Effects of Intercropping and Cultivar Mixtures on Bean Diseases and Yield

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Abstract

The effects of bean intercropping with maize and bean cultivar mixtures on bean angular leaf spot (ALS), rust, floury leaf spot (FLS) and yield were studied for two seasons in Jimma in split plot design with three replications. Intercropping did not significantly (P = 0.05) affect bean diseases or yield. Moreover, no interaction effect between intercropping and cultivar mixtures for all the parameters was observed. However, cultivar mixture significantly (P = 0.05) reduced area under the disease progress curve (AUDPC) and disease severity index (DI) of ALS and rust on the susceptible component of the mixture; but did not significantly affect that of FLS. Cultivar mixture reduced ALS AUDPC and DI by 1 to 27% and 2 to 31%, respectively, and rust AUDPC and DI by 13 to 30% and 9 to 28%, respectively, on the susceptible cultivar. Generally, disease development decreased as the proportion of resistant cultivar in the mixture increased. Yield of the two cultivars was higher in mixtures than in their corresponding pure stands. In mixtures, Brownspeckled gave 5 to 26% more yield than its pure stand and ICA15541 gave 11 to 33% higher yield than its pure stand. The results reflect the possible use of bean cultivar mixtures to reduce bean ALS and rust and increase yield.

Key words: Intercropping, bean, disease

Introduction

Common bean (*Phaseolus vulgaris* L.) is an important crop in Ethiopia and covers a considerable area each year. It is often grown as a cash crop by farmers, and is also used as a major food legume in many parts of the country where it is consumed in different types of traditional dishes (Habtu 1994).

Despite its high economic importance, the average bean yield obtained by farmers in Ethiopia is extremely low (600 to 700 kg/ha) (Habtu 1994). This is attributed to a combination of several yield constraints among which diseases play a major role. The major diseases identified on bean in Ethiopia include rust caused by *Uromyces appendiculatus* Pers., Unger, anthracnose caused by *Colletotrichum lindemuthianum* (Sacc. Magnas), common bacterial blight caused by *Xanthomonas campestris* pv. *phaseoli* (Smith) Dye), angular leaf spot caused by *Phaeoisariopsis griseola* (Sacc.) Ferr, floury leaf spot caused by *Mycovellosiella phaseoil*, bean common mosaic virus, phoma blights and root rots (Habtu 1987). Of these, the major diseases in the more humid parts of Ethiopia including the Jimma area, are angular leaf spot, rust and floury leaf spot (Habtu 1987).

Angular leaf spot is one of the chief agronomic constraints of bean in Africa with a yield loss ranging 20–80% (Correa-Victoria et al. 1989). Yield loss due to rust can be as high as 85% in Ethiopia (Habtu 1994).

In Africa, including Ethiopia, where beans are normally cultivated by small-scale farmers using traditional methods, pest management options are limited. Thus, manipulations of cropping systems provides an important disease management tool which can be readily adopted by small-scale farmers, many of whom already use mixed cropping systems as a means of intensifying production on a limited area of land. It has been reported that diversified agro-ecosystems can reduce disease epidemics to a greater degree than corresponding sole cropping (Chemeda 1996).

Most studies on diversified cropping systems and diseases have concentrated either on the use of more than one crop species (intercropping) or mixtures of cultivars that vary in disease resistance (cultivar mixture) from a sole cropping point of view. However, diversification may also be attained through a combination of varietal mixtures and intercropping. Nevertheless, virtually no research has been done on the combined effect of intercropping and cultivar mixtures on bean diseases and yield, in spite of the fact that a heterogenous cropping system is very common in Africa. The current study was, therefore, done with the purpose of assessing the effect of bean intercropping and cultivar mixtures on bean diseases and yield.

Materials and Methods

The study was conducted at Jimma University College of Agriculture experimental station during the June to November 1999 and 2000 cropping seasons. The experimental site is situated at an elevation of 1722 m a s l and is located in southwestern Ethiopia. The total rainfall at the nearest weather station (7 km away) during the main growing months (April to September) was 951.5 mm and 983.2 mm in 1999 and 2000, respectively. The mean maximum and minimum temperatures were 25.2 °C and 13.1 °C in 1999 and 24.7 °C and 12.8 °C in 2000, respectively.

Two agronomically promising food bean cultivars, Brownspeckled and ICA15541 (Gobe Rasha), obtained from the Ethiopian Agricultural Research Organisation, were used. Based on the CIAT's classification, the growth habit of both cultivars is bushy and determinate type. Brownspeckled is locally widely grown in both sole and intercropping systems, and is moderately susceptible to most foliar bean diseases such as rust, common bacterial blight (Chemeda 1996) and ALS (Fikre Lemessa and Abush Tesfaye 2002). On the other hand, ICA15541, a recently released variety by Jimma Agricultural Research Center specifically for southwestern Ethiopia, is resistant to bean rust, ALS and common bacterial blight (Abush Tesfaye and Leta, unpubl. data). It is also known to be a cultivar highly preferred by farmers in this region. The improved and commonly grown maize variety, BH560, was used as second component of the intercrop.

The experiment was laid down in split plot design with three replications. Cropping system, intercropping and sole, was assigned to main plot and cultivar mixtures with different proportions of Brownspeckled and ICA15541 (100:0, 75:25, 50:50, 25:75 and 0:100) to the sub plots. The experimental plots measured 4 x 3 m. Inter–row spacing was 40 and 75 cm, and intra-row spacing 10 and 30 cm for beans and maize, respectively. In the intercropped plots, maize was planted at the same population density as that of sole maize, whereas the beans were planted at 50% of the population density of the sole crop. In the intercrop pattern, bean was row-intercropped with maize one month after maize planting in a relay system during the time of maize hoeing.

Maize seed was sown in June at a rate of 2 seeds per hill and the resulting seedlings were thinned to one plant per hill after two weeks. Before planting, bean seeds were counted and manually mixed to the required proportions (100:0, 75:25, 50:50, 25:75 and 0:100 Brownspeckled and ICA15541, respectively) and planted in July. Bean seeds were planted one per hole in random order.

After planting, before covering the seeds with soil, 24 (from the middle four rows) and 12 (from the middle two rows) seeds per plot were randomly marked in sole and intercrop beans, respectively, with two different types of stakes representing the cultivars in such a way that the required proportion is maintained in each treatment. This was done because the two cultivars are indistinguishable until maturity. The marked plants were used for assessment of disease and yield. In order to minimize inter-plot interference, data was obtained only from the middle rows. Disease development was under natural condition and no artificial inoculations of pathogens was done.

Disease assessment was made separately on the marked individual (24 in sole and 12 in intercrop) bean plants in each plot at 50% flowering, at podding and at physiological maturity growth stages during 1999 and 2000 cropping seasons. Disease severity, defined as the leaf area covered by the disease symptoms, was recorded on the 1–9 scale (CIAT 1987) and converted into disease severity index (DI) adopting the formula (Wheeler 1969):

$$\mathrm{DI} = \frac{\text{Sum of individual ratings}}{\text{No of pants assessed}} \times \frac{100}{\text{Maximum disease rating}}$$

Area under the disease progress curve (AUDPC) values for disease severity were computed for each treatment by mid–point rule between assessment dates using Van der Plank's (1963) equation as:

$$\mathrm{AUDPC} = \sum_{i=1}^{n}\left(\frac{(xi + xi + 1)(ti + 1 - ti)}{2}\right)$$

where, 'n' = the number of observations; ti = days after planting for the ith disease assessment; and xi = disease severity.

In order to determine disease development in mixtures, mixture efficacy of each treatment was computed based on the AUDPC and DI of ALS and rust. For each treatment, mixture efficacy (ME) was calculated as the relative difference between AUDPC and DI of a cultivar in mixture and a cultivar in pure stand (Finckh and Mundt 1992). That is, ME = 1 - (D_M / D_P) where, D_M is mean disease of a cultivar in mixture and D_P is mean disease of a cultivar in pure stand. Mixture efficacy values were expressed as a percentage by multiplying by 100.

At the end of the growing season the sample plants in each plot were harvested, separated into cultivars and threshed on a cultivar base. As there was a varying number of plants per plot due to the different proportions in the mixtures, mean yield per plant was used to determine the effect of intercropping and cultivar mixture on yield. In order to measure the effect of mixing cultivars on yield, the mixing coefficients of cultivars in mixtures were calculated as the yield of single plant of a component in a mixture divided by the yield of single plant of the same cultivar in pure stand (Davis and Panse 1987).

Analysis of variance and mean separation for AUDPC, DI and yield per plant was performed by the MSTAT-C statistical package (MSU 1989). Correlation coefficient between ALS and rust were also calculated to determine the degree of association between their occurrences.

Results

Disease severity

The major diseases observed during the study periods were ALS, rust and FLS in that order, with more severity in 1999 than 2000. Combined analysis of variance of the diseases indicated a significant variation between the years. Data from the two years are therefore presented separately.

Analysis of AUDPC and DI calculated from disease severity for the individual components of the mixture indicated that there was no significant (P = 0.05) difference in AUDPC and DI of ALS, rust and FLS between sole and intercropping in 1999 and 2000. However, cultivar mixtures significantly affected AUDPC and DI of ALS (Table 1) and rust (Table 2), but did not significantly affect the AUDPC and DI of FLS (data not presented). No interaction effect was observed between intercropping and cultivar mixtures for diseases. As the result for FLS was not significant for all the measured parameters, data for FLS was excluded. Looking at the AUDPC and DI for ALS in 1999, the 50 and 75% resistant cultivar in the mixture had significantly (P = 0.05) lower AUDPC and DI than the pure stands of susceptible cultivar (Table 1). The AUDPC and DI of the mixture with 25% resistant cultivar was not significantly less than that of the pure stand of the susceptible cultivar. In 2000, the AUDPC and DI of the susceptible cultivar in the 75% resistant cultivar mixture was significantly (P = 0.05) lower than the susceptible pure

Table 1. Area under the disease progress curve (AUDPC) and severity index (DI) for angular leaf spot in intercropping and bean cultivar mixtures for mixture components planted at Jimma, Ethiopia, during 1999 and 2000

Treatment	1999				2000			
	Brownspeckled		ICA15541		Brownspeckled		ICA15541	
	AUDPC	DI (%)	AUDPC	DI (%)	AUDPC	DI (%)	AUDPC	DI (%)
Intercropping (IC)								
Intercrop	564.99	31.31	390.67	20.21	445.56	30.66	406.60	27.75
Sole	585.09	32.59	450.28	23.38	460.21	34.43	405.96	28.27
LSD 0.05 (IC)	NS	NS	NS	NS	NS	NS	NS	NS
CV %	2.25	4.04	8.83	9.02	11.95	12.32	15.92	10.93
Cultivar mixture (CM) (Brownspeckled : ICA15541)								
100:0	667.01	37.75	-	-	472.16	34.87	-	-
75:25	603.99	35.42	436.43	21.92	466.65	34.26	430.24	29.94
50:50	536.53	28.41	431.06	22.01	449.84	33.03	410.02	29.63
25:75	492.62	26.24	423.30	22.52	422.89	29.01	399.69	26.85
0:100	-	-	391.113	20.55	-	-	385.17	25.62
LSD 0.05 (CM)	108.7	8.23	NS	NS	42.47	5.34	NS	NS
LSD 0.05 (ICXCM)	NS	NS	NS	NS	NS	NS	NS	NS
CV %	15.03	20.43	10.18	10.72	7.46	12.40	6.89	14.10

Brownspeckled = susceptible component of the mixture ; ICA15541 = resistant component of the mixture; NS – non significant

Table 2. Area under the disease progress curve (AUDPC) and severity index (DI) for rust in intercropping and bean cultivar mixtures for mixture components planted at Jimma, Ethiopia, during 1999 and 2000

Treatment	1999				2000			
	Brownspeckled		ICA15541		Brownspeckled		ICA15541	
	AUDPC	DI (%)	AUDPC	DI (%)	AUDPC	DI (%)	AUDPC	DI (%)
Intercropping (IC)								
Intercrop	547.99	23.63	271.36	14.54	303.03	24.43	171.47	14.09
Sole	624.86	26.64	278.28	16.63	254.33	26.44	169.55	12.81
LSD 0.05 (IC)	NS*	NS	NS	NS	NS	NS	NS	NS
CV %	12.43	13.71	18.66	9.72	11.65	8.94	6.66	11.27
Cultivar Mixture (CM) (Brownspeckled : ICA15541)								
100:0	698.78	30.86	-	-	344.06	27.47	-	-
75:25	606.35	26.34	331.46	18.52	266.97	25.12	177.47	13.58
50:50	527.64	22.22	272.43	16.91	241.99	25.00	174.68	13.12
25:75	512.93	23.15	251.21	13.40	261.71	24.15	171.58	15.23
0:100	-	-	244.17	13.50	-	-	158.32	11.89
LSD 0.05 (CM)	85.36	4.32	33.86	NS	60.11	2.21	NS	NS
LSD 0.05 (ICXCM)	NS	NS	NS	NS	NS	NS	NS	NS
CV %	11.57	12.04	9.80	8.91	17.15	9.98	9.73	11.20

Brownspeckled = susceptible component of the mixture ; ICA15541 = resistant component of the mixture;
NS – non significant

stands, but there was no significant difference between the susceptible cultivar in the 25 and 50% mixture of resistant cultivar and the pure stand. For rust, there was a significant (P = 0.05) difference between the AUDPC and DI of the 25%, 50% and 75% resistant cultivar in the mixture and the susceptible pure stand in both 1999 and 2000 (Table 3). On the other hand, no significant (P = 0.05) difference in ALS was observed between AUDPC and DI of the resistant pure stand and the mixtures. The trend was similar for rust with the exception that the AUDPC of the resistant cultivar in the 75% susceptible cultivar mixture was longer than that for the pure stand. Although not significant, the AUDPC and DI of the resistant cultivar was longer for the mixtures than for the pure stands for both ALS and rust.

The correlation between ALS and rust expressed as AUDPC and DI was positive in 1999 and 2000 (Table 4). However, the association is significant (P = 0.05) only for AUDPC of the susceptible cultivar in 1999.

Yield

During the experiment, better bean growth was observed during 1999 than 2000 cropping season. Combined analysis of variance of bean yield showed significant variation between the two years, bean yield being higher in 1999 than 2000. As a result, yield data from the two years was presented separately.

Intercropping did not show significant (P = 0.05) effect on yield per plant and there was no an interaction effect between intercropping and cultivar mixture (Table 5). However, cultivar mixture increased yield per plant of the susceptible cultivar compared to its pure stand. The yield per

Table 3. AUDPC and DI for ALS and rust in cultivar mixtures and mixture efficacy[a] in reducing disease on mixture components relative to their pure stands planted at Jimma, Ethiopia, during 1999 and 2000.

Cultivar mixture (Brownspeckled:ICA15541)[b]	Angular leaf spot								Rust							
	AUDPC		Mixture efficacy (%)		DI (%)		Mixture efficacy (%)		AUDPC		Mixture efficacy (%)		DI (%)		Mixture efficacy (%)	
	Brownspeckled	*ICA15541*	*Brownspeckled*	*ICA15541*	*Brownspeckled*	*ICA15541*	*Brownspeckled*	*ICA15541*	*Brownspeckled*	*ICA15541*	*Brownspeckled*	*ICA15541*	*Brownspeckled*	*ICA15541*	*Brownspeckled*	ICA15541
1999 season																
100:0	667.01	–	–	–	37.75	–	–	–	698.78	–	–	–	30.86	–	–	–
75:25	603.99	436.43	9.45	-11.59	35.42	21.92	6.18	-6.65	606.35	331.46	13.23	-35.75	26.34	18.52	14.66	-37.18
50:50	536.53	431.06	19.56	-10.21	28.41	22.01	24.75	-7.09	527.64	272.43	24.49	-8.45	22.22	16.91	28.00	-25.26
25:75	492.62	423.30	26.15	-8.23	26.24	22.52	30.50	-9.60	512.93	251.21	26.60	-2.80	23.15	13.40	25.00	+0.74
0:100	–	391.11	–	–	–	20.55	–	–	–	244.17	–	–	–	13.50	–	–
2000 season																
100:0	472.16	–	–	–	34.87	–	–	–	344.06	–	–	–	27.47	–	–	–
75:25	466.65	430.24	1.17	-11.70	34.26	29.94	1.76	-16.87	266.97	177.45	22.41	-12.09	25.12	13.58	8.57	-14.26
50:50	449.84	410.02	4.73	-6.45	33.03	29.63	5.30	-15.66	241.99	174.68	29.67	-10.33	25.00	13.12	9.00	-10.39
25:75	422.89	399.69	10.43	-3.77	29.01	26.85	16.80	-4.82	261.71	171.58	23.94	-8.38	24.15	15.23	12.10	-28.10
0:100	–	385.17	–	–	–	25.62	–	–	–	158.32	–	–	–	11.89	–	–

[a] Mixture efficacy is the relative amount of disease on a cultivar in mixture when compared to a pure stand of that cultivar; [b] Brownspeckled – the susceptible component of the mixture; ICA15541 – the resistant component of the mixture

Table 4. Correlation coefficient (r) between angular leaf spot and rust in the form of AUDPC and DI (%) for bean cultivar mixtures planted at Jimma, Ethiopia, during 1999 and 2000

Correlation between	Correlation coefficient (r)							
	1999				2000			
	Brownspeckled		ICA15541		Brownspeckled		ICA15541	
	AUDPC	DI	AUDPC	DI	AUDPC	DI	AUDPC	DI
Angular leaf spot and rust	0.98*	0.92	0.71	0.26	0.58	0.76	0.90	0.16

* Significant at P=0.05 with n-2 = 2df

Table 5. Effect of maize intercropping and cultivar mixture on yield per plant (g) of individual components of a bean mixture planted at Jimma, Ethiopia, during 1999 and 2000[a]

Treatment	Yield for individual components of the mixture[b]			
	1999		2000	
	Brownspeckled	ICA15541	Brownspeckled	ICA15541
Intercropping (IC)				
Intercrop	4.85	5.53	2.85	4.99
Sole	8.85	12.02	3.32	8.13
LSD 0.05 (IC)	NS*	NS	NS	NS
CV %	15.75	55.38	21.12	20.32
Cultivar mixtures (CM) (Brownspeckle: ICA15541)				
100:0	6.03	-	2.64	-
75:25	6.34	10.03	3.28	7.17
50:50	7.62	9.03	4.37	6.53
25:75	7.39	8.49	4.06	6.68
0:100	-	7.55	-	5.86
LSD 0.05 (CM)	1.22	NS	1.40	1.26
LSD 0.05 (ICxCM)	NS	NS	NS	NS
CV %	21.18	20.05	31.27	8.84

[a] Yield/plant was used for comparison of individual components of mixtures because of the unequal number of plants per plots;

[b] Brownspeckled – susceptible component of the mixture; ICA15541- resistant component of the mixture;

* NS- non significant

plant of the susceptible component in 50% and 75% resistant cultivar was significantly higher than the yield per plant of the susceptible pure stand in both years. Although not always significant, the yield of the resistant component tended to be higher in the mixture than pure stand. Generally, yield per plant of the mixture components was more in the mixtures than in pure stands. For instance, the yield per plant of the susceptible cultivar was 5 to 26% and 16 to 28% more in mixtures than the pure stand in 1999 and 2000, respectively. Similarly, yield per plant of the resistant cultivar was 12 to 33% and 11 to 22% more in the mixtures than the pure stand in 1999 and 2000, respectively.

Discussion

In a review of different intercropping studies, Recheigl and Recheigl (1997) mention that ALS development has been observed to be either less than, equal to, or greater than that in pure stands of bean. Msuku and Edje (1982), Sengooba (1990) and Boudreau (1993) reported increased ALS in maize–bean intercrops speculating that the maize may have induced microclimatic changes such as an increase in humidity, which favored infection by the pathogen. Boudreau (1993) speculated that increased relative humidity and decreased leaf temperatures in maize intercrops favored dew formation and increased ALS severity when beans were grown with maize.

Other studies reported that intercropping reduced the severity of most common bean diseases (Boudreau and Mundt 1992, Chemeda 1996, Galloti et al. 1992). They speculated that in maize–bean intercropping, the maize canopy reduces light penetration into bean plants and decreases bean leaf temperature which reduces infection by pathogens.

In the current study, intercropping had no significant effect on the AUDPC and DI of ALS and rust. This confirms the observation made by Msuku and Edje (1982) who observed no significant difference between ALS severity in intercropping and sole-cropped bean in Malawi.

Two different studies have reported that intercropping reduced the severity of rust (Chemeda 1996, Msuku and Edje 1982. In the present study, however, intercropping did not significantly affect the AUDPC and DI for rust. This is in agreement with the observation of Recheigl and Recheigl (1997) who reported that severity of bean rust was unaffected by intercropping.

On the other hand, results of the current study indicated that creating diversification by mixing resistant and susceptible bean cultivars reduced development of bean ALS and rust in field. For both diseases, AUDPC and DI of the susceptible cultivar were consistently lower in mixtures than in pure stand, which suggests that interplanting the resistant cultivar with the susceptible component delayed inoculum reaching the susceptible component, or reduced the amount of inoculum.

During 1999, the susceptible component in mixtures with 50 and 75% of the resistant cultivar had a significantly lower ALS AUDPC and DI compared with the susceptible pure stand. A similar tendency was also observed in 2000 although a significant difference was observed only for the mixture with 75% resistant cultivar. For rust the 25, 50 and 75% resistant cultivar mixtures all exhibited significantly lower AUDPC and DI than the susceptible pure stand in both years. More importantly, the calculated mixture efficacy values can be interpreted as indicating a favorable effect of mixtures as it has reduced ALS AUDPC and DI from 1 to 27% and 2 to 31%, respectively, and rust AUDPC and DI from 13 to 30% and 9 to 28%, respectively, on the susceptible component of the mixture. It has been suggested that cultivar mixtures would not provide effective disease control for splash dispersed pathogens (Wolfe 1985) such as ALS (*P. griseola*). The result of the current study, however, indicated the possibility of using cultivar mixtures for the management of such diseases. Studies made on other splash dispersed pathogens such as bean common bacterial blight (Fikre 1998) and anthracnose (Nitahimpera et al. 1996) have also demonstrated the effectiveness of cultivar mixtures to reduce disease.

The results of the present study for rust supported results reported by Habtu (1994) and Fikre (1998) at different locations where rust levels were found to be lower in mixtures containing a resistant cultivar than in pure stands of the susceptible cultivar. Davis and Panse (1987) also concluded that the maintenance of genetic diversity of traditional mixtures of bean varieties contributes to protection against rust.

Wolfe (1985) demonstrated that the principle of disease suppression by a mixture of resistant and susceptible individuals relies on the fact that the latter should receive some protection from disease build-up. This is because pathogen reproduction would be less on resistant plants and fewer pathogens would be available for infection. Moreover, the resistant components act as barrier to the spread of the pathogen.

In the current study, disease severity in mixtures increased linearly with the frequency of susceptible cultivar in the mixture. A linear relationship between disease severity and proportion of susceptible plants was also reported by Akanda and Mundt (1996). Leonard (1969), however, reported a logarithmic relationship between rate of disease increase and proportion of the susceptible cultivar in mixture.

According to Nitahimpera et al. (1996), percentage of the resistant cultivar required to protect a mixed population against plant pathogens is not well defined. Jensen and Kent (1963) suggested that 40% resistant plants is adequate to protect a population. However, a level of resistance that is adequate to protect a plant population in one environment may be inadequate for a different crop or in an environment more conducive for disease development (Nitahimpera et al. 1996). Furthermore, variation would be likely to occur between different host-pathogen systems. Our results indicate that a mixture containing 75% of a resistant cultivar was consistently effective in reducing ALS development on the susceptible cultivar. A mixture containing 50% of the resistant cultivar gave variable results, whereas results of the mixture containing 25% were generally not significant. In the case of rust, however, mixtures containing 25, 50 and 75% of the resistant cultivar all effectively controlled the disease. This indicates that the percentage of a resistant cultivar which is adequate to control a disease may be generally different for different pathogens. Epidemiologically, the seed-borne and splash-dispersed pathogen of ALS is very different from the wind-blown rust pathogen. Thus, mode of dispersal system of, the pathogen also affects the use of mixture as a management strategy.

In the current experiment, it was observed that there is a better bean growth and yield in 1999 than 2000, despite the high severity of ALS and rust in 1999 than 2000. Although enough weather information was not taken to explain, it is speculated that the better growth and yield during 1999 than 2000 could be due to variation in the weather conditions between the years.

In the present study, the yield of cultivar mixtures was higher than that of pure stands. The susceptible component in mixtures out-yielded its pure stand by 5 to 28%. Likewise, the resistant cultivar in mixtures out-yielded its pure stand by 11 to 33%. The yield increases of the susceptible cultivar in mixtures over the pure stand could be attributed to the disease control obtained through mixing. In a study by Trutmann and Pyndji (1994), disease reduction was found to lead to a yield increase depending on location, as the response of plants may vary based on the weather conditions. Nevertheless, the yield increase for the resistant cultivar in mixtures over the pure stand where the plants in mixtures are more diseased than in pure stand cannot be related to disease effect. One possible cause of the yield increase could be the competition effect in which the vigorously growing resistant cultivar (ICA15541) (personal field observation) had less competition in mixtures when grown with the less vigorous susceptible cultivar (Brownspeckled) than in pure stand. Recheigl and Recheigel (1997) noted that even with high levels of disease on one or more components of a variety mix, the resistant components could produce more in the less competitive environment and compensate for yield loss. Moreover, Finckh and Mundt (1992) indicated that part of the yield benefit in mixed plots is not a direct consequence of disease reduction, but of positive competition effects between cultivars when mixed.

The magnitude of yield increase in mixtures in the current study over the susceptible pure stand was comparable to increases observed by Trutmann and Pyndji (1994) who obtained yield increases equivalent to 27 to 33% over the local mixture by supplementing the farmer mixture with 25 and 50% of a resistant cultivar. Moreover, similar with the result observed by other studies (Fikre 1998, Finckh and Mundt 1992, Trutmann and Pyndji 1994), it was observed in the current experiment that no single mixture yielded less than the lowest yielding pure stand. It has been frequently reported that mixtures increase yield (Wolfe 1985 and Finckh and Mundt 1992).

In the central African highlands where beans are a critical food source, many farmers prefer cultivar mixtures over a single cultivar (Trutmann and Pyndji 1994). Similarly, bean cultivars with different seed sizes, shapes and colors are mixed in Ethiopia (Habtu 1994). In the present study, cultivar mixture consistently reduced the development of bean ALS and rust and increased yield. Therefore, where ALS and rust are recurring problems, this cultural method may provide an effective, inexpensive, sustainable and fungicide free disease management strategy that can also be used as a component of an integrated bean disease management scheme. In addition, taking into consideration the condition of Ethiopian farmers where bean mixtures contain largest proportion of susceptible cultivars such as Red Wolaita and Mexican 142 (Habtu 1994, Fikre 1998), the mixture with 50% resistant cultivar may be more suitable than the 75% resistant cultivar. Because the 50% proportion would have the advantage of suppressing diseases without bringing genetic erosion in the locally adapted bean germplasm. Moreover, it is likely that the overall yield is better in the 50% proportion than 75% because of the balanced competition between the cultivars in 50 % proportion.

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