided for coffee to control storage pests However in the region fungicide is available and widely used to control late blight on potatoes which fetch high prices at the market

Table 1 Farmer ranking of the most important bean production constraints in the volcanic region and the central plateau of Rwanda

Constraint	Farmer ranking (maximum score 100)
Insects	91
Drought	84
Excess rain	73
Lack of land	65
Lack of manure	60
Labor shortage	25

In the 1986 survey using photographs of disease and pest symptoms no farmers recognized symptoms of specific diseases Of the farmers interviewed in this way all considered anthracnose to be caused by the rain some related phoma blight to rain or insects and angular leaf spot to exhausted soil All considered BCMV symptoms to be a varietal trait rather than an ailment It was concluded that farmers do not perceive diseases as distinct entities rather they relate disease symptoms to the effects of rain depleted soil or varietal traits The relation of angular leaf spot to exhausted soil also suggests appreciation of the relationship between continuous cropping and certain disease symptoms

The 1987 study showed that farmers perceive various forms of moisture as causing damage to plants Not all involve interaction with pathogens (Table 2) Farmers describe damage as being caused both mechanically and due to putrefaction the process of rotting Microclimatic features of rainfall dew and air humidity are considered to be closely interrelated in their effect on plant health having both positive and negative characteristics Farmers recognized that their practices to manage microclimate were associated with some disease symptoms

Table 2 Farmer classification of rain and its effect on the crop

Type of rain	Type of damage	Effect on the crop
As hail	Mechanical	It destroys the crop mechanically
As rain	Mechanical	It physically knocks off flowers
As dew	Mechanical	It looses flowers so that rain or a person can more easily knock then off
As surface flow	Mechanical	It carries away the plants and the good soil
As stagnant water	Putrefaction	It kills the plants
As air humidity	Putrefaction	It rots the plants (Petrifaction)
As soil humidity	Putrefaction	It rots the parts of plants that touch the ground
As sub surface flow	Putrefaction	It cools the roots so that they rot

Moisture damages plants physically in the form of hail rain surface flow or when dew forms inside flowers (*mu uruyange*) which makes the flowers fragile and limp (*koroha*) (Table 2) When it rains flowers either fall off (*kugwa*) or are irreparably damaged (*kuzambya*) Farmers especially dislike rain during the night or early morning at flowering when flowers are already fragile from dew It is also considered bad to weed at flowering while plants are wet At higher altitudes where rainfall and dew are greater farmers sow later to promote flowering (kuyunga) at the beginning of the dry season To prevent dew damaged flowers from dropping farmers space the plants so that they do not touch and dislodge the flowers

Moisture is observed as putrefaction in the form of high air humidity wet soil or as stagnant water which causes rapid rotting (*kubora*) Root rots in the region soil are often associated with *F oxysporum* f sp *phaseoli* Wet soil is also thought to rot plant parts that touch it — especially the pods This is one reason why most farmers in high rainfall areas do not like varieties that sprawl on the ground Stagnant water often occurs in poorly drained valleys and reinforces the local idea that water can kill beans Farmers also observe that water remaining on the leaf's surface will damage it The local analysis is that stagnant water cools the roots and when on the foliage cools the leaves *Kubora* the verb to rot also means to be soaked to the bone to cool and to have had enough It connotes being susceptible to illness for people as well as for plants

Not all villagers have the same explanations for the origins of plant necrosis but a common view is quoted by one villager when plants are sown too close together the leaves (*ibibabi*) meet and touch (*kwegerana*) so the water rests on the leaves without falling to the ground the plants begin to rot As a consequence the farmer preferred to sow varieties with small leaves in humid places since the sun could better penetrate the canopy and the water would evaporate more quickly Equally they weed the crop to dry the vegetation by allowing in light and wind Some farmers synchronize planting to avoid putrefaction They say crops sown in proximity to other already large crops are affected by the odor from older plants which prevents them from growing and yielding well even if they are sown on a fertile field and at an otherwise reasonable time In scientific terms the explanation would be that pests and diseases have had time to develop on the more mature plants which then infect the newly planted crop at a much earlier stage and much more severely than would be the case with synchronous planting It is noteworthy that the importance of synchronous planting is recognized in many parts of the tropical world and is often enshrined in agricultural rituals of first planting by highly respected or religiously powerful individuals

Farmer perceptions concerning crop death and choice of varieties are related to local evaluations of human health Mujynya (1969) defines *ubuzima* as health the vital principle thanks to which the living physically develop and reproduce Health is not directly contrasted to illness Villagers have ways to evaluate their state of health and if it is bad then a natural result may be to become ill An indicator of the state of health of the human body is the amount of blood (*amaraso*) available If there is too little (*amaraso make*) then one becomes weak dizzy and susceptible to illness If one has to much (*amaraso menshi*) then one becomes tense gets headaches and is also likely to fall ill The same idiom is used for plants If plants have too little sap (*amazi make*) they will not grow strongly be uncompetitive with weeds and yield poorly If plants have too much sap they become over ex tended (*gufura*) and liable to putrefy and yield poorly Hard (drier sapless) leaves do not rot as fast as lush ones The idioms for understanding the health of people and crops are linked by the use of a concept adopted from Western medicine *ivitamin* *Ivitamin* is the term used both for soil and body nutrients *Ivitamin* is a concept used today but has replaced a similar concept of vigor but with different social connotation than used in the past (Fairhead 1994) The more there is the more sap or blood there will be When people fall low in blood they go to the local paramedic who provides vitamin B12 for example or they eat certain foods rich in ivitamin such as meats most bean varieties milk sugar palm oil and millet Cassava in contrast is recognized as having little Conversely headaches caused by having too much blood can be treated by blood letting For plants too much ivitamin in the soil leads to too much sap and to over extension (*harashyishe guter gufura*) too little leads to competitive weakness

Gufura the state of having too much sap or being overheated is considered damaging for several reasons Firstly it encourages leaves to touch Secondly to quote a farmer plants with gufura mature later as it takes longer for the extra sap to go to the seed There is too much sap and not enough plant so the leaves and the pods die as if one had poured boiling water over them The plant has overheated rather than been over cooled as described earlier Thirdly climbing beans in a state of gufura often grow from their stake to other plants closing the canopy Consequently the humidity increases on lower parts of plants due to decreased light penetration and air movement This reduces the numbers of successful flowers in lower plant parts The tendency to gufura is linked to variety Varieties that are more likely to gufura are more sensitive to high fertility and rain A disliked feature of some improved varieties is their tendency to gufura Farmers with varieties prone to gufura (vigorous) prefer to sow them in drier and less fertile conditions to control their growth (e g they are sown later or on hard clay soils) Nonetheless if vigorous varieties are grown in fertile conditions other measures are available to mitigate the potential damage such as sowing at reduced densities partially defoliating the plants (gusoroma) or altering the staking density and height Gufura is an important principle in the local assessment and choice of bean varieties

Discussion

In the Great Lakes region farmers did not recognize diseases as individual entities let alone as being caused by living organisms Responses to whether or not they had disease problems in their crop were overwhelmingly negative To a farmer a too vigorous crop with too much sap was susceptible to rain which resulted in putrefaction during periods of high humidity Disease management was integrated into crop protection as a whole Farmers placed more value on avoiding conditions that lead to disease (prior state of health) than on the diseases themselves (Trutmann *et al* 1993) Elaborate crop management strategies revolved around regulating the state of health Farmers disease management strategies were based on preventing rather than curing disease

Farmers clearly have no concept of the biological causes of individual diseases which in medical science is based on the germ theory (Koch 1876) Given this limitation many of their deductions from observations are accurate They recognized symptoms of a number of important diseases as associated with forms of rain soil fertility or varietal traits Although BCMV symptoms are not a varietal trait they may be very common causing leaf tissue of certain susceptible varieties to turn various shades of green Angular leaf spot is often more pronounced on plants in infertile soils Diseases caused by *C lindemuthianum* and *P exigua var exigua* become prevalent under high humidity conditions associated with rain and cause soft rots The importance of humidity for the infection process and consequently for parasitism and plant necrosis is well documented in plant pathology Moisture levels in the foliosphere and the duration of leaf wetness are basic elements that influence the development of many leaf and fruit pathogens (Palti 1981) Farmers by thinking through their observations in their own cultural idioms have developed functional explanations for putrefaction These explanations form the basis for local practices to manage plant diseases (Trutmann *et al* 1993)

This said it is evident from other studies that the indigenous disease management system could definitely be improved Multi seasonal multi regional on farm diagnostic trials indicate that bean yield losses due to diseases remain around 49 8% of actual yield (Trutmann and Graf 1993) To retain perspective plots or fields that do not use traditional practices (e g univarietal stands) often become totally destroyed by disease particularly if the same variety is used over seasons Population pressure in the region is among the highest in Africa and the need for more productivity from the land is clearly recognized by farmers

The information obtained from farmers suggests that preventative rather than curative disease management approaches would be more compatible with local practices and conceptual frameworks Such approaches are also environmentally more sustainable and more cost effective (prevention vs cure) However they are also more knowledge intensive Pesticides are already available but as yet little used on beans Their availability may be changing local attitudes to disease management as suggested by the local name for fungicides umnti w imvura or medicine against the rain We believe that promoting strategies that encourage building on present knowledge systems would discourage building up a dependency on exogenous inputs

In plant protection education that combines traditional knowledge with disease identification basic principles of epidemiology and etiology of diseases and management strategies would be potentially useful In our experience epidemiological principles of diseases are not understood by farmers For example nowhere in the region did farmers remove disease infected plants from their fields — yet this is a technique that is effectively used by farmers in many other parts of the world to reduce crop losses from disease (Palti 1981) Similarly education about pesticides to which farmers are already exposed would promote more selective less dependent use and safer handling of such products and provide farmers a more objective basis for decisions about pesticide use in local systems A better understanding by farmers of basic disease management principles would have major benefits for human health and the environment With new and traditional knowledge farmers themselves would then be able to develop suitable disease management technologies and make better decisions as to which technologies to accept and demand

There is much concern about farmer and gender empowerment — disempowerment associated with the study and use of indigenous knowledge (den Biggelaar 1991 O Brien and Flora 1992) The authors of this paper share the concern but maintain that knowledge of farmers systems and thought framework is essential if external aid is to assist in improving the quality of life of people in rural and ultimately in urban communities Clearly farmers must be the primary players in changes affecting their life Approaches that include the farmer in the process are less likely to end up being rejected or to disempower farmers and destroy the social fabric in farming families and communities If it is to be accepted that there is a role for technology development to improve agricultural production in situations like the Great Lakes region of Africa then the developers must also more critically analyze the way their efforts may influence farmers and in our case how the local knowledge might be used as the basis for improvements that will benefit farmers

We have gained some knowledge about farmers understanding of plant disease The farmers cognitive framework has very practical applications in the management of the effects of rain and plant vigor (Trutmann *et al* 1993) We believe this framework must be considered when developing technologies and should be built on not ignored or destroyed as has often been the case (Thrupp 1989) Farmers systems are always dynamic and adjusting to changing circumstances Any improvement should attempt to build on their positive attributes by expanding the knowledge and range of options available to farmers Apart from making farmers principal actors in the process of technology development there are other ways of empowering farmers One way might be through an educational system that combines aspects of Western technical knowledge with local knowledge An interesting approach promoted by some NGO s is to encourage schools to invite knowledgeable elders to give classes on their farming techniques as part of the regular curriculum (Montecinos pers com) Similar encouragement could be given to agricultural research institutes

Notable similarities exist between the classification of hielo (ice) by farmers in Central America (Bentley 1989 1991) Farmers on both continents associate rain or ice with disease symptoms and elaborately classify various ways these damage plants Farmers on both continents generally appear to lack knowledge of specific disease symptoms of most diseases Are there perhaps common principles in traditional societies on perceptions of disease and crop protection that can be used to guide technology development?

On the other hand we must be cautious not to generalize these results Local knowledge is often region specific Even if farmers in many areas use the same vocabulary the meaning can be very different depending upon the agro ecology of the region As a result although the methods and principles of this study probably have wide application in Africa and perhaps elsewhere the results presented here are geographically specific and cannot be seen as a substitute for working and talking with farmers

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Disease Control and Small Multiplication Plots Improve Seed Quality and Small Farm Dry Bean Yields in Central Africa

Peter Trutmann[1] and Emmanuel Kayitare[2]

ABSTRACT

Clean seed increased yield of dry beans (*Phaseolus vulgaris* L) in the Great Lakes region of Africa Combined cultural management practices decreased the development of disease on pods but did not increase yields The effectiveness of cultural control together with other promising methods to improve seed quality was investigated with farmers on farm in small multiplication plots Decreases in blemished seed were obtained using multiplication plot techniques but after three seasons yield from such seed was different only at $P < 0\;1$ to yield from seed produced with traditional methods Farmers responded favourably to the introduction of multiplication plots due to differences in the seed quality but not because of increased yields from the use of clean seed

Additional index words **disease control seed multiplication Africa *Phaseolus vulgaris* seed quality**

INTRODUCTION

In the Great Lakes region of Central Africa subsistence farming still predominates Holdings average 0 5 ha per household and few external inputs are used particularly on food crops Intensification of production is essential to support the large and rapidly growing population in the region whose diet relies on beans as the major protein source One identified constraint to increased productivity of *Phaseolus vulgaris* L is the quality and quantity of clean seed available to farmers both of farmers own traditional varietal mixtures and new improved cultivars

Traditional seed mixtures in the region are very diverse averaging around twenty recognisable components (Voss personal communication) Farmers have their own specific mixtures for fertile and unfertile soil and for intercropping with bananas (Voss and Graf 1991) Some farmers have a different mixture selected for each field It is impossible to produce clean seed of these diverse mixtures through official schemes Neither is it at present feasible or desirable to replace the genetic diversity of traditional mixtures with single or few cultivars It is difficult to increase yields rapidly in these diverse systems A partial solution would be for farmers to produce good quality seed of their respective mixtures which would result in a reduction in disease and encourage higher yields However little information is available as to how farmers can do so with simple technology adapted to their system and constraints

The second problem concerns efforts of the national programmes to produce sufficient amounts of quality seed of improved cultivars and to promote rapid diffusion According to Sperling (personal communication) speed of diffusion of new cultivars in central Rwanda is restricted by social factors farmers are reluctant to provide seed to non family members and people who are not close friends including neighbours and farmers prefer seed produced on the same hill rather than at some unknown distant place More important perhaps for the present supply of good quality seed of new cultivars is limited Some of these constraints could be reduced through local production of seed by farmers

Quality of seed in the region is strongly linked with the presence or absence of pathogens in seed In the Great Lakes region control of fungal pathogens alone increased on farm yields by 300 450 kg ha^{1} (Perreaux 1988 Trutmann and Graf 1988) Of the pathogens observed the three most common were angular leaf spot (*Phaeoisariopsis griseola* (Sacc) Ferraris) anthracnose (*Colletotrichum lindemuthianum* (Sacc & Magnus) Briosi & Ferraris) and *Phoma* (Ascochyta) blight (*Phoma exigua* Desm var *diversispora*) All three are seed borne In some cases particularly in seed of new cultivars multiplied on a larger scale halo blight (*Pseudomonas syringae* pv *phaseolicola* (Burkholder 1926) Young Dye & Wylkie 1978) which is also transmitted by seed is or is becoming a problem disease Therefore as the major pathogens which limit bean production are seed borne their control through production of clean seed should increase production as long as a significant proportion of the inoculum in the field originates from seed

On farm seed multiplication is not a new concept (Tee 1977 Bono 1981 CIAT 1982) However in the past never or rarely has the concept been applied to improving traditional farmer seed in conjunction with simple improvements to traditional practices and technologies such as seed treatments Work on farmer seed multiplication has been specifically aimed at producing adequate quantities of good quality seed of new released cultivars

The objectives of this study were to evaluate effectiveness of clean seed in raising bean yields in the region and then to develop methodology compatible with

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local practices to reduce seed transmitted diseases Later inexpensive integrated methods were tested on farm together with farmers using small seed multiplication plots by measuring crop yields for three seasons using seed from multiplication plots

MATERIALS AND METHODS

The effect of using clean seed on production of *P vulgaris* was evaluated at Rubona station of l Institut des Sciences Agronomiques du Rwanda (ISAR) P da in 1985 Blemish free seed from a local mixture of *P vulgaris* grown on station in the previous season when the seed crop had been protected with benomyl at 500 g ha^{1} every two weeks to harvest was compared to seed from the same mixture which had not been treated with benomyl Before sowing the seed was selected by women using traditional methods Plots 16 m^2 were sown using local methods which encourage maximum spacing between plants at 350 000 plants ha^{1} Plots were separated by a 1 5 m band sown with soybeans (*Glycine max* (L) Merr) Treatments were replicated five times using a random block design At harvest seed yields were compared

The effects on disease development on pods and seed yield following removal of diseased leaves removal of diseased seedlings and a combination of both compared to local crop management were evaluated at Rubona station in 1985 and 1986 Plots 16 m^2 were sown using traditional seed selection and sowing methods A border of 2 m was sown with soybeans between plots Apart from experimental treatments normal local cultivation practices were maintained Diseases were evaluated at late grainfill using percentage surface area infected as the evaluation criterion The trial wa replicated six times repeated over three growing seasons using a random block design and analysed using analysis of variance (ANOVA) Seed selection after harvest was evaluated as an additional treatment for one season alone and in combination using the above methods

A multiplication scheme was developed for use on small farms integrating information from research on cultural methods of disease control with other promising results These included the use of seed treatments (Trutmann 1987) improvements based on eliminating blemished seed before sowing and other practices in seed production such as eradication of plants with symptoms of viruses and bacteria and selection of healthy plants at harvest To do so seed multiplication plots of 10 m^2 were evaluated with five farmers for four growing seasons in 1987 and 1988 using the following recommendations Farmers were asked to select a fertile plot and sow their mixture early in the season To do so in addition to normal selection criteria farmers were asked and shown how to select only seed without blemishes on the testa and the hilum area Before sowing seed was treated with benomyl (1 g a i kg^{1}) thiram (1 5 g a i kg^{1}) and endosulfan (1 g a i kg^{1}) Seed was moistened with water drops left for 0 5 3 h and sown in plots using local methods The seed was dropped into pockets made by a small hoe in a well prepared seed bed to produce even spacing between plants A 1 m border around the plot was sown with maize or sorghum to reduce inter plot interference After seedling emergence farmers were asked to visit plots at least once per week and to pull out diseased seedlings when plants were dry Later during weeding farmers were asked and shown how to remove the primary leaves from the plants and from the field for composting or burning Plants were removed if they showed symptoms of viruses (especially Bean Common Mosaic Virus) and halo blight Middle to older leaves were removed if infected with anthracnose angular leaf spot Phoma blight and common bacterial blight Farmers were forbidden to enter plots when plants were covered with dew or when wet Plants were harvested early and selected for the cleanest pods Plants with lesions on pods were avoided Pods and seed from heavily diseased plants were used for food Farmers were shown how to select the best seed after harvest and to store it separately for sowing seed for the next season s multiplication plot This same seed was also used to sow in plots to compare yield with seed from the same mixture selected using normal farmers practices To do this two 25 m^2 plots each with either seed selected from multiplication plots or using farmers traditional selection methods were installed on five farms This was repeated for two seasons on farm and for one season together with other participating farmers seed on station At harvest seed weight was measured and farmers were interviewed as to their impressions The phytosanitary quality of seed produced in multiplication plots and farmers normal seed was compared in the third season by measuring the percentage of seeds blemished per 200 g seed per plot (1 kg per treatment) The farms were visited every month Farmers advice and ideas were sought as a matter of routine and at the end of each season a meeting of the group was arranged to discuss merits problems and improvements needed

RESULTS

The difference in yield of a local varietal mixture through using clean or farmer seed is shown in Table 1 Yield increased ($P < 0\ 05$) 21% with the use of disease free seed equivalent to 210 kg ha^{1} Removal of diseased leaves reduced ($P < 0\ 05$) angular leaf spot and both angular leaf spot and anthracnose were reduced ($P < 0\ 05$) using the combined treatment (Table 2) The trials showed that cultural methods were effective in reducing the level of disease on pods and hence seed These methods were more effective if combined and their effects became more evident when repeated over time although they did not improve bean yield However regressions with yield showed strong correlations for angular leaf spot ($R^2 = 0\ 99$) and anthracnose ($R^2 = 0\ 86$)

Table 1 Seed yields from a varietal mixture of dry beans sown using either seed selected by farmers or pathogen free seed

Seed source	Yield (kg ha^{-1})
Traditional	999.6a
Pathogen free	1210.0b[1]

[1] Significantly different at $P < 0.05$ using ANOVA

Table 2 Disease assessment and seed yield of dry bean crops following different disease management treatments

	Disease on pods at maturity (% surface area infected)		
Treatment	Angular leaf spot	Anthracnose	Yield (kg ha^{-1})
1 Control: seed selection before sowing[1]	6.8a	6.2a	1175a
2 Control plus removal of diseased leaves	4.8bc	5.5ab	1190a
3 Control plus removal of diseased seedlings	6.0ab	4.9ab	1207a
4 All treatments combined	3.7c	3.9b	1237a

[1] Most common traditional farmer practice

Numbers with the same letters do not differ significantly ($P < 0.05$) using Duncan's multiple range test

The second experiment on cultural methods was conducted only over one season and included an additional seed selection treatment (Table 3). Seed selection after harvest alone did not affect disease development or yield and only the combined removal of diseased leaves and seedlings reduced anthracnose ($P < 0.05$). There was no direct yield advantage with any method. It is likely that removal of substantial amounts of photosynthetic tissue in treatments reduced the productive capacity of plants as much as removal of diseased tissue aided plants.

Table 3 Disease assessment and seed yield for dry bean crops following different seed selection and disease management treatments

	Disease on pods at maturity (% surface area infected)		
Treatment	Angular leaf spot	Anthracnose	Yield (kg ha^{-1})
1 Control: seed selection before sowing[1]	5.8a	7.8a	535a
2 Control plus seed selection after harvest	6.5a	6.5a	755a
3 Control plus removal of diseased leaves	4.0a	6.6a	420a
4 Control plus removal of diseased seedlings	6.3a	7.8a	395a
5 All treatments combined	4.0a	2.5b	600a

[1] Most common traditional farmer practice

Numbers with the same letters do not differ significantly ($P < 0.05$) using Duncan's multiple range test

The results from on farm research on multiplication plots and yield studies are presented in Tables 4 and 5. There was considerable variation in results between farmers. Nevertheless the percentage of blemished seed decreased ($P < 0.05$) from farmers multiplication plots compared to seed selected using local methods (Table 4). In yield plots sown with seed from multiplication plots there was a consistent trend towards higher confidence in observed yield increases up to the 90% confidence level over three seasons even in the B seasons (March July) with heavy rainfall (Table 5). The results were reflected in farmer comments all five noted that they observed an increase in seed quality but made no particular reference to yield increases. All wanted to continue working with the multiplication plots implying seed quality was sufficiently good to convince farmers of the value of multiplication plots and that the method has benefits understood by farmers but not measured in this study.

Table 4 Proportions of blemished dry bean seed before sowing from multiplication plots and traditional sources after selection

Seed source	% Blemished seed
Traditional	1.2a
Multiplication plot	0.3b

Values with the same letter do not differ at $P < 0.05$

Table 5 Yields of dry beans over three growing seasons from experimental plots for which seed was either (i) traditionally selected or (ii) obtained from small multiplication plots

	Season		
	1987B[1]	1988A[1]	1988B
Treatment	Grain yield (kg ha^{-1})		
Traditional	996a	1140a	705a
Multiplication plot	1055a	1258a[2]	805a[3]
Coefficient of variation	11.4	10.9	15.5

Values followed by the same letter within the same column do not differ significantly ($P < 0.05$) using ANOVA
[1] on farm [2]different at $P < 0.2$ [3]different at $P < 0.1$

DISCUSSION

Marginal changes in farmer practices built on existing traditional techniques rather than large changes are more likely to be accepted in subsistence agricultural systems. The cultural methods tested in this study were based on farmers traditional practices. For example farmers remove the primary leaves at weeding but leave them on the ground where pathogens can still infect plants. In the trials these leaves were removed from the plots and both primary leaves and diseased trifoliate leaves were regularly removed. Seed selection is practiced by virtually all farmers. The traditional methods are excellent in many aspects but can be improved. Farmers commonly retain blemished seed as long as blemishes are not around the hilum. Improved seed selection methods take account of all blemishes.

An extensive survey by Voss (1988) showed that before selection by farmers 19.5% of farmer seed contained lesions. In the present study the quality of seed of the five participating farmers was considerably better. The differences may be due to seasonal variation in disease incidence or because farmers in this study managed their seed better than most farmers.

The results of these studies show that on farm seed multiplication technologies which meet the criteria of small farmers to improve the quality of seed of local mixtures are available. The major problem is that statistically significant increases in yields were not obtained although each season numerical yield increases over normally selected seed were obtained in on farm trials. It must be borne in mind that yields were expected to improve gradually each season as seed quality improved. However such slight improvements in yield of crops grown from better quality seed are unlikely to convince small farmers to adopt the concept of small multiplication plots.

Whether the use of small multiplication plots will be widely adopted in the Great Lakes region and perhaps other regions in Africa remains to be seen Farmers in these studies were not convinced about yield increases after two seasons but were interested in the concept because of visual differences in the quality of seed produced It appears farmers are aware of the value of clean seed and this rather than the tedious process of showing visual increases in yield may be sufficient to convince them of the value of the concept Of primary importance to the successful extension of seed production plots is the education of farmers about diseases and their control and how to use cultural and chemical disease control methods

A factor which is likely to influence the thoroughness of farmer seed selection on many farms and the effectiveness of seed multiplication plots is the availability of seed for sowing Many farmers harvest insufficient seed in an unfavourable season to be able to be very selective in the quality of seed for sowing the next season Consequently the cycle of gradually improving seed quality would need to be repeated The influence of such shortages on seed quality should be further investigated

Extending the methods for general improvement of bean seed could also promote small scale commercial production if adopted by farmers with sufficient land to multiply seed of improved cultivars for their surrounding area The incentive to produce seed commercially for others may initially be a driving force for the acceptance of the simple package It may also be worthwhile to investigate the feasibility of integrating methods of improving clean seed production for other crops together with beans in small multiplication plots An integrated system of seed production may enhance the acceptability of small multiplication plots by farmers

During the study lesions on seed rather than plating tests were used as the criterion for pathogen contamination Firstly laboratory facilities were not adequate at the time of study to do any but the most basic tests which would have enabled isolation of *C lindemuthianum and P exigua* var *diversispora* but not of *P griseola* or permitted precise identification of bacterial pathogens Thus incomplete information would have been available Secondly the use of lesions was used to provide farmers and extension workers with a visual means of checking the cleanliness of seed In addition seed discolouration has been used for grading seed as a measure of severity of infection for crops such as cereals (Christensen 1957) and rice (Neergaard 1970) and appears to be a rough but valid measure of the incidence of seed borne pathogens in beans where infection results in visible discolouration of seed (Neergaard 1977)

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Managing Angular Leaf Spot on Common Bean in Africa by Supplementing Farmer Mixtures with Resistant Varieties

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ABSTRACT

Pyndj M M d T tm P 1992 Manag g a g l leaf p t mm b a Af c by s ppl me t g fa m m xt es w th t nt t es Pl t D 76 1144 1147

Th ffect ess f suppl m t g local be (*Pl l ulg*) m t w th a t s t nt to gul l f sp t au d by *Ph op g ol* w s e l ted th G e t L k s g f Af The s ty of g la l f sp t w l w (*P* = 0 05) f m m xt s suppleme t d w th 25% m e of t t l s BAT76 A285 n th f fo seas s th n m t es w tho t t t l es S g f t de s g la l f spot se ty w e l obt d th ew m tu wh m as g b th g l farm d w res sta t l The ults ggest th t mp t t f l d se a b co t ll d w th mode pl nt b e d g p d ts yst m wh et l m t es p d m te th gh ppl me t t th tha d pl m nt f t g g t d s t by w et How the ppl m tati st ategy s l l m t d beca se t d m t se ma g g mult pl d sea c ld l d t f loc l ge et d sity

In many African countries common bean (*Phaseolus vulgaris* L) is an important protein source (4) and is cultivated predominantly as varietal mixtures The genetic diversity in mixtures is large the mean number of seed types and colors per farmer mixture has been estimated at 20 in Rwanda (15) and 13 in Malawi (7) Each farmer has a different mixture and often has various mixtures Diseases are a major constraint to bean production in the central African highlands which principally encompass Burundi Rwanda and Zaire (11 12 13) and are also important in other African countries (1) Angular leaf spot caused by *Phaeoisariopsis griseola* (Sacc) Ferraris is considered to be one of the most important biotic constraints to on farm yield in the Great Lakes region of Africa (13) and its control is a high priority of national programs in the region

Wolfe (16) reviewed the literature on disease control with multilines and varietal mixtures and noted that host mixtures may restrict the spread of pathogens and their diseases considerably relative to the mean of their components provided components differ in their susceptibility Lyimo and Teri (10) supported this principle for *P vulgaris* in Africa However work in the literature exclusively discusses mixtures as a means of diversification from a monoculture standpoint No reports have specifically investigated the addition of resistant varieties to farmer varietal mixtures for management of disease

The objectives of this study were to determine whether angular leaf spot severity could be reduced in farmer mixtures by supplementing them with new varieties resistant to angular leaf spot to ascertain whether farmer components can be protected and to determine what proportions of new resistant material are required to obtain a protective effect in farmer mixtures

MATERIALS AND METHODS

Studies were conducted at the Mulungu station of l Institut National pour l Etude et la Recherche Agronomiques (INERA) in the Kivu region of Zaire Its geographical and climatological characteristics are 02 19 S 28 45 E altitude of 1 700 m mean temperature of 16 2 C and 1 845 mm of rainfall per annum in a bimodal pattern Angular leaf spot is severe and is the dominant common bean disease On 16 m^2 plots a local farmer bean mixture was sown supplemented with various proportions of angular leaf spot resistant material from the Centro Internacional de Agricultura Tropical (CIAT) breedi g l e BAT76 (growth

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type II, small grained, black seeded) or A285 (growth type II, small grained, yellow seeded). Seeds were sown in a geometric pattern 20 cm apart, which simulated local sowing methods. Seed of the resistant variety was evenly distributed as either 10, 20, 25, 50, 75, or 100% of seed sown in each treatment, depending on the trial. Each resistant plant was tagged with a long peg to distinguish it from the components of farmer mixtures. Plots were separated by twice the distance of the plot length to reduce interplot interference. Soybean (*Glycine max* (L.) Merr.) was planted between plots. The trial was replicated six times in the first season and four times in subsequent seasons, with treatments arranged in a randomized block design. Trials were repeated three times with proportions of resistance of 25–100% and once with proportions of 10–20%.

Angular leaf spot severity was evaluated as the percentage of surface area infected. To measure the effect of resistant varieties on the local bean mixture component, 40 local mixture plants per plot were selected at random. On each selected plant, leaves on the third, fifth, and seventh nodes were evaluated at flowering, pod fill, and grain fill (5). At each of these times, leaves on each node differed in age. Leaves on node 3 at flowering were 28 days old; on node 5, 14 days at flowering, 28 days at pod fill, and 49 days at grain fill; and on node 7, 7 days at flowering, 21 days at pod fill, and 42 days at grain fill. In the third season, whole local mixture plants, not individual leaves, were evaluated. For whole plants, the time from the first leaf stage (when leaf tissue becomes available for infection) to flowering was 30 days, to pod fill 44 days, and to grain fill 65 days. In treatments containing only resistant plants, these plants rather than local mixture components were evaluated. The terms *flowering*, *pod fill*, and *grain fill* were used following CIAT (5). Overall angular leaf spot severity (i.e., the combined disease level of resistant and local mixture components) was obtained by a general angular leaf spot evaluation of all plant foliage in each plot. Results were analyzed using an analysis of variance, and treatments were compared with Duncan's multiple range test. The apparent infection rates (14) were calculated for the logistic model using the third trial when plants were evaluated for total foliar area infected.

RESULTS

Angular leaf spot severity in supplemented local mixture components. Supplementation of local mixtures with 25, 50, or 75% of either BAT76 or A285 resulted in reductions ($P = 0.05$) of disease severity in the local mixture components of new mixtures as compared to disease severity in the pure local mixture treatments measured both as leaves on individual nodes (Table 1) and as total plant foliage (Fig. 1). Confidence levels of differences between treatments improved with time. Defoliation of older leaves on nodes 3 and 5 from disease severity prevented measurement of infection of leaves over all plant growth stages (Table 1).

The apparent infection rate of *P. griseola* in farmer mixture components was most rapid between the primary leaf stage and flowering (Table 2). The incorporation of 25% of A285 into the local mixture reduced the average apparent infection rates on local mixture components and reduced the rate further at

Table 1. Angular leaf spot development on farmer bean mixture components supplemented with a resistant variety using individual leaf evaluations

			Diseased leaf surface area (%)				
			Leaf node number				
		Variety mixture	3	5		7	
Testing season	Variety	(%)	F	F	P	F	P
Early 1987	BAT76	0	5.9	2.1	6.3	1.4 a	2.6 a
		25	4.5 b	2.0	4.1 b	1.3 a	1.6 b
		50	5.1 ab	1.7 a	3.5 bc	1.0 b	1.5 b
		100	1.2 b	1.4	1.8	0.4	0.3 c
Mid 1987	A285	0	5.5 b	1.3	5.7 a	0.1 a	2.3 a
		25	3.6 bc	0.7 a	2.8 b	0.1	0.8 b
		50	6.7	1.0 a	4.1 b	0.1 a	1.3 b
		75	4.8 ab	0.5 a	2.7 bc	0.1	0.1 a
		100	1.0	0.0 a	0.1 c	0.0	0.0 b

0 = susceptible plant.
F = flowering, P = pod fill.
Values in the same column and the same season followed by different letters are significantly ($P = 0.05$) different using Duncan's multiple range test.
Disease severity recorded on resistant plants.

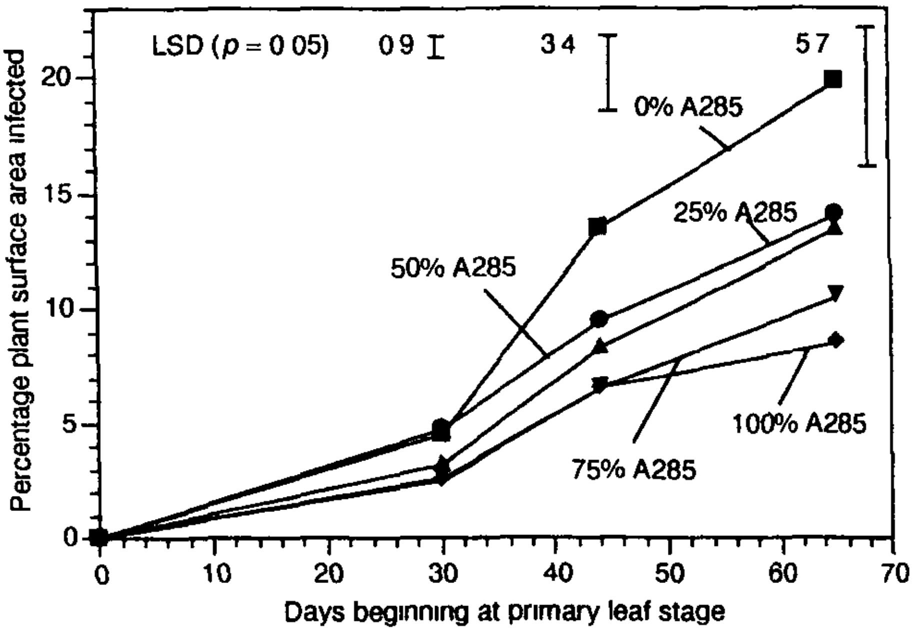

Fig. 1. Development of angular leaf spot on local bean mixture components supplemented with CIAT breeding line A885 in March 1988.

Table 2. Rate of angular leaf spot development on farmer components in bean mixtures supplemented with resistant variety A285

A285 in mixture (%)	Infection rate				Difference in rate per day
	First leaf to flowering	Flowering to pod fill	Pod fill to grain fill	Mean	
0	0.128	0.086	0.021	0.085	
25	0.131	0.057	0.020	0.078	−0.007
50	0.117	0.072	0.025	0.077	−0.008
75	0.109	0.068	0.024	0.073	−0.012
100	0.108	0.071	0.013	0.070	−0.015

Compared to local mixture.

Table 3. Effect of adding low proportions of resistant variety BAT76 to farmer bean mixtures on angular leaf spot severity

BAT76 content (%)	Diseased leaf surface area (%)							
	Node number of leaf							
	3	5			7		Crop total	
	F	F	P	G	P	G	P	G
0	16.6	0.8 b	19.0	20.4	9.6 a	12.1	32.2	37.5
10	16.9	0.8 b	19.0	19.0 a	8.1	10.9 a	27.2 a	33.3
20	18.6	0.9 b	19.1 a	20.8	8.3	11.8	20.3 b	29.1
100	3.1 b	0.5 b	5.1 b	5.9 b	0.3 b	0.4	11.3 b	11.3 b
LSD ($P = 0.05$)	3.2	0.2	1.9	2.7	3.7	2.0	12.3	12.6

Local mixture and BAT76 components evaluated together as a plot estimate.
F = flowering, P = pod filling, G = grain filling.
Values in the same column and the same season followed by different letters are significantly ($P = 0.05$) different according to Duncan's multiple range test.
Disease severity determined on total plot.

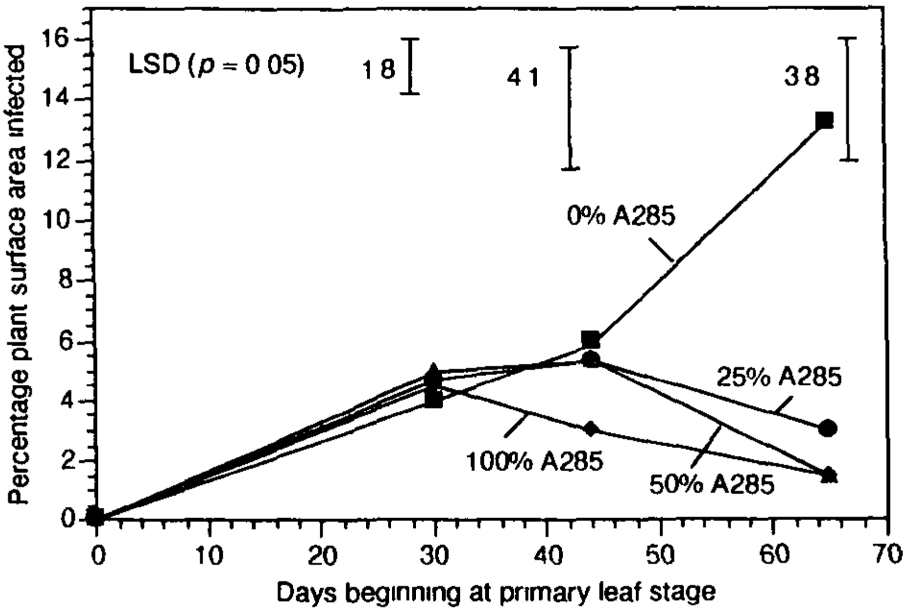

Fig. 2. General angular leaf spot development in mixtures consisting of a local mixture supplemented with proportions of CIAT bred angular leaf spot resistant BAT76, March 1987.

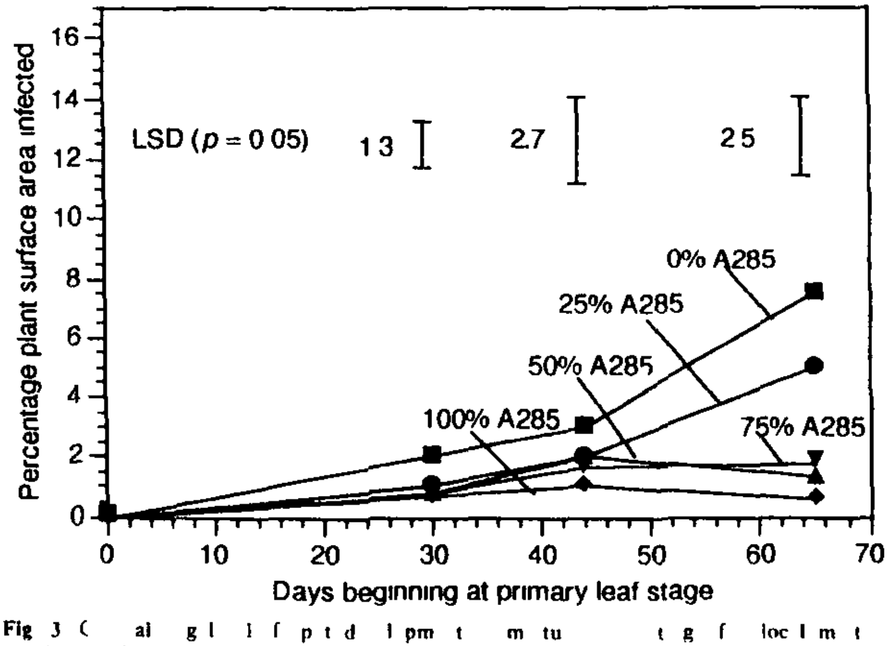

Fig. 3. Course of angular leaf spot development in mixtures consisting of local mixture supplemented with proportions of CIAT bred angular leaf spot resistant A285, September 1987.

higher supplementation levels.

No significant differences in angular leaf spot severity were observed in local mixture components when the local mixture was supplemented with 10 and 20% of BAT76 (Table 3). Disease pressure was considerably higher in the trial compared to that in other seasons.

Effect of resistance supplemented mixtures on disease severity in new mixtures. The mean angular leaf spot severity over four seasons of testing was 20, 8, 14, and 40% of total leaf area of plants in plots from 1986 to 1988. Significant reductions in angular leaf spot severity in the new mixtures were observed when 25, 50, or 75% resistant variety BAT76 or A285 was added to the local mixture (Figs. 2 and 3). No significant differences were observed when a farmer mixture was supplemented with 10 and 20% BAT76, but lower trends of angular leaf spot in new mixtures containing BAT76 were observed (Table 3).

DISCUSSION

Incorporation of relatively low proportions of angular leaf spot resistance in local mixtures reduced disease severity in the farmer components of mixtures supplemented with resistant varieties in three out of four seasons. These results are significant because they show for the first time that disease can be controlled in local bean mixtures by supplementing them with resistant varieties. This suggests that rapid impact on angular leaf spot can be achieved with modern plant breeding products in systems in which varietal mixtures and angular leaf spot predominate without eliminating the existing genetic diversity.

The physical presence of a resistant variety in a farmer mixture protected farmer mixture components and itself contributed directly to the overall level of disease in the mixture. When no protective effect is achieved on local mixture components, perhaps because of very high disease pressure, the physical presence of a resistant variety would provide the farmer with some assurance of production.

In this study, supplementation of local mixtures with 25% of a resistant variety reduced angular leaf spot. The results are encouraging since many previous studies, particularly on rusts of various cereals, suggest higher proportions of resistance are required to adequately protect a host crop. Browning and Frey (2) estimated that to restrict crown rust of oats adequately, the proportion of the resistant component in the mixture must be between 40 and 50%. Jensen and Kent (9) found that no less than 40% of partial protection in a population might provide full protection. Burdon and Chilvers (3) also calculated that a 50% resistant mixture was needed to substantially reduce the rate of spread of *Pythium* *irregulare* Buisman. One of the few reports in which lower proportions of resistance effectively protected susceptible components was published by Jeger et al (8) working with the wheat *Septoria nodorum* Berkeley and the barley *Rhynchosporium secalis* (Oudem.) J. J. Davis disease systems. It may be that the resistance already available in farmer mixtures helps reduce the amount of additional resistance needed to obtain adequate disease reduction.

Single sources of resistance to angular leaf spot were used in this study. However, to ensure diversity of resistance in the future, because significant pathogenic variability of angular leaf spot exists (6), it is desirable to use a broader range of sources. An assortment of productive resistant varieties could be offered to individual farmers, which would encourage the use of diverse resistant sources over a region. Preconstructed mixtures are not likely to be accepted by farmers because this interferes with the flexibility of farmers to tailor mixture composition to specific needs (Trutmann, Voss, and Fairhead, *unpublished*). Multilines are unnecessary where beans are grown in varietal mixtures, but it would be highly desirable to backcross certain competitive productive and preferred local varieties with different sources of angular leaf spot resistance.

Concurrent studies have shown disease reduction to be translated into significant yield increases (Trutmann and Pyndji, *unpublished*), but many questions still need to be resolved. It was evident that under experimental conditions the major inoculum source originated from within the plots, otherwise no protective effect would have been visible (16). Will this phenomenon still hold on farms where fields are often less than an eighth of a hectare and bordered by a different bean mixture? Protective effects have been demonstrated for angular leaf spot; however, it is not known whether similar effects will be observed when farmer mixtures are supplemented with varieties resistant to other important bean diseases.

Supplementation of local mixtures with resistant varieties appears to be a feasible strategy for control of a single important disease, but it is unlikely to be feasible or desirable for multiple disease control. Attempts to control multiple diseases by the supplementation strategy are likely to lead to a large displacement of local varieties and erosion of local germ plasm if substitution of a quarter to one half of local mixture seed is required to obtain protection against each disease. The problem might be managed partly through the development of varieties resistant to multiple diseases, but pyramiding resistance is at present not feasible in many national programs because of a lack of resources and infrastructure. More realistically, approaches in systems where varietal mixtures predominate should incorporate integrated management strategies that control multiple diseases and conserve genetic diversity.

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W h k h h l ff M l g f h l bl h lp

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Partial replacement of local common bean mixtures by high yielding angular leaf spot resistant varieties to conserve local genetic diversity while increasing yield

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Summary

The effect of replacing proportions of local farmer bean (*Phaseolus vulgaris*) mixtures with varieties resistant to angular leaf spot on grain yield was evaluated under local disease pressure in the Kivu region of Zaire Local bean mixtures in on station and in multi locational trials containing respectively 25% or 50% of Centro Internacional de Agricultura Tropical (CIAT) breeding lines BAT76 or A285 resistant to angular leaf spot yielded significantly more than the local mixture alone Yields exceeded expected values in three seasons of on station testing and in two seasons of multi locational trials Yield over the expected was found to be a property of new mixtures not protected with fungicide and were attributed to disease control Relative to expected yields non protected farmer mixture components performed 17% and 16% better than in protected plots and A285 components yielded 24% and 16% better at respectively 25% and 50% A285 supplementation levels A285 increased yields of the local mixture components and benefitted from the local mixture when not protected by fungicide Yield increases in multi locational trials were largely attributed to the higher yield potential of the resistant variety A285 although angular leaf spot severity was significantly reduced It was concluded that high yielding resistant varieties were able to increase bean yield in the region but probably at a substantial cost in genetic diversity in farmer bean mixtures That said a partial replacement strategy is preferable to strategies which encourage complete replacement of local germplasm with one or few high yielding varieties

Key words Mixtures *Phaseolus vulgaris* angular leaf spot genetic diversity

Introduction

In many parts of Africa and particularly the eastern highlands common beans *Phaseolus vulgaris* are predominantly cultivated as varietal mixtures No two varieties are genetically identical although they may possess similar seed types (Adams & Martin 1988) In Burundi Rwanda the Kivu region of Zaire and South west Uganda known as the Great Lakes Region beans are also the principal source of dietary protein (Pachico 1989) Diseases are a major constraint to bean production in the region (Perreaux 1986 Pyndji 1987 Trutmann

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& Graf 1993) The largest yield losses are associated with angular leaf spot caused by *Phaeoisariopsis griseola* (Trutmann & Graf 1993)

Research efforts to increase bean production have centred principally around the selection of high yielding resistant germplasm This strategy promoted by international agricultural research centres (IARCs) and many national agricultural research systems (NARS) has substantially increased yield in numerous cropping systems (Anderson Herdt & Scobie 1988) However although this strategy has also been followed in Africa it is not clear what the impact of high yielding disease resistant varieties will be in the diverse and little understood systems where varietal mixtures predominate Farmers prefer varietal mixtures to pure cultures in part due to yield stability and generally add new varieties into their existing mixtures rather than to replace their mixtures with a new variety (Anon 1984) Under such circumstances it may be that the beneficial properties of these introduced varieties are diluted Although farmers prefer local mixtures over pure varieties adoption of new varieties has in the past lead to substantial or complete displacement of local mixture components and to severe erosion of time tested adapted local genetic diversity available to farmers in areas of Tanzania Uganda and Kenya Considering that genetic diversity is now a recognised strategy for crop protection including disease control (Anon 1989 Wilkes 1992) its maintenance must be a major consideration in efforts to improve the livelihood of subsistence farmers As part of this process we must obtain a better understanding of the interaction of higher yielding resistant varieties with the local mixtures to make better decisions about the benefits of the germplasm strategy for farmers in the African highlands As part of this process the use of a strategy of partial rather than total replacement of local mixtures with high yielding resistant varieties was evaluated

In a recent paper we reported that substitution of 25% of a local bean mixture with a variety resistant to angular leaf spot protected the remaining local mixture components (Pyndji & Trutmann 1992) We suggested the use of resistant varieties to control a single disease might be justifiable because most of the original mixture diversity would be retained but that the strategy might not be feasible, or desirable to control multiple diseases In this paper we elaborate on these findings by reporting on the effect on yield of incorporating angular leaf spot resistant varieties to local bean mixtures We also report on the effects on angular leaf spot severity and yield of incorporating resistant varieties into local mixtures over time and location on the yield contribution of the local mixture and the resistant variety components of the next mixtures and on the potential impact of the strategy of partial replacement on local genetic diversity

Materials and Methods

Three types of trials were conducted 1) on station field trials to evaluate the effect of resistant varieties on yield over three seasons 2) on station trials to determine the yield components of local mixtures containing proportions of a resistant variety and 3) multi locational field trials with collaborating non government organisations (NGOs) to evaluate the temporal and locational effects on these new mixtures The first two studies were conducted at Mulungu station of the Institut National pour l Etude et la Recherche Agronomiques (INERA) in the Kivu region of Zaire Its geographical and climatological characteristics are L 02 19 S 1 28 45 E altitude 1700 m mean temperature 16 2 C and rainfall 1845 mm per annum in a bimodal pattern Angular leaf spot is severe and the dominant common bean disease For the first series of trials 16 m^2 plots were sown with a local farmer bean mixture supplemented with various proportions of a variety resistant to angular leaf spot either the Centro Internacional de Agricultura Tropical (CIAT) breeding line BAT76 (growth type II small grained black seeded) or A285 (growth type II small grained cream seeded) Seeds were sown in a geometric pattern 20 cm apart and 25 seeds m^2 which simulated local sowing methods Seed of the resistant variety was evenly distributed as either 10% 20% 25% 50% 75% or 100% of seed sown in each treatment depending on the trial Each resistant plant was identified with a long peg to distinguish it from the components of farmer mixtures Plots were separated by twice the distance of the plot length to reduce inter plot interference Soybean (*Glycine max* L Merr) was planted between plots The trial was replicated six times in the first season and four times in subsequent seasons with treatments arranged in a randomised block design Trials were repeated three times with proportions of resistance of 25–100% The yield of dry beans was weighed at harvest The disease severity data of these trials has been published previously (Pyndji & Trutmann 1992)

The second series of trials which evaluated the yield components were established using 25 m^2 plots which were sown as described with a local bean mixture supplemented with the CIAT breeding line A285 at proportions of 0% 25% 50% and 100% and sown as described above Mixtures were either left untreated or treated every 14 days with a mixture of 25% a i maneb and 50% a i methyl thiophanate at 3 kg ha^{-1} in 1000 litres water from the beginning of flowering The trial was replicated six times using a randomised block design and repeated two seasons At harvest dry bean yield of the local mixture and the A285 components were measured in all treatments

The third series of trials were established in a radius of 22 km around Mulungu in March 1988 trials at three locations Miti Katana and Mulungu and in September 1988 at four locations Miti Katana Mudaka and Mulungu Plots 50 m^2 were sown with local farmer mixtures mixed with 0% 25% 50% 75% and 100% of the angular leaf spot resistant CIAT breeding line A285 and sown equidistantly as practised by local farmers at 250 000 – 350 000 seeds ha^{-1} Trials were replicated two times per site in March 1988 and three times per site in September 1988 and sown in a randomised block design Treatments were evaluated for yield using an analysis of variance (ANOVA) Disease severity was evaluated as described in Pyndji & Trutmann (1992)

Results

The yields over three seasons of local mixtures supplemented with A285 or BAT76 are shown in Table 1 Significant yield increases equivalent to 27–33% over the local mixture were obtained by supplementing farmer mixtures with 25% of A285 or 50% of BAT76 Yields also exceeded the expected by 2–22% when the local mixture was supplemented with A285 or BAT76 The resistant lines yielded significantly more each season than the local mixture Significant decreases in angular leaf spot severity were also obtained in all three trials and were presented in Pyndji & Trutmann (1992)

Fungicide application significantly increased yield ($P = 0\ 001$) equivalent to a yield increase over unprotected plots of 24% and 30% in the local mixture and A285 respectively (Fig 1) These increases were attributed to the effect of fungal pathogens on yield In local mixtures supplemented with A285 yield increases over the expected were associated with unprotected plots rather than protected plots In protected plots yield of local mixture components was 21% below the expected when supplemented with 25% of A285 whereas in unprotected plots they yielded 4% below the expected a comparative increase of 17% When 50% of A285 was added to the local mixture the yield of the local mixture increased from 11% above the expected in protected plots to 27% above the expected in unprotected plots a comparative increase of 16% In protected treatments A285 incorporated to

Table 1 *Bean yield of bean varietal mixtures consisting of a local farmer mixture containing various proportions of an angular leaf spot resistant variety*

Percentage A285 in local mixture (%)	Yield (kg/ha) Season 1 (BAT76) Actual	Above expected	Season 2 (A285) Actual	Above expected	Season 3 (A285) Actual	Above expected
0	609		1387		677	
25	658	131	1858	384	861	147
50	777	96	1840	280	886	135
75	—	—	1874	227	811	23
100	753		1733		826	
LSD (0 05)	134		280		164	

become 25% of the mixture yielded 17% above the expected whereas in a similar unprotected treatment A285 yielded 41% above the expected yield a comparative increase of 24% When 50% of A285 was added to the local mixture fungicide treatment resulted in a 2% A285 yield increase above the expected whereas in unprotected treatments A285 yielded 18% above the expected a comparative increase of 16% These increases were attributed mutual protection from fungal pathogens in the new mixture by the mixture component and A285

A combined analysis of multi locational trial results over sites and season shows yield differences ($P = 0\ 0006$) were observed between treatments (Table 2) There were also yield differences over season ($P = 0\ 0001$) and site ($P = 0\ 0001$) but no treatment by season or location by treatment interaction for yield (Table 2) Over seasons and site

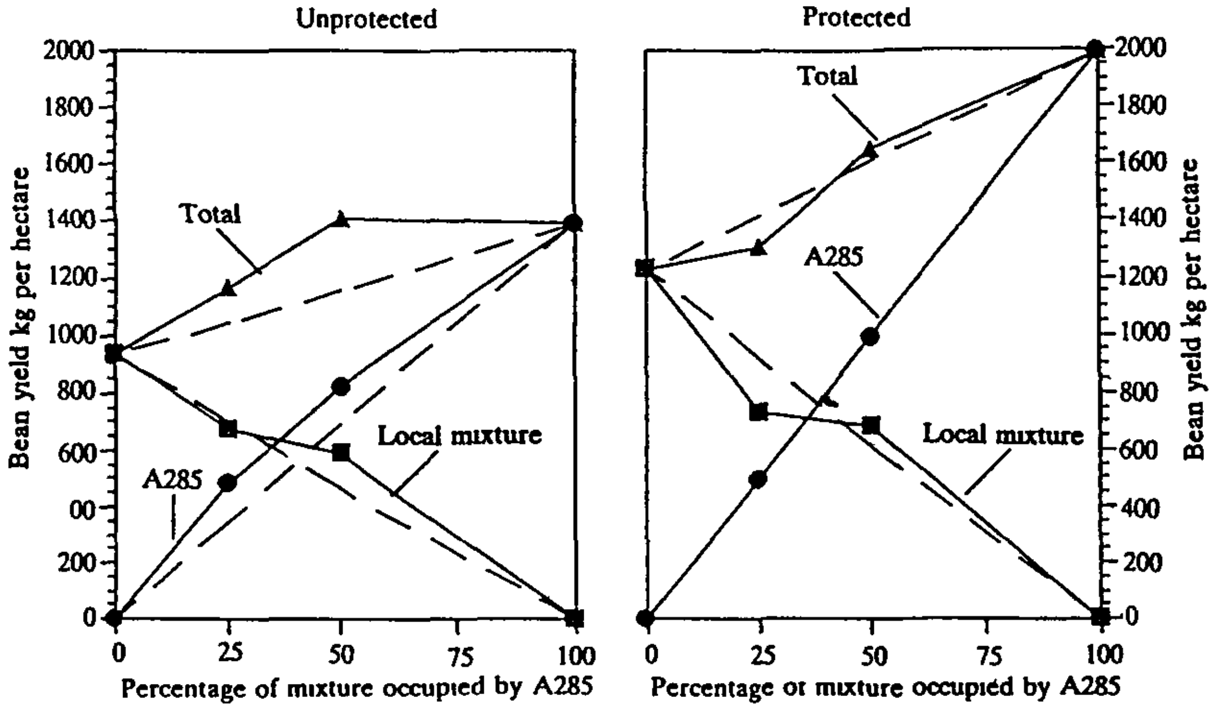

Fig 1 Replacement diagrams of the yield of local mixture and A285 components plotted against the relative frequency of A285 in mixtures in plots unprotected and protected with fungicide

Table 2 *General linear regression models of year site and replication with the dependent variable yield in multi locational trials using 0–100% A285 to local mixtures in replacement series trials*

Source	df	Mean square	F value	Pr > F
Model	47	441145 5672	7 74	0 0001
Error	49	57021 5284		
Year	1	8477885 8594	148 68	0 0001
Site	5	1813153 1202	31 80	0 0001
Replication	13	64629 2343	1 13	0 3256
Treatment	4	332147 5502	5 82	0 0006
Year × treatment	4	153959 8199	0 95	0 4453
Site × treatment	20	40279 0286	0 71	0 8003

R square = 0 881245 C V = 16 99

Table 3 *Effectiveness of A285 supplemented farmer bean mixtures in multi locational multi seasonal trials on angular leaf spot severity at grainfill and yield*

Percentage A285 in local mixtures	Angular leaf spot (% sai)	Observed yield (kg ha^{-1})	Yield over the expected (kg ha^{-1})
0	18 7	1202 3	
25	12 1	1311 7	29 3
50	9 2	1458 4	95 9
75	7 2	1452 0	9 4
100	4 2	1522 7	
LSD (0 05)	2 3	160 4	

mixtures supplemented with 50–75% of A285 yielded 123–327 kg ha^{-1} more ($P = 0\ 05$) and all mixtures supplemented with A285 were less severely attacked ($P = 0\ 05$) by angular leaf spot than local mixtures (Table 3)

Discussion

We have shown for the first time that adding high yielding angular leaf spot resistant varieties to local farmer bean mixtures can result in dry bean yields comparable to that obtained from the high yielding resistant variety cultivated alone However substantial differences were observed between results obtained on station and in multi locational trials On station yields comparable to the resistant variety cultivated alone were obtained in two out of three seasons by displacing a quarter of the local mixture by the high yielding resistant variety whereas similar responses required displacement of half the local mixture in multi locational trials It is evident a strategy of adding high yielding angular leaf spot resistant varieties to local bean mixtures in regions with high angular leaf spot pressure can result in measurable bean yield increases but may require farmers to incorporate these varieties at a level of 25–50% and more of their mixtures depending on location

Yield increases of new mixtures containing the resistant variety and local mixtures were partly due to the higher yield of A285 The resistant variety A285 yielded 26–28% higher under disease pressure than the local mixtures in all trials (Table 4) Also the yield potential" of A285 under station conditions was clearly higher than that of the local mixture as shown by its 64% higher comparative yield over the local mixture under fungicide

Table 4 *Summarised results of the percentage bean yield increase over local bean mixtures by replacing proportions of local mixtures with the angular leaf spot resistant variety A285*

Percentage A285 in local mixtures (%)	Yield expressed as percentage above yield of the local mixture					
	On station trials			Multi locational trials		
	Observed	Expected[1]	Difference[2]	Observed	Expected[1]	Difference[2]
25	30 6	5 9	24 7	9 1	6 7	2 4
50	31 8	11 8	20 0	21 3	13 3	8 0
75	27 8	17 6	10 2	20 8	20 0	0 8
100	28 6			26 6		

[1] Attributed to higher yield of A285
[2] Attributed to reduced angular leaf spot severity

protection This of course may not mean much as local mixtures are selected by farmers for very site specific on farm conditions in which A285 still needs to be tested (Trutmann Voss & Fairhead 1993)

Non-competitive biological factors in A285 supplemented mixtures rather than competition as defined as physical interactions by Clements Weaver & Hanson (1929) appeared responsible for yield increases above the expected We base this view on the observation that no yields above the expected were recorded when treatments were protected with fungicides whereas without protection substantial yields above the expected were observed in both the local mixture and A285 components and the new mixture as a whole Hall (1974) also described non-competitive effects of nitrogen fixation on the yield of Townsville stylo (*Stylosanthes humilis*) on Rhodes grass (*Clhoris gayana*) to be an important factor in plant interference In our studies yield above the expected appeared to be a direct measure of the effect of disease control through mutual protection by A285 and the local mixture components of diseases to which one component was genetically susceptible minus any competitive effects which were not measured On this basis we believe most of the on station yield increases when a resistant variety displaced 25–50% of the local mixture were due to a reduction in disease severity whereas in multi locational trials most of the yield increases over the local mixture came from the genetic potential of A285 (Table 4)

Pyndji & Trutmann (1992) suggested the replacement of 25% of a local mixture might be an effective treatment against one local disease but multiple introductions of similar proportions into local mixtures to control diseases is likely to lead to a serious erosion of local germplasm Yield data from the same on station trials presented in this paper (Table 1) show that yield increases can also be obtained by replacing a quarter of the local mixture with resistant varieties Results from the multi locational trials also support the previous findings that incorporating 25% of A285 into local mixtures can significantly reduce the severity of angular leaf spot (Table 3) However it is clear that in multi locational trials other yield limiting factors masked benefits from angular leaf spot control as half the farmers mixtures needed to be replaced with A285 to observe yield increases There the yield increases came mainly from the intrinsic higher yield potential of A285 rather than from yield above the expected (Tables 3 and 4) These other limiting factors require concurrent control to enable the benefits of angular leaf spot control to be expressed in yield

Given that up to half of local mixtures had to be replaced to obtain measurable yield increases from high yielding resistant varieties the use of a germplasm replacement strategy should be of concern to agricultural scientists to improve long term productivity of still little understood agricultural systems which include highly diverse varietal mixtures The incorporation of new resistant germplasm can result not only in higher yield but also in serious erosion of the diversity of locally adapted bean germplasm whose benefits we are only beginning to understand Nevertheless a partial replacement strategy has the merit of leaving a proportion of local germplasm intact and as such is agroecologically more desirable than the total displacement strategy with HYVs used to date

Farmers indicate a strong preference for their varietal mixtures because of their yield stability and yield It may be that for these reasons most farmers would substitute only a small proportion of their mixtures with a new high yielding resistant variety If this were the case there would be little concern for genetic erosion but how would impact be measured? In fact it appears farmers do not necessarily adhere to their mixtures Historically farmers have changed their mixed systems for univarietal systems Beans became widely grown in uniculture in Kenya and Uganda during the European occupation and in Tanzania through the policies of the government In Rwanda farmers have recently adopted univarietal stands of the high yielding climbing bean G2333 which has been strongly promoted by CIAT and the NARS (Anon 1991) Voss (1992) who strongly argues against the displacement of varietal mixtures suggests that policies could be implemented to discourage people from developing univarietal preferences Given that genetic diversity especially maintenance of the genetic base and prevention of genetic vulnerability are acknowledged as important to sustainable agricultural production (Anon 1989 Wilkes 1992) it will be critical to better understand the impact of the germplasm replacement strategies on genetic diversity in crops and on farmer disease management options especially in regions where there is much social or political pressure to increase crop productivity

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Seed treatments increase yield of farmer varietal field bean mixtures in the central African highlands through multiple disease and beanfly control

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Abstract Seed treatments with fungicides to control seed-borne and root diseases of *Phaseolus vulgaris* and their use with an insecticide treatment to control beanfly (*Ophiomyia spencerella*) were evaluated in diverse regions of Rwanda. Benomyl reduced the severity of diseases caused by *Colletotrichum lindemuthianum*, *Phaeoisariopsis griseola* and *Phoma exigua* var. *diversispora*. Multiregional, multiseasonal on-farm trials using benomyl, thiram and the insecticide endosulfan reduced the severity of seed-borne diseases and beanfly and increased yields of diverse varietal bean mixtures by 25% in regions above 1400 m in elevation. Combined treatments increased bean yields 17% and 35%, respectively, in the September and March seasons. Seed treatments with endosulfan alone increased yields by 17% in multiseasonal, multiregional trials through yield increases in the March season, but not in the September season, owing to low beanfly pressure. Yield increases from endosulfan applications alone occurred in regions below an elevation of 1700 m. A presowing seed treatment of benomyl, thiram and endosulfan was effective over the broadest range of conditions. Seed treatments can reduce farmers' risk of damage from multiple diseases and beanfly, thus substantially increasing on-farm bean productivity; they are effective without promoting genetic erosion of the diverse bean varietal mixtures used by local farmers in the Great Lakes region of Africa, as can occur with genetic replacement strategies.

Keywords Seed treatments; *Phaseolus vulgaris*; subsistence farming; IPM; multiple disease control; beanfly control

Introduction

Chronic food deficits and high population growth rates in Africa have caused serious concern in the international community and have resulted in allocation of substantial aid to the continent. Many international agriculture research centres (IARCs) funded by the Consultative Group for International Agricultural Research (CGIAR) now have projects with African institutions in an effort to develop technologies that will augment production of staple foods.

Phaseolus vulgaris L. is the primary source of protein and an important source of carbohydrates in the highly populated highlands of the Great Lakes region encompassing Burundi, Rwanda, the Kivu region of Zaire and south-west Uganda. It is an important protein source in many other African countries (CIAT, 1981). In the Great Lakes region and other African countries, beans are predominantly grown as varietal mixtures on small farms (Allen *et al.*, 1989) which in the study region average 0.5 ha. Mean on-farm yields per season in Rwanda are estimated as ~850 kg ha^{-1} (Anonymous, 1984).

Together with low soil fertility, diseases are a major constraint to bean production. Control of diseases in diagnostic trials caused yield increases of 300–500 kg ha^{-1} (Perreaux, 1986; Trutmann and Graf, 1987). Similarly, control of insect pests, predominantly *Ophiomyia spencerella* Greathead (Diptera: Agromyzidae), known as beanfly, increased yields by ~150 kg ha^{-1} (Trutmann and Graf, 1987). The predominant diseases are angular leaf spot caused by *Phaeoisariopsis griseola* (Sacc.) Ferraris, anthracnose caused by *Colletotrichum lindemuthianum* (Sacc. et Magn.) Briosi and Cav., Phoma blight caused by *Phoma exigua* (Bub.) Boerema var. *diversispora* and root rots associated principally with *Fusarium oxysporum* Schlecht. f. sp. *phaseoli* Kendrick and Snyder. All of these are either seed-borne or soil-borne. Crop vulnerability to these biological constraints contributes to chronically low yields.

Many conventional technologies to increase bean yields through disease and insect pest control are constrained by economics, cultivation practices and social factors. Even the germplasm strategy successfully employed by IARCs on other continents is limited in many regions of Africa

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owing to farmers use of and preference for complex varietal mixtures that vary between field farmer and region Under these constraints the strategy of chemical seed treatments was considered as a supplement to other technologies Such treatments are cheap easy to apply and use minimal amounts of chemicals which are targeted to seed before sowing Seed treatments are also effective against multiple pathogens and pests and unlike resistant germplasm can be effective on the broad range of mixtures used by farmers without dilution of its effect and do not erode the genetic diversity of farmers bean mixtures through displacement of the mixture components

Chemical seed treatments are widely used in the northern hemisphere and in Brazil for numerous cereal as well as legume crops such as beans and soybeans (Lama Hairston and Boyd 1982 Willis 1983) Seed treatments have been reported to be effective against root rots of beans caused by *Fusarium* spp (Papavizas and Lewis 1975 Gomez and Maya 1978 Willis 1983) *Pythium* spp (Papavizas *et al* 1977 Locke *et al* 1983 Abawi Crosier and Cobb 1985) and *Rhizoctonia solani* Kuhn (Papavizas and Lewis 1975 Segura and Diaz 1975 Abawi *et al* 1985) They are often effective against seed borne pathogens (INTA 1980 Papavizas and Lewis 1975 Bolkan de Silvia and Cupertino 1976 Ellis Galvez and Sinclair 1977) Treatment of infected bean seed has been found to be beneficial in decreasing infection (Ellis Galvez and Sinclair 1976) increasing germination and survival (Lima 1980) emergence (Tanaka and Correa 1982) and occasionally yield (Sirry Higazy and Farahat 1974 Papavizas *et al* 1977) Yield increases with seed treatments have also been reported for other crops (Pedersen Perkins and White 1986 Wright and Hughes 1987)

The objectives of this study were to evaluate the effectiveness of a number of fungicides to control root rots and the principal seed borne pathogens of *P vulgaris* in Rwanda The combined effect of fungicides with endosulfan as a treatment to control diseases and beanfly was then evaluated in multiseasonal multilocational on farm trials The use of endosulfan developed by Irving in Zambia (CIAT 1986) and Autrique in Burundi (Autrique 1987 Autrique and Lays 1987) was also further evaluated and compared with the combined treatment

Materials and methods

Isolation and identification

Thoroughly washed necrotic roots of beans collected from the Zaire–Nile Divide and the Central Plateau of Rwanda were surface sterilized using 70 / ethanol for 1 min and rinsed in sterile water Interface regions of infection were transplanted to potato dextrose agar (PDA) and cultured at 25 C Thoroughly washed root pieces were also placed in Petri dishes containing sterilized distilled water After 1 2 and 4 days roots were evaluated for phycomycetes Fungi isolated were sent for confirmation to the International Mycological Institute Kew England Foliar pathogens were identified according to Schwartz and Galvez (1980) and the local beanfly species was identified using CIAT (1986)

Seed treatment trials

Chemicals and concentrations In the first season seed was dipped in a slurry of benomyl [15 g wettable powder (w p) in 50 ml water per kilogram of seed] or in a metalaxyl slurry of 7 5 g w p in 50 ml water similarly seed was dipped in 1 5 g 80 / thiram or in 2 5 g of a mixture of captan 10 / thiram 26 / and diazinon 21 / or in 3 g endosulfan per kilogram of seed Untreated seed was used as a control In the second season the rates used per kilogram of seed were 2 0 g benomyl 2 0 g carbendazim 0 5 g metalaxyl 1 5 g thiram and 1 5 g endosulfan In on farm trials concentrations of 1 5 g each of benomyl and thiram were used per kilogram of seed in the Bubaruka Highlands in 1986 Endosulfan was used at 1 g kg ^{1} seed Following results from station trials the dose of benomyl was reduced to 1 g kg ^{1} seed in the 1987 and 1988 trials in the Zaire–Nile Divide Central Plateau and the shores of Lake Kivu

Seed treatment procedure Each chemical was weighed added alone or in combination with other chemicals to preweighed seed in a plastic bag moistened with a few drops of water shaken and left for 30 min before sowing

On station trial procedure In September 1986 at Gasenyi station of the Projet Agricole de Kibuye situated at an elevation of 2000 m on the Zaire–Nile Divide benomyl metalaxyl thiram a mixture of thiram captan and diazinon and endosulfan were evaluated for control of root rots and seed borne diseases On plots of area 8 m^2 with 1 m borders seed of a local bean mixture was sown in an equidistant pattern as used by farmers at the rate of 60 seed m ^{2} Treatments were replicated five times using a randomized block design

In April 1987 products were combined to determine whether such combinations could control root diseases and to evaluate the effect of including endosulfan in them At Gasenyi station plots of 10 m^2 separated by 1 m were prepared Seed was treated with (1) thiram and benomyl (2) thiram benomyl carbendazim and metalaxyl (3 and 4) treatments (1) and (2) with endosulfan and (5) benomyl and endosulfan Seed was sown at an equivalent density of 50 seed m ^{2} Untreated seed was used as a control Treatments were replicated five times using a randomized block design

On farm trial procedure Multilocational multiseasonal trials were conducted in the Bubaruka highlands at 1800–2000 m the Zaire–Nile Divide at 1900–2000 m the Central Plateau at 1600–1700 m and the shore of Lake Kivu at 1450 m using a combination of thiram benomyl and endosulfan Endosulfan alone was tested at the above sites and at Bugasera at 1300 m Plots of area 10 m^2 separated by 0 5 m were used for seed treatments Seed was sown by farmers at local densities which varied between 35 and 50 seed m ^{2} depending on farm field and season Untreated seed was used as a control Three trials each with two

Table 1 Effect of seed treatments with some chemicals on plant density root rots beanfly foliar diseases and approximate bean yield at G s y Station (Zaire–Nile Divide) September 1986

Treatment	Plant density at harvest (no ha^{-1})	Beanfly severity (1 9)	Root rot severity (1 9)	Anthracnose (%)	Phoma blight (%)	Vigour (1 9)	Bean yield (kg ha^{-1})
Control	259 000	1 0	3 7 b	10 6 b	10 2 b	5 4	775 b
Benomyl	265 000	1 7	2 0c	1 3c	6 2b	3 5bc	875
Metalaxyl	155 000	1 0	2 1bc	5 0b	11 8 b	3 3	600
Thiram	251 000a	1 0	2 8bc	8 7 b	9 1b	4 1 bc	875
Thiram + captan + diazinon	219 000	1 1	1 9c	12 0 b	9 8 b	5 0 b	850 b
Endosulfan	210 800a	1 0	2 6bc	14 9a	12 5 b	4 8 bc	625bc

Severity 1 = no symptoms 9 = very severe Percentage of surface area affected g l cell t 9 d dry yield per plot was measured to the nearest 100 g Numbers in the same column followed by the same letters do not differ significantly ($p=0.05$) according to Duncan's multiple range test

Table 2 Effect of seed treatments with combinations of products on root rots beanfly and anthracnose at G y Station (Zaire–Nile Divide) April 1987

Treatment	Plant density at harvest (no ha^{-1})	Beanfly severity (1 9)	Root rot severity (1 9)	Anthracnose (%)
Control	351 000 b	5 3	4 4	18 4
Thiram + benomyl	328 200b	4 4	3 8 bc	1 6b
Thiram + carbendazim + metalaxyl + benomyl	377 800 b	4 7	4 0 b	0 5b
Thiram + benomyl + endosulfan	317 800b	2 2b	3 5 bc	1 1b
Thiram + carbendazim + benomyl + endosulfan	408 000a	2 6b	3 0c	1 6b

As in *Table 1* Numbers in the same column followed by the same letter do not differ significantly (p 0 05) according to Duncan's multiple range test

replications per treatment were conducted for two seasons in each region In northern Rwanda trials were sown on eight farms one replication per farm

In three trials in the Bubaruka highlands in 1987 and the Central Plateau and shores of Lake Kivu in 1988 the combination of thiram benomyl and endosulfan was compared with endosulfan alone and fungicide alone Each trial was replicated six times per region

Disease evaluation Plants were evaluated for root rot and beanfly at the fourth compound leaf stage (V4 CIAT 1987) using the mean rating of 10 plants per plot with a severity scale of 1–9 (1 no symptoms 3 mild symptoms 5 moderate symptoms 7 severe symptoms and 9 50% or more of plants dead) In later trials pupae at V4 were counted using 10 plants per plot Foliar diseases were evaluated at grainfill (R8 CIAT 1987) according to percentage foliar surface area affected

Harvesting and weighing At harvest plant density and yield per plot were recorded Owing to equipment shortages yield in the first on station trial was measured to the nearest 100 g In on farm multilocational trials yield was measured to the nearest gram using portable balances accurate to the nearest gram

Statistical analysis Results were analysed using a two way ANOVA and means were separated using Duncan s multiple range test

Results

Seed treatment trials

On station trials Results of the September 1986 trial are presented in *Table 1* Beanfly pressure was very low Benomyl and the combination of thiram captan and the insecticide diazinon significantly reduced root rots Thiram alone did not reduce root rot severity implying that captan rather than thiram was the effective fungicide in the combination In metalayxl treatments phytotoxicity was observed at early stages of the crop due to high product concentration and although root rot severity was not reduced significantly roots appeared to be cleaner than after other treatments Infected roots yielded high proportions of *F oxysporum* and rarely phycomycetes Only benomyl treatments significantly reduced anthracnose severity No treatment significantly reduced Phoma blight although numerical differences were observed between treatments Plants in treatments with benomyl and metalaxyl showed significantly better vigour Significant differences in crude grain yield were observed between treatments Combinations of fungicides in the March season did not reduce root rot severity but root rot and beanfly severity were significantly lower in treatments containing endosulfan (*Table 2*) No treatment significantly increased plant density at harvest in comparison to the control Anthracnose severity was significantly reduced in all fungicide combinations containing benomyl or carbendazim

On farm trials In a general analysis of seed treatment with thiram benomyl and endosulfan in multilocational multiseasonal trials in Rwanda there were significant reductions in the severity of root rots beanfly angular leaf spot anthacnose and Phoma blight but not floury leaf spot (FLS) caused by *Mycovellosiella phaseoli* (Drummond) Deighton (*Table 3*) Overall dry bean yield was also increased by 25% Reductions in disease and beanfly severity were observed in both growing seasons but were greatest in the March season (*Table 4*) No significant reductions were observed in the September season in root

Table 3 Effect over regions and seasons of thiram+benomyl+endosulfan seed treatment on root rot, beanfly, foliar diseases and on-farm bean yield on-farm trials in Rwanda

Treatment	Root rot severity (1–9)	Beanfly severity (1–9)	Angular leaf spot (%)	Anthracnose (%)	Phoma blight (%)	FLS (%)	Bean yield (kg ha^{-1})
Untreated	4.5	3.1	6.2	5.1	6.4	4.9	825.1
Thiram+benomyl+endosulfan	3.5	1.4	3.3	1.4	2.8	4.1	1035.8
p	0.000	0.000	0.000	0.000	0.000	0.2?4	0.000

As *Table 1* floury leaf spot

Table 4 Effect over regions per season of thiram benomyl and endosulfan seed treatment on root rot, beanfly, foliar disease and on-farm bean yield in on-farm trials in Rwanda

	Growing season					
	September			March–April		
Disease, pest, yield	Untreated	Thiram+benomyl+endosulfan	*p*	Untreated	Thiram+benomyl+endosulfan	*p*
Root rot severity	4.0	3.5	0.147	5.0	3.4	0.004
Beanfly severity	1.9	1.2	0.029	3.8	1.6	0.000
Angular leaf spot (%)	1.5	0.9	0.146	9.6	5.4	0.000
Anthracnose (%)	3.7	1.1	0.003	5.9	1.6	0.000
Phoma blight (%)	6.5	3.1	0.017	6.5	2.7	0.000
FLS (%)	6.5	5.0	0.470	4.4	3.8	>0.500
Yield (kg ha^{-1})	1025.2	1195.8	0.024	688.7	926.8	0.000

As *Table 1* As *Table 3*

Table 5 Effect per region over seasons of seed treatments with thiram benomyl and endosulfan and endosulfan alone on bean yield on-farm trials in Rwanda

	Natural regions of Rwanda				
Treatment	Zaire Nile Divide	Buberuka Highland	Central Plateau	Shores of Lake Kivu	Bugesera
Untreated	377.7	1160.7	1202.3	340.6	
Thiram+benomyl+endosulfan	617.2	1440.3	1375.0	528.5	a
p	0.000	0.001	0.057	0.012	n.a.
Untreated	775.0	1160.7	739.9	340.6	411.5
Endosulfan	645.9	1121.5	917.1	627.1	571.3
p	0.326	>0.5	0.033	0.034	0.004

March season only not assessed

Table 6 Effect over seasons of endosulfan seed treatment on root rot and on-farm bean yield on-farm trials in Rwanda

	Bean yield (kg ha^{-1})		
Treatment	September	March	Annual
Untreated	659.0	704.0	673.2
Endosulfan	656.5	851.5	789.6
p	n.s.	0.004	0.002

not significant

rot. Angular leaf spot and beanfly severity were very low in the September season; beanfly and disease severity were more severe in the March season. Correspondingly 17% and 35% yield increases were recorded respectively in the September and March seasons. Yield increases with the combined seed treatment between 14 and 63% were recorded in the regions tested (*Table 5*).

A general analysis of results from endosulfan treated seed shows a reduction in beanfly and a 17% yield increase (*Table 6*). Endosulfan produced no yield increase in the September season, but increased yield by 21% in the March season, which correlated with higher beanfly severity in Rwanda. Yield increases from endosulfan alone were observed only in regions below 1700 m.

In comparative studies the use of endosulfan alone when beanfly pressure was low and disease pressure moderate produced numerically but statistically insignificantly lower yields than controls (*Tables 1* and *7*). When

Table 7 Effect of on-farm seed treatments the northern highlands of Rwanda April–July 1987 disease and bean yield

Treatment	Beanfly severity (1–9)	Root rot severity (1–9)	Anthracnose (%)	Phoma (%)	Angular leaf spot (%)	Bean yield (kg ha^{-1})
Untreated	2.2	4.1	6.1	8.7	5.4	1377bc
Endosulfan	1.1b	3.9a	5.7	8.8	4.5 b	1326c
Thiram + benomyl	2.0	3.8	4.2ab	6.6	3.3bc	1685ab
Thiram + benomyl + endosulfan	1.0b	3.9a	3.3b	6.9	2.9	1728

As *Table 2*

Table 8 Effect of seed treatments with thiram benomyl and endosulfan and benomyl or endosulfan alone on plant density beanfly foliar diseases and yield of late sown beans at Lake Kivu Rwanda March–July 1988

Treatment	Plant density at harvest (no ha^{-1})	Beanfly (percentage of plants attacked)	Angular leaf spot (%)	Phoma blight (%)	Bean yield (kg ha^{-1})
Untreated	139 000b	56.0	9.2a	15.0a	340b
Benomyl	133 000b	53.5	5.0b	10.7b	346b
Endosulfan	228 000	1.5b	5.0b	8.3c	627
Benomyl + endosulfan	226 000	4.0b	5.0b	11.6b	512
Thiram + benomyl + endosulfan	250 000	3.5b	5.0b	5.0d	529

Percentage surface area affected Values in the same column followed by the same letter do not differ significantly ($p=0.05$) according to Duncan's multiple range test

Table 9 Effect of seed treatments with thiram benomyl and endosulfan compared with endosulfan alone on plant density beanfly foliar diseases and yield of late sown beans in the Central Plateau Rwanda March–July 1988

Treatment	Plant density at harvest (no ha^{-1})	Beanfly pupae (no per plant)	Anthracnose (%)	Phoma blight (%)	Angular leaf spot (%)	Bean yield (kg ha^{-1})
Untreated	70 700b	14.3	0.3a	3.5	15.3	118b
Endosulfan	128 200 b	0.0b	0.0	0.0b	18.0a	214 b
Thiram + benomyl + endosulfan	186 800a	2.3b	0.1a	0.1b	12.6a	284a

As *Table 8*

beanfly pressure was high and disease pressure moderate the use of fungicide alone did not increase yield (*Table 8*) Yield increases observed when the endosulfan was combined with benomyl and thiram always produced yields superior or equal to the use of either insecticide alone or fungicides alone (*Tables 7–9*)

Discussion

Fungicide seed dressings can reduce the severity of important seed borne diseases of beans in the highlands of central Africa where diseases limit production Yields can also be augmented with a seed treatment for beanfly (Autrique and Lays 1987) the major insect pest of beans in Africa When these strategies are combined seed treatments provide a powerful tool to increase bean production in subsistence agricultural systems

The combined use of benomyl thiram and endosulfan increased on farm bean yields over natural regions by 173–240 kg ha^{-1} in September sowings and by 170–238 kg ha^{-1} in March sowings Using estimates of consumption per head for Rwanda of 60 kg year^{-1} the use of a combined seed treatment could provide beans for an additional 5–8 persons ha^{-1} year^{-1}

No fungicide seed treatment reduced damage of root rots associated with *F oxysporum* Results were contrary to indications in the literature which show benomyl as effective in controlling *Fusarium* root rots (Gomez and Maya 1978 Willis 1983) Plant mortality continued throughout the growing season and resulted in little difference in plant density at harvest between treatments As root rots were reduced from severe to moderate levels in the second season using endosulfan an interaction appears to exist between beanfly attack and severe root rot

There was evidence of complementarity among the chemicals in protecting the local bean mixtures against various biological constraints The largest yield increases in medium to high altitudes came from the fungicide component whereas at lower altitudes during severe beanfly attack yield increases came mainly from the insecticide component Thus combined treatments would provide a lower risk to farmer s investment in comparison to using a fungicide or insecticide alone

Product combinations could be further targeted to improve their efficiency Specific formulations should depend on country region and season and the capacity of countries to vary formulations In Rwanda the benefit from endosulfan appears to be limited to the March growing season or late sowings when beanfly attack is severe Fungicide treatment is unlikely to be effective in the low lying regions where diseases are not a major constraint In each country diagnostic work and wide ranging on farm testing is essential for efficient targeting of seed treatments

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