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M. A. Bekunda
P. Okori
M. P. Nampala
J. S. Tenywa
E. Adipala

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The effects of inter-cropping maize with beans on maize diseases infestation

G. Bigirwa, H.Warren[†], H. Willson[††], S. Kyamanywa[†††] and T.M. Kalule
Namulonge Agricultural and Animal Production Research Institute,
P.O. Box 7084, Kampala, Uganda
[†]Virginia Polytechnic Institute and State University, 1060 Litton Reaves Hall, Blacksburg, Virginia, 24061-0334 [††]Department of Entomology and Ohio State University Extension, 1991 Kenny Road, Columbus Road, OH 43210
[†††]Crop Science Department, Makerere University, P.O. Box 7062, Kampala, Uganda

Abstract

A study was carried out to assess the effects of inter-cropping maize with beans on maize diseases infestation.Eight diseases were recorded to affect maize with maize streak virus, northern leaf blight (*Exserohilum turcicum*), gray leaf spot (*Cercospora zeae-maydis*), and *Sternocarpella macrospora* leaf blight (*Sternocarpella macrospora*), being most prevalent. Disease incidence ranged between 0% for sorghum downy mildew (*Peronosclerospora sorghi*) to 80% for gray leaf spot. Gray leaf spot was the most common and was in some instances the most severe disease and attacked all varieties irrespective of the cropping system. Despite the high severity scores however, gray leaf spot disease did not affect maize yield. Other diseases also developed irrespective of whether the maize was sole or inter-cropped thus, resulting in no significant difference in disease reaction between mono or inter-cropped maize. In this particular study, intercropping maize with beans was not found to reduce maize streak virus disease incidence and severity as reported in earlier studies. These variable findings underscore the need for further work on disease incidence and development under mixed cropping systems.

Key words: Cropping system, gray leaf spot, yield, *Zea mays*

Introduction

Maize (*Zea mays*) is a major cereal crop in Uganda both as food and cash crop. The importance of the crop has been steadily increasing since 1994 when it ranked second to coffee in fetching foreign exchange for the country (Anon., 1995). Since then it has been among the first five major exports. Most of the maize grown comes from the farms of the poor resource farmers whose yields average about 1.2 t ha^{-1} (FAO, 1998). There are several reasons for this scenario, among them is the growing of low yielding varieties and the others include pests and diseases, declining soil fertility, drought and low plant populations partly due to intercropping systems (Kikafunda-Twine *et al.*, 2000).

Crop mixtures create micro-environments which may be beneficial to one or all the crops involved. However, in some instances the microclimate may create ideal conditions for disease or pest development. There are occasions when they act as alternate hosts for instance maize and sorghum in the case of sorghum downy mildew (Bigirwa *et al.*, 2000). Maize is commonly grown under two cropping systems; as a mono-crop and as an inter-crop mostly with beans. There is however, very limited information on the disease pressure within this cropping system. The trial was therefore set-up with two objectives: (i) to establish whether inter-cropping maize with beans has an effect on reducing maize disease development and progression. (ii) to compare the performance of a commercial open pollinated variety (Longe 1) with local variety under two cropping systems.

Materials and methods

The trials were established on farmers' fields in two sub-counties, Bulamagi and Baitambogwe in Iganga district for a period of four seasons starting from second season 1997 to first season 1999. In each sub-county, two farmers were used and their choice was based on the availability of land, interest and willingness to work with the researchers and ability to manage the trials. During the second season 1997, each of the four farmers was used as a replication, first season 1998, two replications were established at each farm while second season 1998 and first season 1999, three replications were established on each farm. The number of replications increased in the later seasons of testing as a result of farmers' willingness to offer land and confidence in the researchers since all the produce was left with the farmer. More land availed to researchers meant more produce at the end of the season.

Establishment of experimental plots

Two maize varieties, Longe 1 a commercial open pollinated variety and farmers own local variety were used. Each variety was grown as mono-crop and an inter-crop with a bean variety, K132. Each plot measured 10m x 8m. Maize varieties were planted at a spacing of 75cm x 60cm, two plants per hill. Two fertilisers. Phosphorous (as P_2O_5 at 45kg ha^{-1}) and nitrogen (as urea at 60 kg ha^{-1}) were applied. Plots were kept weed- free by regular hand hoeing. Bean (variety K132) was planted at a spacing of 75 cm x 15 cm, one row of beans between two rows of maize, in the commercial variety.

Data collection

Recording of maize diseases commenced 50 days after planting and this was done at an interval of 14 days for five recordings. Two approaches were used in recording diseases. First, incidences of major diseases affecting maize were determined. This was done on 10 plants randomly selected in a row in each plot. The number of diseased plants and the diseases affecting them were recorded. This was repeated three times in different positions of each plots.

In the second approach, 10 plants were randomly selected and tagged per plot and progression of four major diseases, was monitored by scoring severity using a scale of 1-5 (where 1= no or very minor infection, 5= very heavy infection). Disease progression was monitored five times in the growing season. During the last two seasons of testing, a Smith scale was used for scoring severity of gray leaf spot disease (Freppon *et al.*, 1996). Three methods were used to establish the effects of diseases on the 2 maize varieties in the various combinations. These were; assessing severity using a 1-5 scale, area under disease progress curve (AUDPC), for northern leaf blight it was the 1-5 severity scale and AUDPC, while with maize streak virus it was by all assessment methods.

Data analysis

Incidence data were acsine transformed to harmonise variances (Steel *et al.*, 1997). Data were subjected to analysis of variance (ANOVA) using MSTATC statistical software of Freed *et al.* (1988). Area under disease progress curve (AUDPC) (Campbell and Madden, 1990) was calculated for both incidence and severity using the midpoint rule standardized by dividing the AUDPC by the number of days from the first to the last assessment. Since the number of replications and plot sizes were different each season, the data set were not balanced to conduct a season location analysis (Steel *et al.*, 1997). Thus, data for individual seasons and locations are presented.

Results and discussion

A total of eight diseases were recorded during the study period with maize streak virus, northern leaf blight (*Exserohilum turcicum*), gray leaf spot (*Cercospora zeae-maydis*), Common rust (*Puccinia sorghi*), tropical rust (*Puccinia polysora*), brown spot (*Physoderma maydis*), sternocapella leaf streak (*Sternocapella macrospora*) and downy mildew (*Peronsclerospora sorghi*). Of the eight diseases recored, only three were most prevalent; maize streak virus, northern leaf blight and gray leaf spot. Disease incidence ranged between 0% particularly for downy mildew to 80% for gray leaf spot. Gray leaf spot was the most common disease in all fields and had the highest severity, this was followed by northern leaf blight. Although gray leaf spot was most prevalent and severe, it came in late compared to northern leaf blight, maize streak virus and downy mildew which appeared early. The diseases can be grouped into three categories, the early invaders (maize streak virus, northern leaf blight and downy mildew); mid period invaders (brown spot, common rust); late invaders (gray leaf spot, sternocarpella leaf streak and tropical rust). Disease development and progression were generally low during all the 4 seasons of testing due to dry spells experienced.

Disease incidence varied from disease to disease, being conspicuously high on gray leaf spot, followed by sternocarpella leaf streak and northern leaf blight. The highest incidence was recorded on gray leaf spot ranging from 2.7% to 87%. Although severity and incidence were high for gray leaf spot, the disease did not affect yield. This was clearly shown by severely affected plants having big cobs. A possible explanation for this is perhaps due to the fact that the disease tends to set in late when enough photosynthates required for cob formation and development have been accumulated.

Disease pressure on the four farms was similar except during the second season of 1997, where significant differences ($P=0.02$) in incidence were observed on gray leaf spot and tropical rust (Table 1). During the 1999A (first rains of 1999) season however, the level of maize streak virus was noted to vary among farms, being highest at the farms of Kulata and Mukalazi, with scores of 3.3 and 3.2, respectively as opposed to 2.3 at the farms of Byekwaso and Kisseke. The interaction between farmer and crop combination was highly significant ($P \leq 0.001$). In all instances it was high in the local variety irrespective of whether as sole or inter-crop (Table 2).

Significant ($P= 0.003$) variety differences in disease incidence and severity were recorded for maize streak virus (Tables 3-5). Farmers' local varieties were susceptible to maize streak virus compared to Longe 1 the commercial variety. This is not surprising for Longe 1 because it was bred for streak resistance (Anon., 1996). It is also for this reason that farmers are constantly advised to plant Longe 1 for its resistance to maize streak virus in addition to early maturity of four months and high yields. Response to other diseases was not significantly different irrespective of whether the variety was improved or local. This was also found true with the cropping pattern.

There were no significant differences in disease reaction between sole and inter-cropped maize (i.e., inter-cropping did not reduce the level of maize diseases). This is contrary to the findings of Page *et al.* (1999) that inter-cropping maize with beans or finger millet reduces maize streak incidence and severity. The reason given for this is that the inter-crops interfere with the mate seeking behaviour of the male vectors. There are also several instances of the successful use of inter-cropping to alter vector behaviour and thus, reducing the incidence of virus disease. For instance, Ahohuendo and Sarkar (1995) observed that intercropping cassava with cowpeas or groundnut reduced the incidence of African cassava mosaic disease and the population of its whitefly vector. The observed reductions were considered to be due to an effect on the host finding and feeding behaviour of the whitefly. Bottenberg and Irwin (1992) also reported that the incidence of aphid-borne soybean mosaic potyvirus was reduced in soybean intercropped with sorghum.

During the time of disease assessment, there are occasions when one can see clear differences in varietal response to diseases. However, some assessment methods used could not reveal such differences. For instance, differences in *Sternocarpella macrospora* and *Puccinia polysora* were only detected using area under disease progress curve (AUDPC). This tends to imply that for diseases which

Table 3. Disease severities under sole and intecropping cropping systems during the first season of 1998 (1998A).

Farmer	aMSV		GLS		NLB		SLS		PP	
	bSev	AUDPC	Sev	AUDPC	Sev	AUDPC	Sev	AUDPC	Sev	AUDPC
Longe	1.44±0.08b	1.34±0.06	2.74±0.13	2.09±0.10	1.88±0.16	1.58±0.08	1.27±0.56	1.26±0.04	1.25±0.03	1.20±0.03
Longe+beans	1.42±0.09	1.35±0.05	2.50±0.03	2.11±0.08	1.99±0.18	1.83±0.21	1.46±0.16	1.31±0.06	1.43±0.05	1.35±0.04
Local	2.61±0.22a	2.04±0.11	2.84±0.14	2.20±0.10	1.90±0.18	1.51±0.08	1.31±0.05	1.24±0.04	1.40±0.10	1.35±0.04
Local+beans	2.32±0.15a	1.95±0.11	2.64±0.09	2.04±0.09	1.60±0.11	1.40±0.04	1.31±0.10	1.29±0.08	1.40±0.07	1.84±0.04

aMSV = Maize streak virus, GLS = Gray leaf spot, NLB = Northern leaf blight, PP = *polysora* rust, SLS = *Sternocarpella* leaf streak, PS = *Puccinia sorghi*

bSev = Severity assessment on 1 – 5 scale except for GLS where the Smith scale was used; AUDPC = Area under disease progress curve

Values within a column followed by the same letter are not significantly different $LSD_{(0.05)}$.

Table 4. Maize disease severity under sole and inter-crop with beans cropping systems during the second season of 1998 (1998B).

Tretment	aMSV		GLS		NLB		PP		SLS	
	bSev	AUDPC	Sev	AUDPC	Sev	AUDPC	Sev	AUDPC	Sev	AUDPC
Longe	1.6±0.1	35.7±2.0	20.5±1.1	89.4±4.7	1.8±0.1	63.5±2.1	1.3±0.1	·50.6±2.0	1.4±0.1	5.1±2.0
Longe+beans	1.5±0.1	36.6±0.8	20.8±2.0	92/1±4.1	1.9±0.0	62.4±4.5	1.3±0.0	49.5±1.0	1.4±0.0	49.5±1.1
Local	3.6±0.2	69.1±4.3	21/9±2.3	99.9±3.8	1.5±0.1	59.9±2.0	1.4±0.1	53.7±2.1	1.4±0.1	53.1±2.1
Local+beans	3.4±0.1	64.5±5.4	22.0±1.7	93.5±2.3	1.7±0.1	60.0±1.5	1.3±2.2	49.4±2.2	1.4±0.1	51.1±1.7

aMSV = Maize streak, GLS = Gray leaf spot, NLB = Northern leaf blight

PP = *Puccinia polysora* rust, SLS = *Sternocarpella macrospora* leaf streak

bSev = Severity assessed on 1 – 5 scale except for GLS the Smith scale was used; AUDPC = Area under disease progress curve.

Table 5. Yields (kg ha⁻¹) performance of improved and local maize varieties as a mono-crop and intercrop with beans.

Farmer	Treatment	Maize yield kg ha⁻¹				Bean yield kg ha⁻¹	
		1997B	1998A	1998B	1999A	1998B	1999A
	Longe	3347.7±785.5	9312.1±212.8(53)[a]	5354±243.0(59)	8744.7±949.7(62.5)		
Byekwaso	Longe + beans	2968.5±950.3	9166.6±1395.6(55)	4985.7±467.1(55)	8566.7±1038.7(60.6)	524.7±65	347.9±105.7
	Local	1801.7±152.4	7667.9±677.4(42)	4309.7±513.0(48)	6355.6±1512.0(49.0)		
	Local + beans	1775.0±80.0	6481.1±715.0(49)	4512.3±462.9(54)	4889.8±781.3(59)	389.8±79	422.4±107.4
	Longe	2916.2±281.2	6981.1±715.0(65)	4984.0±343.6(54)	8505.8±267.9(62.7)		
Kiseka	Longe + beans	2376.1±281.2	5733.9±261.1(55)	4657.0±550.1(43)	7056.8±1402.5(60.3)	998.5±143	350.7±107.7
	Local	1848.7±125.6	4232.1±530.2(44)	3969.7±779.0(34)	8075.5±342.5(59.3)		
	Local + beans	1927.0±126.0	5060.7±1235.4(44)	3325.7±117.4(40)	6894.3±1317.6(57.3)	1004.5±54	359.1±61.2
	Longe	-	3529.1±1172(52)	5714.7±561.9(43)	7197.5±724.7(50.3)		
Mukalazi	Longe + beans	-	2629.1±1172.7(52)	4651.3±285.7(43)	6364.7±433.5(53.0)	-[b]	605.1±120.4
	Local	-	2615.6±126.9(43)	3149.0±287.3(34)	5630.9±409.1(51.3)		
	Local + beans	-	2219.9±32.8(50)	3550.0±392.5(36)	5455.9±1253.1(52.0)	-	649.7±121.5
	Longe	-	7774.3±2084.1(58)	3220.0±453.0(53.3)	7040.2±364.4(51.3)	752.6±92	915.5±266.7
Kulata	Longe + beans	-	6206.8±1491.9(60)	3116.7±645.2(46.7)	7798.9±1453.7(52.0)		
	Local	-	7059.4±634.8(61)	2298.7±618.1(41.0)	5796.8±1388.4(55.8)		
	Local + beans	-	7548.6±139.9(58)	1872.0±0326.2(35.7)	5733.3±3554.9(52.0)	602.7±100	512.2±151.5

[a]Figures in parentheses are number of maize plants harvested

[b]It was not possible to get bean yields because of drought.

progressively increase with time, their assessment should not be done only once but rather over time and AUDPC calculated to detect differences.

Significant (P=0.01) variety differences were also recorded in yield for nearly all seasons of testing with exception of second season 1997 (Table 4). Longe 1 almost consistently out-yielded the local variety. Higher yields were also realised during the first season of 1998 and least in the second season of 1997 this is partly due to the drought experienced at the time. In many places farmers got no yields as was the case with the last two farmers (Table 4). This was more so with farmers who planted other varieties other than Longe 1 which is known to be tolerant to drought partly because it matures early (Imanywoha and Kyetere, 1997). This can further be reflected by the yields obtained in the second season of 1997 which were almost twice as much as the local variety. Significant (P=0.03) differences among cropping systems were revealed for yield. In all instances the sole crop out yielded the intercrop. This can be attributed to less competition between the two crops and optimum plant population.

There was no significant difference in disease reaction between mono or inter-cropped maize. Therefore, inter-cropping did not reduce the level of maize diseases. Certain plant combinations however, help reduce disease incidence and severity for some pests. Khan *et al.* (1997) observed that inter-cropping maize with *Desmodium uncinatum* reduces the level of *Striga* infestation while an intercrop of maize and *Pennisetum purpureum* reduces the level of cereal stem borers on maize. Intercropping maize with beans reduces the severity of bean rust and bean common mosaic virus while the severity of angular leaf spot and ascochyta are increased in beans (Sengooba, 1994). In this particular study however, inter-cropping maize with beans did not have any effect on maize diseases. Diseases developed irrespective of whether the maize was sole or inter-cropped.

The common practice of farmers intercropping maize with beans cannot be encouraged as a means of reducing diseases of maize. However, for reasons like crop security in case one crop fails, land equivalent ratio, as a means of crop diversification and soil erosion control on hilly slopes, the method can be seen to be of advantage.

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Development of gray leaf spot from inoculated foci on two maize cultivars in Uganda

J. Ayiga, G. Asea[†], G. Bigirwa[††] and E. Adipala[†]
Department of Agriculture, Kyambogo University, P.O. Box 1, Kyambogo, Uganda
[†]Department of Crop Science, Makerere University, P.O. Box 7062, Kampala, Uganda
[††]Namulonge Agricultural and Animal Production Research Institute,
P.O. Box 7084, Kampala, Uganda

Abstract

The spatio-temporal spread of gray leaf spot on maize caused by *Cercospora zeae-maydis* was studied in two locations in central Uganda. Gray leaf spot development was assessed for three cropping seasons at 0.75 m to 5.25 m from inoculated foci on two open-pollinated maize varieties. In all the seasons, disease spread was adequately depicted by both power and exponential models. Distance from inoculum focus significantly ($P<0.05$) affected leaf damage but the effect of direction from inoculated focus was variable depending on the season, location and cultivar. Thus, depending on the location and seasonal variation, genotype effect greatly affects severity of gray leaf spot. Gradients for the two cultivars differed significantly ($P<0.001$) in intercept (a) but not slope (b) of the linearised power disease gradient for the number of lesion on the ear leaf. Our results indicate that maize genotypes affect both increase and spread of gray leaf spot. The rapid flattening of the disease gradient was indicative of long distance dispersal of *C. zeae-maydis* in tropical unlike in temperate environments.

Key words: *Cercospora zeae-maydis*, disease gradients, *Zea mays*

Introduction

Cercospora zeae-maydis (Tehon and Daniels), causal agent of gray leaf spot is an important pathogen of maize *(Zea mays)* world-wide (Ward *et al.*, 1999). The fungus survives on crop residues that is often instrumental in the development of gray leaf spot epidemics (Payne *et al.*, 1983). When conditions are favourable, sporulation has been reported to occur on the surface of crop residues, producing abundant conidia that constitute primary inocula for nearby maize plants (Summer *et al.*, 1981; Lipps *et al.*, 1983). The characterisation of gray leaf spot spread from an inoculum source and selection of empirical models to describe spatial pattern of disease are necessary to further advance understanding of the disease dynamics (Cambell and Madden, 1990). Parameters estimated with this approach can be employed as tools to study the spatial aspect of the disease inoculum foci (Jeger, 1989; Cambell and Madden, 1990). Despite this, there is limited information on the spatial component of gray leaf spot under Ugandan conditions. Since land fragmentation is common in most parts of Uganda, the same plot of land may be grown to maize season after season. In such cases, crop debris may become an important source of inoculum. Hence, it is important to understand the role of local inoculum source on gray leaf development and associated disease parameters. The description of disease gradients from a source of inoculum allows for estimation of the rate of spatial spread of disease. Moreover, it is possible to determine the relative potential for disease spread within different maize cultvars by comparing slope (b) of the gradient, which describes the rate of disease decrease from inoculum source (Gregory, 1968). The objective of this study was therefore to characterize the spatio-temporal patterns of gray leaf spot epidemics, and to determine the effect of maize genotype and direction from inoculated foci on spread of *C. zeae-maydis* on maize in a bimodal agroecology of central Uganda.

Materials and methods

Host genotypes

Two open-pollinated maize cultivars, Longe 1, a moderately resistant and popcorn, a susceptible cultivar (Bigirwa *et al.*, 1999) were used to study the spread of gray leaf spot from inoculum foci. Longe 1 is a commercial cultivar grown in Uganda bred at Namulonge Agricultural and Animal Production Research Institute while popcorn is also a commercial local cultivar that was introduced by a local seed company.

Field plots

Field plots were established during the first rains (March – July) of 1999 at two locations, Makerere Agricultural Research Institute, Kabanyolo and Kyambogo. The experiment was repeated during the second rains (September – December) of 1999 and the first rains (March – July) of 2000. These are subsequently referred to as 1999A, 1999B and 2000A, respectively. The plots were laid on land that was previously planted with sweetpotatoes (*Pomoea batatas* L.) at Kabanyolo and fallow for more than five years at Kyambogo. In both locations, the plots were tractor-ploughed and disc-harrowed before planting. The trials were planted on 19th March 1999 and 29th April at Kabanyolo and Kyambogo, respectively. The plots were arranged in a randomised complete block design with three replications. The experiment was repeated in two subsequent seasons with planting done on 25 September 1999 and 13 April 2000 at Kabanyolo and 1 October 1999 and 21 April 2000 at Kyambogo. Each experimental unit measured 16 x 16 m with 16 maize rows planted at a spacing of 75 x 30 cm. All plots were hand planted with two or three seeds per hill to ensure germination in all the plots but the seedling plants were later thinned to one to maintain a plant population of about 44,000 plants per ha. In both cases, plots were hand weeded at V3 and V8 growth stages (Ritchie *et al.*, 1989).

Inoculation and disease assessment

At the centre of each plot, an area of 1.5 x 1.5 m was marked with a coloured stain to establish inoculum foci. All plants within inoculum foci were inoculated by placing approximately 5 – 10 *C. zeae-maydis* colonized sorghum seeds into the whorls of each plant at V6 growth stage (Ritchie *et al.*, 1989). One pair of plants in each compass direction (N, S, W and E) was tagged at approximately 0.75, 1.5, 2.25, 3.0, 3.75, 4.5 and 5.25 m distance from the edge of the inoculated foci. The tagged plants in each direction were assessed for percentage ear leaf area affected (PELAA) as described by Freppon *et al.* (1996). In addition, the number of gray leaf spot lesions on ear leaf of the tagged plants were counted and used for statistical analysis. Disease assessments commenced 40 days after inoculation at both Kabanyolo and Kyambogo, which corresponded to approximately the R1 growth stage (Ritchie *et al.*, 1989). A total of 4 assessments were made at 7 – 10 days intervals.

For each distance from the inoculum foci, the mean PELAA and gray leaf spot lesion counts were calculated for each cultivar, gradient point and direction of disease assessment. When no significant differences were detected between directions, data for the four compass points were pooled for both cultivars and locations. Data collected at different times were used to compute area under disease progress curve (AUDPC), slope of gradient (b), apparent infection rates (r), and intercept (a). The power model, y = axb (Gregory, 1968) and exponential model, y = aexp (-bx) (Kiyosawa and Shiyomi, 1972) were linearised after log transformation and fitted to the pooled data for each replicate. These models were selected because of their common usage and because similar studies by Asea (2001) on the spread of gray leaf spot from colonized maize residue indicated their suitability. In these models, y is the proportion of disease severity at x units of distance from the inoculum foci and b is the slope. The appropriateness of each model was evaluated on the basis of coefficients of determination (R^2) and plots of residuals against time and distance. Analysis of variance (ANOVA) was used to determine the effect of genotypes, distance and direction on PELAA and lesion counts. The ANOVA was also conducted on r, b, initial disease (Y_i) and final disease (Y_f) and AUDPC. All the mean comparisons were done using Fisher's protected least significant difference (LSD) at $P = 0.05$.

Results

The effect of genotype on the severity of gray leaf spot was highly significant ($P<0.001$) during the three maize growing seasons. There was more disease development on the Popcorn than on Longe 1 as indicated by higher lesion counts, PELAA and AUDPC (Tables 1 and 2). Probably due to seasonal variations, there was greater gray leaf spot development during the second season 1999 than the first season of 2000 and 1999. The main effect of direction from inoculum foci on PELAA was not significant in both seasons of 1999, but significant in the season of 2000. Distance from inoculum foci did not significantly affect PELAA in the first season of 1999, but significantly affected PELAA in both 1999B and 2000A and the trend varied by location (Table 2). There was greater disease development at Kyambogo than at Kabanyolo. The interactive effect of cultivar x direction x location was significant in both 1999B and 2000A. Assessment of gray leaf spot lesion counts on the ear leaf indicated that genotype had significant ($P<0.05$) effect on final lesion count and AUDPC. Consistently, more lesions developed on Popcorn than Longe 1. For 1999A, there was significant effect of distance from inoculum source on both lesion development and AUDPC. Similarly location effect was significant on gray leaf spot development in terms of final lesion counts and AUDPC. The interactive effect of cultivar x direction x location were also significant for the same periods.

Both exponential and power models adequately depicted the spread of GLS across locations and seasons. However, power model was chosen to represent the disease spread because of its common usage (Gregory, 1968; Campbell and Madden, 1990). The main cultivar effect was highly significant ($P<0.001$) for intercept, a in both locations being higher on popcorn than on longe 1. Contrastingly, disease gradients, b were not significantly ($P >0.05$) affected by cultivar, direction and location across seasons. The b values ranged from –0.112 and –0.623 in the three seasons (Table 4).

Discussion

Host genotype had a significant effect on progress and spread of gray leaf spot from the inoculated focus. Our results and those reported earlier on another maize foliar disease, northern leaf blight of maize (Pataky *et al.*, 1986; Adipala *et al.*, 1993) suggest that in moderately resistant and resistant genotypes, spread of C. *zeae-maydis* is limited to neighbouring plants. In this study, spread of gray leaf spot from inoculated foci was dependent on the level of resistance, being restricted on resistant than on susceptible cultivars. The early studies by Payne and Waldron (1983) revealed that genotype significantly affected sporulation capacity of C. *zeae-maydis* if only local sources of inoculum are important.

The power model adequately described disease spread within each genotype grown at the two locations. Interestingly, the gradient parameter b was not significantly affected by genotype effect, yet the number of lesions declined with distance from the source plants. The slope rapidly flattened. These results indicate that apart from the focus expansion, subsequent lesions contribute to lesion development. It therefore appears that in the gray leaf spot pathosystem, genotype resistance levels are critical in generation of inoculum and spread of disease particularly if inoculum source is abundant.

Table 1. Main effect of cultivars and distance from inoculum source on initial disease (Y_i), final disease (Y_f), standardized area under disease progress curve (AUDPC) and slope (r) of logit transformed increase in lesion number of gray leaf spot lesions in two maize cultivars at two locations in Uganda, 1999A, 1999B and 2000A.

Distance	Cultivar							
	Popcorn				Longe 1			
	Y_i[a]	Y_f[b]	AUDPC[c]	r[d]	Y_i	Y_f	AUDPC	r[d]
Kabanyolo1999A								
0.75	2.25	28.0	351.7	0.08	0.0	4.86	68.0	0.07
1.5	1.58	25.0	311.1	0.07	0.0	4.16	62.3	0.07
2.25	1.08	24.0	305.1	0.08	0.0	4.2	58.1	0.09
3.0	1.16	24.0	303.8	0.07	0.0	3.62	45.8	0.07
3.75	1.33	23.0	305.6	0.08	0.0	3.11	38.1	0.06
4.5	1.08	22.0	286.9	0.09	0.0	3.20	36.2	0.07
5.25	0.66	21.0	279.9	0.08	0.0	3.00	35.1	0.07
SED	0.19	0.86	8.68	0.003	0.0	0.26	5.13	0.003
Kyambogo								
0.75	6.9	27.6	355.2	0.06	0.4	7.3	89.3	0.06
1.5	5.2	26.5	346.4	0.05	0.5	5.0	69.7	0.06
2.25	4.3	24.0	337.9	0.04	0.2	9.4	67.8	0.09
3.0	4.2	23.5	326.9	0.06	0.3	6.6	58.9	0.04
3.75	4.0	24.4	318.5	0.05	0.3	5.3	57.4	0.07
4.5	3.5	22.1	290.3	0.05	0.2	4.4	45.1	0.05
5.25	2.9	20.1	289.0	0.05	0.3	4.0	45.0	0.06
SED	0.49	0.96	9.84	0.003	0.04	0.72	5.86	0.006
Kabanyolo1999B								
0.75	6.1	64.3	555.0	0.05	0.0	8.2	60.9	0.07
1.5	3.1	44.1	396.1	0.06	0.0	5.3	55.9	0.07
2.25	3.7	39.0	365.1	0.06	0.0	4.7	48.0	0.06
3.0	4.2	37.0	357.1	0.05	0.0	6.5	37.9	0.08
3.75	4.2	35.5	396.9	0.05	0.0	3.0	36.2	0.05
4.5	4.5	29.0	311.1	0.04	0.0	4.9	27.2	0.07
5.25	3.1	20.1	311.1	0.04	0.0	2.9	33.8	0.06
SED	0.39	5.20	32.07	0.003	0.0	0.71	4.68	0.004
Kyambogo								
0.75	8.4	79.7	719.7	0.05	0.0	18.9	200.1	0.11
1.5	8.1	61.0	552.6	0.05	0.0	15.3	143.3	0.11
2.25	6.7	44.6	503.8	0.05	0.0	9.4	79.4	0.09
3.0	7.4	46.8	553.6	0.05	0.0	8.8	94.3	0.09
3.75	5.4	46.2	383.7	0.05	0.0	9.4	82.5	0.08
4.5	5.7	50.4	493.5	0.05	0.0	4.0	33.0	0.03
5.25	6.0	46.8	601.7	0.05	0.0	6.9	60.9	0.08
SED	0.45	4.82	86.93	0.00	0.0	1.92	21.08	0.01
Kabanyolo 2000A								
0.75	4.5	57.3	529.7	0.02	0.0	9.2	55.5	0.08
1.5	2.2	39.5	343.8	0.03	0.0	3.9	27.0	0.10
2.25	2.5	34.6	396.6	0.04	0.0	3.3	24.5	0.11
3.0	3.0	26.6	277.4	0.04	0.0	4.7	32.3	0.08
3.75	3.1	33.7	377.0	0.04	0.0	2.5	20.6	0.11
4.5	3.1	26.1	301.7	0.03	0.0	6.8	44.7	0.10
5.25	2.8	36.0	380.8	0.03	0.0	1.9	22.8	0.10
SED	0.28	3.96	30.96	0.003	0.0	0.98	4.90	0.005
Kyambogo								
0.75	6.0	70.3	619.4	0.02	0.0	15.1	137.3	0.08
1.5	5.6	56.0	477.1	0.03	0.0	12.4	112.7	0.06
2.25	4.8	31.1	373.8	0.03	0.0	7.5	58.4	0.08
3.0	5.7	40.9	459.0	0.03	0.0	7.0	61.5	0.07
3.75	3.9	42.2	323.8	0.03	0.0	7.8	59.3	0.09
4.5	4.1	37.5	387.8	0.04	0.0	2.5	21.5	0.10
5.25	4.2	55.3	496.3	0.03	0.0	5.1	42.6	0.08
SED	0.33	5.10	36.92	0.002	0.0	1.61	15.26	0.005

[a]Number of lesions on ear leaf 39 days after inoculation
[b]Number of lesions on ear leaf 60 days after inoculation
[c]AUDPC values divided by the number of days from the first to the disease assessment times
[d]Apparent infection rate calculated using linearised logistic model as described by Campbell and Madden (1990).

Table 2. Main effect of distance on final percentage ear leaf area affected (PELAA) and area under disease progress curve (AUDPC) during 1999A, 1999B and 2000A seasons[a].

Distance(m)	1999A		1999B		2000A	
	PELAA[b]	AUDPC[c]	PELAA	AUDPC	PELAA	AUDPC
0.75	14.0	204.7	18.7	231.2	16.2	197.7
1.5	15.7	215.6	15.4	198.7	12.8	168.7
2.25	16.7	214.9	15.1	203.1	11.9	163.4
3.0	13.7	190.8	14.6	199.8	13.1	169.3
3.75	13.7	195.1	13.6	178.5	10.8	154.7
4.5	14.3	189.7	16.1	191.3	10.7	146.6
5.25	14.9	206.7	14.2	181.1	9.6	135.0
$LSD_{(0.05)}$	NS	NS	NS	31.1	2.3	26.5

[a] Pooled data for the four directions (N, E, S and W) for both cultivars and locations.

[b] Final percentage ear leaf area affected assessed 60 days after inoculation.

[c] Area under disease progress curve calculated from PLEAA assessed 4 times and standardised by dividing the number of days between first and last assessment times.

Table 3. Main effect of distance from inoculum foci on last lesion count and area under disease progress curve (AUDPC) of gray leaf spot (GLS) during 1999A, 1999B and 2000A seasons[a].

Distance(m)	1999A		1999B		2000A	
	Lesion number[b]	AUDPC[c]	Lesion number	AUDPC	Lesion number	AUDPC
0.75	3.4	46.3	5.4	69.8	5.2	65.3
1.5	3.5	49.5	4.9	62.5	4.7	57.0
2.25	3.8	49.6	4.2	57.6	4.0	52.3
3.0	3.3	44.2	4.4	59.2	4.2	53.6
3.75	3.4	45.1	4.1	53.5	3.9	49.2
4.5	3.3	42.6	3.8	51.9	3.8	50.0
5.25	3.4	46.9	4.4	58.0	4.1	52.3
$LSD_{(0.05)}$	NS	NS	0.7	9.9	0.7	9.5

[a] Pooled data for the four directions (N, E, S and W) for both cultivars and locations.

[b]Mean final lesion count on the ear leaf 60 days after inoculation.

[c] Area under disease progress curve calculated from lesion number assessed 4 times and standardised by dividing the number of days between first and last assessment times.

Table 4. Regression of numbers of gray leaf spot lesion on the ear leaf on log_{10} distance of Cercospora zeae-maydis infested foci on two maize cultivars.

Assessment time	Cultivar					
	Popcorn			Longe 1		
	b	Yo	R^2	B	Yo	R^2
Kabanyolo1999A						
18 June	-0.42	-4.02	0.66	0.00	0.00	0.00
26 June	-0.30	-2.12	0.65	-0.39	-4.42	0.29
3 July	-0.11	-1.02	0.42	-0.25	-2.94	0.71
10 July	-0.18	-1.00	0.95	-0.26	-3.00	0.91
SED	0.07	0.71	0.11	0.08	0.93	0.21
Kyambogo						
21 July	-0.18	-2.94	0.32	0.00	0.00	0.00
30 July	-0.12	-1.96	0.51	-0.40	-4.12	0.74
7 August	-0.11	-1.02	0.42	-0.25	-2.90	0.71
14 August	-0.19	-0.98	0.82	-0.26	-2.50	0.31
SED	0.02	0.46	0.11	0.08	0.87	0.18
Kabanyolo1999B						
11 December	-0.26	-2.90	0.67	0.00	0.00	0.00
18 December	-0.34	-1.68	0.90	-0.17	-4.28	0.40
24 December	-0.16	-1.15	0.32	-0.11	-3.81	0.05
30 December	-0.85	0.27	0.92	-0.44	-2.57	0.59
SED	0.15	0.55	0.14	0.09	0.96	0.14
Kyambogo						
17 December	-0.23	-2.41	0.74	0.00	0.00	0.00
23 December	-0.24	-1.54	0.45	-0.96	-2.75	0.80
29 December	-0.21	-0.61	0.19	-0.79	-2.20	0.73
5 January	-0.72	0.85	0.75	-0.73	-1.58	0.79
SED	0.12	0.40	0.13	0.21	0.59	0.19
Kabanyolo2000A						
18 July	-0.28	-3.23	0.61	0.00	0.00	0.00
25 July	-0.26	-1.93	0.43	-0.32	-4.57	0.62
1 August	-0.33	-0.93	0.52	-0.33	-4.02	0.40
8 August	-0.74	-0.08	0.67	-0.51	-2.68	0.37
SED	0.11	0.68	0.05	0.11	1.02	0.13
Kyambogo						
20 July	-0.22	-2.76	0.68	0.00	0.00	0.00
28 July	-0.21	-1.81	0.29	-0.12	-3.04	0.86
5 August	-0.25	-0.86	0.26	-0.72	-2.72	0.67
12 August	-0.40	0.37	0.37	-0.78	-1.82	0.71
SED	0.04	0.67	0.10	0.20	0.68	0.91

b=rate of disease decrease over distance, Yo=intercept or logit (Y) and R^2=coefficient of determination
Data are averages for four directions (North, South, West and East of disease assessments from inoculated foci).

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Potential of intercropping napier grass with maize during the establishment phase of napier grass

C.K. Ssekabembe and E.N. Sabiiti
Department of Crop Science, Makerere University, P. O. Box 7062, Kampala, Uganda

Abstract

Napier grass (*Pennisetum purpureum*) serves a variety of functions, which include provision of fodder. However, small scale farmers in East Africa need both food and fodder crops. Hence, research to determine the potential of intercropping napier with maize *(Zea mays)* is relevant. This was done using a range of spatial arrangements. In a relatively drought season (1999b), when measurements were limited to the rows closest to napier-in order to determine its competition on maize, double napier rows alternating with single maize rows resulted in 55-68% reduction in maize dry matter (DM) production. The reduction in DM production was only 14% for the additive mixture. The reduction in napier biomass yield for the row closest to maize row(s) was significantly greater, 67-73%, in mixures in which 2 maize rows alternated with single napier grass rows. In a better growing season (2000a), maize DM production during the grain filling period was 19-76% lower in mixtures (depending on spatial row arrangement) compared to the pure stands, and the additive mixture did not exhibit reduction in maize DM production until the dough stage . Maize grain yield and yield components in the additive mixture and the 1:3 napier:maize row arrangement were not significantly lower than the sole maize, and maize was the dominant species in the mixtures. It was concluded that during the first phase of napier growth (before regular cutting back for fodder commences) it is possible to superimpose a maize row between the pure stand napier without much reduction in maize yield (only 5%). The reduction in maize yield in the 1:3 napier:maize rows arrangement was also negligible (6%). However, zero-grazing farmers who are more interested in napier biomass and a bonus of maize yield would take the 3:1 row arrangement. The higher maize yield for the additive mixture and the 1:3 mixture compared to the others, during the first phase of napier growth, was attributed to the higher population of maize plants in these mixtures. However, maize in these mixtures was competitive against the young napier plants and reduced its biomass production.

Key words: Additive mixture, dry matter, fodder, *Pennisetum purpureum*, spatial arrangement, yield

Introduction

Napier grass (*Pennisetum purpureum* Schum.) originated in East Africa (Maher, 1936) and is the predominant forage grass used in zero-grazing livestock production systems throughout East Africa (Abate *et al*., 1993; Anindo and Porter, 1994). It is also widely used for this and other purposes in other parts of the tropics and subtropics. The grass is important not only as a livestock forage but also for staking various crops (Gollifer, 1973; Niringiye, 2000), provision of mulch, soil erosion control and improvement of soil fertility in general (Bekunda and Woomer, 1996; Niang *et al*., 1998). It is also important in the construction of mud and wattle houses in rural areas. Therefore, napier grass is extremely important in both socio-ecomic terms and in the support of food security.

Most of the functions the napier grass fullfils require large amounts of biomass and the grass is capable of producing enomous amounts of biomass (Whiteman, 1980; Williams, 1980). In East Africa, it can yield about 25 t ha^{-1} without fertiliser application (Goldson, 1977. Perhaps, maximum napier biomass could be produced when grown in pure stands. Unfortunately, small scale farmers who practice zero-grazing in livestock production in East Africa need both fodder (napier grass) and food crops (Ssekabembe and Sabiiti, 1997). This makes it difficult to promote production of napier grass in pure stands. Therefore, there is need to determine the feasibility of joint production of fodder and food crops on the same parcel of land (Ssekabembe and Sabiiti, 1997).

Research conducted in Kenya showed that it is beneficial to intercrop napier grass with legumes such as *Desmodium uncinatum* and *D. intortum* (Wolfang Bayer, 1990) while experience in India indicated that napier grass is aslo compatible with *Leucaena* (Gill and Patil, 1985). In Uganda, beans are the most important grain legumes and for this reason this crop was tested for compatibility with napier grass- the most important fodder species for zero grazing (Ssekabembe and Sabiiti, 1997). The results indicated that bean yields can be reduced by 32% in the first season of napier growth but when napier becomes firmly established, it becomes very competitive and reduces bean yield by 80%. It was hypothesised that a fast-growing and more competitive crop than beans could be more compatible with napier grass than beans. Maize and sorghum that can grow as tall or taller than resprouting napier were suggested to be the food crops that could fit this scenario. These crops are also fairly competitive for below-ground resources because they are heavy feeders (Purseglove, 1972). Therefore, another experiment was initiated at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK) with the main objective of determining the compatibility of napier grass and maize. An additional specific objective was to determine the best spatial (row)arrangement for this mixture. Since the second phase of napier growth (after it has established a strong root systems and regular cutting back has started) presents markedly different competitive effects, only the results of the first phase of napier grass growth (before regular cutting back for fodder commences) intercropped with maize are presented in this paper.

Materials and methods

The experiment was carried out at two locations. The first trial was done in 1999b (i,.e. second rains of 1999), at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK; 0° 28'N, 32° 37'E), 17 km NE of Kampala. The experiment was repeated in 2000a (i.e., first rains of 2000), *albeit* with some modifications of the treatments, at Namavundu village, located 3 km away from MUARIK, which is also the nearest station where meteorological records are taken. The altitude at Kabanyolo is 1200 m and the soils are mostly Oxisols and highly weathered. Both locations had been under grass fallow for several years. The mean daily maximum and minimum temperatures of the area are about 27 and 17°C, respectively. Rainfall distribution is bimodal with April and November as the usual wettest months, but rainfall distribution has been unpredictable in the recent past. The average annual rainfall is 1300 mm.

The napier grass variety used at MUARIK was ILCA16791, which has been reported to be better than the other locally available varieties (Ssekabembe, 1998). However, at Namavundu another variety that was not previously tested (Cameroun) was used because the available planting material from ILCA16791 was severely infested with a suspected virus disease. This problem increased during the off season and lowered the population of healthy plants. This made it difficult to have a second phase of napier growth (after regular cutting commences) at the same site. This is the major reason why the experiment was replanted at Namavundu, hence providing a replicate of the first phase of napier growth.

In both cases, the "replacement series" treatments were spatial row arrangements ranging from 100% napier to 100% maize. According to de Wits "replacement series" technique of forming mixtures (Willey and Osiru, 1972) one row of napier was taken to be equivalent to one maize row. In both trials, the 50:50% mixture consisted of single alternating rows as well as double alternating rows (zonal arrangement). Both trials carried an "additive" mixture in which the recommended pure stand plant population of one species is superimposed on that of the other species, which increases the total plant population per unit area. In effect, between each two rows of pure stand napier, a maize row was planted to form the additive mixture. At Namavundu, the 2:1 napier: maize mixture, in which maize

DM yield reduction was highest at MUARIK, was dropped in favour of a mixture with a higher proportion of maize (1:3 napier: maize). For some "replacement series" treatments in the first trial, below-ground black polythene sheets were placed in trenches dug 40 cm away from the row to prevent the roots of either species from interacting with the other. The sheets were placed up to a depth of 50 cm into the trenches, and the soil returned beginning with the subsoil. The idea was to estimate the effect of below-ground interaction between the species. Due to the difficult of installing below-ground partitions and since below-ground partitions did not show significant below-ground interaction between the two species, at MUARIK, the treatments with below-ground partitions (+P) were also dropped at Namavundu. Hence, the range of treatments were fewer in the replicate of the experiment, and these are shown in Table 1.

Therefore, there were 11 treatments at MUARIK (1999b) and these were reduced to 7 at Namavundu (2000a). In each case, the treatments were arranged in a randomized complete block design with three replications. The plots in each block were 5.5 m long and 5 m wide with 50 cm borders between plots. Napier was grown on 80 cm rows with 50 cm between plants on the row. Maize (variety Longe 1) was also grown on 80 cm rows but spaced 30 cm within the rows. The plots were weeded 3 times in each season. In each season, napier was cut for the first time 4 weeks after maize harvest. Maize matures before the end of each growing season but the first cut for napier (harvesting) is delayed in order to allow the stems time to harden adequately and store organic nutrient reserves in the root stalks that allow resprouting after cutting (Blaser *et al.*, 1955; Sollenberger *et al.*, 1988). Thus, maize grain yield was determined as soon as it matured and was harvested and dried while napier biomass was determined at the end of the growing season (before the onset of the dry season).

Napier biomass yield was determined after oven drying the samples at 60°C for 48 hours. The number of maize and napier rows in the harvest samples depended on the proportion of each species in the treatments but the total sample area was kept constant for all treatments. At MUARIK, where below-ground partitions had been installed, an opportunity was taken to assess the compatibility of the two species, by assessing the competition between two species. Competition is mostly reflected at the interface of the intercrops (the rows closest to the other species in the mixture). Therefore, maize DM was based on the rows closest to napier grass in order to gauge its competition on maize. Total maize DM production was determined along a 2 m length for the rows closest to napier-the rows further away are more or less not influenced by napier grass. More measurements were done at Namavundu. For maize, these included DM production during the grain filling period, grain yield and yield

Table 1. Spatial arrangements used in the napier grass + maize intercropping system at Namavundu, Uganda, 1999-2000.

First trial (at MUARIK)*		Second trial (at Namavundu)	
Napier:maize rows	%	Napier:maize rows	%
0:All	0:100	0:All	0:100
2:1 (-P)	67:33	3:1	75:25
2:1 (+P)	67:33	2:2	50:50
1:1 (-P)	50:50	1:1	50:50
1:1 (+P)	50:50	1:1 (Ad)	50:50
2:2 (-P)	50:50	1:3	25:75
2:2 (+P)	50:50	All:0	100:0
1:2 (-P)	33:67		
1:2 (+P)	33:67		
1:1 (Ad,-P)	50:50		

* -P means without below-ground partitions while +P means with below-ground partitions; Ad indicates the additive mixture and partitions were impossible to install in this treatment.

components, stover dry weight, leaf area per plant (using linear measurements) and plant height at 50% anthesis. Maize DM production was based on 1 m length of samples across the entire width of the plots. The dry matter was determined twice-when the majority of plants were at the blister-milk stage of maize growth and at the dough stage (Hanway, 1963). This is also the time when maize is harvested for silage A 3 m-length sample across the width of the plots was used to determine grain yield and yield components. It was not possible to determine maize grain yield and yield components at MUARIK due to a terminal drought that affected the crop during reproductive growth. However, grain yield is often positively related to and could be predicted from total DM yield especially at flowering time (Hay and Walker, 1989; Isse Mohamud Abdi, 1997). Therefore, determining maize DM production during the reproductive growth period at MUARIK was a fair way of estimating its grain yield and hence, assessment of the potential of the napier + maize mixture. Measurements for napier grass included canopy height, number of tillers per plant and biomass yield at the first cut.

Results and discussion

Although planting was done quite early, during the first trial at MUARIK (1999b), there was prolonged drought which coincided with the reproductive growth for maize. When it was certain that maize would not mature normally during the persistent drought, the crop was harvested for total DM production when the plants were almost at the milk stage. The weather did not improve to have any meaningful grain yield data on part of the plots reserved for the purpose. Theoretically, drought between maize tasselling and silking leads to a delay in silk exertion and reduced seed set (Onwueme and Sinha, 1991). Continued drought into the linear growth phase of kernel development is expected to reduce the average seed weight as a result of reduced assimilate production or duration of the grain filling period (Lorens *et al.*, 1987). As indicated earlier, DM production at flowering time provides a good prediction of grain yield.

Compared to the pure stands, maize DM yield for the first row nearest to napier grass was significantly lower ($P<0.01$) in most mixtures with napier grass (Table 2). The reduction in maize DM yield ranged from 14 to 68%, depending on spatial row arrangement. It was particularly higher for mixtures with double rows of napier alternating with a single maize row. For instance, maize DM reduction in the 2:1 mixture with partitions was 68% compared to 14% in the additive mixture. The reduction in maize DM yield for the additive mixture was not significant ($P<0.01$). These results suggest that double napier rows shaded maize more than single napier rows. Even when other

Table 2. Maize total DM production prior to the milk stage and the first napier biomass yield when the species were intercropped with and without below-ground partitions at MUARIK in 1999b.

Spatial row arrangement		Total maize dry matter		Napier dry matter	
Napier:maize	rows	g 2m^{-2} row length	% yield reduction	g m^{-2} row length	% yield reduction
0	All	4.4	55	5.4	45
2	1 (-P)	2.0	55	5.4	45
2	1 (+P)	1.4	68	4.2	57
1	1 (-P)	2.4	45	5.8	41
1	1 (+P)	2.6	41	5.8	41
2	2 (-P)	2.3	48	6.2	37
2	2 (+P)	2.4	45	6.1	38
1	2 (-P)	3.3	25	3.2	67
1	2 (+P)	4.9	+11	2.6	73
1	1 (Ad)	3.8	14	7.1	28
All	0	-	-	9.8	
$LSD_{0.01}$		1.47		2.67	
CV (%)		29.1		27.7	

environmental resources are available to crops, reduced availability of solar radiation to a crop can severely limit its productivity (Ottman and Welch, 1989). Shading (competition for light) can even be expected to lower the ability of the shaded plants to exploit other environmental resources fully (Donald, 1958; 1963) and hence, a reduction in yield. However, in this particular experiment below-ground competition seems not to have been a strong factor, during the establishment phase of napier grass when its root system is not yet fully developed. Except for the 1:2 napier:maize rows mixture, during the said period maize DM yield for similar "replacement series" treatments with- versus without partitions were not significantly different (P<0.01).

As with maize, napier DM production for the row closest to maize was significantly (P<.01) lower in all mixtures except the additive one. The reduction in napier DM was particularly high when double maize rows alternated with single napier rows, being 73% for the 1:2 mixture with partitions and only 28% for the additive mixture. As with maize DM production, the difference in napier DM production in pure stand and in the additive mixture was not significant (P<0.01). The results indicate the dominance of maize in the 1:2 mixture. Maize dominance of the young napier plants was also apparent in mixtures with single maize rows. That napier biomass was higher in the additive mixture than in the 2:1 napier:maize rows mixture may be explained by greater intraspecific competition in the latter mixture. It seems penetration of light to both species was better in the additive mixture than when double rows of either or both species alternated with the other species.

The results of the first trial, at MUARIK, showed that in a relatively dry year (1999b) DM production on the first rows closest to the other species was significantly (P<0.01) reduced in most mixtures but the additive mixture was generally an exception despite the higher total plant population. In the trial that followed at Namavundu (2000a), the weather was better than during the first trial. It was generally conducive to better plant growth. The results on vegetative growth parameters during the latter trial are shown in Tables 3 and 4.

Compared to the pure stand, maize plant height was significantly (P<0.01) lower in the 3:1 napier:maize mixture, indicating that maize was not competing much for light in this mixture. On the other hand, there could have been some competition for light in the additive mixture (especially when compared to the 1:1 "replacement series" mixture) and the 3:1 mixture. This is because the maize plants in this mixture tended to be taller than those in the pure stands. The tendency for intercropped plants to grow taller than the pure stands suggests competition for light, and this was also reported when finger millet was intercropped with a tall sorghum variety (Ssekabembe, 1983). However, in the present study the difference was not significant (P<0.01). Similarly, maize leaf area per plant was generally not influenced by intercropping. Napier tillering was highest in the pure stand than in the mixtures and was significantly reduced especially in the additive mixture (P<0.01). This could be

Table 3. Effect of intercropping napier with maize on some vegetative growth parameters, at Namavundu, Ugnda in 2000a.

Spatial row arrangement Napier:maize		Maize		Napier grass	
		Height (cm)	Leaf area/plant m^2)	Tillers per plant	Canopy height (cm)
All	0	-	-	9.1	129
3	1	138	0.496	9.2	117
2	2	174	0.430	7.1	116
1	1	156	0.582	5.5	109
1	1(Ad)	182	0.403	3.3	100
1	3	182	0.476	6.6	124
$LSD_{0.01}$		32	-	2.4	23.7
CV (%)		10.5	33.0	11.2	19.2

explained by reduced availability of light at the base of the plants (although in the first trial it was postulated that the additive mixture could have reasonable light penetration-perhaps this does not occur as far as the base of the stem where tillers originate from. A high light intensity that also penetrates to the tiller buds normally promotes tillering through provision of surplus photoassimilates for tiller growth and through a reduction in auxin content (Ibrahim and Asse, 1976; Mohamed and Marshall, 1979; Olugbemi, 1984). However, data on napier canopy height does not suggest that competition for light was prevalent in the additive mixture (where napier plants were significantly ($P<0.01$) shorter) as well as in the other mixtures since canopy height was greater in the pure stand.

Maize total DM production at the blister and dough stages is shown in Table 4. Maize DM was generally lower in mixtures than in the pure stands but this difference was not significant ($P<0.05$) in the 2:2, 1:3 and the additive mixtures, at the blister stage. The 3:1 and 1:1 napier: maize rows mixtures had the greatest reduction in maize DM at both growth stages but when the species were paired or grown in the 1:3 and additive mixtures, the reduction in DM production was relatively small. The additive mixture had a low reduction in maize DM production at the dough stage and even an improvement in DM production at the earlier stage. This is probably because the additive mixture has a higher maize population than the other mixtures. The maize population in the additive mixture was 34709 plants ha^{-1} compared to 31250, 20834, 20834 and 10417 plants ha^{-1} for the 1:3, 1:1, 2:2 and 3:1 napier: maize rows mixtures, respecitvely. The maize population in pure stand was 41667 plants ha^{-1}.

Maize grain and stover yields in the second trial, at Namavundu, are shown in Table 5. Maize grain yield was highest in pure stands but the reduction in grain yield was significant ($P<0.05$) only in the 2:2 and 3:1 napier:maize mixtures. The lowest reduction in grain yield was exhibited by the 1:3 and the additive mixtures. Stover yield was also greater in pure stand than in mixtures. The reduction in stover yield was significant for all mixtures ($P<0.01$). As with grain yield, the reduction in stover yield was greater in mixtures with 2 or 3 napier rows. The reduction in stover yield was also less in the additive mixture and the 1:3 napier: maize mixtures, and was actually negligible in the case of grain yield from these mixtures. For the additive mixture, maize yield and hence, benefits from the mixture, could be increased (or the reduction in yield minimised) by staggered planting of the two species, i.e., by delaying planting of napier grass by 2-3 weeks to give the maize a head-start in growth. Staggered planting time enables peak periods of growth of the intercrops, and hence, competition, not to coincide (Rajat De and Singh, 1981). The possible reduction in napier grass growth and DM production may be overcome when maize matures and is harvested earlier leaving napier grass to exploit the space and environmental resources previously shared with maize. By planting beans 10 days before maize,

Table 4: Maize total DM production at the blister and dough growth stages for the napier grass + maize mixture at Namavundu, Uganda in 2000a.

Spatial row arrangement Napier: maize		Blister stage		Dough stage	
		kg ha^{-1}	% reduction	kg ha^{-1}	% reduction
All	0	-	-	-	
3	1	1153	76	2600	70
2	2	3547	26	6427	27
1	1	1767	63	2853	68
1	1(Ad)	5807	+21	5847	34
1	3	5453	+14	7147	19
0	All	4800		8800	
$LSD_{0.05}$		3391		5099	
CV (%)		47.7		49.9	

Francis *et al.* (1982) were able to attain a 60-89% increase in bean yield relative to simultaneous planting, when beans with a bush growth habit were used.

The results of the experiment indicate that in the first phase of napier growth, maize is more competitive than the young napier grass plants. Replacement of some maize rows with napier (in the 1:3 napier:maize rows mixture) apparently does not result in a significant drop in maize yield. Similarly, in the additive mixture the presence of napier is almost negligible in the first phase since maize yield for this mixture is comparable to the sole maize. Pairing the rows (2:2 mixture) did not increase maize yield above that of the alternating single rows (1:1) presumably because the napier grass is not yet so competitive and zoning it does not make a significant reduction in terms of competition with maize. The partial LERs for maize also indicate that maize was more competitive than napier in all the mixtures. The maize partial LERs realized in all the mixtures were higher than the expected ones.

The high maize grain, DM (blister and dough stages) and stover dry weight reductions in the mixtures with a higher proportion of napier is attributable to the lower maize population in these mixtures. It is also plausible to suggest that the higher yield of the additive mixture (1: Ad) compared to the 1:1 "replacement series" mixture is due to the higher maize population for the additive mixture. Thus, regression of the maize population in the various mixtures (1 = 3:1 napier:maize; and 6 = pure maize) versus the attained grain yield was positive and highly significant ($P<0.003$). As indicated in Figure 1, 90% of the variation in maize yield is explained by the maize population in the tested treatments. Similar conclusions have been made for the first year of the maize + *Robinia pseudoacacia* mixture (Ssekabembe and Henderlong, 1991). Ebwongu *et al.* (2001) also concluded that yield advantages appear to be achievable at higher plant densities of the potato + maize mixture because only the additive mixture gave a yield advantage on the basis of the Land Equivalent Ratio (LER) method of assessing the productivity of crop mixtures.

Maize grain yield components are shown in Table 6. Both yield per plant and number of grains per cob were lower in sole maize than in mixtures, but the difference was significant only in the 3:1 mixture ($P<0.05$). This is probably because intraspecific competition was generally higher than interspecific competition with the young napier plants. The 100 grains weight was not significantly influenced by intercropping the two species.

Total napier DM production at the first cut is shown in Table 7. Napier DM was greater in pure stand than in the mixtures except the 3:1 napier: maize rows mixture. The 1:3 mixture produced almost the

Table 5. Total maize grain and stover yields in the second trial of the napier + maize mixture at Namavundu, Uganda in 2000a.

Spatial row arrangement Napier : Maize		Grain yields		Partial LER*	Stover yields	
		kg ha^{-1}	% reduction		kg ha^{-1}	% reduction
All	0	-	-	-	-	
3	1	509	60	0.39(0.25)	662	81
2	2	686	46	0.54(0.5)	1251	64
1	1	957	25	0.75(0.5)	1858	47
1	1(Ad)	1220	5	0.95(0.5)	2720	22
1	3	1196	6	0.94(0.75)	2720	22
0	All	1280			3482	
LSD0.01		593			634.0	
CV (%)					16.5	

Values presented in brackets are the expected partial LERs on the basis of the land area occupied by maize in the respective mixtures.

same amount of napier DM as the additive mixture, which has a higher population of napier plants. This indicates that maize was very competitive against the young napier plants in the additive mixture. This competitiveness against napier was also partly reflected in reduced napier tillering and canopy height, which were more marked in the additive than in the other mixtures. Comparison of the partial LER and the expected partial LER (Willey, 1979) also indicates the competitiveness of maize not only in the additive mixture but also in the 1:1 "replacement series" mixture. This competition is somewhat reduced in the 3:1 and 1:3 napier: maize rows mixtures; napier partial LERs were higher than expected in these mixtures.

Conclusion

Overall, the results of the present study indicate that during the first season, a farmer interested more in maize grain than napier biomass, can select the 1:1 additive mixture and the 1:3 napier: maize rows mixture. Both mixtures contain a higher population of maize plants than the others. In these mixtures maize grain yield was not considerably reduced compared to the pure stand. Moreover, in addition to the grain yield, these mixtures offer appreciable amounts of napier biomass for livestock feeding. In the previous napier + beans experiment (Ssekabembe and Sabiiti, 1997), a mixture which consisted of more bean rows (1:4 napier grass:beans rows) was similarly recommended for farmers who need a

Table 6. Maize grain yield components during the first phase of napier growth when maize was intercropped with this forage species at Namavundu, Uganda in 2000a.

Spatial row arrangement Napier:maize	rows	Yield per plant (g)	No. of grains per cob	100 grains weight (g)
All	0	-	-	-
3	1	130	417	32
2	2	78	215	37
1	1	83	234	36
1	1(Ad)	73	217	34
1	3	72	196	36
0	All	66	189	35
$LSD_{0.05}$		53	171	5.7
CV (%)		35	38.4	9

Table 7. Total napier grass DM production at the first cut (5 months after planting) at Namavundu, Uganda in 2000a.

Spatial row arrangement Naper:Maize rows		Total dry matter (kg ha^{-1})	Partial LER*
All	0	21698	-
3	1	19142	0.882(0.75)
2	2	10833	0.499(0.5)
1	1	8727	0.402(0.5)
1	1(Ad)	8969	0.413(0.5)
1	3	7095	0.327(0.25)
0	All	-	
$LSD_{0.05}$		6897	

Values presented in brackets are the expected partial LER on the basis of the land area occupied by napier grass in the respective mixtures.

reasonable bean yield with some additional napier biomass for stall-fed cattle or sale. On the basis of the present and the previous experiment, it appears that the optimum spatial arrangement of the napier grass + food crops mixture ranges between 33:67% and 25:75% napier grass + food crops arrangement, i.e., mixtures that contain a single row of napier grass alternating with 3-4 rows of the food crop. One *Calliandra* row alternating with 3-4 rows of napier grass has also been recommended for maximum fodder yields (Franzel *et al.*, 1998).

However, the recommendation is different for zero-grazing farmers who do not wish to jeorpadize the availability of napier grass biomass for the livestock although some maize yield is also appreciated at the same time. In this case, the farmer could adopt the 3:1 napier: maize row arrangement because in this mixture napier grass biomass is not significantly lower than that from sole napier grass yet it offers appreciable additional amounts of maize yield. A notable finding from the present study is that for the first farmer, the additive mixture provides reasonable maize yield in the first phase of napier grass growth when maize is more competitive than napier grass. However, the additive mixture may not sufficiently fulfil the requirements of the second zero-grazing farmer, and the recommendation for the first farmer may not prevail when napier grass cutting commences-after the species develops a fully developed and competitive root system.

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Efficacies and profitability of different fungicides and spray regimes for control of soybean rust(*Phakopsora pachyrhizi* Syd.) in Uganda

R. S. Kawuki, E. Adipala, P. Tukamuhabwa and B. Mugonola[†]
Department of Crop Science, Makerere University, P.O.Box 7062 Kampala, Uganda
[†]Department of Agricultural Economics and Agribusiness, Makerere University, P.O.Box 7062 Kampala, Uganda

Abstract

Three fungicides: Dithane- M45 (contact wettable powder), Saprol and Folicur (both systemic), and three spray regimes, weekly, 2-weekly, and 3-weekly sprays from disease onset to full seed formation, were evaluated against soybean rust incited by *Phakopsora pachyrhizi* Syd. These corresponded to 5, 3, and 2 sprays, respectively. Nam 2 a highly susceptible variety was used in the study. The unprotected soybean had significantly higher rust severities (> 75%) and lower yields (968 kg/ha) as compared to the rust-protected soybean, with rust severities (< 70%) and yields (> 1000 kg/ha). Highest yield increase with Dithane, Saprol, and Folicur of 26.9, 33.3 and 38.9%, respectively were obtained under the weekly, 2-weekly, and 3-weekly spray schedules. The highest economic returns for Dithane (71, 252 Shs/ha), Saprol (127,607 Shs/ha), and Folicur (236, 181 Shs/ha), were obtained under the 2-weekly, 2-weekly, and 3-weekly spray schedules. Rust control was associated with increased seed weight and number of filled pods per plant.

Key words: Glycine max, net benefits, rust severities

Introduction

Fungicides have been used to control soybean rust since the 1950's (Kitani, 1952). Indeed, several studies on fungicide screening and establishment of spray schedules have been conducted in several parts of the world where rust causes substantial damage (Kitani *et al.*, 1960; Hu *et al.*, 1975; Sudjadi *et al.*, 1977; Maiti *et al.*, 1982; Junqueira *et al.*, 1984). Most of these studies indicated yield benefit achieved through use of fungicides to control soybean rust. However, economic analyses of the use of these fungicide applications were often not done and yet this is essential for rationalization of fungicide usage.

In Uganda, soybean rust is a relatively new disease. In other parts of the world where the disease is endemic, fungicides are commonly used for control, especially in absence of resistant or highly tolerant cultivars (AVRDC, 1992). Unfortunately, no fungicides have been evaluated against rust in Uganda, and yet the disease is on the increase and the popular varieties are susceptible, implying destructive control is inevitable. We are also not certain whether recommendations based on trials conducted elsewhere are applicable to local conditions in Uganda. Differences in soybean growing areas with respect to climatic patterns and economic factors greatly influence the use of fungicides as a rust control option, so that fungicide recommendations are often location specific (Bromfield, 1984). It is therefore necessary that fungicide use as a control option against rust be carried out under our local conditions. Therefore, the objective of this study was to evaluate efficacies of three different fungicides and three spray regimes for the management of soybean rust in Uganda.

Materials and methods

The trial was conducted at Namulonge Agricultural and Animal Production Research Institute (NAARI), an area in central Uganda with high rust pressure (Kawuki *et al.*, 2002). The trial was conducted for three consecutive seasons, starting in second rains of 2000 (October 2000 - January 2001), first rains of 2001 (March - June), and second rains of 2001 (October 2001 – January 2002). Here after, these seasons are referred to as 2000B, 2001A, and 2001B, respectively. Nam 2, a popular, medium maturing soybean cultivar (112 days), but highly susceptible to rust (Kawuki *et al.*, 2002) was used in the study. Three fungicides, Dithane M-45 (contact wettable powder), Saprol (Triforine, systemic, Cynamid), and Folicur (Tebuconzole, systemic, Bayer Germany) were applied at rates of 2.5g l^{-1}, 2ml l^{-1}, and 1ml l^{-1}, respectively. Three spray regimes, weekly, 2-weekly, and 3-weekly intervals, corresponding to 5, 3, and 2 sprays a season, were evaluated. Spraying commenced at onset of the disease (when rust symptoms were seen on bottom third leaves) up to R6 growth stage. The crop growth stage was determined following (Fehr and Caviness, 1977). The control plots were not sprayed.

The experiment layout was a split-plot of a Randomised Complete Block Design with three replicates. The main plots comprised of the spray intervals, while the sub-plots were the fungicides. Each experiment plot had four rows 2 m long. Spacing between and within the rows was 60 cm x 5 cm, respectively. A 2 m alley was left between plots and replicates to minimize inter-plot interference. Two rows of Nam 2 were sown between replicates and around the experiment area to increase inoculum pressure. The experiment was kept weed-free by regular hand hoeing. Rust severity was assessed 14 days after the final spray on the upper third leaves of five randomly selected plants from the 2 middle rows of each plot. The 0-9 percentage severity scale, where 0= no disease, and 9= 90% disease plus defoliation was adopted (Walla, 1979 cited by Sinclair, 1982). At full maturity, two middle rows were harvested, sun-dried for 2 days, and then threshed. Plot yield was standardized to 12% moisture content (steinlite model 400-G tester, Stein Laboratories Inc., Kansas). Additionally, 100-seed weight for each plot was determined using a sensitive balance (Precision plus, TP series). Five plants were randomly selected from the remaining 2 rows, and used to determine number of pods/ plant, and the number of filled pods. The percentage of filled pods per plant was then computed.

The entire data were subjected to analysis of variance, using Genstat Computer software (Lawes Agricultural Trust, 1995). Means were compared using standard error of difference (SED). Additionally, an economic analysis to establish the benefit of the different fungicide applications was done. Mean yields for each fungicide treatment across the three seasons was used in the economic analysis. The profitability (net benefit) of each fungicide treatment was obtained following the CIMMYT (1988) procedure. The assumption was that rust was the major factor affecting soybean yield, but yields were reduced by 5% to account for crop management differences that would occur between farmer- managed and researcher-managed field conditions. Under the research-managed conditions, agronomic production practices are strictly adhered to, as opposed to the farmer-managed field conditions. The costs of the fungicide applications are presented in Table 1.

Results

Effect of fungicides on rust development

Rust severity as influenced by fungicide spray regimes are presented in Table 2. For all the spray regimes (weekly, 2-weekly, and 3-weekly), unprotected soybean (controls) had significantly higher rust severities than the rust-protected soybean. The descending trend of rust severities was control> Dithane> Saprol> Folicur (Table 2). It was only dithane-protected soybeans that had significant differences in rust severity between the spray schedules, observed during 2000B and 2001B, with weekly-protected soybean having significantly lower severities. Application of Folicur resulted into extremely low rust severities (10%), in both the 3-weekly and 2-weekly spray schedules

Effect of rust control on soybean yield

Fungicide treatments variously influenced the soybean yields (Table 3). For example, all soybean sprayed weekly yielded higher than the unprotected soybean. However, during 2001A, it was only Folicur-protected soybean that yielded significantly higher than the unprotected soybeans. For the 2-week interval spray schedule, it was only during 2000B and 2001B when rust protected soybean yielded significantly higher than the unprotected soybeans. For the 3-week interval schedule, it was only Folicur protected soybean that yielded significantly higher than the unprotected soybean except during 2001A (Table 3). On average, Dithane had the highest yield increase of 26.9% under the weekly spray schedule; followed by Saprol with 33.3% yield increase under the 2-week interval schedule; and then Folicur with an increase of 38.9% during the three week interval schedule.

Effect of rust control on yield components

Within the weekly spray schedule, rust protected soybean had significantly higher seed weight than the unprotected soybean (Table 4). However, during 2001B, it was only folicur-protected soybean that

Table 1. Cost of fungicide applications used in the cost benefit analysis[1].

Item	Cost (Ug. Shs.)	Total Variable cost
A) Unprotected soybean		
A1) Cost of seed	21, 000	
A2) Land preparation	180,000	
A3) Labor for planting	41, 400	
A4) Labor for weeding	124,200	
A5) Labor for harvesting	62,500	
A6) Labor for threshing	72, 916	
A7) Sub- total	502,016	502,016
B) Protected soybean		
B1) Labor for 5 sprays	104, 166	
B2) Labor for 3 sprays	62, 500	
B3) Labor for 2 sprays	41, 666	
B4) Depreciation of knapsack	12, 600	
B5) Labor for harvesting additional grain	62, 708	
B6) Labor for threshing additional grain	78,125	
C) Dithane M-45 protected soybean		
C1) 5 sprays	104, 166	A1+A2+A3+A4+B1+B4+B5+B6+C1 = 707,324
C2) 3 sprays	62, 499	A1+A2+A3+A4+B2+B4+B5+B6+C2 = 634,408
C3) 2 sprays	41, 666	A1+A2+A3+A4+B3+B4+B5+B6+C3 = 599,949
D) Saprol protected soybean		
D1) 5 sprays	250, 000	A1+A2+A3+A4+B1+B4+B5+B6+D1 = 816,699
D2) 3 sprays	150, 000	A1+A2+A3+A4+B2+B4+B5+B6+D2 = 700,033
D3) 2 sprays	100, 000	A1+A2+A3+A4+B3+B4+B5+B6+D3 = 641,699
E)) Folicur protected soybean		
E1) 5 prays	366, 665	A1+A2+A3+A4+B1+B4+B5+B6+E1 = 879,199
E2) 3 sprays	219, 999	A1+A2+A3+A4+B2+B4+B5+B6+E2 = 737,533
E4) 2 sprays	146, 666	A1+A2+A3+A4+B3+B4+B5+B6+E3 = 666,699

[1] Calculated on per hectare basis. 1USD= 1700 Ug. Shs.

Table 2. Percentage rust severities on upper third trifoliate of Nam 2 under different fungicides and spray regimes.

Treatment	2000B[5]			2001A			2001B		
	Weekly[4]	2-Weekly	3-Weekly	Weekly	2-Weekly	3-Weekly	Weekly	2-Weekly	3-Weekly
Control	72.0	78.6	78.6	80.0	80.0	80.0	72.9	76.0	76.8
Dithane-M45	18.4	53.3	55.3	77.3	77.3	76.6	40.7	58.3	55.9
Saprol	4.0	16.0	24.5	38.0	42.0	44.7	20.0	24.0	31.5
Folicur	0	0	0	6.6	7.66	25.3	8.3	8.8	17.6
SED[1]		7.73			8.78			9.48	
SED[2]		7.95			9.18			6.45	
CV (%)[3]		29.1			21.2			23.5	

[1]separates means of treatments within regimes, [2] separates means of treatments between regimes, [3] Coefficient of variation, [4]Weekly, 2-weekly, and 3 weekly correspond to 5, 3, and 2 sprays, respectively, [5]A and B correspond to first (March-June) and second (October-January) seasons, respectively.

Table 3. Seed yield (kg ha^{-1}) of a rust-susceptible soybean variety Nam 2 under different fungicides management regimes[1].

Treatment	2000B[6]			2001A			2001B		
	Weekly[5]	2-Weekly	3-Weekly	Weekly	2-Weekly	3-Weekly	Weekly	2-Weekly	3-Weekly
Control	964	974	998	744	671	945	984	990	998
Dithane-M45	1327 (26.3)	1276 (23.3)	1085 (9.8)	1083 (27.3)	1015 (22.5)	1001 (21.4)	1354 (26.8)	1424 (30.4)	1250 (20.8)
Saprol	1519 (35.6)	1675 (41.6)	1154 (15.2)	1086 (27.5)	1362 (42.2)	1331 (40.9)	1310 (24.4)	1319 (24.9)	1354 (26.8)
Folicur	1606 (39.1)	1744 (43.9)	1659 (41.0)	1606 (51.0)	1392 (43.4)	1668 (52.8)	1493 (33.6)	1528 (35.2)	1424 (30.4)
SED[2]		208.5			355.9			172.1	
SED[3]		204.2			378.0			181.2	
CV (%)[4]		18.4			41.3			16.9	

[1] percentage yield increase in parentheses, [2] separates means of treatments between regimes, [3] separates means of treatments within regimes, [4] Coefficient of variation, [5] Weekly, 2-weekly, and 3 weekly correspond to 5, 3, and 2 sprays, respectively, [6] A and B correspond to first (March-June) and second (October-January) seasons, respectively.

had significantly higher seed weight than the unprotected soybean. For the 2-weekly and 3-weekly spray schedules, it was only soybean protected with Saprol and Folicur that had significantly higher seed weight than the unprotected soybean.

For each fungicide, no significant differences were observed in seed weight between the different spray regimes, except during 2000B, with soybean protected with Dithane or Saprol (Table 4). For all the three spray schedules, seed weight followed the descending trend with control< Dithane< Saprol< Folicur. Seed weight was significantly lower ($P<0.001$) during 2001A in relation to other seasons.

The applied fungicides also variously influenced the filled pod percentage (Table 5). In the case of the weekly spray schedule, all rust protected soybeans had significantly ($P<0.005$) higher filled pods than the unprotected soybeans, except during 2001B. However, for the 2-weekly and 3-weekly spray schedules, it was only soybean protected with either Saprol and Folicur that had significantly higher filled pods than the unprotected soybean (Table 5). For each fungicide treatment, there was no significant difference in percentage filled pods between the three spray schedules, except with Dithane protected soybeans during 2001B. Results indicate that filled pods were significantly lower ($p<0.001$) during 2001A

Cost benefit analysis

The rust-protected soybean exhibited varying levels of profitability (Tables 6 and 7). Although the unprotected soybean also gave some positive net benefits, these were much lower than the rust-protected soybean, especially for soybean protected with either Folicur and Saprol sprays (Table 7). Highest net benefits for Folicur, Saprol, and Dithane were 236, 181 Shs ha^{-1}, 127, 607 Shs ha^{-1} and 71, 252 Shs ha^{-1}, respectively. These net benefits were a result of 3-week interval, and 2-week interval spray schedules, respectively (Table 7). However, Saprol showed negative net benefits under the weekly-spray schedule.

Discussion

The applied fungicides Dithane M-45, Saprol and Folicur effectively controlled rust infection, and increased soybean yields significantly. However, the level of control depended on the fungicide used and the spray interval. Dithane-M45, which is a protectant wettable powder, provided its best protection when applied at a weekly interval (5 sprays) from disease onset (early pod formation) to full seed formation. On the other hand, Saprol and Folicur, both systemic, showed best protection with 3 and 2 sprays, respectively from disease onset to full seed formation.

Protectant fungicides are plant-surface barriers and are thus ineffective against established infections. Therefore, for effective use they must either be applied before the pathogen enters the plant or applied more frequently during the epidemic to replace the chemical washed-off by the rain. On the other hand, systemic fungicides enter the plant and kill established infections, and are thus more effective against established infections of the rust pathogen *Phakopsora pachyrhizi* than the protectant fungicides. Studies conducted elsewhere (Kitani *et al.*, 1960; Torres and Quebral, 1976; Chen and Nguyen, 1988), indicated that significant differences in rust severity and yield occur between rust-protected and unprotected soybeans, but with systemic fungicides being more effective against rust than protectant fungicides (Hu *et al.,* 1975; Nakamura *et al.,* 1981; Junqueira *et al.*, 1984).

In terms of spray schedule, the study has shown that systemic fungicides require less number of sprays than the protectant fungicides (2 or 3 sprays). As opposed to protectant fungicides, frequent application of systemic fungicides i.e., on a weekly interval, appears to rapidly accumulate toxic residues in the plant that may decrease its yield potential. Lower soybean yields obtained from weekly sprays as compared to two or three weekly sprays gives some credence to this fact. Comparable results

Table 4. Comparison of 100-Seed weight (g) of a rust susceptible soybean variety Nam 2 under different fungicide treatments.

Treatment	2000B[4]			2001A			2001B		
	Weekly[5]	2-Weekly	3-Weekly	Weekly	2-Weekly	3-Weekly	Weekly	2-Weekly	3-Weekly
Control	10.4	10.7	9.9	8.5	8.5	8.1	10.4	10.9	10.8
Dithane	13.4	11.3	11.0	9.6	9.3	8.9.3	11.1	11.0	11.3
Saprol	13.5	13.8	12.1	11.0	11.0	12.1	10.9	10.9	10.9
Folicur	13.5	13.9	13.8	13.9	14.1	13.6	12.6	13.0	12.4
SED[1]		0.60			0.86			0.34	
SED[2]		0.61			0.93			0.35	
CV (%)[3]		6.1			7.2			3.8	

[1] separates means of treatments between regimes, [2] separates means of treatments within regimes, [3] Coefficient of variation, [4] A and B correspond to first (March- June) and second (October-January) seasons, respectively, [5] Weekly, 2-weekly, and 3 weekly correspond to 5, 3, and 2 sprays, respectively.

Table 5. Comparison of filled pods (%) of a rust susceptible soybean variety Nam 2 under different fungicide treatments.

Treatment	2000B[4]			2001A			2001B		
	Weekly[5]	2-Weekly	3-Weekly	Weekly	2-Weekly	3-Weekly	Weekly	2-Weekly	3-Weekly
Control	79.8	79.9	74.9	56.4	57.6	57.1	91.5	89.5	91.2
Dithane	91.5	85.5	78.5	65.3	68.7	68.5	95.3	87.8	95.2
Saprol	97.2	94.6	93.8	72.5	78.0	70.0	95.3	93.7	91.8
Folicur	90.0	91.8	93.1	84.5	87.1	78.5	93.6	95.2	96.0
SED[1]		4.04			5.02			2.06	
SED[2]		4.06			5.39			2.31	
CV (%)[3]		5.7			9.4			3.1	

[1] separates means of treatments between regimes, [2] separates means of treatments within regimes, [3] Coefficient of variation, [4] A and B correspond to first (March-June) and second (October-January) seasons, respectively, [5] Weekly, 2-weekly, and 3 weekly correspond to 5, 3, and 2 sprays, respectively.

were observed by Nakamura *et al.* (1981): best control of rust was achieved when fungicides were applied 2 or 3 times, from young pod to full seed formation.

The economic analysis justifies 2-weekly spray schedule for Dithane, and 2-weekly and 3-weekly spray schedules for Saprol and Folicur, respectively. The lower net benefits observed with weekly and 3-weekly spray schedules of Dithane as compared to the unprotected soybean; suggest that fungicides used in management of soybean rust must be both effective and economically justifiable. Thus, the benefit arising from fungicide application must by far surpass their application costs. Earlier studies reported higher returns from 2 or 3 applications of bayelaton (systemic) as compared to 5 applications of manzate-D, a protectant fungicide (Pupipat *et al.*, .1982). The marginal net benefits obtained from the unprotected soybean appear not to be sustainable when the epidemic becomes more serious in the near future. This illustrates that when highly rust-tolerant cultivars are identified, they can be used for control of soybean rust and may not require fungicide protection.

We conclude that fungicides can provide an economical control option for combating and or minimizing yield losses attributable to soybean rust in Uganda. The profitable fungicide regimes can be utilised by the Uganda Seed Project which is mandated to produce certified seed or even by the farming community which at times prefer growing rust susceptible intolerant soybean varieties. We further recommend that more fungicides (especially systemics) be screened, but with spray schedules being manipulated to comprise of 3, 2 or even 1 spray(s) per growing season.

Table 6. Actual and adjusted yield used in economic analysis[1].

Treatment	Actual yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})
Control	968	919.6
Dithane M 45 X 5 sprays	1325	1258.7
Dithane M 45 X 3 sprays	1238	1176.1
Dithane M 45 X 2 sprays	1112	1056.4
Saprol X 5 sprays	1305	1239.7
Saprol X 3 sprays	1452	1379.4
Saprol X 2 sprays	1280	1216.0
Folicur X 5 spray	1568	1489.5
Folicur X 3 spray	1555	1477.5
Folicur X 2 spray	1584	1504.8

[1] means of yields across 3 seasons. Yields reduced to 5% to account for management differences between farmer and experimental conditions.

Table 7. Cost benefit analysis of different fungicides and spray regimes used in the management of soybean rust[1].

Treatment	Adjusted yield (kg ha^{-1})	Gross Benefit GB) Ug. Shs.	Total Variable Cost (TVC) Ug. Shs.	Net Benefits (NB) Ushs.
Control	919.6	551,760	502,016	49,744
Dithane X 5 sprays	1258.7	755,2220	707,324	47,896
Dithane X 3 sprays	1176.1	705,666	634,408	71,252
Dithane X 2 sprays	1056.4	633,840	597,949	35,891
Saprol X 5 sprays	1239.7	743,850	816,699	-72,849
Saprol X 3 sprays	1379.4	827,940	700,033	127,607
Saprol X 2 sprays	1216.0	729,600	641,699	87,901
Folicur X 5 sprays	1489.5	893,700	879,199	14,501
Folicur X 3 sprays	1477.5	886,500	737,533	148,967
Folicur X 2 sprays	1504.8	902,880	666,699	236,181

[1] Calculations based on per ha. USD=1700 Ushs. Gross Benefit = yield x price (Ushs 600), this was the farm gate price per kg of soybean that a farmer would receive. Net Benefit = GB- TVC.

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Seed-borne mycoflora of sesame seeds and their control using salt solution and seed dressing with Dithane M-45

P.J. Mudingotto, E. Adipala and S.B. Mathur†

Department of Crop Science, Makerere University, P.O. Box 7062, Kampala, Uganda
†Danish Government Institute of Seed Pathology for Developing Countries (DGISP), Thorvaldsensvej 57, Frederiksberg C, DK-1871, Copenhagen, Denmark

Abstract

Although seed is key in agricultural production, the seed health status of sesame seeds grown in Uganda is largely unkown. Seed health test of 30 seed samples from different parts of Uganda revealed the presence of 12 fungal species, namely, *Acremonium* sp., *Alternaria sesami*, *A. sesamicola*, *Bipolaris* sp. *Cercospora sesami*, *Corynespora cassiicola*, *Fusarium equiseti*, *F. moniliforme*, *F. pallidoroseum*, *Macrophomina phaseolina*, *Myrothesium roridum* and *Phoma* sp. High incidence, 0.3 – 68% of *A. sesamicola* and 0.3 – 29% of *C. sesami* were recorded in 29 and 30 seed samples, respectively. The rest of the pathogens occurred in moderate levels, 0.3 – 5% for *Acremonium* sp., *Corynespora cassiicola*, *A. sesami*, *F. equiseti*, *M. phaseolina*, *F. pallidoroseum*, *F. moniliforme* and *Phoma* sp. and in trace amounts, 0 – 0.3% for *Bipolaris* sp. and *M. roridum*. These pathogens caused seed rot, poor germination and seedling mortality. Two control measures; sorting by salt solution and seed-treatment with Dithane M-45 were used to separate healthy seeds from diseased ones, and kill seed-borne fungi, respectively. Both sunken and floated seeds had infected and healthy seeds in the samples tested indicating the use of salt solution, was not effective for obtaining healthy seeds in sesame. Seed treatment with Dithane M-45 killed all the mycoflora except *A. sesamicola* which was detected in 4 out of 14 samples but with a reduced incidence of 0 – 0.5% as opposed to 0 – 66% in the control. Thus, seed-dressing with Dithane M-45 is recommended for control of sesame seed-borne pathogens.

Key words: Fungi, seed health testing, seed treatment, sorting

Introduction

Sesame (*Sesamum indicum* Linn.) is one of the most important oil seed crops in the sub-Saharan Africa. The oil is used for a variety of purposes, namely, cooking, soap manufacture, food and medicine as well as an adulterant for olive oil. Sesame oil is also used as an important ingredient in most cosmetic industries. In addition, seeds are added to cookies and other baked goods and made into candy. Sesame meal is an excellent, high-protein source (34 to 50%) for poultry and livestock feeding (Oplinger *et al.*, 1990).

In Uganda, the yield of sesame is 300 – 430 kg ha^{-1} compared to the potential yield of 2250 kg ha^{-1} (FAO, 2000). Low quality seeds have been reported among the most important constraint to sesame production (Mathur and Kabeere, 1975; Singh *et al.*, 1980; Yu *et al.*, 1982). Work by Mathur and Kabeere (1975) revealed high incidence of seed-borne pathogens such as *Alternaria sesamicola*, *Cercospora sesami*, *Corynespora cassiicola*, *Fusarium* spp. and *Macrophomina phaseolina*, with *A. sesamicola* and *C. sesami* being most predominant and causing heavy seedling mortality and seed rot.

In general, however, limited research has been conducted on seed quality and seed health of sesame seeds from Uganda. Also, little work on control of seed-borne pathogens of sesame has been done. Yet according to Venter (2000) the first step towards the attainment of maximum crop yield is the use of high quality seeds. The objectives of this study therefore, were to determine the health status and quality of sesame seeds produced in Uganda, and to identify plausible control strategy against seed-borne fungal pathogens of sesame.

Materials and methods

Thirty seed samples collected from various parts of Uganda during the 2000/2001 crop season, comprised of varieties locally grown by farmers as well as those released by the Natural Research Organisations. Seed samples were stored at 25°C and 28°C at Makerere University before transferring them to Denmark. In Denmark, the seeds were stored at 5°C at the Danish Government Institute of Seed Pathology for Developing Countries (DGISP) for 3 weeks before the start of experiments. All the seed samples were assigned accession numbers and working samples of approximately 7g, were drawn from each accession following the International Rules for Seed Testing (ISTA, 1999) and seed health, germination and control of sesame seed-borne fungi investigated.

Seed health testing

Seed samples of 30 Ugandan cultivars were assayed for seed health. Detection of seed-borne fungi was done by blotter method following procedures outlined by ISTA (1999) and Mathur and Kongsdal (2000). Four hundred seeds randomly selected from each working sample of 7 grams were plated on three pieces of well water-soaked blotters in plastic petri-dishes (9 cm in diameter). Each petri-dish contained 25 seeds and were incubated at 20±2 °C for 7 days under alternating cycles of 12 hours darkness and near ultraviolet (NUV) light (Philips, TLD 36 W/08). After incubation, seeds were observed for the growth of fungi under a stereo-binocular microscope. The fungal species were identified by their "habit characters" and later confirmed by morphological characteristics of the fruiting bodies, conidia and spores using a compound microscope (Mathur and Kongsdal, 2000). Percentage incidence of pathogenic fungi was computed and recorded.

Germination test

The seed samples were also assayed for germination capacity using Top of Paper (TP) method (ISTA, 1999). Four hundred seeds in replicates of 100 were taken at random from each working sample. Subsequently, each replicate sample was divided into sub-samples of 50 seeds each and spaced uniformly and adequately apart on three pieces of well water-soaked filter paper in germination boxes (16x10 cm). The germination boxes with their contents were incubated in a climate room with day and night temperatures of 26°C and 24°C, respectively for six days. The number of normal and abnormal seedlings, ungerminated (dead) seeds was recorded.

Control of seed-borne fungi by salt sorting

Five sesame seed samples randomly selected from accessions with germination percentage >75%, the minimum recommended by the Uganda Seed Project (USP) (ST, 1994), were used in the experiment to separate fungal infected seeds from healthy seeds using salt solution. Four hundred seeds were taken from each sample and separated by density using 0%, 2.5% and 5% salt concentrations. At each level of salt concentration, sunken seeds and floated seeds were separated and assayed for seed health and germination. The number of seeds tested at each level of salt concentration depended on the quantity of sunken and floated seeds.

Control of seed-borne fungi using Dithane M-45

Fourteen sesame seed samples treated with Dithane M-45 at a rate of 2.0g kg^{-1} were assayed for both germination and seed health. These levels of infection were considered, namely, high (= 50%), moderate (=20 & <50%) and low infections (< 20%). For each category the test samples were selected randomly. The seeds were dressed with the fungicide and kept for about 24 hours after which the seed health and germination assays were conducted.

Data analysis

All the data collected in the laboratory were subjected to analysis of variance (ANOVA) using Sigmastat – 2.0 computer package. Means separation were performed using Tukey test at $P = 0.05$.

Results

Seed health

Twelve fungal species belonging to 9 genera were identified, but the level of seed infection varied among the samples (Table 1). The most predominant pathogens detected were *Alternaria sesamicola* and *Cercospora sesami.* The pathogens with moderate occurrence and low incidence were *Fusarium moniliforme, Phoma* sp., *Acremonium* sp., *F. equiseti*, *Corynespora cassiicola, Macrophomina*

Table 1. Incidence (%) of different fungal species detected by blotter method in 30 sesame seed samples from Uganda[1].

DGISP Accession No.	Fungal species[2]											
	Acs	As	Asc	Bs	Cs	Crc	Fe	Fm	Fp	Mp	Myr	Ps
46494	0.5	0	40.3	0	25.8	0	0	1.8	0	0.3	0	1.8
46498	0	0	60.8	0	5.8	0	0	0.5	0	2	0	1
46507	0	0	36	0	26	0	0	2.8	0.5	0.5	0	0.3
46511	0	0.5	23	0	17.3	0.3	0	1.5	0	0	0	0.5
46512	0	0	56.5	0	7.3	0.5	0	3	0.3	0	0	1.5
46513	0	0	28.3	0	24.5	0	0	2.3	0	0.3	0	0
46516	0	0	0	0	16.3	0	0	0	0	0	0	0
46517	0	1	68.3	0	20.3	0	2.3	0.3	2.5	0	0	3.8
46520	0	0	3.8	0	4.5	0	0	0	0	0	0	0
46522	0	0.3	53	0	4.3	0.5	0	0	0.3	0	0	1.8
46530	0	0.5	29.3	0	21	0	0	1.5	0.3	0	0	0.3
46532	0	0.5	34	0	14.5	0	0.3	2.3	0	0.3	0	1
46533	0	0	26	0	16	0	0.3	2.5	0	0	0	0.8
46534	0.3	0	20.3	0	16	0.5	0.3	0.8	0.8	0	0	1
46539	0	0	43.3	0	19.3	0	0	1.5	0.3	0.3	0	2.8
46540	0	0.3	23.5	0	16.3	0	0	0.8	0.3	0.5	0	0.8
46541	0	0	58.5	0	11	1	0	4.5	2.3	0	0	1.5
46542	0	0.3	57.8	0.3	11.5	0	0.3	0.5	0.3	0.8	0	0.3
46543	0	0	36.3	0	16	0.5	0	2	0.3	1	0	0
46544	0	0	0.8	0	5.5	0	0	0.3	0	0	0	0.5
46545	0	0	1.3	0	6.8	0	0.3	0	0.3	0	0	4.3
46546	0	0	0.5	0	1.8	0	0	0.3	0	0	0	0.3
46547	0	0	0.3	0	0.3	0	0	0	0	0	0	0
46548	1.5	0.5	47.8	0	16.8	0	0	0.3	0.3	0	0	0.8
46549	0	0	15.3	0	28.5	0.3	0	2	0.5	0	0	0.3
46550	0	0	24	0	17.8	0.5	0	3.5	0	0	0	2
46552	0.3	0.3	22	0	14.8	0.3	0	3.8	0	0	0.3	1.5
46555	0	0.3	50	0	24	0	0	0.5	0	0	0	0.5
46556	0	0	58.3	0	3.8	0	0	0.8	0	0	0	0.8
46558	0	0	65.5	0	23.8	0	0	0.3	0	0	0	0.3

[1]Four hundred seeds were tested as recommended by ISTA (1999).

[2]Acs = *Acremonium* sp., As = *Alternaria sesami*, Asc = *A. sesamicola*, Bs = *Bipolaris* sp., Cs = *Cercospora sesami*, Crc = *Corynespora cassiicola*, Fe = *Fusarium equiseti*, Fm = *F. moniliforme*, Fp = *F. Pallidoroseum*, Mp = *Macrophomina phaseolina*, My = *Myrothesium roridum*, Ps = *Phoma* sp.

phaseolina, *A. sesami* and *F. pallidoroseum*. Those occurring in only one sample and with very low incidence were *Bipolaris* sp. and *Myrothesium roridum*. Besides the pathogenic fungal species, saprophytic fungi were also detected, namely, *A. alternata*, *Aspergillus* spp., *Cladosporium* sp., *Penicillium* sp. and *Rhizopus* sp (Fig. 1).

Germination test

Fourteen of the 30 sesame cultivars had germination percent of = 75%, which is within the threshold set by the Uganda Seed Project (ST, 1994). The cultivars which had lower germination percentage had seedlings associated with various defects including decayed roots, hypocotyls and cotyledons (Fig. 2).

Control of seed-borne fungi by salt sorting

Seed health test of both sunken and floated seeds revealed that *Alternaria sesamicola* and *Cercospora sesami* were still the dominant pathogens. *C. sesami* was present in all the samples (100%) and *A. sesamicola* was detected in 80% of the samples tested at all levels of salt concentration, including the control. Unlike the sunken seeds, *Macrophomina phaseolina* was not detected in all the salt floated seeds. The range of infection in floating seeds (FS) was slightly higher for most of the pathogens than in sunken seeds. For instance, incidence of *A. sesamicola* ranged from 0 – 72% in floating seeds compared to 0 – 64% in sunken seeds at the same salt concentration level (0%) (Table 2). Both sunken and floated seeds at different salt concentrations achieved < 75% germination (Table 3), the minimum recommended by the Uganda Seed Project (ST, 1994).

Control of sesame seed-borne fungi by Dithane M-45

Seed treatment with Dithane M-45 eliminated all seed-borne pathogens, as detected by the blotter test, except *Alternaria sesamicola* which was still detected in 29% of the samples assayed (Table 4). Even then, the range of seed infection by *A. sesamicola* in the Dithane M-45 treated seeds reduced drastically to 0 – 0.5% compared to 0 – 66% in untreated seeds (Table 4).

Twelve of the 14 accessions showed increase in germination percentage as a result of seed treatment with Dithane M-45 as compared to the untreated ones. Unlike the untreated seeds, the number of abnormal seedlings due to primary infection was greatly reduced in the treated seed samples. For instance, brown discolouration and decay of roots seen on seedlings from the untreated seeds were not observed on seedlings treated with Dithane M-45 (Fig. 3). No improvement was detected in two accessions (46520 and 46544) (Table 5).

Discussion

Several seed-borne fungal pathogens were identified in this study. These included *Alternaria sesami*, *A. sesamicola*, *Bipolaris* sp., *Cercospora sesami*, *Corynespora cassiicola*, *Fusarium equiseti*, *F. moniliforme*, *F. pallidoroseum*, *Macrophomina phaseolina*, *Myrothesium roridum and Phoma* sp. These results therefore correlate with earlier reports that sesame seeds are heavily infected by a number of seed-borne pathogens (Mathur and Kabbere, 1975; Singh *et al.*, 1980, 1983; Yu *et al.*, 1982; Richardson, 1990; Poswal and Misari, 1993). *Alternaria sesamicola* which had the highest incidence of 68% is known to cause Alternaria leaf spot and blight (Singh *et al.*, 1980, 1983; Yu *et al.*, 1982). *Cercospora sesami* which causes Cercospora leaf spot occurred on all the seeds assayed although with varying incidence. Heavily infected seeds did not germinate an indication that the pathogen was responsible for failure in germination. The disease has been reported by Poswal and Misari (1993) to spread from leaf to leaf and plant to plant very fast once established. There is a need therefore to eradicate these two predominant pathogens. However, other pathogens detected in moderated to trace amounts should not be ignored because they may pause a threat to sesame production in the long run.

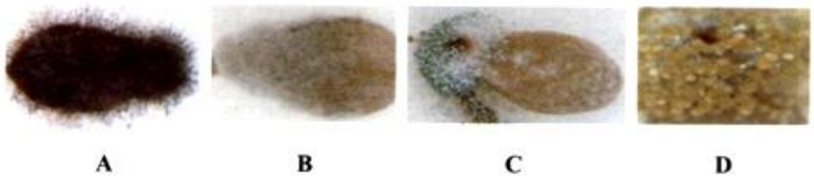

Figure 1. Sesame seeds showing different fungal growth which developed during incubation for seed health test. A: Alternaria sesamicola, B: Cercospora sesami, C: Penicillium sp., D: Aspergillus flavus.

Figure 2. Defects shown by sesame seedlings as a result of fungal infection in the germination test. A: Cotyledons necrotic, B: Whole seedling decayed.

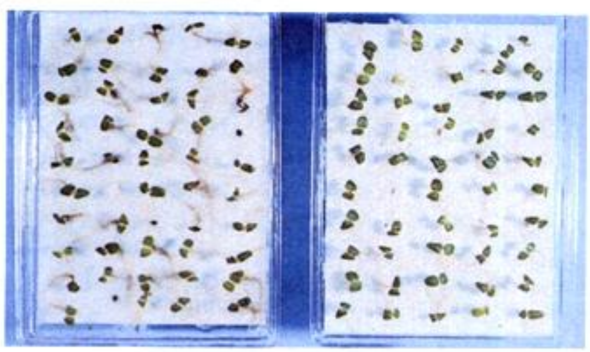

Figure 3. Germination of untreated and Dithane M-45 treated sesame seeds. Seedlings from untreated seed (left) show decay and discoloration of roots due to primary infection; treated seed have clear appearance (right).

Table 2. Occurrence (%) of different fungal species on sesame seed detected in salt medium.

Fungal species[1]	Samples infected (%)[2]				Range of infection (%)			
	0	2.5	5	Ufs	0	2.5	5	Ufs
				Sunken seeds				
As	20	20	20	20	0 – 2	0 – 0.4	0 – 0.4	0 - 1
Asc	80	80	80	80	0 – 64	0 – 48	0 – 57	0 - 68
Cs	100	100	100	100	12 – 25	15 – 22	12 – 23	7 - 26
Fe	20	0	20	20	0 – 4	0	0 – 0.4	0 - 2
Fm	60	60	40	80	0 – 1	0 – 1	0 – 1	0 - 3
Fp	40	40	20	60	0 – 3	0 – 2	0 – 0.4	0 - 3
Mp	20	20	20	20	0 – 0.3	0 – 0.4	0 – 2	0 - 1
Ps	80	80	60	80	0 – 3	0 – 3	0 – 0.3	0 - 4
				Floated seeds				
As	20	20	0	20	0 – 2	0 – 2	0	0 – 1
Asc	80	80	80	80	0 – 72	0 – 52	0 – 50	0 – 68
Cs	100	100	100	100	12 – 28	13 – 25	17 – 25	7 – 26
Fe	20	20	20	20	0 – 2	0 – 1	0 – 1	0 – 2
Fm	20	20	40	80	0 – 2	0 – 1	0 – 1	0 – 3
Fp	40	40	40	60	0 – 3	0 – 1	0 – 1	0 – 2
Mp	0	0	0	20	0	0	0	0 – 1
Ps	60	60	80	80	0 – 9	0 – 6	0 – 3	0 – 4

[1]As = *Alternaria sesami*, Asc = *Alternaria sesamicola*, Cs = *Cercospora sesami*, Fe = *Fusarium equiseti*, Fm = *F. moniliforme*, Fp = *F. pallidoroseum*, Mp = *Macrophomina phaseolina*, Ps = *Phoma* sp.
[2]0 = water without salt, 2.5 = 2.5% salt solution, 5 = 5% salt solution Ufs = Unfloated seeds.

Table 3. Germination using top of paper (TP) method of sunken seeds (SS) and floated seeds (FS) in salt medium solution [1, 2]

DGISP Acc. No.	Unfloated seed[3]	0% salt concentration	2.5% salt concentration	5% salt concentration
		Sunken seeds		
46507	71a	73a	70a	73a
46512	69a	60b	67a	66a
46516	64a	54b	65a	66a
46517	59a	59a	61ab	64b
46558	57a	66b	59a	72c
		Floated seeds		
46507	71a	59b	66c	72a
46512	69a	52b	52b	64c
46516	64a	51b	58c	61ac
46517	59a	36b	37b	44c
46558	57a	39b	49c	60a

[1]Pooled data for 2 tests.
[2]Means in the same row followed by the same letter are not significantly different at P =0.05
[3]Unfloated seeds: seeds not separated in salt solution and used as a control.

Germination tests revealed that sesame seeds produced in Uganda have low germination capacity, less than 50% of the seed samples tested meeting the national standards of = 75% germination. A key factor which reduced germination percentage was infection by pathogenic fungi. These fungi affected roots, hypocotyls and cotyledons. Infected roots were decayed, hypocotyls necrotic and cotyledons decayed as a result of primary infection. These results correlate with earlier findings by Mathur and Kabeere (1975). Plants which were raised from infected seedlings remained stunted with spots on all the leaves and eventually collapsed after 40 – 45 days of growth. However, the tolerant plants developed severe spots and blight on leaves and pods.

Table 4. Frequency of occurrence (%) of different fungal species on untreated and Dithane M-45 treated sesame seed samples as detected by blotter test.

Fungal species	Samples infected (%)		Range of infection (%)	
	Untreated seed	Treated seed	Untreated seed	Treated seed
Alternaria sesami	14	0	0 – 1	0
A. sesamicola	93	29	0 – 66	0 – 0.5
Cercospora sesami	100	0	3 – 25	0
Corynespora cassiicola	14	0	0 – 1	0
Fusarium equiseti	14	0	0 – 3	0
F.moniliforme	79	0	0 – 6	0
F. pallidoroseum	38	0	0 – 3	0
Macrophomina phaseolina	14	0	0	0
Phoma sp.	79	0	0 – 3	0

Table 5. Germination of untreated and Dithane M-45 treated sesame seed samples using top of paper (TP) method[1].

DGISP Accession No.	Germination percentage[2]					
	Test 1		Test 2		Mean[3]	
	Untreated seed	Treated seed	Untreated seed	Treated seed	Untreated seed	Treated seed
46494	84	94	80	93	82a	94b
46498	64	83	62	83	63a	83b
46507	70	87	73	87	72a	87b
48512	73	84	70	83	72a	84b
46516	61	70	66	74	64a	72b
46517	58	82	58	81	58a	82b
46558	52	88	60	90	56a	89b
46522	74	88	73	86	74a	87b
46533	65	85	69	89	67a	87b
46548	77	88	78	90	78a	89b
46556	76	91	78	91	77a	91b
46541	84	90	82	90	83a	90b
46544	62	63	62	64	62a	64a
46520	52	54	46	51	49a	53a
Mean	68	82	68	82	68	82

[1]Top of paper (TP) method: seeds are germinated on top of one or more layers of paper which are placed into transparent boxes (ISTA, 1999).

[2]Normal seedlings: seedlings that show the potential for continued development into satisfactory plants when grown in good quality soil and under favourable conditions of moisture, temperature and light (ISTA, 1999).

[3]Means in the same row followed by the same letter are not significantly different at P =0.05.

Salt sorted seeds

The presence of fungal species in the sunken seeds thought to be free of infected seeds is an indication that salt solution did not separate healthy from infected seeds. The number of samples infected and the range of infection by various pathogens was similar to that of the control (unfloated) seeds. This implies that both sunken and floated seeds had more or less similar numbers of diseased and healthy seeds. Similarly in the germination test, of the 3 salt concentration levels compared, none of them produced seeds with the minimum germination percentage of = 75% recommended by the Uganda Seed Project, suggesting that salt solution did not effectively separate diseased and healthy seeds. This was confirmed when most of the floated seeds presumed to be diseased were found healthy and vice-versa. However, this control measure has been reported to work with rice (Mabagala, 2001), eggplant and tomato (Quazi, 2001).

Dithane M-45 treated seeds

Results of the blotter test showed that seeds treated with Dithane M-45 were free from seed-borne pathogens as opposed to untreated seeds. Similar results were obtained in germination where apart from increased germination, there was significant reduction in number of abnormal seedlings resulting from primary infection. The results correlate with earlier reports that seed treatment with various fungicides killed seed-borne fungi and improved seed germination (Kumar and Agarwal, 1998; Jagadeesh and Lokesh, 1999; Vasundhara and Gowda, 1999). However, it is not clear whether all the seed-borne inoculum was killed since Dithane M-45 is a contact fungicide, and probably acted on only the superficial fungi.

This study revealed that Dithane M-45 treated sesame seeds had better germination and less mycoflora infection compared to untreated seeds. Since these results were only based on laboratory and greenhouse work, we recommend that field experiments be conducted for purposes of verification under field conditions and also to establish seed to seedling transmission of the seed-borne pathogens. Attention should be given to the two common pathogens, *A. sesamicola* and *C. sesami*.

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Farmers' perceptions of pests and pesticide usage in Masaka district, Uganda

W.Tinzaara and E. M. Tukahirwa†
Makerere University, Institute of Environment and Natural Resources, P.O. Box 7062, Kampala, Uganda
National Agricultural Research Organization, Kawanda Agricultural Research Institute, P.O. Box 7065, Kampala, Uganda
†IUCN Regional Office for Eastern Africa, PO Box 68200 Nairobi Kenya

Abstract

A random sample of 60 semi-commercial farmers selected in Masaka district, Uganda, from six counties were interviewed to investigate their perceptions of pesticide usage and pests of crops and animals. The banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) and nematodes were reported to be the worst pests for the banana (*Musa* spp.) crop, while the maize stalk borer, *Busseola fusca* Fuller (Lepidoptera: Noctuidae) was reported to be the major pest of maize *(Zea maydis)*. Many farmers felt that the insecticides they use are sufficiently effective against the pests, the only issue being one of availability. Non-chemical methods of pest control employed in this area include good crop husbandry, like destruction of crop residues after harvest. Only a few farmers were aware of the role of biological control and the significance of weeding in crop pest management.

Key words: Agricultural chemicals, integrated pest management, semi-commercial farmers

Introduction

To meet the food needs for growing populations, many pesticides are currently applied to large areas for crop and animal production in developing countries resulting in the pollution of food, air, water and soil (Edwards, 1983). It has become evident in recent years that the use of pesticides may have harmful effects on the flora and fauna in and around areas where the pesticides are used. Pesticides have adverse effects on the biological agents of the pest whose eradication is desired, thus resulting in a rise of pest population (Pimental and Edwards, 1982; Edwards, 1987; Freemantle, 1993). The rise in the pest population then necessitates a more intensive use of pesticides in quantities that are appropriate.

The use of chemical pesticides for agricultural production in Uganda has been growing steadily for the last few decades (Tukahirwa, 1991). It has been estimated that over 1 million kilograms of pesticides are presently used in Uganda annually (Tukahirwa, 1991). The increasing rise in pesticide usage in Uganda was also reported by Bazirake (1993). Moreover, pesticides are increasingly considered indispensable tools in Uganda's agriculture (Tukahirwa, 1984), despite the growing concern about their adverse effects on humans and the environment.

Sole reliance on pesticides not only fails to provide permanent control of pests and diseases, but also increases problems in agro-ecosystems (Metcalf, 1980; Flint and Van den Bosch, 1981; Tait, 1983; Dent, 1991;). There are reports of deleterious effects of pesticides on invertebrate population on farms where pesticides have been used intensively for many years in Uganda (Kizito, 1989; Tinzaara, 1994). This behavior could also result in negative consequences, such as the development of resistance by pests against the chemicals. Furthermore, the low levels of education of farmers may also exacerbate environmental and/or ecological damage by chemicals, mainly through excessive application. The farmers' safety is also jeopardized by poor handling of these chemicals which can lead to poisoning, and in severe cases, death. Thus, although pesticide chemicals are valuable to smallscale farmers, there is need to integrate other methods of control with judicious use of these chemicals, to minimise pesticide overuse.

In a survey conducted in Uganda (Gold *et al.*, 1993) in the banana cropping system, farmers reported that they would be willing to use pesticides but are limited by the high costs and lack of information on how to use insecticides. However, it was reported that a number of the same farmers applied chemicals to horticultural and other annual crops, suggesting that insecticide use was more a question of economics than information.

Therefore, the study was conducted to identify what farmers perceive as their most serious pest problems, determine the extent of pesticide usage and to assess level of awareness with regard to the potential hazards of the chemicals. It is hoped that the data generated will contribute to the design and development of a farmers' awareness training programme of pesticide usage, to ensure that the amounts and toxicities of pesticides used are in accordance to the guidance of the concerned extension staff and for adoption of IPM concepts.

Materials and methods

A survey was conducted in Masaka district from October 1994 to May 1995. Masaka district is located between longitudes 31° 45'E and 32° E and latitudes 0° 20'S and 0°21'S, and the area experiences a bimodal rainfall regime, with the rains falling from March to May, and September to November. Consequently there is continued agricultural activity for most of the year, which may lead to enhanced application of pesticides by the farmers. The major crops grown in the district are bananas, coffee, maize, and beans.

Interviews were conducted in six counties that included Mawogola, Bukoto, Kalungu, Lwemiyaga, Bukomansimbi and Masaka Municipality. In each county, a random sample of 10 farmers was taken from a list of farmers provided by the local agricultural extension officers. All 60 farmers were interviewed using a structured questionnaire. To minimise bias, the questions were interactive and open ended, rather than asking the farmers to select an answer among fixed choices. The questionnaire was first pretested and adjustments made accordingly. The local Agricultural extension Officers in their respective areas assisted in arranging the meetings. After covering basic information and type of crops grown, the questions focused on crop/animal production constraints, pests, pesticides used and other pest control methods. The interview was concluded with naming and describing common arthropods by farmers to assess their pest knowledge base. Samples of the arthropods were placed in vials containing 70% alcohol and taken for identification at Zoology Insect Museum, Makerere University. The questionaire was also designed to capture information on the kinds of weeds and herbicides used on individual farms.

Results

Farmers' perception of pests

All farmers reported that their crops suffer from various insect pest problems (Table 1). Majority of farmers interviewed identified the banana weevil (86.5%) and nematodes (18.0%) as the most common pests of banana, and were able to give descriptions of their feeding habits and the type of damage they cause. Some farmers reported weevil damage symptoms ranging from reduced bunch size on individual plants, to loss of entire fields through toppling or failure of stools to reproduce. It was, however, difficult for farmers to distinguish uprooting which is commonly attributed to nematode damage, from snapping believed to be caused by weevils (Feakin, 1977; Stover and Simmonds, 1987; Sarah, 1989). Quite often damage symptoms caused by diseases such as *Fusarium* wilt and Black sigatoka, or even soil deficiencies, were attributed to weevils. The black ant *Odontomachus tryglodytes* was reported to be a pest of bananas in that it tunnels at the base of the plant and exposes roots.

Farmers (57.4%) reported serious problems and infestation of maize by stalk borers (*Busseola fusca*) and were also able to give accurate descriptions of their feeding habits and the type of damage they caused. Farmers' knowledge of other insect pests of other crops was however, much more limited, though most farmers acknowledged that pests pose great losses to crop production.

Extent of pesticide usage

Most farmers acknowledged the use of pesticides to control insect pests on their crops. When farmers were asked to name the pesticides used, the information given was sketchy mainly because they kept no farm records. The pesticides currently used by farmers are presented in Table 2.

Most farmers (81.7%) reported that they do usually achieve reduction in damage to crops through the use of pesticides. Farmers were nostalgic about the use of pesticides like Dieldrin, DDT and Aldrin, but expressed different reasons for discontinued use of the chemicals. The reasons included: the pesticides are no longer effective (34.4%); pesticide banned from use (3.0%); or a pesticide environment degradation (16.4%). A few farmers who did not use any pesticides on their crops said they could not afford the cost.

There is a general belief among farmers that pesticides are considered the best tool in crop protection. The effectiveness of pesticides was highly perceived by farmers, which presumably encouraged more of them into adoption of pesticide usage. All farmers freely responded that pesticide application increases yield. More than 40.0% of the farmers asserted that pesticide usage increases crop yields by 50.0% or more. With this view by the farmers, it is clear that the trend for usage of pesticides will increase.

When farmers were questioned about the timing of spray, 34.0% said that they spray as soon as they notice an infestation or when the extension officer in charge advises them to spray. Fifty percent (50.0%) of the farmers reported that routine spraying is done to crops like maize, beans and tomatoes, with different rates as shown in Table 3. Most banana farmers reported that they apply chemicals every after weeding and desuckering, while others apply chemicals every rainy season. Cattle were dipped or sprayed routinely about once per fortnight.

Table 1. Common arthropod pests of crops and animals reported by farmers in Masaka district.

Crop/animal	Common/scientific name	Respondents (%)	Ranking
Banana (n=57)	Banana weevil (*Cosmopolites sordidus*)	88.5	1
	Nematodes	18.0	2
	Ants	1.6	3
Beans (n=60)	American bollworm (*Heliothis armigera*)	6.6	1
	Black bean aphid (*Aphis fabae*)	3.6	2
Coffee (n=38)	Coffee berry disease (*Hypothenemus hampii*)	29.4	1
	Ant	14.8	2
	Antestia bugs (*Antestiopsis* spp.)	4.8	3
Maize (n=60)	Maize stalk borer (*Busseola fusca*)	57.4	1
	Cutworms (*Agrotis* spp.)	9.8	2
Cattle (n=23)	Ticks	92.4	1
	Tse tse flies	4.8	2

n= number of farmers responding.

Farmers reported different frequencies of pesticide application to crops and animals (Table 4). Few farmers apply rates as recommended by manufacturers or as guided by the extension staff. However, even those farmers who sprayed more than the recommended times did realise that the extra applications do not necessarily lead to overall increase in yield. Some farmers, however, admit that they lack information on the recommended rate of pesticide applications to crops/animals, and the side effects of the pesticides.

Farmers (78.7%) followed instructions given on the pesticide containers by the manufacturers to determine the amount to add to a sprayer. Other farmers (9.8%) are guided by agricultural extension staff, while a few others (4.9%) do not clearly know what to do.

Table 2. Pesticides presently used by farmers in Masaka district for a given crop/animal.

Crop/animal	Trade name	Active ingredient	Respondents (%)
Banana (n=60)	Furadan	Carbofuran	67.2
	Marshal	Carbosulfan	1.6
	Primicid	Pirimiphos-ethyl	6.6
	Ambush	Cypermethrin	1.6
	†Local insecticide		1.6
Maize (n=60)	Ambush	Cypermethrin	49.2
	Salut		14.2
	Dithane M-45	Mancozeb	1.6
	Sumithion	Fenitrothion	4.9
Coffee (n=60)	Ambush	Cypermethrin	50.0
	Sumithion	Fenitrothion	3.3
Beans (n=60)	Salut		13.1
	Sumithion	Fenitrothion	4.9
Cattle (n=23)	Supona	Clorfenvinphos	37.7
	Piglease		8.2
	Steledone		3.3
	Spoton		6.6
	Nilzan		6.6
	Decatix		4.4

† = Mixture of ashe, pepper (*Capsicum spp*) and cattle urine.

Table 3. Farmers' frequency of pesticide application to crops and animals in Masaka district.

Frequency	% farmers responses					
	Furadan	Ambush		Salut		Supona
	Banana (n=40)	Maize (n=30)	Coffee (n=14)	Beans (n=8)	Maize (n=9)	Cattle (n=23)
More than once a week	-	8.2	-	-	-	5.1
Once a week	-	14.3	5.8	15.6	9.8	69.7
More than once a month	-	-	52.7	49.8	49.8	24.3
Once a season	8.1	77.6	38.1	40.4	39.3	-
Three times a year	18.3	-	3.4	-	-	-
Once a year	73.6	-	-	-	-	-

Farmers appear to be conscious of the dangers of most pesticides. Eighty percent (80%) of the farmers do not normally mix more than "the usual amounts" when the pest problem is worse than normal, the reason given being fear to overdose plants/animals. Furthermore, a majority of farmers (78.7%) indicated the need for skills before one could properly spray. In this area, the farmers either hire a professional sprayer or spray the pesticide themselves. Farmers who spray usually own themselves Knapsack Sprayer and enough household labour. Contracted sprayers usually have their spraying machines, and are responsible for pesticide mixing. In the latter case, farm owners provide all the pesticides (herbicides or insecticides) to cover the land area agreed upon.

However, farmers lacked proper education on the hazards of the chemicals and the correct methods of spraying. Regarding agricultural risk factors, 90.0% of the farmers used liquid formulations, 62.0% applied pesticides in mornings, while 37.0% considered wind (strength and direction) obstractions irrespective of the time of day. Twelve percent (12.0%) of the farmers used boots or gloves and 42.0% wore face masks in form of handkerchiefs as protective clothing. This however, provides minimal protection and may instead increase risk. With regard to personal habits and practices, 88.0% changed clothes, while 74.0% took showers after pesticide application. However, some farmers (5.0%) ate and 8.0% smoked while applying pesticides.

Other pest management practices

Crop resistance

Crop resistance is not clearly understood by farmers as an important component of pest management. Despite the lack of knowledge, some farmers especially for the banana crop could name some banana cultivars which have varying degrees of resistance to weevil damage. Ndiizi (AB genome group) and

Table 4. Farmers' ranking of weeds common in their fields (crops) in Masaka district.

Crop	Weed name	% farmer responses			
		Most serious		Least serious	
		1	2	3	4
Banana (n=60)	*Bidens pilosa*	29.5	34.1	25.0	11.4
	Digitaria scalanum	17.6	58.8	17.8	5.9
	Lantana camara	15.2	10.8	43.5	30.4
	Commelina spp.	29.4	47.7	9.5	4.8
	Oxalis spp.	21.3	3.3	-	-
Maize (n=60)	*Bidens pilosa*	42.3	30.1	23.1	3.8
	Digitaria scalanum	54.3	27.3	9.1	9.8
	Lantana camara	15.0	-	60.0	25.0
	Commelina spp.	38.1	47.0	9.5	4.8
	Oxalis spp.	-	100.0	-	-
Coffee (n=38)	*Bidens pilosa*	31.8	13.6	36.4	18.2
	Digitaria scalanum	47.6	23.8	23.8	4.8
	Lantana camara	10.5	26.3	31.6	31.6
	Commelina spp.	25.0	56.3	12.5	6.3
	Oxalis spp.	83.3	16.7	-	-
Beans (n=60)	*Bidens pilosa*	57.1	23.8	9.5	4.8
	Digitaria scalanum	40.0	40.0	20.8	-
	Lantana camara	36.7	20.0	53.3	20.0
	Commelina spp.	46.2	46.2	7.7	-
	Oxalis spp.	60.0	40.0	-	-

Bogoya (AAA) cultivars, for example, were named by farmers as having higher resistance, compared to other cultivars. Farmers were apparently not so well aware of resistant varieties of other crops, probably indicating that this area relied on bananas as a major staple food crop.

Biological control

Farmers (44.0%) were aware of beneficial insects in the cropping systems. Some farmers reported black ants (*Odontomachus tryglodytes*) as predators of the banana weevil, while other farmers (12.5%) reported that ants repel *Antestia* bugs from coffee plantations. All farmers are apparently not aware of the role of insect parasites and fungal pathogens in reducing insect pest infestations.

Cultural control

Farmers employ a number of cultural control practices against crop pests, and are aware that pests reside in the crop residues. From the survey, 66% of the farmers interviewed indicated that maintaining clean farms helps to control pests and diseases. Cultural practices like weeding, pruning and mulching are practiced by farmers even though their role in pest management is apparently not so clear to them. They do all these things under the general framework of crop husbandry.

Traditional pest control practices

Traditional methods of pest control are not wide-spread in Masaka district. A few farmers use the "traditional insecticide" made by mixing ashes, red pepper (*capsicum sp*) and cattle urine and applied by spreading it around banana stools. Some farmers, especially for banana (54.0%) indicated that they practice trapping and hand picking of weevils. Hand picking of weevils is less effective even though 52.5% of farmers recognised it reduced pest numbers.

Extent of herbicide usage

The weeds that are common on farms in Masaka district are presented in (Table 4). Farmers generally consider weeds one of the constraints of production. *Digitaria scalanum*, *Bidens pilosa*, *Commelina spp* and *Oxalis spp* were reported to be the most common and serious weeds in all crops. Other weeds, but of less seriousness include *Lantana camara* and *Eurphobia* spp.

Some farmers (13.0%) were aware of the importance of weed control in insect pest management by reducing alternative host plants and shelter for pests. Farmers indicated that weed control increased crop yields. Most farmers reported that effective weed control increased yields by an average of 60.0%. Hand-hoeing was a commonly reported method of weed control, but herbicides are also in use. Gramoxone (Paraquat) and Roundup (Glyphosate) were the most commonly used herbicides (Table 5). It was reported by majority of farmers that herbicides are used when the weeds are intense, especially after the rainy season and/or when manual labour is scarce.

Constraints to crop and animal production

Table 6 summarises the various constraints to production. According to the survey, pests and lack of agrochemical are the major constraints to production for both crops and animals. Drought, labour, weeds, transport, and availability of market were among the less serious constraints to farming. This implies that farmers were likely to use lots of pesticides, despite the limited knowledge of how to properly apply them.

Discussion

The results suggest that most farmers in Uganda and Masaka district in particular, generally believe that pesticides are the best tool in crop and animal production. These farmers will continue to use pesticides unless persuaded otherwise because pesticides have an immediate knock-off effect.

The recommended number of applications and the required dosages are still not clear to some farmers. Some farmers do not follow instructions as recommended by pesticide manufacturers or as advised by extension staff. Such behavior is likely to result in development of resistance by pests, which consequently leads to use of yet more pesticides. Excessive application of pesticides also leads to damage of natural enemies populations (Pimental and Edwards, 1982; Edwards, 1987; Dent, 1991). In addition, farmers apply pesticides in a manner that disregards agricultural risk factors and without considering personal safety. Such behavior ultimately has disastrous impacts to human health, leading to poisoning and death.

Farmers in Uganda seem to overestimate and attach great importance to pest losses. Pesticides are considered as the panacea to all pest problems. The implication here is that farmers are likely to continue using lots of pesticides despite the limitations on their knowledge of how to properly apply them and the likely disastrous consequences to human health and the agro-ecosystems. In this regard, farmers need to be sensitised to adopt the IPM approach which is a better strategy for controlling pests.

Table 5. Number of farmers that use herbicides to control weeds in crops.

Herbicide	Crop	Herbicides users
Gramoxone (Paraquat)	Banana	36
	Coffee	23
	Maize	6
	Beans	12
	All crops	12
Roundup (Glyphosate)	Banana	14
	Coffee	21
	Maize	8
	Beans	4
	All crops	17
Stompu (Pendimethalin)	Maize	5
	Beans	6
	All crops	6

Table 6. Number of farmers naming constraints to production of crops and animals.

Constraint	Farmers responding				
	Banana (n=60)	Maize (n=60)	Coffee (n=38)	Beans (n=60)	Cattle (n=60)
Pest (insects)	19	12	3	9	4
Weeds	7	5	5	2	-
Drought	8	7	4	7	3
Agrochemicals	37	2	13	7	3
Land shortage	3	1	-	-	2
Labour	10	9	6	8	4
Transport	11	1	7	4	1
Poor soils	3	-	-	-	-
Market	5	1	3	2	-
Diseases	3	-	-	-	2
Information	3	-	3	-	-

However, adoption of IPM requires knowledge of the bionomics and ecology of the pest (Bottenberg, 1995; Smit and Matengo, 1995; Tukahirwa, 1991).

In a nut shell, the survey revealed that the problems of crop production are overwhelming many farmers in Masaka district, particularly the pests. The attitudes of farmers and grass root extension staff in Uganda are still in favour of pesticide application for pest and weed management. However, because of envisaged negative ecological impacts of most of these chemicals there is need to integrate other methods of control with judicious use of chemical pesticides. There is need to design an education and awareness programme for farmers to help them adopt better and more environment friendly pest management practices. Farmer education should focus on filling the gaps in indigenous knowledge concerning pest relationships, the proper use of chemical pesticides, the role of natural enemies, and importance of non-chemical control.

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The potential of crop rotation in the management of bacterial wilt of potato in southwestern Uganda

M. Katafiire, E. Adipala, B. Lemaga[†], M. Olanya[††], R. El-Bedewy[††] and P. Ewell[††]
Department of Crop Science, Makerere University, P.O. Box 7062, Kampala, Uganda
[†]PRAPACE, P.O. Box 22274, Kampala, Uganda
[††]International Potato Centre (CIP), P.O. Box 25171, Nairobi, Kenya

Abstract

Bacterial wilt (BW) of potato *(Solanum tuberosum)* caused by *Ralstonia solanacearum*, is a major constraint to potato production in southwestern Uganda. It is a recalcitrant disease and one of the plausable management options is crop rotation. However, the suitable crops to be incorporated in a crop rotation regime with a view to reduce BW inoculum levels have not been systematically identified. Studies to identify crop(s) that would in the subsequent season delay on-set of wilt, reduce wilt incidence, lower latent infection, reduce *Ralstonia solanacearum* populations in the soil and increase tuber yield were conducted at Kachwekano Agricultural Research and Development Centre. Trials were carried out for three consecutive seasons during 2000A, 2000B, and 2001A in wilt-infested plots using the randomised complete block design. In 2000A and 2001A all study plots were under potato. The rotation crops (*Sorghum bicolor, Triticum aestivum, Zea mays, Eleusine carocana, Ipomea batatas L., Daucus carota, Phaseolus vulgaris* and *Solanum tuberosum* L.) were planted in the same plots during 2000B. Rotation with *Sorghum bicolor, Triticum aestivum, Zea mays, Eleusine carocana*, delayed on-set of wilt incidence, reduced wilt incidence and latent wilt infestation, and gave higher marketable tuber yield than the other rotation crops evaluated in the study. One-season rotation crops improved the shelf-life of consumption potatoes but not of seed tubers because of latent infections that were detected after subjecting the tubers to incubation at high temperature and indirect enzyme-linked immunosorbent assay on nitrocellulose membrane (NCM-ELISA). Using any one of the evaluated rotation crops was assessed to reduce BW inoculum and was thus better than continuous cultivation of potato.

Key words: Marketable yield, one-season rotation crops, *Ralstonia solanacearum, Solanum tuberosum*, wilt incidence

Introduction

Bacterial wilt (BW) of potato (*Solanum tuberosum* L.) caused by *Ralstonia solanacearum* E. F. Smith (*Rs*) is an important seed and soil-borne disease in south western and other potato growing areas of Uganda. In south western Uganda, potato is the number one cash crop and the fourth important food crop (Adipala, 1999; Lemaga *et al*., 2001). Most households survive on less than one hectare while others depend on rented land for cultivation. The farming community comprises of 70% subsistence growers who practice intensive cropping without any form of organised rotation, and continuous cultivation of potato is common resulting in increased incidence of various diseases, particularly bacterial wilt (Adipala *et al*., 2000; Tusiime *et al*., 2000). Thus, application of crop rotation as a bacterial wilt control strategy is limited, but can be enhanced by selection of multipurpose crops that can be used in a crop rotation regime because there are crops that support substantial amounts of the bacterium in their rhizosphere and others that aggressively suppress it in a relatively short time (Terblanche and De Villiers, 1999). Lemaga *et al*. (2001) and Hayward (1994a) recommend crop rotation as a component of integrated disease management (IDM). Potato grown in the highlands is only attacked by race 3 biovar 2-A, whose host range is restricted to potato and tomato, but also remains latent in a wide range of host weeds (Hayward, 1994b). Due to the pathogen's exceptional ability to survive in soil and the rhizosphere of some non-host plants, it renders most single management practices ineffective in controlling the disease. In this study therefore, use of clean planting material, application of fertilisers and control of other diseases and pests were used in combination with selected rotation crops to investigate their potential for BW management. The goal was to identify effective rotation options that are suitable for the control of bacterial wilt within the existing farming systems in south western Uganda. The specific objective was to identify multipurpose crops that are appropriate for a crop rotation regime that would in the subsequent season delay on-set of wilt, reduce wilt incidence, lower latent infection, reduce *Ralstonia solanacearum* populations in the soil and increase tuber size and yield.

Materials and methods

The research focused on *Ralstonia solanacearum*, race 3, biovar 2-A, prevalent on herbaceous weeds, potato tubers and other host crops in Kachwekano (Tusiime *et al.*, 2000; Lemaga *et al.*, 2001). Studies were conducted between 2000 and 2001, at Kachwekano Agricultural Research and Development Centre (01° 16'S, 29° 57'E) located at an altitude of 2200 metres. The experiments were conducted for three consecutive seasons during 2000A, 2000B and 2001A, in bacterial wilt-infested plots, measuring 6 m x 4 m with 1 m alley between plots, laid out in a randomised complete block design with three replicates.

Prior to planting the 2000A experiment, the disease pressure in the selected wilt-infested field was further increased by planting a bacterial wilt susceptible tomato variety (money-maker) for 6 weeks. Tomato plants that did not wilt within 28 days after planting (DAP) were artificially inoculated by stem-puncture technique, using a pure culture of *R. solanacearum* bacterial ooze that had been isolated from tubers infected and cultured in the laboratory on the modified Kelman's growth medium (Priou *et al.*, 1998). After all tomato plants wilted, their remains were chopped into very small pieces and spread evenly in the field to ensure uniform inoculum level in the field (Tusiime *et al.*, 2000; Lemaga *et al.*, 2001)

During 2000A potato was grown in all experimental plots to simulate the shortened rotation existing in the south-western Uganda and to create uniform field conditions. The crops were observed and data on pathogenicity soil sterility and incubation tests taken. In addition data on BW disease incidence and tuber yields were taken. During 2000B, the same experimental plots were planted to *Sorghum bicolor*, *Triticum aestivum*, *Zea mays*, *Eleusine coracana*, *Ipomea batatas* L., *Daucus carota*, *Phaseolus vulgaris* and *Solanum tuberosum* L., food crops commonly grown in the highlands of southwestern Uganda. The following one-season rotation sequences: potato-sorghum-potato, potato-finger millet-potato, potato-carrots-potato, potato-beans-potato, potato-sweetpotato-potato, potato-maize-potato, potato-wheat-potato, potato-potato-potato, were used and the varieties were as follows: sorghum-Kenya, finger millet-local (Entachweka), carrots-Nantes coreless, beans-K20, sweetpotato-local (Magabari), maize-Longe 1, wheat-Chiriku, potato-Victoria.

Potato, sweetpotato, maize and sorghum were spaced at 30 cm within rows and 75 cm between rows. Carrots, wheat and finger millet were spaced at 5 cm within rows and 30 cm between rows. Beans were spaced at 15 cm within rows and 30 cm between rows. The potato variety was selected because it is popular with the farmers due to its moderate tolerance to bacterial wilt and good marketability. During 2001A season, potato was again grown in all the study plots to test the effect of the rotation crops on the subsequent potato crop. Data were collected on percentage of wilted plants on a weekly basis starting from the on-set wilt of symptoms. Plants that were partially or completely wilted were all considered wilted and staked to avoid confusion in the subsequent recording and also to avoid missing out the plants that died off early in the season. Final wilt incidence for each treatment was calculated as percentage of total number of plants emerged.

The initial soil fertility of the field experimental plots was determined, and the necessary nutrients were added using the following inorganic fertilisers: urea, single super phosphate and muriate of potash according to Buekema *et al.*, 1990 and Lemaga *et al.*, 2001. The most common pests and diseases i.e., potato aphids and late blight were controlled using Ambush super (Karate) Lambda cyhalothrin 2.5 % and Ridomilgold (MZ), 63.5 WP Mancozeb 56 % + Metalaxyl 7.5 %, respectively. During 2000A and 2001A the experimental crops were sprayed twice and during 2000B they were sprayed thrice using both the insecticide and the fungicide stated above following the manufacturers recommended rates. All rotation crops were managed by following the recommended agronomic practices.

Tubers were harvested when 75% of the plants reached senescence. Weights of ware tubers, seed size and bacterial wilt infected tubers were recorded separately at harvest (Lemaga *et al.*, 2001). Indicator plant /pathogenicity test was used to test *R. solanacearum* inoculum levels in the soil (Priou *et al.*, 1999) before planting 2000A trials and after each season. The tomato variety, money maker was used for the tests. About 8 kg of infested soil was collected from the rhizosphere of the different rotation crops; soil collected from each plot was mixed thoroughly before loading it into plastic trays measuring30 cm by 60 cm. From each field plot, two tray loads were collected and in each tray 50 viable seeds were planted. The wilted tomato plants were recorded weekly and percentage wilt was calculated based on the number of tomatoes emerged.

Three different methods were used to determine latent infection in tubers and these were: sterile soil tests, incubation at high temperature for six weeks and indirect enzyme-linked immunosorbent assay on nitrocellulose membrane (NCM-ELISA) tests. From each field plot, 120 tubers externally symptom-less were collected, wrapped separately, and allowed to cure at Kachwekano for 2-3 weeks. For each test, 40 tubers were used and were divided into replicate samples for the first two tests and four replicate samples for the last test. Incubated tubers were subjected to 29° C for 45 days. Tubers were observed for bacterial wilt ooze weekly during the first four weeks and daily during the last two weeks. Tubers used for the sterile soil tests were stored for three months to induce sprouts and were then planted in the sterile soil medium loaded in plastic trays of 30 cm by 60 cm and watered with cool boiled rain water. After two weeks, the emerged plants were observed for wilt symptoms on daily basis. In both cases, tubers that showed bacterial wilt symptoms were removed, recorded and disposed-of carefully (Tusiime *et al.*, 1996a). At the end of 21 and 45 days the remaining tubers were cut into two and ring discolouration was observed and recorded. The average percentage of bacterial wilt latent infection was calculated.

The third set of 40 externally symptom-less tubers was subjected to indirect enzyme-linked immunosorbent assay on nitrocellulose membrane (NCM-ELISA) tests. Tubers were washed using tap water, rinsed in distilled water and dipped in 5 % sodium hypochlorite (NaOCl) solution before the extraction (Priou *et al.*, 1998). The knife, the cuticle remover, and tweezers were flame sterilised. A thin slice was cut from the stolon-end and the cuticle remover was used to collect not more than 0.5 g per tuber. Four replicate samples were used and each comprised of 10 tubers. The tuber pieces for each replicate were collected in a plastic bag and weighed before adding the sterile citrate extraction buffer on the basis of 2 millilitres per gram of tissue and kept separately. The potato tissue was crushed using a pestle to facilitate extraction of *R. solanacearum*. To avoid oxidation, the plastic bags containing the samples were kept on ice for not more than an hour. The samples of the tuber extracts (0.5 ml) were enriched right away, with 0.5 ml of selective modified Kelman's medium without Tetrazolium chloride (SMSA) according to Priou *et al.* (1998). The enriched broth was incubated for 48 hours before loading the samples on the nitrocellulose membrane. Latent infection in stems and root segments of the rotation crops was also determined following a similar procedure.

All the data collected were subjected to analysis of variance using Genstat 4.23 release statistical package. Percentage values were transformed into $\log_{10}$ before analysis.

Results

Data collected during the shortened season simulation are presented in Table 1. The baseline information revealed that BW inoculum is prevalent in the soils of the study area. The effects of one-season rotation crops on the subsequent potato crop were as shown in Table 2. *Sorghum bicolor*, *Triticum aestivum*, *Zea mays*, *Eleusine carocana* crops grown during 2000B season had a significant effect on the subsequent potato crop by delaying on-set of wilt for longer periods than *Ipomea batatas* L., *Daucus carota*, *Phaseolus vulgaris* and *Solanum tuberosum* L. repeat. They also reduced wilt incidence and latent infection, increased tuber size and yield, and improved the shelf-life of ware potato. Incubation at high temperature more efficiently detected latent *R. solanacearum* infection than indirect enzyme-linked immunosorbent assay on nitrocellulose membrane (NCM-ELISA) or sterile soil medium method. During 2000A and 2000B NCM-ELISA method did not detect latent *R. solanacearum*, but during 2001A, latent infection was detected in tubers from plots that had been under *Ipomea batatas* L., *Daucus carota*, and *Phaseolus vulgaris*. The tubers harvested from *Solanum tuberosum* L repeat plots had clear bacterial ooze symptoms, whereas the tubers from plots previously

Table 1. Baseline information for bacterial wilt of the shortened crop rotation in south western Uganda at Kachwekano during first rains 2000.

Treatment	Pathogenicity test %		On-set of wilt (days)	Wilt incidence (%)	Sterile soil test (%)	Incuba-tion test (%)	Ware potato yield ($t\ ha^{-1}$)	Seed tuber yield ($t\ ha^{-1}$)	Diseased tuber yield ($t\ ha^{-1}$)	Total tuber yield (%)
	02/2000	07/2000								
Future sweetpotato plot	62	39	44	35.3	64	72.5	14.1	2.8	1.0	17.8
Future wheat plot	60	37	44	33.7	65	72.5	14.1	2.8	0.8	17.8
Future potato plot	60	36	44	34.7	67	71.5	14.0	2.8	0.8	17.6
Future maize plot	62	35	44	34.7	67	72.5	14.1	2.8	0.9	18.3
Future millet plot	60	36	44	34.7	64	72.5	14.2	2.8	1.0	17.7
Future carrots plot	60	37	44	32.7	69	72.0	14.1	2.7	0.8	17.9
Future sorghum plot	60	36	44	35.3	68	71.5	14.0	2.8	0.9	17.6
Future Phaseolus beans plot	62	39	44	34.7	65	72.5	14.1	2.8	1.0	17.9
$LSD_{(0.5)}$	2.3	4.7	2	4.7	10.8	4.7	0.5	1.0	2.0	0.7
CV%	3.2	11.5	0.01	6	19.1	13.0	2.7	2.3	17.7	2.4

Table 2. Effect of one-season rotation crops on days to on-set of wilt, final wilt incidence, pathogenicity, incubation and sterile soil tests at Kachwekano during 2000B and 2001A.

Treatment	onset of wilt (days)	Wilt incidence (%)	Pathogenicity test (%)		Sterile soil test (%)	Incubation test (%)	Ware potato yield ($t\ ha^{-1}$)	Seed size yield ($t\ ha^{-1}$)	Diseased tubers ($t\ ha^{-1}$)	Total tuber yield ($t\ ha^{-1}$)
	2001A	2001A	2000B	2001A	2001A	2001A	2001A	2001A	2001A	2001A
Sweetpotato-potato	28	26	16	12	74	60.2	5.6	4.6	2.6	12.8
Wheat-potato	42	6	8	6	55	33.9	9.5	4.5	0.6	14.5
Potato-potato	21(45)	72(20)	88	86	87(100)	70.1	1.1(29.9)	1.0(1.7)	8.3(6.3)	10.5(37.8)
Maize-potato	35	8	10	8	57	40	8.6	3.8	0.1	13.1
Finger millet-potato	35	8	11	10	64	40.2	8.3	3.3	0.7	12.2
Carrots-potato	28	16	17	15	79	60.5	6.3	2.7	4.5	13.5
Sorghum-potato	45	4	7	6	68	30.8	9.8	2.3	0.5	12.6
Beans-potato	28	26	24	22	82	70.7	2.5	2.8	6.4	11.8
$LSD_{(0.05)}$	5.2	9.2	21.3	8.8	9.2	7.5	1.4	1.2	0.2	1.5
CV %	13.3	30.5	19.1	20.7	15.5	13.0	16.1	28.7	22.6	15.7

In the brackets are data for potato rotation crop 2000B.

under *Sorghum bicolor*, *Triticum aestivum*, *Zea mays*, and *Eleusine carocana* tested negative. The stem and root segments of *Sorghum bicolor*, *Triticum aestivum*, *Zea mays*, and *Eleusine carocana* tested negative, whereas those of *Ipomea batatas* L., *Daucus carota*, *Phaseolus vulgaris* and *Solanum tuberosum* tested positive. During 2001A, there was significant statistical difference between latent infection detection using sterile soil medium method and incubation at high temperature, ware potato, seed size tuber and diseased tuber yield and total yield. Tubers harvested from plots previously under *Sorghum bicolor*, *Triticum aestivum*, *Zea mays*, and *Eleusine carocana* were able to store for a longer time without rotting (more than three months) than those harvested from plots that had been under *Ipomea batats* L. and *Daucus carota* (one month) which were in turn stored longer than tubers from plots that had been under *Phaseolus vulgaris* and *Solanum tuberosum* (less than three weeks)

Discussion

Low wilt incidence in the field cannot be relied on as an indictor of low level of the bacterium in the soil as shown by high percentage latent infection obtained after subjecting potato samples collected from plots previously under *Sorghum bicolor*, *Triticum aestivum*, *Zea mays*, and *Eleusine carocana* to incubation under high temperature. Although incubation under high temperature takes longer, it gives higher latent wilt counts and could be carried out by the farmers at their own farms and obtain results. The NCM-ELISA method although very fast in detecting *R. solanacearum* latent infection, requires a wide range of equipment and only technical personnel based at already established research institutions must be available to assist the farmers to determine the health status of their seed tubers. This limits its use to only the rich farmers or non governmental organisations (NGOs) who can afford to transport their seed tuber samples to these locations, thus rendering it un affordable to the poor farmers that form the majority of the farming community in southwestern Uganda. The farmers could also carry out the sterile soil medium method on their own but, it is demanding in terms of containers in which to load sterile soil, collecting the soil, sterilisation equipment and labour for watering.

The effect of *Sorghum bicolor*, *Triticum aestivum*, *Zea mays*, and *Eleusine carocana* one-season rotation on the BW infections of subsequent *Solanum tuberosum* crop indicates the effectiveness of crop rotation measures for the control of BW. On set of wilt was delayed and there was decreased wilt incidence, increased tuber size and yield and prolonged shelf-life of the subsequent potato crop were these crops were planted before the potato. *Ipomea batatas* and *Daucus carota* and the worst effect was from *Phaseolus vulgaris* and *Solanum tuberosum* L. repeat. However growing any of the evaluated crops was better than repeating *Solanum tuberosum* L. and our studies therefore point out that this should be avoided.

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Integration and dissemination of green manure cover crops in small scale farming systems: Successes and constraints in eastern Uganda

R. Miiro, A. Esilaba[†] and D. Soniia[†]
Department of Agricultural Extension/Education, Makerere University,
P.O. Box 7062, Kampala, Uganda
[†]CIAT Uganda, P.O. Box 6247, Kampala, Uganda

Abstract

The integration of *Mucuna, Lablab* and *Crotalaria* into the farming systems of eastern Uganda was studied in the year 2000. Quantitative and qualitative survey methods of data collection were used with 52 households including former experimenting farmers, and their neighbours. *Mucuna, Lablab* and *Crotalaria* were consistently used for 7 seasons, with a mean seasonal use of 15, 10 and 7 experimental farmers, respectively. The quick restoration of soil fertility on the farms, presence of support technologies like clean cassava planting materials, and the selling of green manure seed enhanced crops use. The use of *Crotalaria* however, dropped from 34% in the first season to 10% in the last season. Constraints to the integration included drought, labour bottlenecks, and storage difficulties particularly for *Lablab* and *Crotalaria* seed. The crops had been adapted for domestic and farm uses, with the women dominating their dissemination. Aspects of non-adoption and dis-continuance of the crops were traced to poor farmer group management and lack of information. Soil fertility improvement, sale of seed and size of land were among the factors advanced to explain the integration of crops. Participatory extension can reinforce the existing successes, while an in-depth adoption study of the green manure can be part of further research.

Key words: Adaptation, legumes, planting materials, soil fertility management

Introduction

Increasing soil-nutrient depletion, declining soil fertility and crop yields are common features of farming in sub-Saharan Africa (Stoorvogel and Smaling, 1990; Smaling *et al.*, 1997). Integrated nutrient management (INM) strategies have been considered as promising options for soil fertility management, because of their suitability under local biophysical, economic and social conditions (Smaling *et al.*, 1997; Smaling *et al.*, 1996). Integrated nutrient management (INM) technologies bridge the gap between high external input and the extreme forms of traditional low external input agriculture and are therefore recommended for the resource poor farm households who form the majority of farmers in eastern Uganda (Miiro *et al.*, 2001). This region is characterized by a high population density (230 persons/square kilometre), continuous cultivation with minimal nutrient replenishment and reduced fallow periods (Wortmann and Eledu, 1999). There is need therefore to enhance soil fertility management.

Crotalaria *(Crotalaria ochroleuca)*, Mucuna (*Mucuna pruriens*), and Lablab (*Dolichos lablab*) green manures were introduced in Imanyiro subcounty, Iganga district during 1994 to 1996 as alternative soil fertility improvement technologies for improving crop yields and control of weeds in maize-bean cropping systems as observed from earlier studies (Wortman *et al.*, 1998).

Fischler and Wortman (1997) reported that the green manure cover crop technologies were adapted by the farmers in a number of ways including planting *Mucuna* at the same spacing as maize such that after uprooting the cover crop, the maize would be planted in the same holes. *Canavalia* was reportedly experimented as a green manure in maize and beans and as a cover crop in bananas. *Crotalaria* was grown in young cassava, coffee and pineapple and used as mulch. *Crotalaria* seed was mixed with bean seed to control bean bruchids, and its leaves served as a vegetable (Wortmann *et al.*, 1999). To support the participatory research process, some technologies such as improved varieties of cassava, maize and bean seeds were also introduced. Farmers were facilitated and encouraged to form a credit society.

About four years (1996-2000) have passed since the three green manure cover crops *(Crotalaria, Mucuna and Lablab)* were recommended and disseminated to farmers in this area. There is thus a need to establish the consistent use, integration, scaling up and diffusion of the green manure cover crops and constraints associated with these utilisation. An empirical study to assess integration and adaptation of green manure cover crops among participant farmers was instituted to gain insights into the initial overflow effects to neighbours and other farmers. Pertinent research questions included: to what extent had green manure cover crops been integrated and adapted within the farming systems of the farmers who participated in the research? What reasons led to the integration? Was there any on-farm up-scaling and spreading of the technologies to other farmers? What were the benefits and constraints of using the cover crops? What were the reasons for the spread of the green manure crops or other related technologies? How were the neighbours and dropout farmers affected by the technologies? To what extent had dissemination of the technologies taken place. The research was undertaken as part of the CIAT project on improving INM practices on small-scale farms in Africa using Participatory Learning and Action Research (PLAR).

Materials and methods

The study was conducted in five villages from Buyemba and Mayuge parishes in Imanyiro sub-county, Mayuge district, Uganda. The target population included all the farmers who participated in the trials and were still practicing the use of green manure cover crops, farmers who dropped out of the trials, and neighbouring farmers to the former. The sample consisted of purposively selected twenty-one (21) members of the farmer participatory research group who were still practicing and each participant's immediate farming neighbour irrespective of the direction of 22 neighbours, and nine (9) farmers who dropped out from the initial participant group thus a sample size of fifty-two (52) was used. Focus group discussions (FGDs) were held with 2 separate groups of 6 men and 6 women to understand the dynamics and effects (benefits and constraints) of the green manure crops in the farming community. In addition, a formal survey questionnaire was administered with participating and non-participating farmers to capture the extent of integration of the green manures in terms of numbers of users of each of the green manure cover crops since they were introduced in 1994, as well as adaptations/innovations with the technologies. The survey also captured the diffusion or spread of the technologies from the initial participating farmers to neighbouring and other farmers in the community as well as the respondents' socio-economic characteristics. The study covered farmers' experiences between 1994 and 1996.

Survey data was analysed using simple descriptive and comparison statistics assisted in desegregating the different crops, farmer groups, time differences, and other variables likely to affect integration, up-scaling and spreading of the technologies.

Results

Integration of green manure cover crops into farming systems of participant farmers

The integration of green manure cover crops into the farming systems of the participant farmers involved the consistent use of the green manure crops by the farmers who participated in the original experiments established by determining the proportion of the farmers who grew *Mucuna, Lablab*, and

Crotalaria between the long rains season (season A) of 1997 to season A of the year 2000 (Fig. 1). *Mucuna* registered a high level of continued use among the original participating farmers. The initial proportion of users was 76% in season A of 1997 while in season A of 2000 there were 62%. *Mucuna* was followed by *Lablab*, and *Crotalaria*. For each of the 15, 10 and 7 farmers who tested and were still practicing the growing *Mucuna*, *Lablab*, and *Crotalaria*, respectively the average number of those who continued growing for all the 7 seasons was 12, 8, and, 4 for each respective crop.

Factors that affected the integration of the green manure technologies

All farmers (21) who participated in the original trials and were part of the study indicated that they were continuing with the use of either, one, two or all of the three green manure cover crop species. Qualitative interviews with the participating farmers indicated that the main reason for continuing with the green manure cover crops was their key role in restoring soil fertility.

Other reasons included: (1) The provision of complimentary technologies such as cassava and banana planting materials, bean seed, agro-forestry tree species as incentives to encourage farmers to attend to the experiments, but also as part of a systems approach to solving the other problems farmers had given by the researchers; (2) The integration of the farmers' indigenous technical knowledge (ITK) with in the research protocols; (3) The sale of the green manure seed from the trials was also an incentive for farmers to attend to their experiments especially seed harvesting which was a difficult activity. The seed sales also encouraged intensified growing of the cover crops for quality planting seed; and (4) Use of the cover crops for other purposes: such as foliage from the cover crops as a livestock feed. Table 4 shows the changes in the level of soil fertility of farmers' fields at all topographical levels (along the catena) as perceived by the farmers, after growing two or all of three green manure cover crops.

Constraints of integrating the green manure cover crops into the farming systems

According to the 21 participating farmers, the main constraint of growing green manure cover crops was the prevailing drought conditions. This brought about temporary breaks in growing of the cover crops among the farmers. Secondly, farmers indicated that the limited use of the green manure cover crops to only soil fertility improvement and not as food for humans constrained integration. It was also reported that the opportunity cost of leaving land under fallow with *Crotalaria* was high as the successful harnessing of *Crotalaria* seed required that the legume stays longer in the field. There was difficulty in obtaining clean seed of *Lablab*, because it was easily attacked by pests. Farmers endeavored to control the pests by spraying with an artificial pesticide.

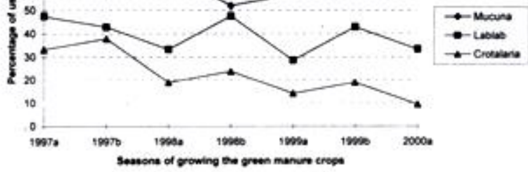

Figure 1. Trend of growing green manure cover crops by farmers between the seasons of 1997a and 2000a.

Farmers were also concerned that *Mucuna* a fast growing, proliferous cover crop produced seed that could not be eaten. The crop also had climbing tendencies when intercropped with other crops adding to labor demands of managing the main crops such as bananas and coffee. The crops affected by the climbers would not yield well. Farmers indicated that the labour demands of *Mucuna* needed a committed person who valued its benefits to grow it.

The immediate neighbouring farm-households (22) to the participant farmers indicated that they were aware of the existence of the green manure cover crops, but had not used them. The reasons for this included:- lack of adequate information on the crops, lack of land and time to plant them, lack of seeds, as well as lack of husbandry skills for the crops.

The 9 farmers who dropped out shared their reasons for dropping most of which were managerial, administrative, organisational and socio-economic concerns. The reasons were: -

- Poor leadership of the farmers research groups leading to inequity in opportunities for selling the green manure seed
- Failure to sell seed from the green manure cover crops
- Lack of a reliable market for the green manure seed
- Lack of funds to buy planting seed for the green manure cover crops
- Failure to provide credit to the farmers as promised by the research team
- Initiation of a women's credit organisation called FINCA funded by the United States Agency for International Development (USAID) in the area diverted some of the participants to other business activities other than the green manure trials
- Difficulty in scaling up green manure cover crops on the small farming land available as well as insecure land tenure
- Social problems such as death of a relative, or attending to a sick family member.

Despite these problems, this set of farmers expressed interest in the technology, and intended to resume on acquiring seed at an affordable price and on surety of a market for the seed. Another objective of resuming was to improve the fertility of their soils.

On-farm scaling up and adaptation of green manure crop use

Over 60% of the participant farmers had not expanded their fields under green manure cover crops due to lack of sufficient land and the need to reserve land for food production. Lack of security of land tenure and labour constraints were the other reasons. However, there were rotations of the green manure cover crops and use as intercrops with the food crops. On average, the green manure crops were planted in the same field 4 times, the range was 1 to 10 times.

Forty three percent (43%) of the participant farmers indicated that they had tried using the green manure cover crops in new ways besides what the researchers had demonstrated during the trials. Sixty seven percent (67%) of those who used the green manure crops in new ways had innovated with *Mucuna*, while 22% had innovated with *Crotalaria*. The ways in which the participant farmers adapted and innovated with the technologies are shown in Table 1.

For *Crotalaria* the basic recommendation was to use it as an intercrop with maize and as a one-season cover crop - a one season fallow crop, whose crop residues at maturity were to be used as a mulch in

Table 1. Farmers innovations with the green manure cover crops.

Green manure cover crop	Recommended utilisation method	Modification in utilisation	Non-agronomic modifications
Crotalaria	Intercrop with maize or as a one season fallow crop	Ploughing into the soil	Leaves were used as a vegetable and as a medicine for stomach pains
	When mature, uproot and mulch in maize, beans, sorghum, millet, cotton, etc.	Intercrop with beans to control nematodes and other bean diseases	
	Thresh pods to get seed.	Seed put together with bean seed during storage controls bean storage pests	
	Mulch		
Mucuna	Use it as a one season fallow crop, uproot at planting and mulch in the following crop	Intercrop with maize	Efforts to crash seed to make chicken feed
	Keep seed for future use		Mixing its dried leaves with maize bran to make chicken feed
	Use as cover crop in banana plantations		Fresh vegetation used as a feed for goats and cattle
Lablab	Grow for two seasons as a fallow crop, uproot at planting and mulch in the following crop		Seed and the leafy vegetation edible
	Use as a fodder crop and as cover crop in banana plantations		Seed cooked like beans for source
			Dried and powdred leaves also as a source

annual crops. Farmers innovated with *Crotalaria* by using it as mulch in coffee, and incorporation of the *Crotalaria* residues into the soil. They also used *Crotalaria* seed, to protect beans against storage pests such as bean weevils. *Mucuna* was recommended to be used as a one season fallow crop, where a crop would be planted and mulched with *Mucuna* after harvesting the green manure. Using Mucuna as a cover crop in banana plantations was also recommended. Intercropping *Mucuna* with maize was one of the adaptations in the use of the green manure besides the following non agronomic innovations: crashed *Mucuna* seed was experimented as a poultry feed. Dry *Mucuna* leaves were mixed with maize bran to make chicken feed, while its fresh vegetation was used as a livestock feed (goats and cattle). *Lablab* was recommended to be used as *Mucuna* , as well as a fodder crop. Using lablab as human food was the major innovation mainly by eating its leaves both as a fresh and a processed/dried vegetable. The seeds were also boiled like the common bean and eaten as a source of protein. *Canavalia* was used as an intercrop in coffee, maize and bananas. Vetiver grass, which was meant to stabilise soil bunds against soil erosion, was used as a thatching material for houses.

Sources of seed and seed sales

Farmers ensured that they had enough seed of the green manure crops by saving from previous season harvests (Fig. 2). Sixty seven percent (67%) of the farmers indicated that they saved *Mucuna* seed, while 24% indicated that they saved *Lablab* and *Crotalaria* seed. However 75% of the farmers indicated that they had also obtained seed from fellow farmers. Fifty-five (55%) and forty six percent (46%) of the farmers obtained seed for *Mucuna* and *Lablab*, respectively from other farmers.

Eighty one percent (81%) of the participant farmers indicated that they had sold some of their green manure seed. Fourty seven percent (47%) of the farmers had sold seed to the leader of the Farmer Participatory Research Group, while 24% had sold to CIAT, and 6% to their fellow farmers. Eighty-nine percent (89%) of the participating farmers who had sold green manure seed had sold *Mucuna* seed, while 38% had sold *Lablab* and *Crotalaria* seed each. *Mucuna* was sold at an average price of $0.52 a kilogram, and ranged from $0.28 to $1.7. The price for Lablab seed ranged from $1.14 to $ 5.71, while the average was $3.23 per kilogram. A kilogram of Crotalaria seed was sold at a mean price of $1.71. The exchange rate used was 1,750 Ugandan Shillings per United States dollar.

About 1908kg of *Mucuna* seed were sold, with an average of 159kg of seed per farmer. The total amount of *Lablab* seed sold was 43.5kg, with an average of 10.87kg of seed per farmer. Twenty-six (26) kilograms of *Crotalaria* seed had been sold with an average of 5.2kg per farmer.

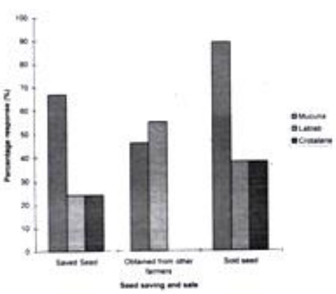

*Figure 2. Green manure **cover crop seed saving, access and sale among farmers.***

Farmer to farmer dissemination of the green manure cover crops

Ninety five percent (95%) of the participant farmers had shared information on green manure crops with other farmers 290 in total. Each participant farmer had on average shared with 17 farmers. The other farmers who were using the green manure crops after participating farmers shared with them were 86 for *Mucuna* (Table 2). Fifty three (53) farmers were using *Lablab*, while 31 farmers were estimated to be using *Crotalaria*. Table 3 shows that 66% of the participant farmers indicated that women participated in the sharing with others about the green manure cover crops, while 38% were men (Table 3). Sixty six (66%) of the participant farmers said women in the community were reached most, and 57% said that small holder peasant farmers were reached most followed by subsistence farmers (43%).

Discussion

There was a decline in the proportions of farmers growing *Lablab* and *Crotalaria*, while *Mucuna* experienced a slight rise in the proportion of growers in season A of the year 2000. The major explanation for these declines is drought stress. Internal averages based on the number of farmers growing the particular technology reveal a higher level of consistent use over the 7 seasons (15, 10 and 7 for *Mucuna*, *Lablab* and *Crotalaria*, respectively). This can be attributed to the increases in soil fertility brought about by the use of the green manure cover crops. This was also an indicator of farmers' extent of integrating the green manure cover crops into their farming systems. Given the four years (which is close to the five year period permitted for adoption of soil technologies) had elapsed since the actual trials had been completed; the present level of green manure crop use by the participant farmers shows integration of the technologies. The apparent position of *Mucuna* is due to its prolific nature, and easy harnessing of seed, which can also be used in the next season. The relatively constant low level of *Lablab* use is mainly due to the ease with which its seed were attacked by pests making

Table 2. Use of green manure crops by secondary farmers told by participating farmers.

Green manure	Number of respondent	Total number of other users	Mean number of other users	Standard deviation (SD)	Range
Mucuna	12	86	7.17	6.32	23
Lablab	7	53	7.57	7.74	22
Crotalaria	2	31	15.5	13.44	19

Table 3. Household member participation in sharing about green manure cover crops and most reached group (n=21).

Household member	Frequency (f)	Percentage (%)
Women	14	66.0
Men	8	38.0
Children boys	1	4.8
	Member of the comunity reached most	
Women	14	66
Men	8	38
Children boys	2	9.5
	Types of farmers reached most	
Type of farmer		
Small scale peasants	12	57
Subsistence farmers	9	43

seed saving for the next season difficult. Thus, seed to replant is rarely available especially when the drought affected the harvest.

Crotalaria had the lowest proportion of farmers continuing to grow it, and registered an increasing decline of this proportion due to difficulties in getting seed. The crop takes longer period to mature (7 months). This possibly could not fit in an area with land scarcity. These trends of use (intermittent falls and rises) did not however, imply that farmers were giving up with the green manure crops. Qualitative discussions with the farmers revealed objective intentions to grow the crops when the conditions are conducive, such as availability of seed and rain.

Despite the above observations, there were improvements in the level of soil fertility of farmers fields at all topographical levels as perceived by the farmers after growing either, both or all of the 3 green manure cover crops. The positive changes in soil fertility after using the green manure cover crops at all levels can be attributed to the their biological nitrogen fixing (BNF) capacity, the high biomass and release of nutrients during the decomposition process (Fischler, 1997). It is observed that soil fertility changes at the hill top were only up to only the "fertile" level (Table 4) possibly due to physical nature of the soils at hill tops. These soils are characterised by gravel, and thin layers of top soil due to their erodibility, particularly if there is little soil cover. The soil fertility changes at the foot hill changed from poor to very fertile, because of the likelihood of deposition of soils eroded from hill sides and the deep layer of top soil. A good proportion of farmers with fields at the flat terrain also reported a change in the fertile level, confirming the potential of the green manures to restore fertility of such soils which are usually exhausted due to over cultivation.

The reasons farmers indicated for continuing to use green manure cover crops do reflect that a priority need of the farmers is the productivity of their soils (Wortmann *et al.*, 1999). Fischler (1997) reported high on-farm trial maize yields after use of *Mucuna, Lablab* and *Crotalaria* as soil fertility replenishing technologies. Provision of other support technologies may genuinely explain their response as often farmers have other needs, which if not met may affect their acceptance of a new technology. The support technologies were many and helpful, possibly providing the participants a choice menu and thus appealing to their commitment to the research/development process. Use of their indigenous knowledge in some of the aspects of research fitted well with the concepts of participatory research where solutions must consider what the would be users know and build on it making the whole process potentially sustainable (van Veldhuizen, *et al.*, 1997). The sale of the green manure cover crop seeds was a strong incentive, which even though it was not the original motive of the project, might have attracted farmers to work hard. Farmers are always looking for sources of funds so they can meet other needs in the setting that can only be met by money. The use of the cover crops for other purposes

Table 4. Level of soil fertility (indicated at %respondents) before and after planting green manure cover crops along the catena of farmers' fields (n=21).

Topography	Level of soil fertility				
	Very poor	Poor	Average	Fertile	Very fertile
		Before planting the green manure cover crops			
Hill top	-	19	4.8	-	-
Flat land	9.5	33.3	4.8	14.3	-
Gentle slope	4.8	4.8	-	-	-
Foot hill	-	4.8	-	-	-
		After planting the green manure cover crops			
Hill top	-	-	-	23.8	-
Flat land	-	-	4.8	42.9	14.3
Gentle slope	-	-	-	4.8	4.8
Foot hill	-	-	-	-	4.8

as farmers are able to spread risks to other shocks such as lack of animal feed, or vegetable source for home use was another additional measure.

The immediate neighbours could have adopted, if they had practical knowledge and training on the importance of the green manure cover crops as well as how they are utilised. However, the attempts to innovate among the participant farmers shows a higher level of innovativeness compared to their neighbours (assuming that there were no other forms of innovativeness with other technologies among neighbours). This could additionally explain the non-adoption of green manure cover crops among the neighbours. If neighbours had a high level of innovativeness they would have been more curious about the technologies and thus moved higher on the innovation-decision process. This process range is through knowledge or awareness, persuasion, implementation and then confirmation stages (Rogers, 1983). It is also possible that a socio-economic gap was created between the participant and their non-participant neighbours as a result of the technologies, leading to resentment among neighbours towards trying out the technologies.

The experiences of the drop out farmers are a reflection of the consequences of an innovation as observed by Rogers (1983). The behaviour of the leadership and the inequalities involved in the distribution of green manure cover crop seed may be classified as an undesirable and unanticipated consequence of the technology. This can lead to a social gap between the drop out farmers, and the research effort. The entire milieu of reasons for dropping out of the research hinges around the way the management of the research activity (including the roles of the farmers, their leaders, the researchers, the resources and the methodology).

Despite the lack of expansion of the area under use of the cover crops on the participants fields, the frequency of use of the technology was high (an average of 4 times in fours years after the trials). This expressed increased appreciation of the role of the technologies in restoring the soil fertility, and one of potential sustained use among the farmers.

Innovations or what Rogers (1983) calls re-inventions of the green manure technologies occurred among the participant farmers. Rogers (1983) argues that re-invention occurs at the stage of implementation of the innovation-decision stage and that its an action taken by an adopter. This puts the 43% of the farmers who had innovated with the green manure cover crops on a possible list of adopters. Re-invention is regarded as beneficial to the adapters, due to the flexibility it provides in the process of adopting a technology. Additionally re-invention may encourage customisation of the innovation, making it fit the local conditions, this is also part of the participatory research process. The re-invention and innovation provides for self reliance of the users and through the processes of experimenting may lead to a system of innovativeness (Reijntjes *et al.*, 1992).

The management of green manure seed seemed to take a central role in the growing of the green manure cover crops, as seed was the only product of the green manure cover crops from which money could be earned directly. The profitability of an innovation is said to increase its adoption (Rogers, 1983). There were indications of farmer frustrations with failure to harvest seed of *Lablab* and *Crotalaria*, whose seed fetched more money than the proliferous *Mucuna*. Most importantly, seed saving was important if the green manures were to be grown in coming seasons.

Diffusion of the green manure cover crops spread from the participant farmers to other farmers in the community, justifying the role of farmer to farmer sharing. Indeed farmer to farmer information exchange is the most common way of information spread among farming communities (Campbell and Garforth, 2001). Ninety five percent of the farmers indicated to have told some one else about the green manure cover crops. A total of 290 other farmers had been told. The mean number of those who were observed practicing per participant farmer was 7 for each of the green manure crops. What may have prompted this may be the good soil improvement results and better crop yields after using the cover crops observed among the participant farmers. The role of women in households in disseminating the information can be explained by their important role contributing to most of the agricultural activities, and possibly due to their information exchange networks which function better than those of men (Campbell and Garforth, 2001). This probably explains why more women were reached as compared to the other gender.

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Linear programming approach to optimal cowpea marketing in Soroti and Pallisa districts of Uganda

C.F. Emaju, V. Kasenge[†], W. Ekere[†] and E. Adipala[††]
Department of Agriculture, Soroti District, P.O. Soroti
[†] Department of Agricultural Economics and Agribusiness, Makerere University, P.O. Box 7062, Kampala, Uganda
[††]Department of Crop Science, Makerere University, P.O. Box 7062, Kampala, Uganda

Abstract

Cowpea (*Vigna unguiculata* L. Walp) is an economically and nutritionally important grain legume in northern and north eastern Uganda. The crop is grown both for subsistance and as cash crop. However, increased production of cowpea as a cash crop will depend on reliable market information. This study was designed to assess the nature of cowpea marketing and establish how optimally it is marketed within the districts of Pallisa and Soroti. Primary data were collected from 72 traders in rural and urban centers of Pallisa and Soroti districts, using pre-tested structured questionnaires. The data were analysed using descriptive statistics and a linear programming (LP) transportation model. The results indicated that a majority of traders were male and sole proprietors. At both wholesale and retail levels, transport costs accounted for the highest percentage of total marketing costs incurred by traders. Poor storage and seasonal fluctuation in demand were among the leading marketing problem. Farmers generally took the largest share of the consumer price. Use of the LP transportation model showed that traders did not optimally distribute their cowpea. The current level of operation was 10% lower than the optimal level. For optimality, Katakwi zone should supply 1164 kg of cowpea to Soroti market. Similarly, Gweri zone should put on the market 2544 kg of cowpea in Soroti. In Pallisa district, Apopong, Putiputi, Ikiiki and Agule cowpea sources would supply only the Pallisa market. The various problems faced in the marketing system were contributing to the difference between the optimal level of transactions and current level.

Key words: Farmers, markets, optimality, traders, transportation model, *Vigna unguiculata*

Introduction

Cowpea (*Vigna unguiculata)* is an important staple and cash grain legume crop in north-eastern Uganda grown for its edible leaves and grain (Sabiti *et al.*, 1993). Significant quantities are also used as animal feed mostly in developed countries (FAO, 1994).

However, the overall area cultivated per household in the study area is small ($\simeq$ 0.5 ha per household) and production is mostly constrained by labour availability, especially without animal traction (Adipala *et al.*, 1997). The situation is worse in Soroti district where nearly all livestock was lost during insurgency and cattle rustling. For the last five years, therefore, Pallisa district has committed more land to cowpea and has in turn produced more grain than Soroti district.

Uganda's grain legumes face growing domestic and regional demands as part of the non traditional export crops whose earnings have continued to grow over the past years. Their marketing and pricing efficiency could be improved if producers and other market participants were better informed of market conditions. However, cowpea marketing in the study area is constrained by several factors. Production of the crop is by small scale farmers on scattered holdings and geographically concentrated in areas that are often found some distance from major consumer markets. The infrastructure in the rural areas is poor and communication networks are not sufficiently developed. This therefore makes movement of commodities from supply to demand points difficult. The virtual absence of price information system also hinders producers and traders in their transactions. Generally, wholesale traders have greater mobility and are better informed of the market situation. Consequently, they often take advantage of the less informed producers although traders do not often optimally distribute cowpea from producers to consumers. Related studies on other agricultural products have come to similar conclusions. Mugisha (1994) used the transportation model to determine the optimum level of banana distribution in Uganda. He found that the quantity of bananas marketed was not optimal and suggested partial and temporal adjustments in banana distribution for banana traders to increase their profits by 38.47%. Nakachwa (1995) also used the transportation model to determine the optimum level of fresh fish distribution in the central region of Uganda. It was found that the distribution of fresh fish was not optimal and hence suggested that to reduce costs adjustment in fresh fish distribution was necessary so that the fish traders raise their profits by 85.6% from 14.39%.

However, these recommendations have not been adhered to and this has resulted in a situation whereby traders earn low profits, while farmers receive unattractive prices that do not motivate them to produce more for the market. A system allowing a fair play for the marketer, the consumer, and the farmer, therefore, needs to be developed. The principal purpose of this study was to assess the efficiency of the current marketing network of cowpea in Soroti and Pallisa districts, paying particular attention to distribution channels, market structure, conduct and performance. Specific objectives were to 1) estimate the marketing margins of cowpea, 2) identify the major infrastructure, informational, institutional, socio-economic and financial constraints within the cowpea marketing system and propose mitigative measures, and 3) determine the optimum supply points of cowpea to markets to minimize transfer costs.

Methodology

Research design and sample selection

This was a descriptive and market diagnostic study conducted in the districts of Pallisa and Soroti on a previous study by Sabiti (1995), which identified these districts as main cowpea production and marketing areas in eastern Uganda. Within the districts, counties that ranked high in cowpea production were chosen. A total of six counties were selected, three per district. Subsequently two markets were selected per county. Thus, a total of thirteen markets were selected , six in Pallisa and seven in Soroti. In total 36 respondents in Pallisa and 36 in Soroti district were selected in each market using the fish bowl method and interviewed with a pre tested questionnaire.

Data description and sources

Primary data were collected during the market surveys. During the surveys, data were collected on prices, marketing costs, characteristics of traders, marketing channels, type of marketing problems faced, quantities of cowpea supplied, sources of supply, distribution of demand and respective margins were computed. Problems encountered in marketing cowpea were also recorded and ranked. Also identified were major market participants and services rendered; average costs incurred; size of market margins; price spreads and farmer's share of the consumer's shilling.

Data Analysis

Quantitative and descriptive statistics were used to analyze the data collected. To analyse marketing constraints, ranking methods were used. To determine the various margins and shares , the following equations were used.

Share to the farmer = $\frac{Px \times 100\%}{Py}$ 1

Wholesale margin = $\frac{Pw - Px \times 100\%}{Py}$ 2

Retail margin = $\frac{Py - Pw \times 100\%}{Py}$ 3

Where: Px, Py, Pw refer to farmgate price, retail price and wholesale price respectively.

To determine the optimal distribution of cowpea for the two districts, theLinear programming (LP) transportation model was used. The transportation model for this study was specified to determine the amount of cowpea to be delivered from different production sources to major consuming markets with the objective of minimizing costs. The problem was specified in an LP transportation framework using the following standard summation notation:

Let X_{ij} = amount of goods transported from source i to destination j.
C_{ij} = cost per unit for transferring goods from source i to destination j.
Assuming also that there are: m = sources and n = destinations
and S_i = Quantity of goods available (supply) at source i.
d_j = Quantity of goods required (demanded) at destination j.

Then the problem is the following:

$$\text{Min} \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}X_{ij} \quad \text{.......... 4}$$

The minimization problem is subject to the following critical constraints.

$$\sum_{j=1}^{n} X_{ij} \leq S_i \ (i = 1, 2, \ldots, m) \quad \text{.......... 5}$$

Meaning amount transferred from source i to all destinations must not exceed the amount available at that source.

$$\sum_{j=1}^{m} X_{ij} \geq d_j \ (j = 1, 2, \ldots, n) \quad \text{.......... 6}$$

Amount transferred to destination j, from all sources must be at least as great as the requirements at that destination.
The transportation problem is balanced when the total available at the sources equals the total required at the destinations.

$$\text{Thus} \sum_{j=1}^{m} S_i = \sum_{j=1}^{n} d_j \quad \text{.......... 7}$$

Si, dj, Xij $\geq$ 0 (for all i,j) 8

That is, no negative goods can be transferred from source to destination.

By solving equation (1), the optimal solution to the transportation problem can be determined. Equation 4 is the objective function for minimizing costs. Equations 5, 6, 7 and 8 represent supply constraints, demand constraints and non-negativity of the variables, respectively. Primary data collected from the cowpea sources and study markets during the district market survey (DMS) were incorporated in Table 2, as required by the transportation model for analysis.

The cowpea supply zones included Katakwi, Usuk, Wera, Orungo, Asamuk, Otuboi, Kaberemaido, Kyere, Gweri, Pallisa, Butebo, Kameke, Agule, Ikiiki, Putiputi and Apopong. The selected markets included Orungo, Ocorimongin, Usuk Mission, Soroti, Tubur, Katine, Wera, Palisa, Ikiiki, Kameke, Kanyum and Kamuge.

When formulating the transportation problem, the following assumptions were considered:

(a) Traders were free to purchase cowpea from any source i for sale at any market j
(b) Different sources produced different amounts of cowpea, and different markets have different demand potentials for cowpea.
(c) Transfer costs are functionally related to the quantity of cowpea handled.
(d) There is an even flow of cowpea supply throughout the year between all points of demand. A steady flow can be achieved by holding sufficient stocks at each cowpea supply zone.

Despite the above assumptions, the following restrictions prevailed and were included in the model as the constraints:

(a) The total amount of cowpea supplied to each market could not exceed the potential demand otherwise the problem would have no feasible solution, given non-negative transfer costs (Simmons, 1972).
(b) The amount of cowpea supplied from each source to any of the markets could not be increased given high market demand.

Results and discussion

Characteristics of Traders

The results indicate that generally, cowpea trade is dominated by married males while women played a minimal role. Although many schools of thought believe post primary education as a key to success, primary school leavers accounting for 50 percent of the respondents interviewed dominate the trade in cowpea. The study revealed that cowpea selling generates employment for the unskilled, semi-skilled, and those who do not have enough capital of their own. These types of traders comprised 86 and 94% of the retail traders of cowpea interviewed in Pallisa and Soroti districts, respectively (Table 1). Earlier, Buphal (1994), noted that the existence of petty retailers or vendors in the vegetable trade helped in creating competitive conditions. Cowpea business is largely a retail trade with wholesaling at less than 50%. Majority of traders interviewed ran their own business and sold other products that largely comprised farm produce. In terms of experience in cowpea marketing, on average, traders had spent 6.5 years trading in cowpea with a minimum period of one year and a maximum of 28 years. This is a clear indication that cowpea trade has provided a living for many traders for quite sometime.

Cowpea distribution channels

Wholesalers in both districts relied mostly on direct purchase of cowpea from farmers. A similar case was observed with retailers. Other middlemen comprised brokers, agents or "kilograms boys" as referred to in Pallisa district. However, purchases of cowpea were not restricted to one source only. For example, 60% of wholesalers in Pallisa district purchased their cowpea from more than one source (Table 1). The rest purchased directly from the farmers. About 7% of the retailers purchased cowpea from fellow retailers. In both districts, the most important customer to a wholesaler was the retailer. This is usually the case in a normal marketing channel. However, in Pallisa district, middlemen were very important to wholesalers, which was not the case in Soroti district. Overall, the consumer was the most important customer to the retailer. Also, there were indications that inter-trade within channels exists. The results also showed that in either case, traders sold to more than one customer. Also, traders strived to buy from farmers and sell to the consumer. A clearly defined typical food-marketing channel is therefore not evident. It is prompting to suggest that a well-established wholesale structure is not in place under such a marketing arrangement.

According to Singh (1994), wholesale markets play a critical role in efficient allocation of resources, in transmitting price signals to adjust demand and supply, and improving productivity and competitiveness. Additionally, as stated in MAF (1984), an absent wholesale structure prevents the build-up of security and market stabilizing stocks. Such a situation has resulted in supply disruptions and subsequent instability in price as has often occurred in cowpea marketing in the study area.

The cowpea distribution channel was modelled from the results of the district market survey (Fig. 1). There was a clear indication that a strong linkage exists between certain sections of the marketing channels, probably because of differences in marketing margins. For example, producers dealt more

Table 1. Characteristics of cowpea traders.

Item	Description	Respondents (%) (n = 72)	
		Pallisa	Soroti
Sex	Male	97.2	80.6
	Female	2.8	19.4
Age	18 – 25 years	-	11.1
	26 – 30 years	16.7	13.9
	> 30 years	83.3	75
Marital status	Single	5.6	2.8
	Married	94.4	94.4
	Divorced	-	2.8
Education	None	19.4	2.7
	Ended at primary	50.0	50.0
	Secondary	25.0	41.7
	Tertiary	5.6	5.6
Type of traders	Retail	86.1	94.4
	Wholesalers	11.1	16.7
	Dealers	2.8	2.8
Type of business	Sole proprietor	91.7	88.9
	Partnership	8.3	11.1
Type sold	Only cowpea	19.4	5.6
	Also other products	80.6	94.4

with retailers who finally sold to consumers. Wholesaler-consumer linkage was also very strong. Sharma and Prihar (1994) observed this kind of relationship between the strength of the linkage in the marketing channels and the marketing margins. Sharma (1994) reported that net margin were highest in the channel where produce was directly sold to the retailer.

Cowpea losses

Poor storage facilities present a significant obstacle to reasonable price and market stability. In Pallisa, 75% of the traders incurred losses in cowpea marketing, while in Soroti district all traders reported losses in cowpea marketing. The losses were mainly incurred in storage and attributed to insect pests (Table 2) but insect problems were less serious in Pallisa compared to Soroti district. Additionally, price flactuations because of over supply was another important factor causing decline in cowpea production in both Pallisa and Soroti districts.

In Pallisa, traders used insecticides to control pests unlike in Soroti. Some traders were, however, unaware of pesticides, and those who were aware of their availability claimed they were too expensive. Fuglie (1995) in a study on potatoes in Tunisia found that improved pest control during storage, significantly reduced variation in market prices and quantities. A similar strategy in the study districts could possibly reap the same benefits, more especially in Soroti where only limited attention is paid to storage pest problems.

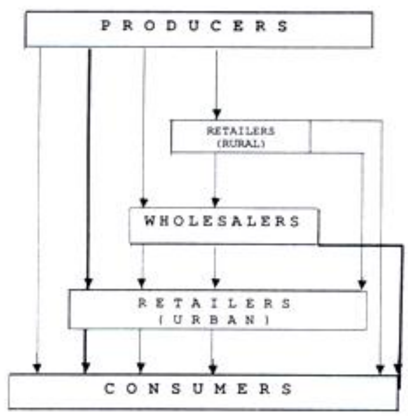

Figure 1. The generalised cowpea distribution channel.

Table 2. Percentage response on cause and frequency of losses in cowpea.

Type and cause of loss		Responses (%)	
Type of loss	Cause	Pallisa	Soroti
Storage	Insect pests	38.9	100
Storage	Rodents	11.1	13.9
Storage	Loss in weight	2.7	2.8
Revenue	Drop in prices	58.3	30.6

Marketing problems

Anumber of marketing constraints were identified and ranked by the respondents as shown in Table 3. In Pallisa, the most important constraint to cowpea trade is fluctuation in demand. This is brought about by the seasonal nature of production. Fluctuation in demand is followed by rapid crop spoilage which leads to losses both in quantity marketed and purchase of agrochemicals. In Soroti, traders considered rapid crop spoilage as the most serious problem in cowpea marketing. As mentioned earlier, traders have not yet entered into the culture of treating grain with pesticides since most of them were not aware or found them expensive. In both districts fluctuating demand and rapid grain spoilage were considered serious problems.

Marketing information

A good internal and external market information system is a prerequisite for effective marketing arrangement as it guides efficient production and resource allocation decisions (King, 1995). In Pallisa District 58 percent of the traders had access to market information compared to 30% in Soroti (Table 4). Devine and Marion (1979) stated that lack of price information results in price dispersion across chains. This is probably the reason why the standard deviation of both farm-gate and consumer prices in Pallisa district were (28.9; 49.5, respectively) smaller than in Soroti (54.7; 56.0 respectively). In a homogenous product market, price dispersion represents an undesirable imperfection in that dispersions in price do not reflect accurately the differences in costs and preferences. When the data were disaggregated, according to marketing channels, it was found that in both districts, wholesalers were more informed of the prices than retailers. Wholesalers, because of their greater mobility, had more information about the market used the opportunity to exploit the other traders and producers.

Means of transport

In both districts, the most important means of transport used by traders to take produce to the market were bicycles. Nearly 74% of traders in Pallisa and 63% in Soroti used bicycles compared to 21% who used vehicles in both districts. Reliance on bicycles permits movement of only small quantities of produce to the market and therefore limits production to subsistence level.

Table 3. Rating of selected cowpea marketing problems in Pallisa and Soroti districts

Marketing problems	Rating (%)	
	Pallisa	Soroti
Fluctuating demand	75	50
Rapid spoilage in store	66.7	77.8
Poor transport	5.6	22.2
Lack of capital	2.8	8.3
High marketing fees	-	5.6

Table 4. Availability of price information among traders.

Market participants	Percentage informed		Percentage not informed	
	Pallisa	Soroti	Pallisa	Soroti
Both wholesalers and retailers	58.3	30.6	41.7	69.4
Wholesaler	60.0	66.6	40.0	33.3
Retailers	12.9	23.3	87.1	76.7

Marketing costs, prices and margins

A number of studies on marketing costs have revealed that transport cost is a major problem in marketing of produce (Mugisha, 1994; Njoku, 1994). Virender and Khatkhar (1994) in their study of marketing of grapes in Haryana observed that transport and packaging material are the major components of the marketing costs. In another study, Sudaryanto (1994) reported that a high marketing margin is primarily due to high transport costs and produce losses. In this study, transport accounted for the highest share of marketing costs followed by storage (Table 5)

Prices and marketing margins

On average, cowpea prices were comparatively higher in Soroti district than in Pallisa (Table 6). The average price difference between the two districts at all levels was Shs. 47.72. In Pallisa average farm gate, wholesale and consumer prices were Ug. Shs. 258; 283 and 331 compared to an average of Ug. Shs. 308; 327 and 380, respectively in Soroti district. As shown in Table 6, retail margins were higher than wholesale margins in both districts and producers in Soroti district earned more returns from their produce than farmers in Pallisa. However, in both districts, the producer took more than half of the revenue. This signifies that the marketing system favoured the farmer rather than the trader.

In India, Kumar (1994) reported higher marketing margins for rice retailers than other market intermediaries. In Haryana, India, Chhikara *et al.* (1993) noted that the producer's share in the consumer's price is only 40%. The cowpea producer is therefore comparatively better off and this supports observation by Sabiti (1995) that production of cowpea is profitable in this region.

Determining the cost-efficient distribution of cowpea using the transportation model

Traders generally aim to maximise profits by minimising costs while rendering good services. Results showed that in the various markets studied, the urban markets of Pallisa and Soroti were major consumers of cowpea. Data from the two districts were combined and analysed using the transportation

Table 5. Marketing costs.

Type of marketing cost	Pallisa		Soroti	
	Average	%	Average	%
Transport	21.2	36.0	16.5	33.5
Storage	19.8	33.6	-	0.0
Produce preparation	8.0	13.7	2.8	5.7
Handling costs	3.3	5.7	14.3	29.1
Packaging	2.7	4.6	7.4	15.0
Marketing fees	3.8	6.4	8.3	16.7
Total	58.9	100.0	49.3	100.0

Table 6. Producer shares and marketing margins in cowpea grain trade.

Item	Share (%)	
	Pallisa	Soroti
Producer share	78.1	81.0
Wholesale margin	7.7	5.2
Retail margin	14.3	14.0

model with the objective function being the minimisation of costs subject to the various structural constraints. The data used are shown in Table 7, and the optimal solution is given in Table 8.

The optimal solution from the model indicates that if distribution is done efficiently, cowpea trade in the region can be achieved at a minimum cost of Ug. Shs. 5,865,416. However, given the prevailing distribution plan used by the cowpea traders, cowpea distribution was done at a cost of Ug. Shs. 6,476,458. This means that the current performance is 10% more costly. Reorganising of the cowpea distribution routes could rectify this difference by minimising distribution cost and addressing other constraints such as high cost of transport, handling, crop spoilage, packaging costs and inadequate infrastructure.

There were significant differences in distribution of cowpea from various sources to destinations. For example, Soroti market received cowpea from eleven sources, yet for cost minimisation, it could be supplied by seven only. On the other hand, two sources from Pallisa district (Pallisa and Butebo), supplied two markets in Soroti District. For optimality, only Butebo could supply the Soroti market. The randomness in the existing distribution pattern can be attributed to the fact that traders mainly deal in small quantities and use own bicycles to transport the produce in which implicit costs are not accounted for by the traders.

The results shown in Table 7 indicate that Katakwi zone supplied 1164 kg of cowpea to four markets, 125 kg to Ocorimongin, 147 kg to Usuk mission, 772 kg Soroti and the rest to Wera. However, based on the model, in order to minimise marketing costs, all the supply from Katakwi should go to Soroti market, which is much further than the rest. This is plausible, since most cowpea from Katakwi reaches Soroti on vehicles, which is comparatively a cheaper means of transport compared to bicycles with small loads that dominate the distribution of cowpea to other markets. On the other hand, Usuk zone supplies 1053 kg to three markets, Ocorimongin 330 kg, Usuk mission 293 kg and the rest to Soroti market. For efficiency, the model suggests that 93% of this should be supplied to Ocorimongin, which is another conduit to the Soroti market and the remainder should be sold at the local market (Usuk mission).

Another important source of cowpea, Orungo zone supplies 1032 kg to six markets Ocorimongin 168 kg, Orungo 235 kg, Soroti 204 kg, Tubur 150 kg, Katine 135 kg and Usuk Mission 140 kg. The model suggests that, two markets should be supplied; 621 kg to Katine and 411 kg to Orungo market. Most of the cowpea is again sent to the furthest market. Similarly, Asamuk zone supplies 1138 kg of cowpea to seven markets, Soroti market receiving 33.7% and the largest share from all the markets. The model again reduces the destinations to only three Soroti markets, furthest away takes the largest share of 51.4%.

Pallisa zone, the biggest supplier of all the sources with 2992 kg, supplies to seven markets, two in Soroti district and five in Pallisa district. In all 36.7% was supplied to Soroti while 63.3% remained in Pallisa district. The model suggests that this zone supplies only four markets and that all cowpea remains in Pallisa district. Another important source of cowpea, Butebo zone supplies 1862 kg to six markets, five in Pallisa district and one in Soroti district. According to the transportation model, this source should supply to only two markets, one in Soroti district (76.7%) and the rest to one market in Pallisa district. The rest of the four supply zones in Pallisa district, Agule, Ikiiki, Putiputi and Apopong supply on average 3 markets in Pallisa district, and should continue supplying only to Pallisa market. This is irrespective of the fact that the costs incurred in supplying these markets are relatively higher.

It is therefore evident according to the model that higher savings from supplying other markets compensate the high costs normally incurred supplying these markets. For example, according to the current distribution network, it costs Ug. Shs. 284,618; 399,080; 287,540 and 405,532 to supply Ikiiki, Kameke, Kanyum and Kamuge markets, respectively. According to the model, costs can be reduced and savings of up to 9% and 4% can be made from supplying Ikiiki and Kameke markets, respectively.

Admittedly, there are various goals in trade in addition to minimising costs/maximising returns such as satisfying consumer utility, and keeping in business even if there are zero profits (Livesey, 1989; Derbertin, 1992). Therefore traders still maintain certain routes although they are making losses as long as they satisfy these other goals.

Table 7. Raw data for transportation model.

Source of cowpea	Orungo	Ocorimongin	Usuk Mission	Soroti market	Tubur	Katine	Wera	Pallisa market	Ikiiki	Kameke	Kanyum	Kamuge	Total supply (kg)
Katakwi		$125^{381.11}$	$147^{335.67}$	$772^{334.24}$			$120^{330.85}$						1164
Usuk		$330^{329.14}$	$293^{342.31}$	$430^{352.88}$									1053
Wera	$150^{354.85}$	$200^{355.00}$		$640^{356.23}$		$155^{334.55}$	$300^{307.00}$						1445
Orungo	$235^{344.67}$	$168^{370.33}$	$140^{369.33}$	$204^{366.53}$	$150^{365.23}$	$135^{353.55}$							1032
Asamuk	$140^{354.80}$	$155^{356.60}$	$80^{357.00}$	$383^{357.00}$	$105^{356.74}$	$125^{355.40}$	$150^{312.36}$						1138
Otuboi	$66^{344.95}$			$356^{334.55}$	$68^{366.08}$								579
Kaberemaido				$565^{265.02}$									565
Kyere				$327^{394.04}$									327
Gweri				$2347^{341.84}$	$50^{343.24}$	$147^{342.65}$							2544
Pallisa				$847^{366.56}$		$250^{373.89}$		$1056^{312.95}$	$308^{293.90}$	$156^{307.90}$	$150^{309.95}$	$225^{311.85}$	2992
Butebo				$332^{263.88}$				$477^{322.75}$	$227^{271.30}$	$144^{296.88}$	$350^{293.88}$	$332^{294.60}$	1862
Kameke								$792^{322.85}$		$546^{290.52}$	$130^{324.40}$	$175^{323.00}$	1643
Agule								$615^{320.72}$		$166^{320.72}$	$155^{321.80}$	$135^{320.95}$	1071
Ikiiki									$220^{379.42}$				220
Putiputi								$470^{319.60}$	$153^{320.52}$	$80^{299.90}$	$126^{294.75}$	$270^{293.80}$	1099
Apopong								$500^{319.95}$		$224^{323.40}$		$180^{324.33}$	904
Total demand (kg)	591	978	660	7203	373	901	570	3910	908	1316	911	1317	19638

Note: The superscripts represent per unit costs (Ushs) to a given market from the respective source

Overall, the model seems to direct that the marketing of cowpea be confined to the respective districts with minimal inter-region trade although much of it must be taking place alongside the borders. This is logical, because bicycles are the main source of transport, and this is relatively expensive over long distances. Long distance haulage only becomes inexpensive when vehicles are used.

An efficient marketing system for agricultural products is important if a country is to move from a subsistence economy to a commercial based one.

A clear difference was observed between optimal and current level of operation hence the need to reorganize cowpea distribution if traders are to minimize costs. A number of marketing constraints were identified which accounted for the high costs currently incurred. These included high crop spoilage, costly handling and packaging, marketing fees and inadequate infrastructure. These factors could explain the 10% difference between the optimal level and current level of operation. At both wholesale and retail levels transport costs are the major marketing costs. Fluctuating in cowpea supply is also responsible for instability in cost outlays and prices in cowpea marketing. The cowpea marketing structure is generally competitive with many buyers and sellers and a price structure which varies from market to market in the districts. Lack of working capital may explain why most traders handle small amounts of cowpea traded at the markets. Based on the results of this study the following recommendations can be made:

1. Transport costs which are a major handicap to an efficient distribution of cowpea from producers to major markets could be reduced by handling produce in bulk and using vehicles over long distances.

2. Improved storage facilities should be promoted at both producer and trader level in order to increase the shelf life of cowpea and avoid supply disruptions during off-season. Additionally, use of safe pesticides for storage should be encouraged.

3. Policies should be put in place to give credit facilities to support cowpea traders so as to break the working capital constraint. Loan availability should be accompanied by conducive borrowing environment that includes manageable interest rates.

4. Lack of sufficient information about cowpea markets has largely confined the consumption and marketing of this crop to the north and north-east. There is therefore need to collect and disseminate information on cowpea prices, market and costs incurred, demand and potential use.

5. The revelation in this study that cowpea farmers in the study area realised the highest share of the consumer price is a production incentive in itself and should prevail in the search for optimal distribution of cowpea.

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Characterising low production patches in cropped fields of the Kigezi highlands, Uganda.

M.A. Mateete Bekunda and G. Manzi†
African Highlands Ecoregional Programme and Tropical Soil Biology and Fertility Programme, P.O. Box 239, Kabale, Uganda
†Department of Soil Science, Makerere University, P.O. Box 7062, Kampala, Uganda

Abstract

Intensification of land use has led to land degradation over much of the African highlands. One of the indicators of this degradation are the low production patches of land within cropped fields that have captured farmers' attention and desire for special know-how on their management. The farmers of the Kigezi highlands in south-western Uganda have a local name, *Ebeija*, describing the condition of crops growing on these land patches, and relating this condition to soil fertility. Soils from selected low production patches of land in the Kigezi highlands were characterised for their nutrient status by chemical analyses of soil and plant tissue samples, and the limiting nutrient approach in pot and field trials so as to identify the potential soil management needs for these patches. Nutrient concentration levels in soils and bean (*Phaseoulus vulgaris* L.) foliar tissues indicated that potassium was the deficient nutrient, averaging 0.23 cmol kg^{-1} and 0.94%, respectively. The limiting nutrient studies indicated best crop yield response (up to 156%) from the combined application of potassium, phosphorus and micronutrients. In smallholder farming systems, such nutrient combinations can best be achieved through integrated fertiliser management.

Key words: Bean, farmers, land patches, limiting nutrients, low fertility, potassium

Introduction

Intensification of land use in the East African Highlands in the absence of external nutrient inputs has led to soil nutrient depletion and land degradation mainly through the processes of erosion and harvest removal. Because of their mountainous nature, the nutrient depletion rates in the highlands probably exceed the depletion rate estimates for East Africa of 40 kg N, 7 kg P and 25 kg K ha^{-1} yr^{-1} (Stoorvogel and Smaling, 1990). The farmers of the Kigezi highlands have also recognised that the degree of soil fertility depletion within farms is variable and may result in patches of land within farms that are less productive (Anon., 1999). *Ebeija* is a local name used to invariably describe the stunting and yellowing appearance of crops growing on such lands or the infertility status of the soils themselves. Perhaps *ebeija* is equivalent to *Lunnyu* soils, a Luganda version describing patches of unproductive land recorded as early as 1954 to be common in Ssese Islands, Lake Victoria Crescent, Kigezi, Ankole and Busoga (Chenery, 1954). Similar low fertility land patches have been described in the western Kenya farming systems (Woomer *et al.*, 1998).

Rehabilitation of such low fertility areas by the smallholder farmers has predominantly depended on nutrient resources recycled within farm. There is growing interest in biological alternatives that can augment these resources, occasional supplementation with inorganic fertilisers, and also strategies of managing (integration) these resources to optimise crop response from them. This requires good diagnosis of the nature and extent of the problem. We, therefore, applied established methods of determining crop nutrient requirement including soil and plant tissue analyses, greenhouse and field

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experiments (Davidescu and Davidescu, 1982; Colwell, 1994) to determine the nutrient(s) that limit crop productivity in the low fertility patches.

Materials and methods

The impact of ebeija on yield

Land identified as having typical low fertility patches was prepared using the handhoe, sub-divided into twenty seven plots of 4.5 x 4.5 m each and planted to beans (var. K132) at a spacing of 50 x 10 cm. It was envisaged that the effect of soil fertility constraints on crop growth and yield would be variable in the different plots but that the relationship needed to be established. At pod formation (stunting, yellowing and curling of leaves, limited poding), when the *ebeija* symptoms are most prevalent, the affected beans per plot were counted and later plotted against the bean seed yield. *Rhizoctonia* root rot, which is common in the area and causes similar symptoms to beans as *ebeija*, was determined by recording lesions and cankers on lower stems of ten randomly selected plants in a plot. It was found to be minimal (0.9% infection).

Soil and plant tissue characterisation

Soil and bean leaf samples were obtained from 13 *ebeija* sites. At each site, six auger soil samples were taken randomly from bean fields and with low soil fertility patches to a depth of 20 cm and mixed into a composite sample. About 1 kg of the composite sample was processed for analysis according to Anderson and Ingram (1993). From the same low fertility patches, fully expanded upper leaves were randomly taken at flowering from several beans exhibiting *ebeija* symptoms, dried in the oven at 65°C for 48 hours, and ground to pass a 1 mm mesh. Samples were analysed for different nutrient elements at the Tropical Soil Biology and Fertility Programme's analytical laboratories in Nairobi.

Limiting nutrient pot trial

The study was conducted at Makerere University Agricultural Research Institute, in a glasshouse under natural conditions (light, temperature, humidity). The soil used in the study was from Rubaya, Kabale district, sampled from three *ebeija* sites, mixed, air dried, sieved (<2 mm), mixed with quartz sand in a ratio of 3:1 (soil:sand) and transferred to plastic pots (3 kg pot^{-1}). The trial consisted eight treatments; a control and nutrient elements (added at 50 kg ha^{-1}) being N, P, K, N+P, N+K, P+K and N+P+K, and replicated 8 times. The fertilisers were weighed and thoroughly mixed with the soil before potting. Four maize seeds (cv Longe 1) were planted in each pot, and the seedlings thinned to 2 per pot at two weeks after germination.

Moisture was maintained near field capacity by weighing and replacing the deficit with distilled water. However, four replicates also received weekly 20 ml aliquots of the Broughton and Dillworth nutrient solution (Somasegaran and Hoben, 1985), free of N, P and K.

Shoots were harvested by cutting 10 mm above the soil surface, after 10 weeks of growth. Samples were oven dried at 65°C for 48 hr and weighed to determine biomass. A second crop of maize was planted in the same pots without soil disturbance, to determine the residual effects of the treatments under similar management to that of the first crop.

Limiting nutrient field experiment

The study was conducted in Rubaya sub-county, Kabale district, south-western Uganda from February to December 2000. Kabale district lies approximately between latitudes 1°00' and 1°30'S, and longitudes 29°18' and 30°09'E, at an altitude of between 1500 – 2750 m above sea level. The mean annual rainfall ranges between 1000 and 1500mm in a bimodal distribution with peaks in March to April and October to November, allowing for two cropping seasons in a year. Average temperature ranges between 9 and 23°C (Kabale District Meteorological Office, 1999).

Like the rest of other parts in the district, Rubaya is made up of undulating hills with steep convex slopes of 10 – 60° with gentle (5 – 10°) foot slopes. About 10% of the cultivated area is on slopes of more than 20° (Lindblade *et al.*, 1996). The soils on these slopes are predominantly (>70% coverage) ferralitic sandy clay loams (Harrop, 1960). Historically, farmers have practiced terracing (Lindblade *et al.*, 1996) to counter the erosional effects of cropping on steep slopes. During the first rains of 2000 (season 1), treatments similar to those applied in the glasshouse experiment were also applied to six farmers' *ebeija* fields but without a micronutrient treatment. The farm fields constituted the replications. Fertilisers were spread by hand on the seedbeds and incorporated into the soil using a handhoe. Common bean (var. K132) was used as the test crop; it was planted in rows at a spacing of 50 by 10 cm. Plot sizes varied depending on the size of the low fertility patches, from 8 to 20m^2. The crops were weeded twice. During the second season, only the treatments involving the nutrient combinations (N+P, N+K, P+K, N+P+K), and the control, were applied to fresh fields.

Results

The impact of ebeija on yield

The relationship between yield and the number of plants exhibiting *ebeija* symptoms was significant (Fig.1); the yield declined sharply to less than 50% of that obtained in the plots without *ebeija* with about 10% of the plants bearing visual symptoms, and then gradually stabilising at about 30%.

Soil and plant tissue characteristics

The results in Table 1 show variation in ranges of the major soil nutrients determined. Potassium (K) was the only nutrient whose mean value was less than the critical value (only one sample had a value above the critical value) suggesting that K could be the limiting nutrient in the low fertility patches. Bean leaf sample analysis yielded K content values that were in the deficient range while P and N values were adequate (Table 2).

Pot trial

For the first crop, significant yield increases were obtained with fertiliser P, but were enhanced further by fertiliser P plus K (Fig. 2A). The effect of micronutrients was significant ($P<0.05$) and appeared to be more pronounced in the treatments where the plants responded to macronutrients. There were no

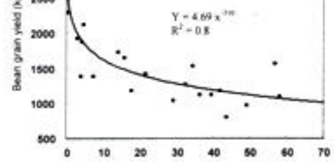

Figure 1. Relationship between bean grain yield and percent of bean plants with ebeija symptoms.

significant residual effects of the treatments (second crop, Fig. 2B). Here, the response to micronutrients was not residual because they continued to be applied.

Field trial

Treatment effects on bean yield were not significant in the first season (Table 3) but significant yield increases resulted from treatments with K and P combinations in the second season trial.

Discussion

In East Africa, the near universal response of crops to nitrogen and widespread deficiencies of phosphorus have led to the belief that these are the most severely depleted nutrients (Lekasi, 1998;

Table 1. Chemical characteristics of soils from the low fertility patches.

Characteristic	Mean value	Range	Critical value*
pH	5.3	4.5 - 6.0	5.5
Exchangeable calcium (cmol$_c$ kg^{-1})	6.1	3.3 - 7.7	2.6
Exchangeable magnesium (cmol$_c$ kg^{-1})	2.2	0.8 - 3.1	0.3
Exchangeable potassium (cmol$_c$ kg^{-1})	0.2	0.1 - 1.0	0.5
Extractable phosphorus (mg kg^{-1}	7.7	2.8 - 19.8	5.0
Organic carbon (%)	2.5	1.2 - 3.5	1.5
Total soluble nitrogen (%)	0.28	0.15 - 0.35	0.12

*Source: Okalebo *et al.*(1993); the cut off value between the low and medium rating was adapted as the critical value.

Table 2. Chemical characteristics of leaves from bean plants growing on low fertility patches.

Characteristic	Mean value	Range	Critical value*
Nitrogen (%)	5.24	4.54 - 6.20	3.5
Phosphorus (%)	0.48	0.36 - 0.57	0.3
Potassium (%)	0.94	0.57 - 1.56	3.0
Calcium (%)	2.05	1.07 - 3.26	0.8

*Source: Okalebo *et al.* (1993).

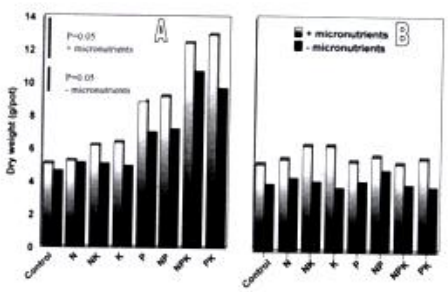

Figure 2. Growth response of maize ***seedlings to N, P, and K with and without micronutrients*** *in first (A) and second (B) crops.*

Woomer *et al.*, 1998). Indeed, rehabilitation of low fertility patches in the western Kenya highlands is based on a fertiliser kit formulated to restore fertility by contributing P from a Tanzanian phosphate rock and nitrogen from urea and rhizobial inoculants (Woomer *et al.*, 1998). For long, potassium application to soils has received least attention of the three major fertiliser elements.

The different methods used to characterise the low soil fertility patches suggest that the limitation to soil productivity on *ebeija* sites is a combination of K, P and micronutrients. In fact, the application of K alone may not result in appreciable crop responses, leading to increased yields even when limiting (as seen from soil and plant tissue analyses results), in conditions where it affects uptake of other nutrients (Anderson, 1972). This makes sense considering that farmers participating in the study claimed to have obtained yield responses on these sites with diammonium phosphate (DAP) fertiliser only when it was applied together with high rates of livestock manure. The DAP alone supplied N and P while the manure was a source of other nutrients, including potassium and micronutrients. But the use of high rates of manure in the highlands cannot be a widespread option given a limited livestock ownership rate of around 1-2 cattle per farm (Olson, 1995). The need for supplementary inorganic fertilisers is likely to increase. The analysis results of *Lunnyu* soils reported by Zake (1986) also showed potassium and phosphorus to be below the limiting nutrients for Ugandan soils.

Earlier studies indicated potential areas where potassium deficiency was to be expected as being on very sandy, very acid or calcareous soils (Evans and Mitchell, 1962; Anderson, 1967; Lock, 1969). The soils of the Kigezi highlands are acidic (Table 1), are continuously cultivated, receive high rainfall (>1000 mm per annum) and consequent greater leaching, all of which are conducive to potassium shortage. The test crops used in this study were responsive to this shortage but crops with relatively low nutrient demand may not act as indicator crops in the field. Soil and plant tissue analyses remain faster techniques for identifying limiting nutrients and correcting deficiencies before crops mature. In East Africa, early attempts to correlate soil analyses with crop response were mainly with phosphorus (Foster, 1972) and nitrogen (Robinson, 1968). It was observed that since the coefficients of variation with regard to nitrogen and potassium analysis in leaf tissue were low, this offered a useful guide to these nutrient requirements in crops (Robinson and Freeman, 1967). The introduction of high yielding but more nutrient-demanding crop varieties, increasing cropping intensity and improved cultural practices will probably result in an increase in demand for nutrients. The new developments and adaptations in analytical techniques (e.g., Anderson and Ingram, 1993) need to be considered and related to plant responses as a cheaper means of defining the constraints of the affected soils, increasing our knowledge of nutrient removal by crops, and applying of appropriate nutrient inputs to overcome the constraints.

Table 3. Bean yield response on ebeija sites to applied nutrients.

Treatment	season 1 yield t ha^{-1}	season 2 yield t ha^{-1}
Control	0.58	0.54
Nitrogen (50 kg ha^{-1})	0.55	nd
Phosphorus (50 kg ha^{-1})	0.53	nd
Potassium (50 kg ha^{-1})	0.69	nd
N + P	0.58	0.73
N + K	0.70	0.67
P + K	0.73	0.93
N + P + K	0.89	0.94
LSD(5%)	ns	0.21

nd, not determined; ns, not significant.

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Evaporation measurement and validation of meteorological models

E.J. Wasige, M.M. Tenywa, J.B. Byalebeka†, J. G. Majaliwa and A. Lufafa
Department of Soil Science, Makerere University, P.O. Box 7062, Kampala, Uganda
†NARO, Kawanda Agriculture Research Institute (KARI), P.O. Box 7065 Kampala, Uganda

Abstract

Identification of the best-fit meteorological model for evaporation measurement in a particular agroecological zone is a pre-requisite for cost-effective land management. A simulation experiment was conducted at Makerere University with the objective of determining the best-fit model for estimating evaporation. Meteorological data was collected from Makerere Meteorological Station and applied to different models to estimate potential evaporation. Actual evaporation from three mini lysimeters was used to validate models. Actual evaporation from the lysimeter varied between 2.6 to 6.73 mm day^{-1}. Results showed that measured actual evaporation was greater in the afternoon than in the mornings and varied significantly ($P<0.05$) over days. After a linear regression analysis of measured actual evaporation against estimates from meteorological models, models were ranked in the order of best fit as Priestley and Taylor, Makkink, Abtew, Hargreaves, Romanenko, Penman, Turc, CROPWAT, and Penman-Monteith.

Key words: Actual evaporation, land management, lysimeter, simulation, Uganda

Introduction

Evaporation is a key element in the water balance (Stroosnijder, 1987). Excessive evaporation contributes significantly to moisture deficit in agricultural production and thus reduces food production. Evaporation measurement in a particular agroecological zone is a pre-requisite for proper land management. Meteorological models provide the fastest and the cheapest method of estimating evaporation because they do not involve soil-plant complexities. Mini lysimeter measurements of evaporation can be used to validate models to be used for field evaporation estimates (Boast and Robertson, 1982; Stroosnijder, 1987). Although the necessary equipment are available, these studies have not been conducted in Uganda. Thus, this study was conducted to avail information for evaporation measurements and validation of meteorological models.

Materials and methods

Experimental site

The experiment was conducted at Makerere University, Kampala. The site is located between latitude 0° 19'E and longitude of 32°34'E and at an elevation of 1200 m a.s.l. Three simple mini lysimeters (Trambouze *et al.*, 1998) each of base 30x30 cm and 50 cm high were constructed. In order to reduce weight, the lysimeter frame was made of plastic sheets reinforced with metallic angle bars on the sides. The base of the lysimeter was perforated to allow free drainage. The top part of the lysimeter was open to air and covered only whenever there was a rainfall incidence. Each lysimeter was filled with 56kg sandy clay loam (sand 54%, clay 22% and silt 24%). The experiment was conducted during the month of July 2001. Data were analysed using two way ANOVA procedures in Genstat statistical package.

Measurements

The soil in lysimeters was slowly brought to saturation (water added until it starts to drain from the bottom) and allowed to drain for 24 hours to field capacity (Klute, 1986). During the experiment, lysimeters were exposed to sunshine and weights taken at 8.00 am, 1.00 pm and 6.00 pm using a weighing balance of 50 g sensitivity. The soil moisture content in the lysimeter was restored to field capacity every evening by adding the amount lost through evaporation. The daily actual evaporation rate was determined by dividing volume water (cm) lost through evaporation and lysimeter surface area. Atmospheric physical parameters (maximum and minimum temperature, wind speed, relative humidity and sunshine hours) for the month of July 2001 were collected from Makerere meteorological station. At Makerere meteorological station, wind speed is measured using a cup-counter anemometer exposed at a standard height of 2 m. Air temperature and humidity observation were measured at height of 2 m using maximum and minimum thermometers and dry – bulb and wet- bulb thermometers, respectively. The campbell-stokes tropical sunshine recorder was used to record sunshine hours. This instrument is exposed in sectors N.E. to S.E. and S.W to N.W. and the main base mounted at 1.22 m. Nine meteorological methods (Abtew, Hargreaves, Makkink, Priestley and Taylor, Turc, Romanenko, Penman, Penman-monteith and Penman-Monteith FAO CROPWAT software of version 5.7, Oct. 1991) were tested.

Best fit model selection criteria and model ranking

Nine meteorological models were tested in this study with the objective of establishing the best-fit model. The models were; Abtew, Hargreaves, Makkink, Priestley and Taylor, Turc, Romanenko and Penman (Xu and Singh, 2000), Penman-Monteith and CROPWAT. These models are elaborately described by Makkink (1957) and FAO (1998).

The best model was selected on the basis of unbiased and high precision. The bias was assessed by examining the value of the slope (a) and intercept (b), of the regression between observed and estimated values. Precision was assessed using standard error (S.E) and determination of correlation coefficient, r for each model. For the ideal model, $a= 1$, $b =0$ $S.E = 0$ and $r = 1$ (Majaliwa, 1998). The models were ranked after a comparison of mean values of the above four parameters for each model in terms of closeness to ideal values. The best model was given a ranking value of 1.

Results and discussion

The results indicated that evaporation significantly ($P<0.05$) varied with time of the day, and over the days. Evaporation in the afternoons (1.00 p.m-6.00 p.m.) was generally higher than that in the mornings (8.00 a.m-1.00 p.m.). This could be explained by the diurnal variation of temperature since there is a strong agreement between daily air temperature and evaporation (Xu and Singh, 1998). At mid-day (12.00 pm), the sun is at its maximum elevation and the maximum amount of solar radiation is being received. Due to the atmosphere being heated from below by the slow process of conduction and convection, a delay of between two or three hours after mid-day generally occurs before the maximum air temperature and maximum evaporation are reached. The maximum temperature therefore occurs in the afternoons (Mwebesa, 1970) and hence maximum evaporation. For two groups of the pairwise (1, 4, 5 and 2, 3, 4), a significant difference ($P<0.05$) was observed for daily evaporation (Fig. 1).

The models were significantly different ($P<0.05$) with respect to the slope (Table 1). The best-fit models are; Priestley and Taylor, Makkink, Hargreaves, Abtew, Romanenko, Penman, Turc, CROPWAT, and Penman- Monteith respectively. The models can also be classified in two groups of

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Effect of selected preservation methods on the shelf life and sensory quality of 'Obushera'

Y. B. Byaruhanga and M. Ndifuna
Department of Food Science and Technology, Makerere University,
P. O. Box 7062, Kampala, Uganda

Abstract

'Obushera' is a predominantly lactic acid bacteria fermented gruel produced from sorghum and or millet flour, whose shelf life is limited to 1 - 2 days. A study aimed at exploring possibilities of extending the shelf life of 'obushera' with least effect on its quality characteristics was conducted. Sorghum grains were germinated, dried and ground into flour, which was used to produce porridge. This porridge was then fermented, into 'obushera', for 48 h with previously made 'obushera' as a starter. The 'obushera' was divided into four portions each of which was subjected to one of the following treatments: pasteurisation, refrigeration, pasteurisation combined with refrigeration and a control. The treated 'obushera' was analysed for pH, alcohol content, total acidity, lactic acid bacteria counts and yeast counts at two day intervals during storage. The acceptability of the 'obushera' subjected to the different treatments was evaluated using a 25 member panel. Pasteurisation stopped the fermentation process by reducing the number of lactic acid bacteria and yeasts to almost undetectable levels. It also increased the shelf life of 'obushera' from 2 days to over one month. Refrigeration only slowed down the rate of fermentation and subsequent deterioration of the 'obushera'. The refrigerated porridge became unacceptable by the eighth day. There was no significant difference in quality of 'obushera' treated with pasteurisation alone and that subjected to pasteurisation combined with refrigeration. The sensory evaluation results showed that the pasteurised 'obushera' was acceptable. The results show that it is possible to increase the shelf life of 'obushera' beyond the traditional two days with little adverse effects on its sensory properties using pasteurisation at 78°C for 10 minutes.

Key words: Cereal beverage, fermented, sensory evaluation, Uganda

Introduction

Lactic acid fermentation of foods is widely practised in Uganda as a household-level technology to process and preserve a number of products. One such products is 'obushera'. 'Obushera' is a sweet and sour non-alcoholic beverage popular among the people of south, west and central Uganda. It is consumed as a refreshing drink and a weaning food. 'Obushera' is prepared by mixing pre-germinated sorghum or millet flour in warm water to make a slurry of 8 to 10% solids (w/w) to which previous 'obushera' or pre-germinated flour is added to initiate the lactic fermentation. The traditional processing and properties of 'obushera' have been reviewed by Muyanja (2001). Today, there are a number of small enterprises that engage in the production and sale of 'obushera'. With increasing urbanisation and industrialisation, it has become necessary to improve the production process and increase the shelf life of 'obushera'.

Most of the work done on 'obushera' and related fermented gruels has concentrated on the microbiology and nutritional aspects of the products (Muyanja, 2001; Lorri, 1993). Halm *et al.*, (1993), Lorri and Svanberg (1993) and Mbugua (1984) reported that these products are predominantly lactic acid fermented although yeasts are involved as well. Earlier findings indicate that lactic acid fermented cereals have improved safety due to the production lactic acid and other antimicrobial agents

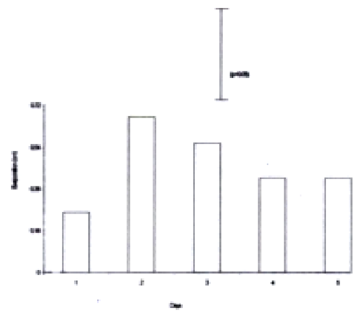

Figure 1. Mean evaporation for five days.

Table 1. A summary of means for slope (a), intercept (b), Standard Error (S.E), and correlation coefficient (r) for regression of 5 days of evaporation from 3 mini lysimeters with potential evaporation from meteorological models with.

Model	Intercept (b)	Standard error (s.e)	Correlation coefficient (r)	Slope (a)	1-a	Best fit model
Makkink	0	0.353	0.563	1	0	1
Priestley & Taylar	0.01	0.193	0.663	1	0	1
Hargreaves	-0.02	0.197	0.567	1.02	0.02	3
Abtew	0.05	0.197	0.563	0.95	0.05	4
Romanenko	0.17	0.277	0.283	0.82	0.18	5
Penman	0.16	0.35	-0.073	0.82	0.18	5
Turc	-0.04	0.227	0.443	0.74	0.26	7
CROPWAT	0.02	0.227	0.453	2.78	1.78	8
Penman-Monteith	-0.04	0.207	0.547	3.2	2.2	9
LSD(0.05)	ns	ns	ns	1.67	ns	

ns = Nonsignificant

no pairwise significant difference as; group one (Makkink, Priestley and Taylar, Hargreaves, Abtew, Romanenko, Penman, and Turc), and group two (CROPWAT, and Penman- Monteith).

Conclusion

Evaporation in the afternoon was greater than in morning. Nine models were evaluated in this study using meteorological data from Makerere university weather station. Priestley and Taylor and Makkink models have been found to be the best models.

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(Byaruhanga *et al.*, 1999; Kingamukono *et al.*,1994; Olsen *et al.*, 1995; Svanberg *et al.*,1992). Some other bacterial species e.g., *Bacillus* species and coliforms have been implicated in the spoilage of fermented cereal gruels (Lorri, 1993; Holzapfel, 1984). Little work, however, has been done on the product shelf-life and manufacturing practices yet these are important to the small enterprises that deal in these products. A major problem facing the producers and consumers of 'obushera' is its short shelf life. Traditionally, a batch of 'obushera' product has to be consumed within 1-2 days of its production. This is because beyond this period, the fermentation process continues into the alcoholic stage and the product becomes too sour, which is undesirable. To extend the shelf life of 'obushera', the processing method (s) should stop the fermentation and also preserve the product without adversely affecting its quality.

Pasteurisation and chemical preservation have been used to preserve food singly or in combination. Efiuvwevwere and Akoma (1997) used pasteurisation and chemical preservation to extend the shelf-life of kunun-zaki, a Nigerian fermented cereal gruel. Gimbi *et al.* (1997) used pasteurisation alone to preserve a fermented millet-based weaning gruel. Chemical preservation alone however, did not yield good results mainly because it does not stop the fermentation process. Producers of 'obushera' in urban areas in Uganda use refrigerators for storage, however, this does not stop the fermentation process. Low temperatures just slow down the fermentation process. Thus, with time the product becomes too sour and alcoholic. Very little information exists in literature on the improved production and preservation of 'obushera'. This work was undertaken to provide recommendations with regard to extension of the shelf life of 'obushera' using pasteurisation while optimising the product quality.

Materials and methods

Samples and preparation

The production of 'obushera' used in this study was based on the traditional process. Red sorghum grains were purchased from a market in Kampala. The grain was screened to remove dirt and chuff. The sorghum grain was then kept on a damp cotton cloth covered with banana leaves for three days. This allowed germination of the seeds. The germinated grain was sun dried on stainless steel trays. The dry germinated grain was then gently pounded in mortar, with a pestle, to separate the grain from the germinated roots. The pounded grain was winnowed to retain clean grain. The clean grain was then milled into a flour using a hammer mill.

Preparation of 'obushera' base

Sorghum flour was mixed with hot water in the ratio of 1:4 (flour:water) in the following order: the flour was first mixed with a small amount of cooled water to form a slurry to which the rest of boiling water was added to make 12 l of the flour-water mixture. The mixture was left to stand for about 5 minutes, this was then referred to as 'obushera' base. Two batches of the 'obushera' base were prepared.

Preparation of starter culture

To start the fermentation, pre-germinated sorghum flour was added to each of the two batches of 'obushera' base at a rate of 5% (w/w) of the sorghum flour. The mixture was thoroughly stirred and fermented at ambient temperature (25 - 28°C) for 48 h to yield duplicate batches of 'obushera' culture. The preliminary 'obushera' cultures were recycled in 'obushera' base at an inoculation rate of 5% (v/v) followed by incubation at ambient temperature for 48 h. This procedure was repeated four times leading to duplicate batches of obushera culture hereafter referred to as starter culture.

Preparation of obushera

The 12 l of 'obushera' base were left to cool to a temperature below 35°C. The cool 'obushera' base was then inoculated with 5% (v/v) starter culture and left to ferment for 48 h at ambient temperature (25 - 28°C) to yield 'obushera'. The resultant 'obushera' was subjected to the treatments described below.

Treatments

All batches of 'obushera' were packed and sealed in clean and sterile 250 ml glass bottles. The first was kept on the shelf at ambient temperatures (25 – 28° C). This served as the control. The second batch was kept in a refrigerator (7°C). The third batch was pasteurised by the following procedure. The filled bottles were put in a hot water gyrating bath. The internal temperature of 'obushera' was monitored with a mercury thermometer. When the internal temperature of 'obushera' in the bottles reached 78°C, the bottles were sealed and held at that temperature for 10 min. This was to allow for pasteurisation of this batch of 'obushera'. The 'obushera' was cooled, immediately after pasteurisation, by putting the jars in a gyrating cold water bath. This batch was then kept on a shelf at ambient temperature (25 - 28°C). The pasteurisation at 78°C for 10 min was established in preliminary work (results not shown) which was aimed at optimising pasteurisation conditions. The fourth batch was pasteurised as described above and then kept in a refrigerator at a temperature of 7°C.

Drawing of samples for analysis

At intervals of two days, 2 bottles were taken from each of the treatments for chemical and microbiological analyses.

Chemical analysis

Determination of pH and titratable acid

The pH of 'obushera' was determined using a glass electrode connected to a standard PW9420 pH meter (Philips). Titratable acidity was determined by titrating 10 ml of sample diluted with 10 ml of distilled water against 0.1M sodium hydroxide solution and phenolphthalein as indicator. The titratable acidity was calculated as percent lactic acid (w/w) (Ayebo and Mutasa, 1987).

Determination of alcohol content

The per cent alcohol content (m/m) of 'obushera' was determined using the method described by Kirk and Sawyer (1991) in which results obtained in specific gravity were converted to percent alcohol.

Microbial analysis

The viable colonies of yeasts were enumerated by spread plating 0.1 ml of serial dilutions of the samples onto sterile Potato Dextrose Agar (Oxoid CM139) and incubating at 25°C for 5 days. The number of colony forming units (c. f. u.) per ml of sample were counted and calculated after incubation (Anon., 1987).

The viable colonies of lactic acid bacteria were enumerated by using the pour plate method (Harrigan and McCance, 1976) using 1 ml of serial dilutions of sample on MRS Agar (Oxoid CM361) and incubated at 28°C for 48 h. Typical colonies of lactic acid bacteria were counted. The number of c.f.u. per ml of sample were calculated after incubation (Anon., 1987).

Sensory evaluation

A panel of 25 untrained persons was used to evaluate acceptability of 'obushera' subjected to different treatments using a nine point hedonic scale where scores 1 = Like extremely and 9 = Dislike extremely (Amerine *et al.*, 1965). This was done every two days during the storage period. On the 14^{th} day fresh control and refrigerated 'obushera' were prepared. The porridge was presented to the panellists in cups coded with 3 digit random numbers.

Shelf-life

After monitoring the changes in the stored 'obushera' for 14 days, the shelf-life of the pasteurised 'obushera' was estimated using the equation for the slope of the titratable acid graph $y = mx + c$ where y is the % titratable acid at a given time, m is the slope of the graph, x is the time in days and c is the intercept at the y axis. Since a titratable acid content of 0.95%, often attained in spontaneous fermentations after 96 h, obushera becomes too sour and undesirable, the time taken for the pasteurised 'obushera' to attain 0.95% titratable acid was taken to be the estimated shelf-life of the product.

Data analysis

The microbial counts were converted to Log_{10} c. f. u. /ml. This, together with the chemical and sensory data were subjected to ANOVA using Statistical Package for Social Science (SPSS). Correlations, standard deviations and the least significance difference between means were determined at a probability level of 5%.

Results

There was a general increase in the number of lactic acid bacteria and yeasts with subsequent increase in the amount of titratable acid and alcohol in the 'obushera' during storage (Figs. 1, 2, 3 and 5). Figures 1 and 2 show a reduction in the number of yeasts and lactic acid bacteria upon pasteurisation as compared to the control. There was a concomitant decrease in pH with the increased titratable acid in 'obushera' during storage (Figs. 3 and 4). Alcohol production also increased with the control and refrigerated 'obushera' showing the highest increase (Fig. 5). Acid production and lactic acid bacteria

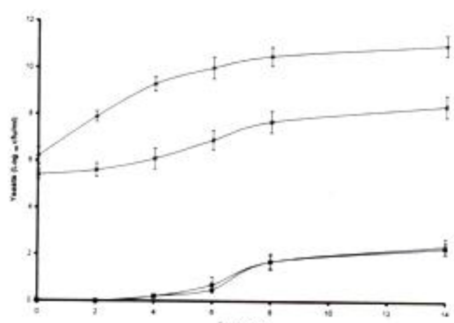

Figure 1. Changes in yeast population of pasteurised (■), pasteurised and refrigerated (▲), refrigerated (X) and the control (◆) 'obushera' during storage. (Error bars are standard deviation).

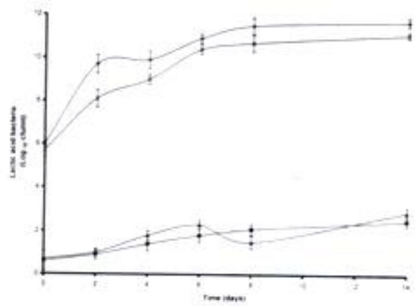

Figure 2. Changes in lactic acid bacteria population of pasteurised (■), pasteurised and refrigerated (▲), refrigerated (X) and the control (◆) 'obushera' during storage. (Error bars are standard deviation).

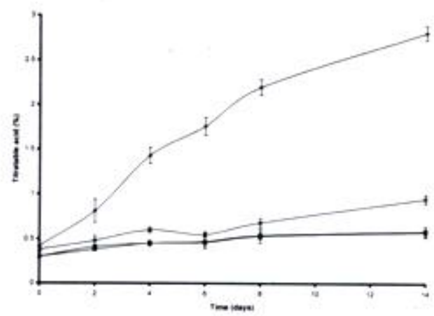

Figure 3. Changes in the % titratable acid of pasteurised (■), pasteurised and refrigerated (▲), refrigerated (X) and the control (◆) 'obushera' during storage. (Error bars are standard deviation).

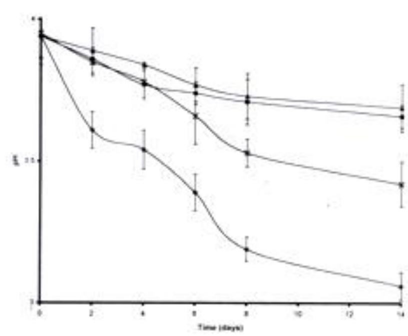

Figure 4. Changes in the pH of pasteurised (■), pasteurised and refrigerated (▲), refrigerated (X) and the control (◆) 'obushera' during storage. (Error bars are standard deviation).

growth were positively correlated ($\alpha = 0.05$) with $r = 0.99$ for pasteurised, $r = 0.81$ for pasteurised and refrigerated, $r = 0.81$ for the refrigerated and $r = 0.87$ for the control obushera. Alcohol production and yeasts growth were positively correlated ($\alpha = 0.05$) with $r = 0.89$ for pasteurised, $r = 0.92$ for pasteurised and refrigerated, $r = 0.95$ for the refrigerated and $r = 0.98$ for the control obushera. The sensory evaluation results show that the pasteurised 'obushera' was acceptable (Table 1). The refrigerated and control treatments exhibited an offensive odour, thus were not acceptable, after six and 2 days of strorage, respectively.

Discussion

Pasteurisation

Pasteurisation at 78°C for 10 minutes reduced the population of lactic acid bacteria from 5.8 $\log_{10}$ c. f. u./ml to 0.6 $\log_{10}$ c. f. u./ml and that of the yeasts from 6.2 $\log_{10}$ c.f.u./ml to undetectable levels. Efiuvwevwere and Akoma (1997) reported a similar reduction of lactic acid bacteria in "Kunun-zaki",

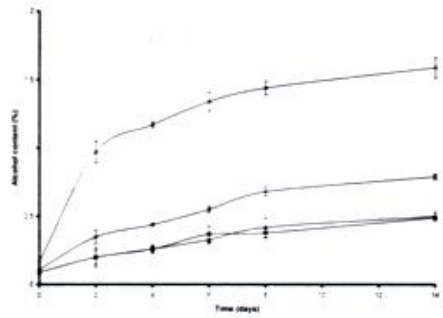

Figure 5. Changes in the % alcohol content of pasteurised (■), pasteurised and refrigerated (▲), refrigerated (X) and the control (◆) 'obushera' during storage. (Error bars are standard deviation).

Table 1. Mean sensory scores for 'obushera' subjected to different treatments.

Treatment	Mean score for acceptability[c] at							
	0 days	2 days	4 days	6 days	8 days	10 days	12 days	14 days
Pasteurised	3.00 (0.25)[a]	2.65 (0.29)	3.05 (0.56)	3.04 (0.49)	2.80 (0.37)	2.96 (0.61)	2.98 (0.39)	2.75 (0.11)
Pasteurised and refrigerated	2.50 (0.43)	2.75 (0.44)	3.21 (0.41)	2.69 (0.30)	2.95 (0.35)	2.72 (0.43)	3.30 (0.51)	3.04 (0.17)
Refrigerated	2.77 (0.33)	2.86 (0.32)	3.10 (0.28)	4.35 (0.63)	nd[b] (0.30)	nd	nd	4.04
Control	2.52 (0.36)	nd	nd	nd	nd	nd	nd	2.58 (0.48)

a. Figures in parentheses are standard deviation
b. Sensory score not determined because product had offensive odour
c. 1 = Like extremely and 9 =Dislike extremely.

a fermented millet beverage. Yeasts in Oyokpo, a Nigerian millet beer were reduced after pasteurisation (Iwuagwu and Izuagbe, 1985). Lactic acid bacteria counts in the pasteurised obushera that was stored at room temperature showed a slight increase of 2 $\log_{10}$ cycles through the storage period. Despite a reduction to an undetectable level after pasteurisation, yeast growth was detected after 2 days of storing the 'obushera' at ambient temperature.

Although pasteurisation destroys most vegetative forms of microbes in food, some species of yeast and lactic acid bacteria as well as spores may survive the pasteurisation process (Jay, 1992). The survival of thermo-resistant species of lactic acid bacteria and yeast was probably responsible for growth of lactic acid bacteria and yeasts during storage of the pasteurised 'obushera'. The detection of yeast cells after 2 days of storage suggests the presence and survival of ascospores which could have germinated after that time of storage at ambient temperature.

During the storage of pasteurised 'obushera', the titratable acid and alcohol content increased from 0.3 - 0.58% and 0.09 - 0.49%, respectively. The pH of the pasteurised 'obushera' was reduced from 3.94 to 3.66. The strong correlation between lactic acid bacteria and titratable acid and that between yeast growth and alcohol content of pasteurised 'obushera' indicate that the surviving micro-organisms were responsible for the subsequent changes in these parameters during storage.

Pasteurisation combined with refrigeration

According to Gould (1996) spores of psychrotrophic bacteria, are easily destroyed by pasteurisation while the spores of mesophiles and thermophiles, which might survive pasteurisation, cannot grow at the refrigeration temperatures. Thus, a combination oi pasteurisation and refrigeration would result in an enhanced shelf life. However, there was no significant difference, for all the parameters measured, between the pasteurised and the pasteurised and refrigerated 'obushera'. This implies that pasteurisation alone is enough to achieve increased shelf life of 'obushera' without additional refrigeration. Refrigeration can, however, be used to chill 'obushera'.

Refrigeration

The use of refrigeration alone only slowed down the growth of yeasts and lactic acid bacteria in 'obushera'. Lactic acid bacteria and yeast counts in the refrigerated 'obushera' increased tremendously during the storage period. The increase in the control treatment was, however, more than that observed in the refrigerated 'obushera'. The pH and titratable acid of refrigerated 'obushera' ranged between 3.42 - 3.95 and 0.38 - 0.95 %, respectively during the storage period. The alcohol content increased from 0.11 to 0.79%. The refrigerated 'obushera' was not acceptable to the panellists after 8 days. This observation lends support to the fact that refrigeration alone only slows down the growth of micro-organisms but does not stop the growth and activity of the micro-organisms (Jay, 1992). This also explains the lower counts of yeasts and lactic acid bacteria observed in the refrigerated 'obushera' as compared to the control.

Sensory evaluation and shelf-life

The control 'obushera' became unacceptable and was rejected by the panellists after 2 days. The refrigerated sample remained acceptable for 8 days after which the panellists rejected it. The 'obushera' samples subjected to pasteurisation alone and the combined treatment of pasteurisation and refrigeration remained acceptable through the monitoring storage period of 14 days. At the end of 14 days of storage, the 'obushera' subjected to pasteurisation and pasteurisation combined with refrigeration were most acceptable, with their mean scores for acceptability index not being different from those of freshly prepared 'obushera'. This shows that 'obushera' can be preserved by pasteurisation, refrigeration and combined pasteurisation and refrigeration with no adverse effects on its sensory properties. Similarly, Efiuvwevwere and Akoma (1997) successfully used pasteurisation of kunun-zaki at 70°C for 30 minutes with out adverse effects on the sensory properties of the product. The shelf-life projections based on the changes in the titratable acid and pH indicated that the pasteurised 'obushera' could be stored at ambient temperature for 32 days without decreased sensory quality.

Conclusions

The results show that it is possible to increase the shelf life of 'obushera' beyond the traditional two days with out adverse effects on its sensory properties using simple preservation methods. Although refrigeration increased the shelf life, this was to a limited extent. Pasteurisation at 78°C for 10 minutes alone was adequate to increase the shelf life of the product with no added advantage resulting from combined pasteurisation and refrigeration. Refrigeration, however, may be used to chill 'obushera'.

Although pasteurisation reduced the microbial population in 'obushera', some heat resistant forms of microbes survived and these were responsible for some changes in 'obushera' during storage at ambient and refrigeration temperature. Such surviving microbes do not cause spoilage of 'obushera' during the normal storage time.

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