Agronomic Performance and Economics of Yield Loss Associated With Angular Leaf Spot Disease of Common Bean in the Southern Highlands of Tanzania

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Abstract

Angular leaf spot (ALS) caused by *Pseudocercospora griseola* is among the devastating diseases of common bean (*Phaseolus vulgaris* L.) in the Southern Highlands of Tanzania (SHT). This study was conducted to assess the agronomic performance and economics of yield loss associated with the disease on five bean cultivars that are widely grown by farmers. The cultivars were evaluated in a split plot design with a randomized complete block arrangement during 2012/2013 and 2013/2014. The main plots were two rates of fungicide and a control whereas the subplots consisted of cultivars. Data were collected on disease severity, yield, and yield components. Analysis of variance was

done and marginal rate of returns determined using partial budget. Results indicated significant decrease in yields, number of pods, seeds, and seed weight at $P < 0.05$ for untreated plots. Decreases in yield were associated with ALS disease severity that in turn was influenced by cultivar and rate of fungicide used. Higher grain yield losses of as much as 61% and the lowest marginal rate of returns were recorded for unsprayed plots during heavy rains. Fungicide usage at the recommended rates should be considered during heavy rains and breeding for resistance should be taken as an economical and sustainable strategy for managing the disease.

Angular leaf spot (ALS) caused by *Pseudocercospora griseola* is one of the major diseases of common bean (*Phaseolus vulgaris* L.) in the Southern Highlands of Tanzania (SHT). *Pseudocercospora griseola* is a seed-borne pathogen that infects bean seedlings early in the season, and secondary infections occur rapidly under favorable conditions. The pathogen survives on infected seed, off-season bean plants, and saprophytically as mycelium and conidia in association with host residues on or near the soil surface (Waggoner and Berger 1987). Following infection, *P. griseola* produces a toxin which damages chloroplasts, resulting in red tissues contrasting with the normal green color (Cardona Alvarez and Walker 1956). Additionally, the pathogen has the ability to colonize intercellular spaces of the palisade cells of the leaf and other aerial parts resulting in angular lesions (Monda et al. 2001; Waggoner and Berger 1987). It has been reported that maximum disease development by *P. griseola* occurs between flowering and pod setting, a period characterized by an increase in the photosynthetic rate in common bean (Patterson et al. 1978). The occurrence of ALS at these stages of plant development reduces the net assimilation rate through a sink effect in which the causal pathogen diverts carbon fluxes from the growing seed for its own growth (Farrar 1992). As a result, seeds borne by infected plants are few, shriveled, and often discolored. Since seed yield of common bean is influenced by the number of pods per plant, number of seeds per pod, and average seed weight (Sinha 1977), reducing any of these yield components will lead to lower yields with an additional negative effect on seed quality (Stenglein et al. 2003). Yield reductions due to plant disease have also been documented on barley infected with *Rhynchosporium secalis* and in peanuts infected with *Cercosporium personatum* (Bourgeois et al. 1991; Walters et al. 2014).

There are several methods that have been proposed to study the relationship between yield loss and disease severity. However, the most common is area under the disease progress curve (AUDPC),

a quantitative summary of disease intensity over time that directly links yield losses with diseases, and it has been used in potatoes, maize, rice, beans, and pea (Filho et al. 1997; Godoy et al. 2003; Simko and Piepho 2011; Su et al. 2001). This model considers the number of times disease severity is evaluated and the duration of the epidemic (Su et al. 2001). The AUDPC is useful especially for evaluating facultative (hemibiotrophic and necrotrophic) pathogens like *P. griseola* that cause varying degrees of damage to plants throughout the growing period of the crop (Correa et al. 1989).

The economics of yield losses or gains on various crops can be determined from yield levels that provide the highest or lowest financial returns to investments in producing or protecting the crop against diseases (Egbe and Idoko 2010). Yield losses are expressed as the difference in yield between diseased and disease-free crops and can be determined in experimental plots using fungicide management (Lemessa et al. 2011; Madden and Nutter 1995; Sileshi et al. 2014).

This study was conducted to assess the agronomic performance and economics of yield loss associated with ALS on five widely grown bean cultivars as an effort toward developing sustainable control measures against *P. griseola*.

Materials and Methods

Description of the study area. This study was conducted at the Uyole Agricultural Research Institute (ARI-Uyole) located in the SHT. The Institute is situated at 8°53'S and 33°39'E at altitude of 1798 meters above sea level. The soils are loam and well drained, and the air temperature ranges from 18.0 to 23.7°C with a peak relative humidity of 95% during the rainy season. The location is characterized by unimodal rainfall that occurs between December and May, allowing for two plantings of common bean. This type of weather favors ALS disease development, and ARI-Uyole is one of the hot spots for ALS in the region. Additionally, the trial site had been planted with common bean in the previous years, ensuring abundant natural inocula from infested plant debris.

Experimental material and cultural procedures. Five cultivars of common bean widely grown and highly preferred by the farmers in the SHT, but ALS susceptible—Kabanketi, Maini, Kigoma, DRK (Uyole 96), and Kasukanywele (Uyole 94)—were used in the experiments. The seed was obtained from the local market where they are sold as farm-saved and untreated with fungicide. Kabanketi, Maini, and Kigoma are landraces, whereas DRK and Kasukanywele were

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released as improved cultivars more than twenty years ago. About one kilogram of seed was purchased for each variety. Four trials were conducted in 2012/2013 and 2013/2014: two at the beginning of the rainfall during heavy rains (December to March, with average rainfall of 668.9 mm) and two toward the end of the rainy season (March to July, average rainfall 255.6 mm) also known as the light rain season. Common beans are mainly planted twice in a year.

The trials were laid out in a split-plot arrangement of a randomized complete block design with three replications. The main plots were assigned to fungicide sprays while the subplots contained the five cultivars. Each subplot measured 2 m × 3 m and consisted of five rows, each hand seeded with 32 seeds at 10-cm intrarow and 50-cm interrow spacing. Border rows of 'Dorea', highly susceptible to *P. griseola*, were planted in all of the four sides surrounding the trial to increase inoculum pressure. Agronomic practices including fertilizer applications (N at 30 kg/ha and P₂O₅ at 60 kg/ha) and weed management were as per recommendations for common bean production in the SHT. Plants were sprayed with insecticide (Actellic 50 EC) containing 500 ai g/ha (49.02% w/w) pirimiphos-methyl using a backpack sprayer 10 days after planting and at pod setting to protect the plants against the bean fly and bean pod borers.

Fungicide application. In all the four trials, the main plots consisted of three treatments: (i) "no fungicide treatment," where no fungicide was applied, a common practice with most of bean farmers; (ii) "farmers' practice" in which the fungicide is applied once at a rate of 50 ml/ha at late pod filling stage; and (iii) fungicide at the recommended rate of 400 ml/ha applied four times at vegetative stage, flower initiation, late flowering, and pod filling. A preventive foliar fungicide (Othello TOP; Sineria, Maastricht, The Netherlands) containing

azoxystrobin 200 g/liter difenoconazole 125 g/liter SC commonly available in the SHT was used. The fungicide was applied using a backpack sprayer (SOLO) with an average flow rate of 400 liters/ha and a nozzle discharge of 500 ml/min.

ALS disease evaluations. The trials were exposed to natural ALS inoculum. Disease severity was scored at 10-day intervals starting from the first appearance of the trifoliate leaf to physiological maturity of the bean plants. The International Center for Tropical Agriculture (CIAT) 1 to 9 scale was used to assess the disease in each sub plot, where 1 to 3 indicates none or sparse lesions; 4 to 6 indicates well-defined lesions but sparse; and 7 to 9 indicates many and well-defined lesions (Van Schoonhoven and Pastor-Corrales 1987). Disease severity ratings were used to calculate AUDPC for each subplot according to the formula used by Campbell and Madden 1990:

$$AUDPC = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2} \right) (t_{i+1} - t_i) \quad (1)$$

where t_i is time in days of each reading, y_i is an assessment of the disease (proportion of infected leaves (at a 1 to 9 CIAT scale), and n is the total number of observations made. Other foliar diseases of common bean such as anthracnose and leaf rust were observed but with very low levels of infection and were recorded as negligible. ALS is easily differentiated from other common foliar diseases due to its well-defined angular lesions characterized by fluffy sporulation on the underside of the foliage. Infected pods develop oval lesions with reddish-brown centers surrounded by darker colored margins.

Yield and yield component evaluations. Data were collected for plant height, number of plants per plot, number of pods per plant, and

Table 1. Analysis of variance for traits evaluated on five bean cultivars under different fungicide rates in ALS disease-prone environments of the Southern Highlands of Tanzania during the 2012/2013 and 2013/2014 heavy rains and light rains bean cropping seasons, respectively

Source of variation	df ^x	AUDPC ^z		Pods per plant		100 seed weight		Grain yield (kg/ha)	
		MS ^y	P>F	MS	P>F	MS	P>F	MS	P>F
Experiment 1: 2012/2013 heavy rains									
Replication	5	50056	...	47.5	...	49.7	...	1263154	...
Fungicide	2	77974	0.005	9.9	0.21	316.3	0.001	9188312	0.017
Error (a)	10	8499	...	5.5	...	15.4	...	1458771	...
Cultivars	4	1941	0.139	2.2	0.86	265.6	0.001	244550	0.003
Fungicide × cultivars	8	1814	0.120	6.4	0.49	10.4	0.963	148999	0.014
Error(b)	60	1074	...	6.8	...	34.7	...	56000	...
Total	89	...	...	...	...	...	...	...	...
Experiment 2: 2012/2013 light rains									
Replication	5	38150	...	8.41	...	248.2	...	1270330	...
Fungicide	2	205874	0.001	30.14	0.03	18.3	0.017	307712	0.035
Error (a)	10	5662.0	...	...	...	8.6	...	64060	...
Cultivars	4	1282.0	0.426	2.61	0.53	446.3	0.001	80154	0.053
Fungicide × cultivar	8	584.0	0.450	3.10	0.49	15.6	0.963	66712	0.723
Error(b)	60	1309.0	...	3.30	...	40.9	...	100836	...
Total	89	...	...	...	...	...	...	...	...
Experiment 3: 2013/2014 heavy rains									
Replication	5	4743.8	...	17.79	...	2.86	...	5620	...
Fungicide	2	278921.1	0.001	160.67	0.001	944.90	0.001	13301731	0.001
Error (a)	10	727.1	...	5.69	...	3.94	...	11713	...
Cultivars	4	3960.0	0.001	11.29	0.001	21.70	0.002	148730	0.023
Fungicide × cultivar	8	302.7	0.901	1.55	0.692	6.56	0.184	57885	0.319
Error(b)	60	712.0	...	2.22	...	4.43	...	4854	...
Total	89	...	...	...	...	...	...	...	...
Experiment 4: 2013/2014 light rains									
Replication	5	1902.4	...	19.00	...	762.4	...	567760	...
Fungicide	2	39087.8	0.001	5.34	0.44	262.9	0.001	1326833	0.002
Error (a)	10	952.8	...	6.02	...	14.4	...	101213	...
Cultivars	4	1119.7	0.040	12.90	0.014	841.1	0.001	469887	0.001
Fungicide × cultivar	8	718.7	0.133	1.74	0.870	11.3	0.160	52906	0.760
Error(b)	60	438.2	...	3.80	...	7.4	...	85834	...
Total	89	...	...	...	...	...	...	...	...

^x df = degrees of freedom.

^y MS = mean square.

^z AUDPC = area under disease progressive curve.

number of seeds per pod for each sub plot. Plant height was measured in centimeters from ground level to the top of the canopy. At maturity all plots were harvested and the seeds were cleaned to remove all unwanted materials such as plant debris and soil and then weighed. Yield from each plot was determined without removing shriveled or discolored seed. Hundred seed weight was taken for each plot and recorded in grams. Thereafter, the diseased seeds were sorted out and clean seed was expressed in kilograms per hectare.

Economics of yield losses. Yield losses or gains were determined on market-valued seed to estimate the total returns or losses in United States dollars (USD). The price of a tin (20 kg) of beans was obtained from the local markets where the five cultivars were sold. Total costs of production (labor, fertilizers, fungicide applications, fungicide, weeding, and harvesting) were determined and recorded on a hectare basis. Calculations were not performed on untreated plots. The untreated plots were left to avoid creating a huge difference in the results when compared with the treated plots.

Data analysis. The AUDPC was calculated for each cultivar using the Microsoft excel program. Analysis of variance was performed on AUDPC, yield, and yield components using Genstat software version 14.1 (Payne et al. 2011). Fisher's least significant difference test was used to separate treatment means at $P \leq 0.05$. Correlation

analysis was done for combined means over replicates and the cropping season to examine the relationship between disease (AUDPC) and yield data. Percentage yield loss was calculated for each cultivar using the following:

$$\text{Yield loss} = [(YSP - YNF)/YSP] \times 100 \quad (2)$$

$$\text{Yield loss} = [(YSP - YFP)/YSP] \times 100 \quad (3)$$

where YSP is yields obtained from plots sprayed with fungicide at the recommended rates, YFP is yields obtained from plots sprayed with fungicide at farmers' rates, and YNFs is yield obtained from unsprayed plots.

Cost-benefit analysis was done and marginal rate of return (MRR) was calculated for the market-valued seed using the partial budget analysis method (Katungi et al. 2011). The following formula was used to calculate marginal rate of return (MRR):

$$\text{MRR} = (NB_2 - NB_1)/(TVC_2 - TVC_1) \quad (4)$$

where MRR = marginal rate of return, NB_1 = net benefit after using farmers' rate of fungicide, NB_2 = net benefit for using fungicide at the recommended rates, and TVC_1 (total variable costs) for treatment one

Table 2. Fungicide treatment means by cultivar for agronomic traits evaluated during 2012/2013 cropping seasons

Fungicide applications rates	Cultivars	2012/2013 heavy rain season				2012/2013 light rain season			
		AUDPC ^y	Pods per plant	Seed weight	Grain yield (kg/ha)	AUDPC	Pods per plant	Seed weight	Grain yield (kg/ha)
None	Kigoma	255.0 ab ^z	11.8 ab	34.7 ef	1223 ghij	254.2 a	10.2 cd	29.9 ef	1861 d
	Kablanketi	262.5 ab	12.5 ab	33.9 f	1517 efghi	230.0 ab	10.6 bc	28.5 e	1887 cd
	Maini	245.8 ab	13.7 ab	34.3 f	1389 fghij	230.8 ab	9.6 d	29.6 ef	1919 bc
	Uyole 94	226.7 abc	11.3 b	43.1 abcd	1847 bcd	251.7 a	9.7 d	41.3 a	1956 bc
	Uyole 96	205.0 bc	12.3 ab	44.1 abc	1656 bcde	226.7 ab	10.7 bc	39.9 cd	2005 ab
Farmers' practice	Kigoma	263.3 a	13.6 ab	34.7 ef	1631 bcde	225.0 ab	10.7 bc	33.2 de	2042 ab
	Kablanketi	219.2 bc	14.2 a	36.7 def	1467 efgh	207.5 bc	9.5 d	30.3 ef	2203 ab
	Maini	223.3 bc	11.5 b	38.0 cdef	1467 efgh	233.3 ab	10.6 bc	31.5 de	1868 d
	Uyole 94	237.5 abc	13.8 ab	42.1 abcd	1572 efgh	237.5 ab	10.5 bc	41.5 a	2196 ab
	Uyole 96	223.3 bc	12.2 ab	42.2 abcd	1678 bcde	225.0 ab	11.0 bc	40.6 ab	2053 ab
Recommended	Kigoma	145.0 de	13.3 ab	41.0 bcde	2411 bc	87.5 de	13.3 a	35.5 cde	2272 a
	Kablanketi	155.0 de	13.3 ab	42.0 abcd	2486 bc	90.8 cd	11.0 bc	29.8 ef	2084 ab
	Maini	146.7 de	14.5 a	41.6 abcd	2514 ab	90.0 cd	11.6 bc	32.0 de	2122 ab
	Uyole 94	137.5 e	13.3 ab	46.8 ab	2472 bc	92.5 cde	12.6 ab	38.4 bc	2073 ab
	Uyole 96	155.0 de	12.8 ab	48.3 a	2775 a	79.2 e	11.5 bc	39.0 bc	2048 ab

^y AUDPC = area under disease progressive curve.

^z Means followed by the same letter within a column are not significantly different according to Fisher's least significant difference test at $P < 0.05$.

Table 3. Fungicide treatment means by cultivars for the agronomic traits evaluated during 2013/2014 bean cropping seasons

Fungicide applications rates	Cultivars	2013/2014 heavy rain season				2013/2014 light rain season			
		AUDPC ^y	Pods per plant	Seed weight	Grain yield (kg/ha)	AUDPC	Pods per plant	Seed weight	Grain yield (kg/ha)
None	Kigoma	282.5 a ^z	10.2 fg	35.0 cde	972 e	155.8 a	12.0 bc	38.1 fg	1989 de
	Kablanketi	239.2 bcd	10.2 fg	37.7 b	1147 cde	130.0 bc	12.5 ab	42.1 e	1892 de
	Maini	253.3 abc	9.2 g	36.3 bc	1231 bcd	153.3 ab	10.8 cd	36.2 g	1984 de
	Uyole 94	242.5 bc	11.2 ef	34.2 cde	1369 bc	139.2 abc	11.6 abc	52.2 bcd	1975 cde
	Uyole 96	245.8 bc	10.6 efg	32.6 e	1450 b	148.3 abc	12.5 ab	51.1 cd	2178 abcd
Farmers' practice	Kigoma	265.8 ab	10.5 efg	34.7 cde	1111 de	151.7 ab	11.2 bc	41.5 e	1728 e
	Kablanketi	211.7 d	10.3 fg	34.5 cde	1111 de	134.2 abc	11.2 bc	42.4 e	2056 de
	Maini	234.2 cd	10.3 fg	36.2 bcd	1194 cde	123.3 c	10.3 cd	40.7 ef	2323 ab
	Uyole 94	235.0 cd	12.2 de	32.8 e	1222 bcd	145.0 abc	11.2 bc	52.8 bc	2068 bcd
	Uyole 96	230.0 cd	11.3 ef	33.9 de	1278 bcd	134.2 abc	13.5 a	54.1 bc	2150 abcd
Recommended	Kigoma	91.7 e	13.3 cd	45.1 a	2375 ab	95.0 d	11.3 bc	42.4 e	2648 a
	Kablanketi	69.2 ef	15.0 abc	45.6 a	2306 ab	84.2 def	11.2 bc	49.1 d	2552 ab
	Maini	72.5 e	13.5 bcd	44.2 ab	2417 a	87.5 de	9.6 c	44.1 e	2477 abc
	Uyole 94	79.2 e	15.2 ab	43.8 ab	2292 ab	68.3 ef	11.7 bc	55.6 ab	2387 abc
	Uyole 96	75.8 e	15.8 a	44.1 ab	2417 a	61.7 f	11.6 bc	57.8 a	2419 abc

^y AUDPC = area under disease progressive curve.

^z Means followed by the same letter in a column are not significantly different according to Fisher's least significant difference test at $P < 0.05$.

and TVC₂ was the total variable costs associated with the usage of treatment.

Results

Analyses of variance are presented in Table 1. The *F* value for the fungicide × cultivar interactions was significant ($P \leq 0.05$) only for yield during the 2012/2013 rainy season indicating that fungicide performance did not depend on the type of cultivar grown or the season in which they were planted. On the other hand, the effect of fungicide was consistently significant at $P \leq 0.05$ for AUDPC, seed weight, and grain yield for all the years in which the trials were conducted. Significant differences were also observed for the number of pods per plant in 2012/2013 light rains and in 2013/2014 heavy rains. Significant differences between cultivars were also observed particularly for seed weight and yield (Table 1).

Mean comparisons of fungicide by cultivars are presented in Tables 2 and 3. Angular leaf spot was severe in nonsprayed plots for all trials, but more so during heavy rains. A comparison of fungicide treatment means indicated that plots sprayed with “Othello TOP” at recommended rates of 400 ml/ha had the lowest scores for AUDPC, higher numbers of pods per plant, increased seed weight, and yield compared with unsprayed and those sprayed following farmers’ application rates. The mean number of pods per plant varied between fungicide treatments for all seasons in which the five cultivars were evaluated (Table 2). Seed weight and yield differed between cultivars, and the differences were maintained across seasons regardless of whether the rates of fungicide applied were those recommended or farmers’ practice. In all four bean cropping seasons in which the

trials were conducted, higher yields were consistently obtained during light rains compared with heavy rains.

When the harvested crop was sorted into market-value seed, plots sprayed with the recommended rates during heavy and light rains showed higher yields compared with the unsprayed and farmers’ practice (Fig. 1, 2). Shriveled and discolored seed were more prevalent in unsprayed plots for all five cultivars evaluated. High yield losses that ranged from 44.2 to 57% and 39 to 61% were obtained during heavy rains under farmers’ practice and no treatment, respectively. However, lower yield losses ranging from 6.1 to 37.8% and 6.0 to 25% occurred during light rains under farmers’ practice and no treatment, respectively (Table 4).

ALS disease severity. Correlations among AUDPC pods per plant, hundred seed weight, market-value seed, and yield were highly significant and negative during heavy rains. However, the relationship between pods per plant and yield was weak, although the value obtained was significant (Table 5). As the AUDPC increased, the number of pods per plant, 100 seed weight, market-value seed, and yield decreased as indicated by high, negatively correlated values. However, the market-value seed was strongly and positively correlated with grain yield regardless of the season in which the cultivars were evaluated (Table 5).

Economic analysis. The cost-benefit analyses for the treatments used in this experiment are presented in Table 6 and 7. The total variable costs and the total returns increased with the recommended fungicide treatments of 400 ml/ha.

The trend of benefits produced when cultivars were subjected to the three treatments was consistent during heavy and light rains. However, during light rains there were higher yields in plots sprayed following farmers’ practice and nonsprayed plots compared with those obtained during heavy rains. The average net benefit of all treatments during heavy rains was USD \$620/ha with a range of \$284 to 1041/ha while during light rains the mean was \$1169/ha and the range was \$846 to 1410/ha. Based on the net benefit, ‘Kigoma’ had higher benefits (\$1410.25) followed by ‘Kablankeiti’ (\$1340.05). High marginal rates of return (MRR) were obtained with ‘Kablankeiti’ (\$11.50) during heavy rains followed by ‘Maini’ (\$10.25). It is worth noting that the prices used were current during the study

Fig. 1. Mean marketable seed obtained during heavy rains in 2012/2013 and 2013/2014. NS = not sprayed; FP = farmers’ practice in which plots were sprayed once at the later stage of crop development (R4) with 50 ml of Othello TOP; SP = fungicide-sprayed plots at the recommended rates of 400 ml of Othello TOP per hectare. Error bars represent standard deviation of means at $P \leq 0.05$. Different letters denote significant differences between treatments.

Fig. 2. Mean marketable seed obtained during light rains in 2012/2013 and 2013/2014. NS = not sprayed; FP = farmers’ practice in which plots were sprayed once at the later stage of crop development (R4) with 50 ml of Othello TOP; SP = fungicide-sprayed plots at the recommended rates of 400 ml of Othello TOP per ha. Error bars represent standard error of means at $P \leq 0.05$. Letters of the same type denote nonsignificant differences between treatments.

Table 4. Percentage yield losses comparing data collected during the heavy and light rains in the Southern Highlands of Tanzania

Cultivars	Heavy rains % yield loss		Light rains % yield loss	
	FP ^y	NS ^z	FP	NS
Kigoma	48.6	49.5	37.8	27.1
Kablankeiti	57.4	61.0	17.1	25.2
Maini	50.2	47.5	6.1	16.8
Uyole 94	44.2	39.9	12.4	15.6
Uyole 96	44.7	45.6	2.4	6.0

^y FP = farmers’ practice in which plots were sprayed once at the later stage of crop development (R4 = mid-pod setting where 50% of pods are at maximum length) with 50 ml of Othello TOP.

^z NS = plots not sprayed with fungicide.

Table 5. Correlations between AUDPC yield and yield components during the 2012/2013 and 2013/2014 heavy rains^y

Heavy rains	Light rains				
	AUDPC	POP	HSW	MVS	GY
AUDPC	1	−0.0457	−0.0681	−0.3967	−0.2475
POP	−0.3565** ^z	1	0.2810*	0.154	0.5115**
HSW	−0.7290**	0.1890*	1	0.5115**	0.1748
MVS	−0.8968**	0.3889**	0.7462**	1	0.6606**
GY	−0.8730**	0.3531**	0.7181**	0.9788**	1

^y AUDPC = area under disease progressive curve; POP = pods per plant; HSW = hundred seed weight; MVS = market valued seed; GY = grain yield.

^z * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.001$.

period. Common bean prices in the SHT depend on the crop's supply and demand in the market.

The MRR indicating investment and recovery of the money was high when the recommended fungicide rate of 400 ml/ha was applied four times. Differences in MRR were apparent between heavy and light rain seasons. Cultivar Maini showed the lowest MMR with a negative value under farmers' practice of applying fungicide during heavy rains, whereas losses in investment occurred with 'Kigoma' under farmers' practice during light rains (Table 6,7).

Discussion

This study revealed that *P. griseola* caused significant disease during heavy rains that were characterized by mild temperatures (17 to 24°C) and high relative humidity (95%). These conditions have been reported to support the pathogen's ability to infect, germinate, and subsequently sporulate on susceptible cultivars (Celetti et al. 2005; Monda et al. 2001). We report here high values for AUDPC particularly with 'Kigoma' and 'Kabblanketi' receiving no fungicides during heavy rains. However, lower AUDPC values occurred with the same cultivars during light rains where temperatures were higher and leaf wetness duration was shorter.

Fungicide applied at the recommended rates of 400 ml/ha allowed the crop to attain physiological maturity with minimal disease occurrence. On the other hand, fungicide applied following farmers' practice did not significantly reduce ALS as the rates were low and the

application was too late. As a result, seed from infected plants were of poor quality, discolored, and shriveled with low market value. Seed yield in common bean is determined by yield components that include pods per plant, seeds per pod, and seed weight. Photosynthesis is necessary for good seed weight and foliar diseases such as ALS results in underweight seed (Celetti et al. 2005). Necrosis and defoliation caused by *P. griseola* on unsprayed plants would have less chlorophyll and thus lower respiration and less carbon assimilation. Reductions in chlorophyll and consequently lowering carbon assimilation have been reported on bean plants infected with angular leaf spot disease (Bassanezi et al. 2002).

Although common bean is one of the major and basic foods in the SHT, growing beans during heavy rains without any control measures will result in losses of more than 50%, especially to 'Kabblanketi' which is highly preferred. Small farm holders in the SHT recycle seed from season to season with little understanding of the importance of seed-borne diseases. In this regard, seed resulting from the heavy rainy season is likely to be contaminated with *P. griseola*, resulting in significant disease occurrence in the following planting. This is considered one of the primary reasons why ALS is on the rise in the SHT and bean production is going down. Unfortunately, a majority of the population depends on beans as a major source of protein.

The relationships between the AUDPC, seed weights, and yield were similar in that all showed negative associations with ALS, suggesting the necessity of optimizing disease management practices to

Table 6. Economic analysis of marketable seed by fungicide treatment during the 2012/1013 and 2013/2014 heavy rains

Cultivars	Fungicide treatment ^y	Grain yield (kg/ha)	Costs that vary (USD)	Gross farm benefit (USD)	Net benefit (USD)	MRR ^z
Kigoma	NS	823	150.00	534.95	384.95	...
Kigoma	FP	906	178.12	588.90	410.78	0.91
Kigoma	SP	1921	237.50	1248.65	1011.15	10.11
Kabblanketi	NS	667	150.00	433.55	283.55	...
Kabblanketi	FP	854	178.12	555.10	376.98	3.32
Kabblanketi	SP	1996	237.50	1297.40	1059.9	11.50
Maini	NS	945	150.00	614.25	464.25	...
Maini	FP	891	178.12	579.15	401.03	-2.25
Maini	SP	1919	237.50	1247.35	1009.85	10.25
Uyole 94	NS	865	150.00	562.25	412.25	...
Uyole 94	FP	931	178.12	605.15	427.03	0.53
Uyole 94	SP	1967	237.50	1278.55	1041.05	10.34
Uyole 96	NS	938	150.00	609.70	459.70	...
Uyole 96	FP	1000	178.12	650.00	471.88	0.43
Uyole 96	SP	2054	237.50	1335.10	1097.6	10.53

^y SP = plots sprayed with fungicide at the recommended rates of 400 ml/ha; FP = farmers' practice in which plots were sprayed once at the later stage of crop development (R4 = mid-pod setting where 50% of pods are at maximum length) with 50 ml of Othello TOP; NS = plots not sprayed with fungicide.

^z MRR = marginal rate of return.

Table 7. Economic analysis of market-valuable seed by fungicide treatment during the 2012/1013 and 2013/2014 light rains

Cultivars	Fungicide treatment ^y	Grain yield (kg/ha)	Costs that vary (USD)	Gross farm benefit (USD)	Net benefit (USD)	MRR ^z
Kigoma	NS	1848	150.00	1201.20	1051.20	...
Kigoma	FP	1575	178.12	1023.75	845.63	-12.6
Kigoma	SP	2535	237.50	1647.75	1410.25	9.51
Kabblanketi	NS	1815	150.00	1179.75	1029.75	...
Kabblanketi	FP	2010	178.12	1306.5	1128.38	3.51
Kabblanketi	SP	2427	237.50	1577.55	1340.05	3.56
Maini	NS	1977	150.00	1285.05	1135.05	...
Maini	FP	2233	178.12	1451.45	1273.33	4.92
Maini	SP	2377	237.50	1545.05	1307.55	1.21
Uyole 94	NS	1973	150.00	1282.45	1132.45	...
Uyole 94	FP	2046	178.12	1329.9	1151.78	0.33
Uyole 94	SP	2338	237.5	1519.7	1282.2	2.19
Uyole 96	NS	1869	150.00	1214.85	1064.85	...
Uyole 96	FP	2000	178.12	1300.00	1121.88	2.02
Uyole 96	SP	2308	237.50	1500.20	1262.70	2.37

^y SP = plots sprayed with fungicide at the recommended rates of 400 ml/ha; FP = farmers' practice in which plots were sprayed once at the later stage of crop development (R4 = mid-pod setting where 50% of pods are at maximum length) with 50 ml of Othello TOP; NS = plots not sprayed with fungicide.

^z MRR = marginal rate of return.

reduce infections, particularly during heavy rains. Although the same trend was observed during light rains, the association was not significant, probably because of lower disease pressure caused by weather conditions in those seasons.

Economic analysis revealed high returns in plots sprayed with fungicide at the recommended rates of 400 ml/ha. For every U.S. dollar invested, it was recovered with the additional profit of \$11.50 for 'Kablankei' and \$10.25 for 'Maini' from shifting from no fungicide spray and farmers' practice types of ALS disease management to applying recommended rates of 400 ml/ha of the fungicide. Following farmers' practice of a reduced rate of fungicide applied late in the season, the dollar invested was lost for 'Maini' and 'Kigoma' was lost with the MRR of -2.25 and -12.6 for 'Maini' during heavy rains and 'Kigoma' during light rains. A treatment is considered a worthy investment by the farmer if the MRR is higher than the minimal acceptable rate of return of 100% (CIMMYT 1998). Therefore, in the SHT, the current farmers' fungicide practices are not economical at least regarding 'Kigoma', 'Uyole 94', 'Uyole 96', and 'Maini'. Consequently, a farmer will gain little if fungicides are sprayed on cultivars Kablankei, Kigoma, Maini, Uyole 94, and Uyole 96 during light rains. It has been shown that, when disease severity is low and there is minimal yield loss, applying fungicides will not result in either yield or economic advantage when individual variety is considered (McGrath 2013).

The findings of this study indicate that the application of fungicides when beans are grown during heavy rains is necessary to sustain crop quality and yields in the SHT. During the light rain period, farmers may gain little if fungicides are applied. Education of farmers regarding the nature of seedborne disease and the proper use of fungicide to reduce losses caused by ALS in beans is necessary. Consequently, resistance breeding against *P. griseola* would be ideal for long-term management of ALS, an important disease of common bean in the SHT.

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