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Efficacy and Cost-Benefit Analysis of Indigenous Technical Knowledge versus Recommended Integrated Pest and Disease Management Technologies on Common Beans in South Western Uganda

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Abstract

The common bean is the second most important food and third economically important crop after banana and coffee in the South Western Agro-Ecological Zone of Uganda. Farmers' returns to investment in bean production are consistently negative mainly due to losses resulting from collective effects of insect pests and diseases that cause damages at the various plant growth stages. This research study was carried out to 1) identify the major insect pests and diseases affecting the common beans in the zone; 2) test and compare the performance of the local/traditional practices versus integrated pest and disease management (IPDM) technology combinations; 3) determine the yield performance of improved varieties under the different pest control practices; 4) evaluate the profitability of the different pest and disease management practices. Results showed that cutworm, thrips, aphid and defoliating beetles were the major insect pests, while angular leaf spot, ascochyta blight, anthracnose and the bean common mosaic virus (BCMV) were the major diseases. Improved varieties managed with the recommended IPDM technology combination were more protected compared to the farmers' indigenous practices. The climbing varieties had significantly higher yield (3.4 t/ha) than the local bush variety (1.2 t/ha). Consequently, the application of indigenous practices resulted in negative returns to investment while the combination of research recommended technologies including judicial inorganic pesticide application led to positive returns to investment in bean production. The marginal rate of return (MRR) of IPDM technologies including inorganic pesticides was two times greater, implying that integration of improved variety with recommended agronomic crop management technologies plus judicial chemical application is economically feasible for increased common bean production in South Western Uganda.

Subject Areas

Agricultural Science, Plant Science

Keywords

Common bean, Production, Indigenous Technical Knowledge, IPDM, Marginal Rate of Return

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is an important staple and non-traditional cash crop in the South Western Agro-Ecological Zone (SWAEZ) of Uganda, where it ranks second after banana [1] and third after banana and maize [2] nationally as a major food crop. Although common bean production in most parts of Africa has been traditionally smallholder based [3], beans provide a growing source of income for rural farmers from the previous annual African sales worth over US$ 580 million (Uganda Export Promotion Board, 2005). Bean production has for a long time been mainly by women, and largely for home consumption [4], but recent studies have revealed that the production is increasingly becoming more for income generation for both males and females [5]. Even if the area under bean production in Uganda increased to 241,915 ha in 2008-2009, the current production still is insufficient to meet the local and regional demand due to losses resulting from mainly biotic stresses of which pests and diseases are major [6] [7].

In Africa, common bean losses caused by abiotic and biotic factors are aggravated by a combination of the multiple complexity of systems [8] that include: Use of low quality seed, inappropriate crop management practices, inappropriate crop rotation and low soil fertility and moisture. Unfavourable weather conditions characterized by insufficient rainfall, prolonged dry periods and development or re-occurrence of aggressive pests and disease pathogens are also serious constraints to bean production. Many of the preferred bean landraces and popular improved commercial varieties are susceptible to the major pests and diseases. Moreover, many improved bean varieties recommended for food security and agro-enterprise businesses have not been highly adopted by farmers due to the above production constraints.

The farmers use various practices to manage common bean production constraints such as indigenous technical knowledge [9] without necessarily considering their efficacy, costs and benefits. While chemical application is known to be effective, most farmers cannot afford its regular recommended application [9] [10]. The effectiveness and economic validity of many traditional pest and disease control practices used by farmer in SWAEZ are not well known. Breeding efforts in Uganda have contributed many improved varieties that are resistant to specific disease but susceptible to others partly because of the high bean pathogen diversity in the country [6].

Integration of multiple technologies is considered to be the best option that does not only effectively manage the target bean production constraint [11], but also solves other associated or non-target constraints. Moreover, farmers' full acceptance and adoption/adaption of any IPDM (integrated pest and disease management) technology is motivated by the technology's performance in solving the most important problems with less or affordable resources [12]. Previous studies have shown that for any agricultural technology to be well adopted by farmers, its financial gains/profitability must outweigh the cost of its use, implying that farmers' acceptance decisions are made based on utility maximization [13]. For example, labour demanding technologies are less likely to be fully adopted by farmers, especially those whose financial resource is low, and probably those with fewer household members [14]. Interestingly, the land races or local varieties commonly grown by farmers for home consumption seem to be highly stress tolerant [15], whereas most improved bean varieties preferred for marketing are succumbing to insect pest and disease damages. The aim of this study was to evaluate the efficacy and profitability of different farmers' ITK practices versus recommended IPDM technologies in controlling the major common bean pests and diseases in the SWAEZ, bearing in mind that the effectiveness and economic validity of most pest and disease control practices used by farmers are not well known.

2. Materials and Methods

Two experiments were carried out on-station at Mbarara Zonal Agricultural Research and Development Institute in the South Western Agro-Ecological Zone located at 0˚36'S; 30˚42'E and 1443 meters above sea level. The zone experiences two rain seasons of which the March to June season is shorter while the August to December season is longer. The peak rainfall months are normally April and November, with an average annual precipitation of 1200 mm. The dry spells occur in January-February and June-August annually. The actual prevailing data were not collection during the experimentation period. To identify varieties that are high performing and well adaptable to the semi-arid conditions, 16 improved climbing bean varieties (**Table 1**) acquired from the Bean Program at National Agricultural Crop Resources Research Institute (NaCRRI) were evaluated for agronomic (yield) performance against a local bush bean variety (Kahura) through an on-station experiment during the 2013B and 2014A seasons. The experiment was randomized complete block design (RCBD), and the plant spacing was 50 cm × 20 cm in 5 m × 2 m plots. The sowing rate was 65 - 90 kg/ha depending seed size and growth habits. Staking of climbing varieties was done two weeks after planting using 2 m long sticks. Weeds were controlled by

Table 1. The main background information about the common bean varieties used in this study.

Variety name/code	Local name	Year of release	Owners Maintainer and seed source in Uganda	Optimal production altitude range	Characteristics	Duration to maturity (days)	Grain yield (T/Ha)	Special attributes
MAC 16	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust
MAC 19-2/209	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust
MAC 29	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust
MAC 32	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust
MAC 34	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust
MAC 35-1	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust
MAC 35-2	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust
MAC 4	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust
NABE 4	POA 2	1999	NARO	1000 - 1600	Bush	80 - 85	1.5 - 2.5	Resistant to BCMV, Br and anthracnose, red seeded, good for export
NARE 14			NARO	1000 - 1600	Bush	80 - 90	1.5 - 2.5	Tolerant to low soil fertility and root rot diseases
NABE 10C	Umubano	1999	NARO	>1600	Climbers	85 - 100	2.5 - 3.5	Resistant to anthracnose but susceptible to rust, red small seeds, leaves suitable for consumption
NABE 12C		2005	NARO	>1600	Climbers	90 - 110	2.3 - 3.0	Tolerant to anthracnose, root rot, CBB, rust and BCMV
NABE 8C	Ngwinurare	1999	NARO	>1600	Climbers	90 - 110	2.5 - 4.0	Tolerant to CBB, large red seeds, leaves suitable for consumption
NYIRIGIKOTT	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	
RWV 1077	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust and BCMV
*RWV 1555	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust and BCMV
RWV 2005	Nil	Nil	NARO	1000 - 1600	Climbers	>90	2.5 - 4.5	Tolerant to anthracnose, root rot, CBB rust and BCMV
KAHURA	KAHURA	Nil	Nil	1000 - 1600	Bush	Nil	1.5 - 2.5	Nil

Sources: http://tasai.org/wp-content/themes/tasai2016/info_portal/Uganda/National%20Crop%20Variety%20List%20for%20Uganda%20(2015).pdf. Climbers: bean varieties that require staking. Nil: Information was not available.

regular hand hoeing. No irrigation, fertilizer, or other crop management practices were applied.

During the 2013B, 2014A and 2014B seasons, five varieties were selected and evaluated under different integrated pest and disease management technologies. The treatments comprised of varietal (NABE 12C, NABE 10C, RWV 1555, MAC 34, MAC 35-1) and non-varietal pest and disease management technologies that included: 1) Fungicide (the fungicide used was Ridomil with active ingredients mancozeb and metalaxyl) + insecticide (Fenkill-Fenvalerate 20 EC); 2) Farmers' indigenous practices included: a) Tobacco + Ash; b) Farm yard manure (FYM); c) Tithonia; 3) Controls (all varieties minus spraying). Application rates of the above different pest and disease management technologies were according to either the manufacturer's, farmer's innovations or research recommendations as follows: Ridomil fungicide at 120 g per 15 litres (2.5 kg/ha) of water plus fenkill insecticide at 30 ml per 15 litres of water; Tobacco crushed leaves (20 green leaves) plus Ash (4 handfuls) mixed with 20 litres of water; FYM (8 - 10 kg per ha); Tithonia leaves (10 double handfuls of ground Tithonia leaves were mixed with 20 litres of water and kept for not less than 12 hours prior to application). The spray treatments were applied twice every month per season. The experimental design was split plot with inter-row and intra-row spacings of 60 cm × 20 cm. In 2014A and 2014B the second season's experiments were planted using both climbing (NABE 12C and NABE 10C) and bush (NABE 14 and NABE 4) bean varieties (**Table 1**). The experimental design, treatments and management practices were similar to the previous season.

Insect pests and diseases were identified based on the bean disease and pest identification and management manual [16], while the quantitative data on pest and disease incidences (number of whole plants affected, expressed as percentages) and severities (percentage area of plant tissues affected by the disease pathogen) were measured as described by Corrales and van Schoonhoven (1987). Plant agronomic data were collected weekly starting from germination onwards up to physiological plant maturity following the CIAT Standard Systems for Evaluation of Bean Germplasm [17]. Dry grain yields were measured after harvesting, drying and threshing. Pest, disease and yield data were subjected to analysis of variance (ANOVA) using the GENSTAT programme. The Least Significant Difference test (LSD) at 5% probability level was used to separate significant means. To determine the economic benefit of pesticide usage, data were subjected to partial budgeting to determine the profitability of each pest and disease management technology [18]. Partial budgeting was also used to determine the net benefits of the different technologies by examining the variable costs, income and resource requirements associated with a particular technology. Economic analysis was done using the average yield data obtained from the three seasons' (2013B, 2014A, 2014B) experiments. Gross revenue was calculated using prevailing local market price (Uganda shillings 1850 or US$ 0.8) for one kilogram of dry grains.

3. Results

3.1. Major Insect Pests of Common Beans in SWAEZ

All growth stage of the local and improved bean varieties was infested by insect pests, of which the most common were defoliating, sucking and cutting insects (Table 2). This study revealed that pest incidence varied across the different varieties and plant growth stages causing varying levels of damage. The young seedlings were mostly infested by the larva of cut worms (*Agrotis* spp.) that fed on young tender shoots and stems at the soil surface causing death of many plants. The common bean foliage beetles (*Ootheca bennigseni*) formed inter-vein holes in young tender leaves starting from vegetative stage 1 to beyond vegetative stage 4 (third trifoliate leaf). Striped bean weevil (*Alcidodes leucogrammus*) was observed on the bean plants but its symptoms were not observed partly because the most destructive stage (larvae) that infests plant stems was absent. The black bean aphids (*Aphis fabae*) infested the plant stems, growing shoots and leaves sucking sap, which led to leaf and shoot deformation, and eventually retarded plant growth. Aphid infestation occurred on plants experiencing moisture stress during the dry periods.

3.2. Major Diseases of Common Beans in SWAEZ

The most common viral disease was the bean common mosaic virus (BCMV), while bean root rots caused by *Pythium* spp., and *Fusarium solani* f. sp*. Phaseoli*; anthracnose caused by *Colletotricum lindemuthianum*, angular leaf spot caused *Phaeoisariopsis griseola* and ascochyta blight caused by *Ascochyta phaseolorum* were the common fungal diseases. Bacterial blight (*Xanthomonas phaseoli*) was the major bacterial diseases detected. However, the most destructive diseases were the root rots (Figure 1), bacterial blight, BCMV (Figure 2) and anthracnose (Figure 3) with incidences or severities varying across the bean varieties. The BCMV spread by aphids was more severe on climbing varieties: NABE 10C, RWV 1555 and NABE 14, which display the typical common mosaic leaf symptoms of dark green necrotic sections on leaves, down curling of the leaf margins, under development of leaves and general stunted plant growth.

3.3. Yield Performance of Improved Climbing versus the Local Common Bean Varieties

Both climbing and the bush varieties had lower yields than expected potential yield of 4.0 - 5.0 t/ha and 1.0 - 2.5 t/ha, respectively. The yield performance of the climbing bean varieties varied across season, with 2014A producing higher yields than the 2013B season (Table 3). The low yields harvested from 2013B were mainly caused by the prolonged dry spell and insufficient rainfall, which are unfavourable to the growth and yielding of climbing beans. All climbing varieties had significantly ($P \leq 0.05$) higher yields (1.4 - 3.6 t/ha) than the local bush variety that yielded 1.2 t/ha during 2014A. Variety RWV1555 had significantly higher average yield (3.6 t/ha) than varieties MAC 19, MAC 29, MAC 34,

Table 2. Description of insect pest damages identified on common beans in the SWAEZ.

Pest	Description
Cut worm (*Agrotis* spp.)	Affected seedlings by cutting and eating through the tender young plant stems at the soil surface. The larva stage was the most destructive, and every plant attacked by cut worm died. Under high population this pest can damage an entire field if uncontrolled
Beetle-defoliators (*Ootheca* spp.)	The most common foliage beetles (*Ootheca bennigseni*) infested the plants starting from vegetative stage 1 to beyond vegetative stage 4 (third trifoliate leaf). The pest caused inter-vein holes in the leaves of young plants. As plant growth continued, the pest damages disappeared, implying that the pests mostly infested young tender leaves
Striped bean Weevil	The *Alcidodes leucogrammus* was observed on the bean plants but its symptoms were not observed partly because the most destructive stage (larvae) that mostly infest plant stems was absent
Aphids (*Aphis* spp.)	The winged aphids (*Aphis fabae* and *A. craccivora*) affected the plant stems, growing shoots and leaves where they fed by sucking sap. These pests deformed leaves and shoots, eventually retarded plant growth. The pest infestation occurred on plants experiencing moisture stress during the dry periods
Thrips	High populations of white flower thrips (*Megalurothrips sjostedti*) appeared on bean varieties at flowering stage. Apart from causing flower aborting, the physical symptoms were not visible to the un-aided eye. Other studies have shown that both nymph and adult thrips infest plants causing damage to petals and stigma
Flower and pollen beetle	The mylabrisspp., which feeds on flowers, appeared but they were very few
Bugs	The giant coreid bugs (*Anoplocnemis curvipes*) were observed between the full vegetative and reproductive stages

Table 3. Yield performance of improved climbing and bush varieties during 2013B and 2014A.

Bean Variety	**Yield (Kg/ha)**			
	2013B	**2014A**	**[a]Yield increase**	**[b]% increase 2011A**
MAC 16	1429	2153	991	46.0
MAC 19-2/209	1726	2853	1691	59.3
MAC 29	1929	2488	1326	53.3
MAC 32	1510	2189	1027	46.9
MAC 34	958	3388	2226	65.7
MAC 35-1	2319	2629	1467	55.8
MAC 35-2	2057	2492	1330	53.4
MAC 4	2040	2353	1191	50.6
NABE 10C	1831	2854	1692	59.3
NABE 12C	1973	2224	1062	47.8
NABE 8C	1422	1370	208	15.2
NYIRIGIKOTT	859	1728	566	32.8
RWV 1077	1847	2772	1610	58.1
RWV 1555	2015	3634	2472	68.0
RWV 2005	1656	2738	1576	57.6
*KAHURA	-	1162		
$LSD_{(P \leq 0.05)}$	**NS**	**1206**		
CV (%)	**39.6**	**29.7**		

[ab]Yield increases on climbing varieties versus local bush bean variety. *Bush or non-climbing bean variety.

Figure 1. Severe root rot disease infection on a local common bean variety.

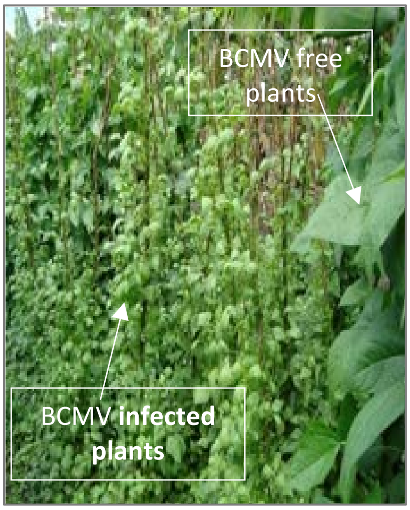

Figure 2. Bean common mosaic virus infection on climbing bean variety, NABE 10C.

Figure 3. Anthracnose (*C. lindemuthianum*) infected bean variety, NABE 4.

MAC 35-1, MAC 35-2, RWV 107, RWV 2005 and NABE 10C (Table 3). NABE 8C and Nyirigikott had the lowest yield, while the yields of MAC 4, MAC 16, MAC 32 and NABE 12C ranged from 2.2 t/ha to 2.6 t/ha during 2014A. The consistently yield losses of local bush and improved climbing beans during the two seasons were mostly caused by pests and diseases, which allowed for the evaluation of the different pest and disease management technologies on the performance of selected varieties (RWV1555, MAC 35-1, MAC 34, NABE 10C and NABE 12C).

3.4. Efficacy of IPDM and Indigenous Technologies in Control of Common Bean Insect Pests and Diseases

Foliage beetles: Bean leaf damages by defoliators started immediately after seedling germination and gradually increased on plants where no pest control measures were applied. Signficantly ($P \leq 0.05$) low leaf defoliation occurred on MAC 34, MAC 35-1 and NABE 12C, whereas the levels leaf damage of NABE 10C and RWV 1555 slightly increased at 49 DAP during 2014B (Figure 4). Although leaf damage was generally low under all treatments, analysis of average defoliation showed that the control plots had signficanlty higher percentage leaf area damaged (20.8%) while the inorganic insecticide treated improved varieties had low damages (3.7%) (Figure 5). The indigenous technologies (Tithonia, Ash + Tobacco and FYM) maintained leaf damages below 25%, but there were no significant differences among the effects of all indigenous technologies and the control at $P \leq 0.05$. Analysis of the peak percentage leaf area damaged determined that the improved varieties plus inorganic chemical combination (Fenkill + Ridomil) significantly suppressed foliage damage to about 3.3%, while the indigenous technologies FYM, Tithonia and Ash + Tobacco suppressed leaf defoliation to 10.2%, 9.9% and 12.1%, respectively (Figure 5).

Bean Common Mosaic Virus (BCMV): The bean common mosaic virus (BCMV) disease was assessed by counting the plants showing the disease symptoms per plot. The first symptoms of bean common mosaic virus appeared at six weeks after sowing in 2015B, and the disease incidence was higher on NABE 10 and NABE 14 than on NABE 12C and NABE 4 (Figure 6).

Angular leaf spot: Angular leaf spot appeared at four weeks after sowing, and was assessed at R6 (flowering stage - as first flower opens) and R8 (pod filling) plant growth stages using 0% - 100% standard scoring scale [17]. Although the disease was low and not significantly different at R6, slight disease severity increase was noted in the later assessment. The disease severities on plants treated with the fungicide and indigenous technologies were significantly different from the non-treated plants (Table 4). Moreover, application of the fungicide was more effective than the indigenous technologies (Tithonia, Ash + Tobacco and FYM).

Anthracnose disease: Anthracnose, appeared at 4 weeks after planting, and at stage R6 the disease severity was very low (Table 5). Although at stage R8, the disease had spread to most plots, its severity remained lower than 2.5% [equivalent to 3 on the 1 - 9 scale [17] on most plots under the different treatment.

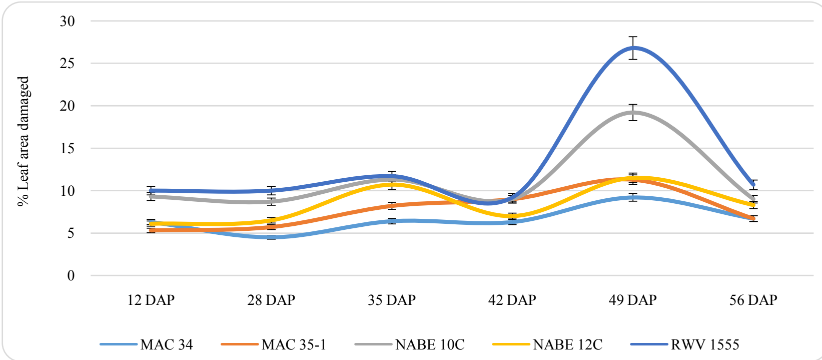

Figure 4. Trend of percentage leaf area defoliation of different bean varieties by insect pests during the early vegetative growth stages.

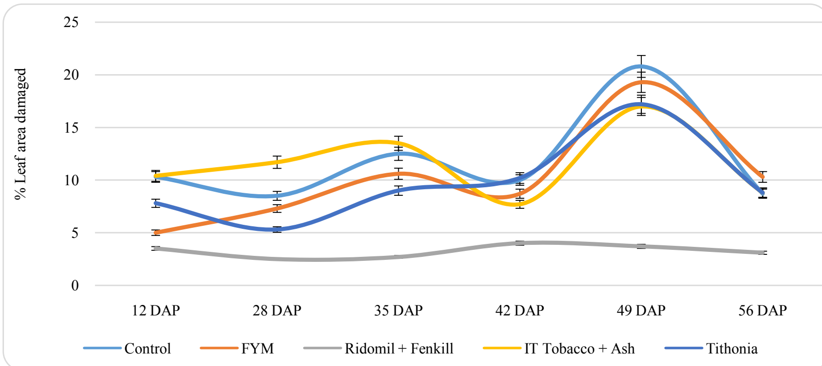

Figure 5. Trend of percentage leaf area defoliation of bean plants treated with different pest control practices during the early vegetative growth stages.

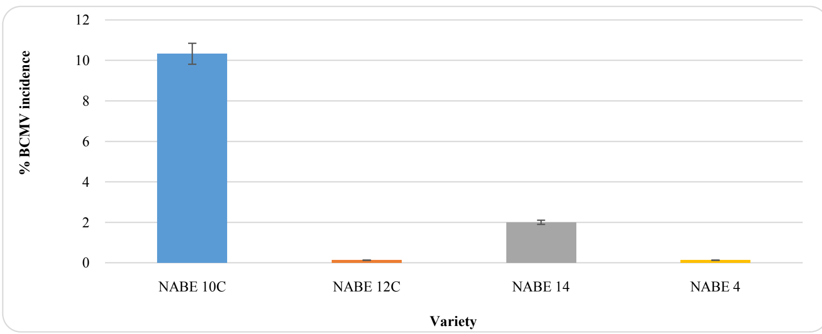

Figure 6. Incidences of bean common mosaic virus on improved varieties.

Table 4. Percentage leaf area infection by angular leaf spot under pesticide applications.

Pesticide application	Variety				Average
	NABE 10C	**NABE 12C**	**NABE 14**	**NABE 4**	
Farm yard manure	5.0	8.3	10.0	10.0	8.3
Fenkill + Ridomil	3.3	8.3	8.3	4.2	6.0
Ash + Tobacco	5.8	6.7	7.5	13.3	8.3
Tithonia	6.7	10.8	11.7	11.7	10.2
Control	9.2	10.0	7.5	10.0	9.1

Table 5. Percentage leaf area infection by anthracnose disease under pesticide applications.

Pesticide application	Variety				Average
	NABE 10C	NABE 12C	NABE 14	NABE 4	
Farm yard manure	2.5	2.5	1.7	1.7	2.1
Fenkill + Ridomil	2.5	1.7	2.5	1.7	2.1
Ash + Tobacco	2.5	2.5	3.3	1.7	2.5
Tithonia	2.5	1.7	6.7	2.5	3.3
Control	3.3	1.7	1.7	2.5	2.3
Average	2.7	2.0	3.2	2.0	

3.5. Yield Performance of Common Bean Varieties Managed with IPDM and Indigenous Technologies

The second season (August-December) per year is usually characterized by higher and long rains, but unexpectedly the 2014B season was generally dry with insufficient rainfall, which severely affected varieties NABE 10, NABE 12C, RWV 1555 and MAC 34 resulting in low yields. The low performance of RWV 1555 resulted from a combination of factors including insufficient rainfall and the high incidence of BCMV. A similar scenario occurred in 2015A (February-June) resulting in low yields from all varieties. However, the 2015A and 2015B seasons' yields were significantly different ($P \leq 0.05$), with the NABE 10C and NABE 12C yielding slightly higher than the bush varieties (NABE 14 and NABE 4). Generally, NABE 10C, NABE 12C and MAC 34 had higher yields across the three seasons.

Overall, the common bean yield performance under the different pest management technologies varied across season with inorganic pesticide combination sprays leading to the higher yields, while pest and disease management with indigenous technologies resulted in lower yields that were not significantly different from the ones from control plots. Apart from the 2015B, all sprayed plots had higher yields than non-sprayed ones during the 2014B and 2015A. Also plots sprayed with a combination of inorganic insecticide + fungicide (Fenkill + Ridomil) had significantly higher yields than the control in the 2014B and 2015A (Table 6). These results clearly showed the high efficacy of inorganic pesticides against major insects and fungal diseases resulted in higher yield gain over the non-treated plants compared to FYM and ITK (Tithonia and Tobacco + Ash). Therefore, treatment of improved varieties with inorganic pesticides resulted in significantly higher pest and disease control as well as yields compared to the local bush beans (Figure 7). Of three indigenous technologies, farm yard manure resulted in significantly higher yield gains than Tithonia and Ash + Tobacco.

3.6. Profitability of IPDM versus ITK Pest and Disease Management

Based on partial budgeting, most technology combinations produced total revenues

Table 6. Common bean yield performance under IPDM and indigenous technologies.

Pest Management technology	Yield (Kg/ha)				
	2014B	2015A	2015B	Average	Average yield increase
Ash + Tobacco	2469	2361	3924	2918.1	74.7
Fenkill + Ridomil	3168	2787	4587	3513.9	670.5
Farm Yard Manure	2944	2875	4052	3290.3	446.9
Tithonia	2409	2260	3719	2795.9	−47.5
Control	2205	2221	4104	2843.4	0.0
$LSD_{(P \leq 0.05)}$	343.6	554.6	760.4		
CV (%)	47.1	26.8	22.6		

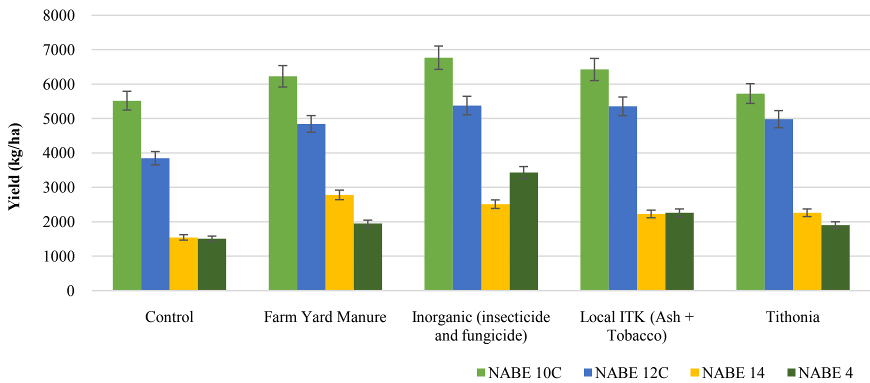

Figure 7. Yield performance of four improved bean varieties under inorganic technologies and ITK pest and disease management.

in the range of Uganda shillings (UShs.) 5,173,000 - 6,500,000; whereas the revenue for the non-treated bean fields was UShs. 5,260,000 (Table 7). Use of Farm yard manure (FYM) was the most expensive because of the high amounts required per unit area (7 - 10 tonnes) plus the high labour and transport costs incurred. The cheapest technologies were Tithonia and Ash + Tobacco partly because their recommended application rate was low. Unlike the FYM, Tithonia and Ash + Tobacco, very small amounts of inorganic pesticides (Ridomil and Fenkill) were required per unit area. Although inorganic pesticide application was relatively expensive, their use resulted in higher pest control leading higher yield, total income and net profits. This analysis showed that there was no benefit in using Tithonia for management of common bean pests and diseases because its application resulted in negative returns to investment. Both inorganic technologies and ITK produced positive net benefits (*i.e.*, the total revenues were higher than the variable costs), but the inorganic technologies generated higher net benefits than the other practices. The marginal rate of return (MRR) of inorganic pesticides was two times greater, implying that this technology was economically feasible since the marginal rates of return or break-even points were greater than one (Table 7).

Table 7. Partial budgeting for IPDM and indigenous technologies used in management of the major bean pests and diseases in SWAEZ.

Pest management technology	Variable cost of inputs (shs/ha)	Variable cost of labour	Total input + labour costs	Financial cost/interest rate at 25%	Total variable cost (shs)	Total revenue (shs)	Net benefit (shs)	Change in cost due to technology use	Change in revenue due to technology use	MRR
Ridomil + Fenkill	1,156,300	125,000	1,281,300	320,300	961,000	6,500,000	5,539,000	961,000	1,240,000	1.3
Tithonia	694,400	125,000	819,400	204,900	615,000	5,173,000	4,558,000	615,000	−87,000	−0.1
Ash + Tobacco	708,300	125,000	833,300	208,300	625,000	5,399,000	4,774,000	625,000	139,000	0.2
FYM	1,800,000	25,000	1,825,000	456,300	1,369,000	6,087,000	4,718,000	1,369,000	827,000	0.6
Control	0	0	0	0	0	5,260,000	5,260,000	0	0	0

Average local market price of common beans at the time of the study was Ushs. 1850 per kg. MRR—Marginal rate of return.

4. Discussion and Conclusion

The continuous decline in common bean production in Uganda bears significant implication not only on the rural farmers' food security, nutrition and income, but also other major bean producing, trading, processing and consuming enterprises in Africa [19]. Although the common bean is a very important crop in Uganda, it is mainly produced with minimal agro-inputs by rural small holder farmers [20]. The increase in land acreage under common bean production by farmers attempting to meet the increasing local and regional demand has been challenged by many abiotic and biotic stresses [20], of which insect pests [21] and diseases including angular leaf spot [7], common bacterial blight [22], anthracnose and root rots [23] are major. The effects of the numerous pests and diseases range from mild symptoms to severe plant damages, which normally result in significant yield losses [10] [24].

To increase the yield and production of common beans by the majority small-holder farmers, integration of effective and economically viable resources or practices for management of the abiotic and biotic constraints is essential. Variety development through breeding has released very many improved varieties that display diverse levels of pest and disease resistance depending of their genetic composition and/or backgrounds and prevailing environments. Enriching the nutritive and commercial values of common beans in Uganda is expected to play a big role in promoting bean consumption, but the low profitability of this commodity is still a major hindrance to investment in production by most farmers. This study identified the major common bean insect pests and diseases; assessed their damages and evaluated the efficacy and economic feasibility of the available management practices in the SWAEZ of Uganda.

Insect pests: Damages caused by widely known major common bean pests including cutworms (*Agrotis* spp.), aphids (*Aphis* spp.), beetle defoliators (*Ootheca* spp.), and thrips (*Megalurothrips*) [10] were observed at every plant growth stage during each season. Cutworm and aphid infestation occurred during dry periods when seedlings and plants were experiencing moisture stress, while defoliators and thrips were common on young plants during early vegetative and flowering stages, respectively. Although cutworm is widely considered a minor pest, occurrence of its caterpillars in high populations is known to destroy an entire young crop within a short period. Aphids (*Aphis* spp.), beetle defoliators (*Ootheca* spp.), and thrips (*Megalurothrips*) have been reported to cause 37%, 18% - 31% [25] and 40% - 100% [26] yield losses elsewhere when not well controlled with appropriate technologies.

Further assessment of bean leaf defoliation revealed that most of the damages occurred during early vegetative plant growth, but the high and low pest incidence trends observed in the current study was associated with probably the changes in pest population due to the changing climatic conditions [27], or pest transformation into non-infesting development stages [10]. Initial seedling infestation by defoliating beetle started at 5% - 10% at 12 DAP, and subsequently increased at a low rate on each variety until the peak level (9% - 27% at 49 DAP). The decline in pest infestation at 49 DAP implied that either the mature foliage was unpalatable to the pests, alternatively the environmental conditions were unfavourable to their survival. Effective control of insect pests on common beans has been difficult mainly because of the differences among pest infestation mode, development stage, environment and plant growth stage. Because the extent of crop loss depends on all above factors, each of them requires specific effective control measures to prevent the possible yield losses. Therefore, integrating multiple pest management technologies including varietal, cultural and judicial pesticide application can enhance the resilience of common beans to severe insect pest damages and yield losses.

Common bean diseases: Of the numerous viral, fungal and bacterial diseases that affect the common bean in Uganda (angular leaf spot; bean common mosaic virus (BCMV); bean root rots; anthracnose; ascochyta blight and common bacterial blight) identified on both bush and climbing varieties during each season, the root rots, common bacterial blight and BCMV were most severe partly agreeing with previous studies [22] [28] [29]. Studies have shown that pathogen diversity, amount of inoculum, bean variety, environmental conditions, infection time and plant growth stage influence the level of disease incidence or severity. The BCMV was severe on climbing varieties (NABE 10C, RWV 1555 and NABE 14) yet these varieties were developed purposely to mitigate crop losses caused by the most destructive the root rots, which were severe on bush bean varieties. Climbing beans are not only highly resistant to root rot disease, but also their yield per unit area is twice as much or more than that of bush bean varieties [30]. However, studies have shown that crop losses caused by BCMV and BCMNV impact severely on susceptible cultivars resulting total yield losses. Angular leaf spot is major disease in the sub-Saharan regions where it has caused yield losses of 61% [24].

Research has developed improved varietal and non-varietal technologies to mitigate the losses caused by the numerous pests and diseases. Yield losses per unit area result from accumulated pest/disease caused damages starting from germination to post harvest. Increase in area under bean production without applying effective and economically viable IPDM technologies to mitigate the above losses may not increase farmer's returns to investment in bean production. Integrating high performing varieties with judicial inorganic chemical application was the most effective and economically feasible IPDM technology combination, followed by application of FYM as a strategy for indirect pest and disease control. The high quantities of inputs needed to apply indigenous technologies such as FYM coupled with the high transport costs make it too expensive for the farmers to sustain especially where farmers have to transport the bulky materials for longer distances. Although Tithonia, Ash + Tobacco technologies were used in the smallest quantities, and were cheaper than other technologies, they were not effective in mitigating losses caused by pests and diseases. Varieties NABE 12C and NABE 4 were selected as the most disease (virus) resistant varieties, while the insecticide-fungicide combination was the most effective and economically viable IPDM innovation. Therefore, since majority of rural farmers cannot afford continuous application of the inorganic technologies at the recommended rates, this research proposes a further study on combining inorganic and indigenous technologies. If found effective, it will reduce the cost of managing major bean pests and diseases and eventually lead to higher yields and economic returns to investment in bean production.

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