Ethiop. J. Agric. Sci. 26(2) 83-97 (2016)

Potato Bacterial Wilt Management in the Central Highlands of Ethiopia

Bekele Kassa

Ethiopian Institute of Agricultural Research

Holetta Research Centre, P.O. Box 2003. Addis Ababa, Ethiopia

አህፅርኦት

በኢትዮጵያ የድንች አጠውልግ በሽታ በድንች ምርት ላይ ዋና ስጋት ሁኖ ይገኛል፡፡ ይህ ጥናት በሶስት ወረዳዎች ማለትም በሻሽመኔ በቱሉቦሎ እና በወሊሶ የድንች አርሶ አደሮችን በማሳተፍ እ.ኤአ 2011 እና 2012 ዓ.ም. የመኸር ወቅት የተካሄደ ነው፡፡ የሰብል ፈረቃን በመጠቀም በሽታውን ለመከላከል የተደረገው ሙከራ ግን በሻሽመኔ አካባቢ በሚገኙ ሶስት ቀበሌዎች እ.ኤ.አ 2011 እስከ 2015 ተካሂዷል፡፡ የምርምሩም ዓላማ ገበሬው ከበሽታ የፀዳ የድንች እርሻ ማሳ እንዲኖረው ማስቻልና የድንች አርሶ-አደሮች ስለበሽታው ያላቸውን አመለካከት በማስለወጥና ትክክለኛውን ግንዛቤ እንዲኖራቸው ጥረት ለማድረግ በተለይም የበሽታው መንሰዔ ምንነት፣ ስነ-ዑደት፣ ምንጭ፣ እንዲሁም በሽታውን ለመከላከል ያሉትን አማራጮች የሰብሉንና የበሽታውን ዕድገት መሰረት ማዕከል ባደረገ የምክክር መደረክ በተደገፈ የገበሬ መስክ ትምህርት ቤት በማቋቋምና የትምህርት ቤቱ አባል በማድረግ በተጨማሪ የበሽታው አስተናጋጅ/የማይጠቁ ሰብሎችን ለአንድና ለሁለት የምርት ዘመን በማፈራረቅ በሽታው በድንች ላይ የሚያደርሰውን ከፍተኛ የምርት ጥፋት ለመቀነስ ይቻል ዘንድ አሳታፊ የምርምር ጥናት ተካሂዷል፡፡ የጥናቶቹም ውጤት እንዳሳየው ከምርምር የወጡ በሽታን የመከላከል ቴክኖሎጅዎችን ወደ ገበሬው ለማስረፅ ውጤታማ አካሄድ መሆኑን አመላክቷል፡፡ ሙከራው ከመካሄዱ በፊት በተሳታፊ አርሶ አደሮች ላይ በተደረገ ዳሰሳ ሁሉም አርሶ አደሮች የበሽታውን መንስዔም ሆነ ገላጭ ምልክቱን የማይለዩት ሆነው ሲገኙ የበሽታው መንሰዔ ዝናብ እና ጭጋግ ነው ብለው የሚያምኑ ሲሆን ሙከራውና በመስክ የግንዛቤ ማስጨበጫ ተከታታይ ውይይትና በተግባር የተደገፈ ስልጠና ለአንድ መ□ር ወቅት ከተከናወነ በኋላ ከአባላቱ ውስጥ 65 በመቶ የሚሆኑት ተሳታፊ አርሶ አደሮች የበሽታውን መንስዔ፣ ምልክቱን፣ የሚሰራጭበትን መንገድና በአርሶ አደር ደረጃ ሊተገበሩ የሚችሉ የድንች አጠውልግን፣ የዋግንና የቫፕረስ በሽታዎችን ለመከላከል የሚያስችሉ ዘዴዎችን አውቀዋል፡፡ ለአንድ የምርት ዘመን ድንች-አደንጓሬ-ድንች፣ ድንች-ጥቅል ጎመን-ድንች፣ ድንች-ካሮት-ድንች የተፈራረቀበት መደብ የበሽታው ክስተት 22.1, 15.4 እና 27.3% በቅደም ተከተል ሲመዘገብ በተከታታይ ድንች-ድንች የተተከለበት መደብ ላይ 22 ግን 45.2 % ተመዘግቧል፡፡ በአንድ ወቅት ፈረቃ የበሽታው ክስተት መጠን ከድንች ምርት ጋር ያለውም ግንኙነት አሉታዊ እንደሆነ ውጤቱ ያሳያል፡፡ ለሁለት ጊዜ ፈረቃ ማለትም ድንች-ጎመን-ጎመን ድንች እና ድነች-ጎመን-ካሮት-ድንች ፈረቃ ከድንች-ቦሎቄ-ቦሎቄ-ድንች፣ ድንች ካሮትካሮት-ድንች ፣ ድንች-ካሮት-ቦሎቄ-ድንች እና ድንች-ጎመን-ቦሎቄ-ድንች ፈረቃ የበሽታውን ክስተት በከፍተኛ ሁኔታ የቀነሰው ሲሆን ምርቱም ከበሽታው ክስተት ጋር ያለዉ ግንኙነት አሉታዊ መሆኑ ተረጋግጧል፡፡ በአጠቃላይ ሁሉም የተካተቱት የፈረቃ አማራቸጮች ድንች ሳይፈራረቅ ከተተከለው ጋር ሲወዳደር የበሽታውን ክስተት መጠን በፈረቃው ምክንያት የበሽታው ክስተት ቀንሷል እንዲሁም ምርቱም ተሻሽሏል፣ የምርምሩ ሙከራ የሚያሳየው በሴሽን የተደገፈ አካሄድ ቴክኖሎጅን ወደአርሶ አደሩ ለማስረፅ ተደማጭነት ያለው መሁኑን አመላክቷል፣ ለአንድና ለሁለት የምርት ወቅት ድንች በጎመንና በቦሎቄ መፈራረቅ በሻሽመኔ ሁኔታ በመስክ የድንች አጠውልግን ክስተት የሚቀነስ ሲሆን በኮረት ውስጥም የተዳፈነ የበሽታውን መንስዔ ለመቀነስ ይረዳል ከዚህም በተጨማሪ ምርቱን ያሻሽላል፡፡

Abstract

In Ethiopia, bacterial wilt caused by ***Ralstonia solanacearumis*** *the major threat to potato production. Farmers are not aware of the causes of potato diseases and they believe that all types of diseases are caused by rain and mist. Research has been carried out in four districts namely Shashemene, Tulubolo, Welmera and Welisso f rom 2011 to 2012 main crop seasons however; the research was extended to 2014 in Shashemene district. The purposes of the research was to change the perception of farmers and address the causes, sources and management options of the disease and assist farmers to develop healthy potato farms; Farmers field school(FFS) extension approach supported by sessions harmonized with crop phenology was used to assess the effect of one season rotation (Potato - Beans - Potato; Potato - Cabbage - Potato; Potato - Carrot - Potato and Potato - Potato - Potato)and two seasons rotations (Potato - Beans - Carrot - Potato; Potato - Beans - Cabbage -Potato; Potato - Beans - Beans - Potato;*

Potato - Carrot - Carrot - Potato; Potato - Cabbage - Carrot -Potato; Potato - Cabbage - Cabbage - Potato and Potato - potato - potato - potato) with none host crop species on the development of the disease. At the inception of the project, all members of the group were introduced to potato diseases and their causal agents through farmers field school extension approach. After subsequent sessions, experimentation, and demonstration at field level, more than 65 % of the farmers in the group were able to identify symptoms, causative agents and means of dissemination and possible management measures of potato wilt, late blight and viruses. The result showed that, the extension approach was found to be effective in stimulating farmer's perception by considering their goals in the targeting and design of innovations. One season rotation of potato with beans cabbage and carrot significantly ($P<0.05$) reduced the incidence of the disease by 22.1, 15.4 and 27.3% respectively as compared to the mono crop potato which had 45.2 % incidence. The correlation between mean tuber yield over disease incidence in one season and two seasons rotation shad negative and significant $Y = -0.2588x + 29.767$ *($R^2 = 0.7946$) and $Y = -0.177x + 28.019$ ($R^2 = 0.4597$) respectively. Potato - Cabbage-Cabbage-Potato and Potato - Cabbage-Carrot-Potato had significantly ($p<0.05$) lowest disease incidence compared to Potato – Beans– Beans- Potato, Potato - Carrot- Carrot- Potato, Potato - Carrot– Beans- Potato and Potato - Cabbage– Beans- Potato rotation however, all treatments significantly ($P<0.05$) reduced the incidence of the disease and increased marketable tuber yield compared to the mono crop potato. The result of these researches suggested that FFS through session supported extension approach was found to be effective to generate and disseminate bacterial wilt management technologies. One and two season rotation with beans and cabbage reduced wilt incidence, latent infection in tubers and increased tuber yield under Shashemene condition.*

Introduction

In Ethiopia, Bacterial wilt of potato is caused by *R. solanacearum*, Race 3 (Yaynu, 1989) so all results reported and conditions drown in this article hold true only for this race. Since BW cannot be controlled by chemicals and persists in the soil for a long time, it is increasingly becoming a major threat to potato production in Ethiopia. The destructiveness of this pathogen and its exceptional ability to survive in soil (Hayward, 1991; Jackson, and González, 1981) plant debris and root hairs of host plants (Graham, et al,. 1979 ;Granda & Sequeira, 1983) the presence of a variety of weed species that are symptom less carriers of the pathogen (Rueda,. 1990, Tusiime et al., 1996b; Sumaina, *et al.*,1989), infested seed tubers (Kelman, 1998) as well as its means of dissemination contribute to massive crop loss (Kelman, 1998). However seed tubers are the major path of dissemination for BW. Bekele and Abebe, 2013 reported that, tubers harvested from infested soils and used as seed for the next season convey the pathogen latently. Hence, tubers with latent infection take the largest share in dissemination of the disease as well as for huge tuber yield loss.

Healthy seed of improved potato varieties insure good harvests and is the measure components of integrated BW management (Elphinstone, and Aley, 1992). However, improved varieties developed in research centers have not been made use of by farmers because of lack of agencies that could multiply and supply healthy certified seeds to the farming community. Hence, all potato farmers in the country often save and plant seed from their own fields year after year or buy the smallest sized tubers and latently infested tubers from local markets (Low, 1997; .Lung'aho, *et al*.,. 2007; Bekele, and Abebe, 2013).

These practices exposed farmers to disease build-up in the field and to get low yield (Ephrem, *et al*,. 2011; Habtamu, *et al*., 2012). Bekele and Abebe (2013) revealed that the incidence of the disease increased and tuber yield declined when tubers retained and used as a seed for more than three years (Bekele and Abebe, 2013).On the other hand, various research results (Bekele, and Berga, 2001; Allen et al., 1992; French, 1994; Gildemacher, *et al*., 2007; Lung'aho, *et al*., 2007; Lemaga *et al*., 2005) have shown that, planting clean healthy seed tubers, sanitation specifically rouging at early stage of the crop and field hygiene, disinfection of agricultural tools, positive selection, minimum tillage, improved cultural practices, sorting and improved postharvest handling of seeds reduce the incidence of the disease and enable to increase tuber yield. To address these concerns, it was considered that training of farmers and participatory technology development are important elements. According to Bekele et al., (2002) promoting participatory research coupled with crop phenology based sessions and conduct training at field level helped farmers to make decision on control measures (Bekele et al., 2002). The "Farmers Field School (FFS) supported by phenology based sessions" has been used in integrated pest management (Ortez, et al., 1999) and found effective in participatory technology development (Gallangher, 1993, Ortez et al., 1999, Van de Fliert and Braun, 1999).

Since bacterial wilt is also soil borne, rotation with non-host crops to BW were suggested as a management approaches to reduce the incidence of BW**.** Several research reports indicated that crop rotation helps to significantly reduce the disease (Kloos et al. 1991 Kishore, *et al.,* 1994; Lloyd, 1976; Van der Zaag, 1986;B ekele and Berga, 2001; Berga *et al*, 2005);Verma and Shekhawat, 1991;Gunadi et al. ,1998. According to Verma and Shekhawat (1991) a five-year rotation that included wheat, lupine and maize reduced wilt and increased yield. Higher potato yields were also obtained under crop rotation in the presence of bacterial wilt in Kenya (Barton *et al*., 1997). In the south east Ethiopia, a diversity of crops: pulses, cereals, vegetables, root crops and sugarcane are grown. However, these crops are sometimes rotated with potato but often potato comes successively for two or three seasons which may probably contributed to the high level of bacterial wilt incidence in the area. Therefore the study was undertaken to increase farmer's knowledge on bacterial wilt through FFS extension approach and to generate participatory BW management technologies using one and two-season rotations with beans and vegetables.

Materials and Methods

Two hundred forty seven (77 female and 170 male) farmers in ten farmers research groups, with an average of 26 farmers in each group, were organized in 2010 main cropping season in four districts namely: Shashemene **(**3 groups)**,** Tulubolo (3 groups), Welmera (2 groups) and Welisso (2 groups) to assist farmers to develop healthy potato farms. The groups were organized based on voluntary bases and the high initial level of enthusiasm on BW management. The methodology and approach for implementation of the experiment was problem oriented, participatory activity-based approach with sessions. The field sessions were typically based on crop phenology (Table 1). For this purpose, for each group, two 10 x 10m plots were planted with the local variety and in one of the plots farmers exercise major BW control measures like rouging, reduced hilling, disinfection of tools, etc. whereas the second plot was left without any interventions to manage BW. However, late blight was managed with one spray of fungicide Ridomil MZ 63.2 % WP and two sprays of the fungicide Dithane M-45 80 % WP, starting from the first visible symptom of the disease. During the growth period of the crop, farmers diagnosed the disease, learned about the causative agent, symptom, life cycle, way of dissemination, thorough discussion and recorded the development of the disease in their field. Finally, they made yield comparison between the two plots to have some idea about the effect of the disease on yield and yield components. In order to exercise post-harvest handling of seed tubers, all groups in the three districts constructed diffuse light store (DLS) based on cost sharing. Bacterial wilt participatory management technology development using one and two seasons crop rotation with none host crops (either beans, cabbage or carrot) to the *Ralstonia solanasearum* were conducted only at Shashemene on permanent plot where the area is considered as a hot-spot for the disease and which was thought to be the main source of infected seed for the rest of potato growers in the country.

Table 1. Type of sessions, their objectives and activities made by the FFS group members

Type	Objectives	Activity
Introduction to FFS	Introduce the mode of operation of FFS	Introduction and discussion
Potato seed quality and selection of planting materials.	Differentiate and select diseased and healthy tubers	Seed sorting planting and hands on learning
Knowledge and practices of farmers on bacterial wilt control	Base line information	Questioner/ Discussion
Potato seed quality (seed size, physiological stage, and physical and pest damage) sorting	To assist farmers to recognize symptom and proper stage of seeds	Discussion and diagnosis
Crop management (field preparation, fertility management, planting and hilling) Symptom and diagnosis of bacterial wilt (in field and tubers), late blight and viral diseases	To assist farmers to adopt improved practices Diagnosis and Identification of pests	Field exercise, hand on learning Discussion and diagnosis
Causes of potato wilt, development, life cycle (mode of transmission of the causative agent)	Learn the cause and life cycle of the pathogen	Group discussion, learning exercise, observation
Bacterial wilt management (removal of infected plants, clean seed, sanitation of tools	Demonstrate sanitation and create awareness	Discussion, learning Exercise & observation
Harvest and storage considerations	Create awareness on pre and post - harvest considerations,	Discussion, learning Exercise and DLS visit

Crop rotation: Crop rotation experiments were conducted by three FFS groups organized in three Kebeles namely Edola Burka, Fagi Fole, and Hurso Simbo, near Shashemene District. However, farmers from the rest of the districts had an opportunity to visit and exchange ideas through field days organized at the mid growth stage of the crop and during harvest. One set of one-season and one set of two-seasons rotation trials were carried out in mildly infested fields with an initial mean incidence of 47.8 %. In order to evaluate the effects of the crop species selected to be rotated with potato for BW incidence, the fields were used for three (one season rotation) and four (two season rotations) consecutive years as permanent plot (Table 2). The local variety "Nech Abeba , susceptible to BW, was planted as a sole crop in 2011 main season preceding to the main treatments and in the year 2013 (for one season rotation) and 2014 (for two seasons rotation) after the rotated crops. The one season rotation trial was carried out in year 2011, 2012 and 2013 and the two season's rotation experiment was done in 2011, 2012, 2013 and 2014 main seasons. Since the local variety used was highly susceptible to late blight, the major disease of potato under main rainy season cropping, was controlled with one spray of Ridomil MZ 63.2 % WP and two sprays of Dothane M-45 80 % WP starting from the first visible symptom of the disease at a rate of 3 kg ha^{-1} and 2.5 kg ha^{-1} respectively

Experimental design: The design was randomized complete block with four replications with plot size of 6 x 6 m. The local potato variety NechAbeba was planted before and after revolving crops in 75 cm x 30 cm spacing between rows and plants and fertilizers was applied at planting in the form of urea and di-ammonium phosphate (DAP) at a rate of 165 kg and 295 kg respectively. Crops that are commonly grown in the area by farmers were included in the treatments. Spacing between rows and plants for Cabbage, and Beans were 75 x 30 cm and 40 x 10 cm respectively whereas Carrot seeds were drilled in 20 cm separated furrows. Fertilizer was applied at the rate of 100 kg DAP).Potato late blight was controlled with Dithane-M45 and Ridomil-MZ, based on need application, each of which was sprayed.

Treatments

Table 2. Crop species considered in one and two season rotation, Shashemene

Treatment	
One season rotation	**Two seasons rotation**
Potato - Beans - Potato	Potato - Beans - Carrot - Potato
Potato - Cabbage - Potato	Potato - Beans - Cabbage - Potato
Potato - Carrot - Potato	Potato - Beans - Beans - Potato
Potato - Potato - Potato	Potato - Carrot - Carrot - Potato
	Potato - Cabbage - Carrot - Potato
	Potato - Cabbage - Cabbage - Potato
	Potato -Potato - Potato - Potato

Disease assessment: Assessment of the disease was started at the onset of wilt symptoms and observed on a weekly basis. Plants that showed either complete or partial wilting were all considered wilted and staked to avoid double counting in subsequent assessments. Wilt incidence for each treatment was then calculated as percentage of total number of plants emerged. Disease progress was plotted by considering the disease incidence against time. At harvest, 200 tubers were randomly sampled from each treatment and diagnosed for the presence of latent infection in the laboratory after the tubers were incubated at 32 ±2 °C that helps to promote symptoms in the latently infected tubers converted in to percentage (Rueda, 1990).

Yield components: The middle six rows of each plot were harvested after 95 days at senescence. Marketable, unmarketable and rotten tuber weight were recorded and converted in to hectare bases.

Statistical analysis

Percent wilt incidences was transformed into square roots before analysis and yield components for statistical comparisons and were subjected to analysis of variance (ANOVA) at 0.05 significant level using Statistical Analysis System (SAS) Version 9.11 (SAS Institute Inc.2003). Differences between means were assessed using Duncan's Multiple Range test.

Result and Discussion

Extension system

Farmers appraisal on potato pests revealed that insect pests such as aphids, potato tuber moth (PTM) mole rat, cut worm and termites were recognized as production constraints (Figure 1A).Late blight ranked first as the major constraint followed by bacterial wilt, scab and viruses (Figure 1B). Though, farmers acknowledge the availability of technologies to control late blight, they have confessed that they had no knowledge about the management. However, they considered wilt as the most important potato production constraint because of two reasons, as farmers said, first the disease increases year after year and attack both local and improved potato varieties and secondly they thought that it is not possible to control wilt hence, no interventions attempted to manage the disease. Prior to the inception of the research activity, all group members (100 %) did not know the causes of potato wilt and the majority of them believed rain and fog as causative agents. Moreover, they were not able to differentiate symptoms caused by insect pest or pathogens (Table 3). In addition the role of seed quality, crop management and storage considerations in bacterial wilt management were not known by farmers. Subsequently, farmers were not in a position to reduce the negative effects of the disease on yield and quality of the produce.

After series discussions and demonstrations, all FFS groups, farmers were able to diagnose and identify disease symptoms caused by different causative agents at field level, a mean of 53 % of the group members were able to change their views and understood about the causes of diseases in general and specifically knew the causative agent of bacterial wilt and late blight and ready to practice effective control measures. Moreover, the willingness of farmers to involve and contribute to the development of bacterial wilt control technologies was with full enthusiasm. However, a mean of 33 % of the farmer participants still acknowledge the need for additional session and back up. In general, the approach was found effective to transfer knowledge about BW and helped farmers to discover the advantage of knowledge about BW and enabled them to improve production practices and to produce disease free seed tubers. The results of this study agreed with the findings of Bekele, et al., 2002; Gallangher, 1993; Ortez *et al*., 1999, Van de Fliert and Braun, 1999 in which FFS approach is the most reliable approach to transfer knowledge intensive technologies like pest control for a reasonable number of farmers with in a season.

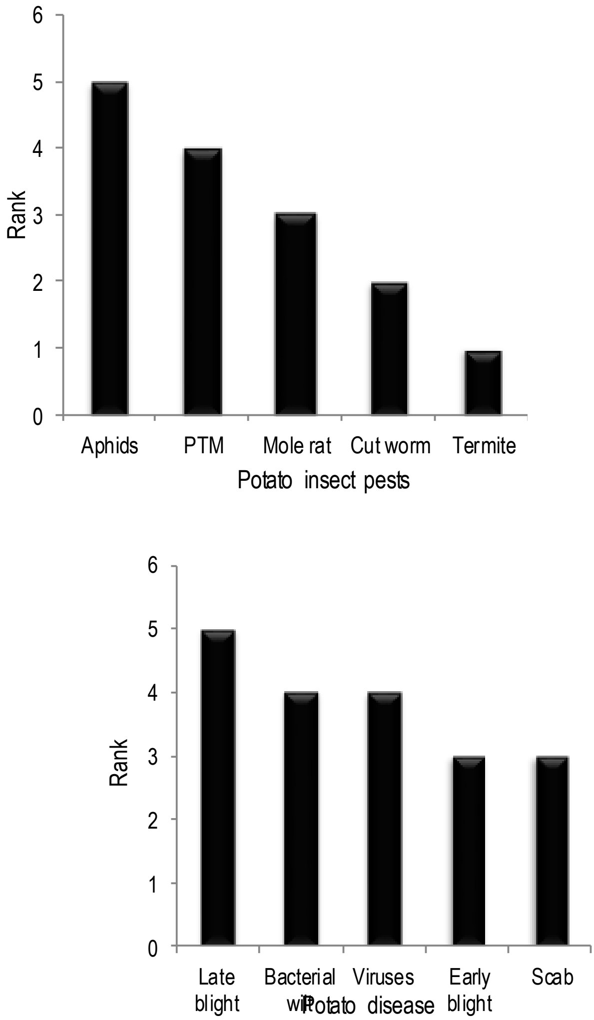

Figure 1. Rank of insect pest and diseases in potato production as ranked by group members in Shashemene (mean of 3 groups). Rank 5 refers as first priority and 0 as list priority

In 2011, plots that farmers groups managed had 21.3 % incidence of the disease whereas the incidence in unmanaged control plot was 36.4 %. The wilt control intervention, which was supported by session, under taken by the FFS group farmers helped to reduce the incidence of the disease by 70.9 %.As a result, yield increased by 40.6 % as compared to the untreated control(Table 4). In the year 2012, when the retained seed from each treatment was planted in the following year, in the plot with farmers' disease management interventions, the incidence of the disease was reduced by 73.8% and marketable yield was increased by 53.8 % compared to the control plot.

Table 3. Percent means response of the ten FFS group members on different components accomplishment of the sessions.

Session	New Knowledge(A)	Need additional session (B)	Ready to practice (C)
Introduction to FFS	100	5	95
Potato seed quality & selection planting materials supplementary experiments,	47	53	16
Knowledge & practices of farmers on bacterial wilt control	70	30	60
Potato seed quality (seed size, physiological stage and physical and pest damage) sorting	63	37	10
Crop management (field preparation, fertility management, planting and hilling)	24	76	60
Symptom and diagnosis of bacterial wilt (in field and tubers), late blight and viral diseases	90	23	63
Cause of potato wilt, development, life cycle(mode of transmission of the causative agent) & supplementary experiment	100	0	100
Bacterial wilt management (removal of infected plants, clean seed, sanitation of tools)	50	50	50
Harvest and storage considerations	67	33	20
Mean	67.0	33.0	52.6

New knowledge- implies that, participants had no knowledge before the execution of the activity; Need additional session- implies need additional session to associate themselves with the subject; Ready to practice – implies that the farmers have believed in the components of the session and promised to practice without hesitation. Column 2&3 considered as 100% whereas data in column 4 was generated by considering column 2 as 100%.

Table 4. Bacterial wilt incidence and potato tuber yield as influenced by farmer's disease control interventions, 2011-2012, Shashemene

Year	Disease incidence (%)			Tuber yield kg plot $^{-1}$		
	Managed plot	Unmanaged plot	Percent reduced	Managed	Unmanaged	Percent increased
2011	21.3	36.4	70.9	2479.5	1763.7	40.6
2012	12.6	47.1	73.8	2948.2	1161.5	53.8
Mean	16.95	41.75		2713.8	1462.6	

One season rotation: one season rotation had no significant effect on the onset of the disease. The symptom of the disease was recorded with in the same week in all treatments but, the disease appeared slightly earlier on the control treatment. Unlike the onset of the disease, the progress of the disease became relatively faster on mono cropped potato compared to potato-beans-potato, potato-carrot-potato and potato-cabbage-potato treatments (Figure 3). Mean disease incidence in one season rotation was as high as 34.3 %.Although, the incidence of the disease did not differ significantly among the three rotational crop species, rotation potato with cabbage had the lowest incidence followed by beans and the list effect was recorded when potato was rotated with carrot. However, all of them significantly ($P < 0.05$) decreased BW incidence when compared to the mono cropped potato treatment (Table 5). The highest wilt incidence (45.2 %) was recorded when potato was planted for three consecutive years while the lowest (15.4%) being recorded in potato-cabbage-potato followed by potato-beans-potato (22.1%) and potato- carrot-potato (27.3%). Cabbage in the system reduced BW incidence by 43.5 % and 77.3% over rotation with beans and carrot respectively. This result was agreed with the findings of Berga et al., (2005) in which beans helped to reduce BW when used as a rotational crop. However, since the pathogen can survive in soil for years (Hayward 1991) one season rotation may not be sufficient to significantly suppress the development of the pathogen but still the rotation crop may evolve in the change of physical and chemical properties of the soil which determine conduciveness for the disease development as stated by Jan et al., (2008).

Percent latent infection in tubers did not vary significantly among treatments. However, it was found slightly higher in rotation treatments compared to mono crop potato. Mean latently infected tubers of treatments was 21.2 %. The highest (25.9%) percent latently infected tubers were recorded on potato-carrot-potato followed by 23.2 % and 19.4 % on potato-cabbage-potato and potato-beans-potato treatments respectively. The lowest (16.3 %) was on the mono cropped potato treatment. This result was not surprising since if a variety is susceptible to the disease, the largest proportions of infected tubers are often rot and discarded during harvest. It should be noted that the suppression of field symptom by the rotation crop may not warrant reducing a potential danger of latently spreading of BW. As it was reported by Berga, (1999), less susceptible potato varieties to bacterial wilt have the potential to be latently infected and promote the spread of BW if they used as a seed. However, this technology demonstrated its significant role to wear potato production systems, since latent infection do not affect the market.

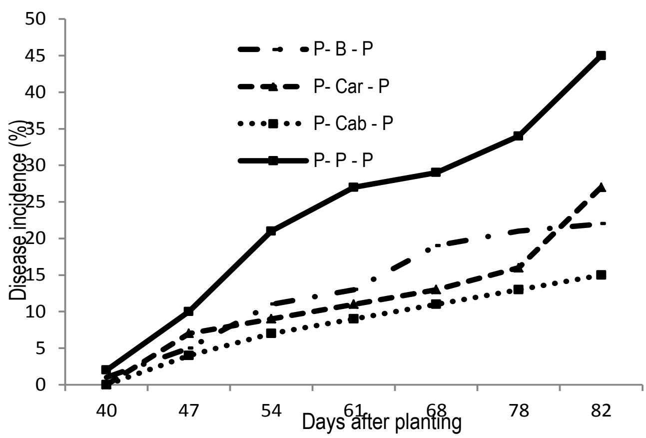

Figure 3. One season rotation of potato (P) with Beans (B), Carrot (Car) and with Cabbage (Cab) on the progress of the disease

Total and marketable tuber yields were significantly ($P < 0.01$) increased with a rotation of non-host crops to the pathogen as compared to the mono crop control treatment. The lowest incidence of BW 15.4%, 22.1% and the highest marketable potato yields 24.8 and 26.4 t ha^{-1} were recorded after rotations with cabbage and beans respectively (Table 5). In contrast, the lowest (21.3 t/ha) yield were obtained following rotations with carrots, which allowed slightly highest incidence (27.3 %). Rotation with beans carrot and cabbage helped to get 33%-77 % yield advantage. This could be because these crops do not exploit soil nutrients at the soil depths of 5-10 cm, where the potato is most active hence, the high yields after relatively deep rooted crops is expected. Gunadi et al. (1998) reported that potato yields following rotations with crops that have longer roots, such as maize and tomatoes may perform better. This suggests that the nutrient exploitation of crops selected for rotation with potatoes should be considered. The cabbage, which is the second most important horticultural crop in Shashemene, could be very suitable for rotation where BW is the major threat for potato production.

Table 5. Effect of one-season rotation with vegetables and beans on incidence of bacterial wilt and potato yields

Treatment	Bacterial wilt incidence (%)	Latent infection (%)	Total yield tha^{-1}	Marketable yield tha^{-1}	Increase in Marketable yield (%)
P - B - P*	22.1b	19.4a	26.4a	25.5a	77.1
P - Cab -P	15.4b	23.2a	24.8b	21.3b	47.9
P - Car - P	27.3b	25.9a	21.3c	19.1b	32.6
P - P - P	45.2a	16.3a	18.1d	14.4c	-
Mean	34.3	21.2	22.65	20.07	
CV %	11.2		9.13		

**P-B-P = Potato-Beans-potato; P-Cab-P = Potato-Cabbage-Potato; P-Car-P = Potato-Carrot-Potato and P-P-P = Potato-Potato-Potato; Means followed by the same letter in a column are not significantly different at 5 % probability level.*

The negative relationship of potato yield (Y) and wilt incidence (X) is given by Y= -0.2588x+29 .767 (R2 = 0.79) (Figure 4). The regression of total tuber yield (t/ha) over bacterial wilt incidence (%) recorded in one season rotation clearly indicated that yield significantly (P=0.05) decreased as disease incidence increased when potato comes after potato as opposed to rotation with beans, cabbage and carrot, where the incidence of the disease has decreased and tuber yield had increased.

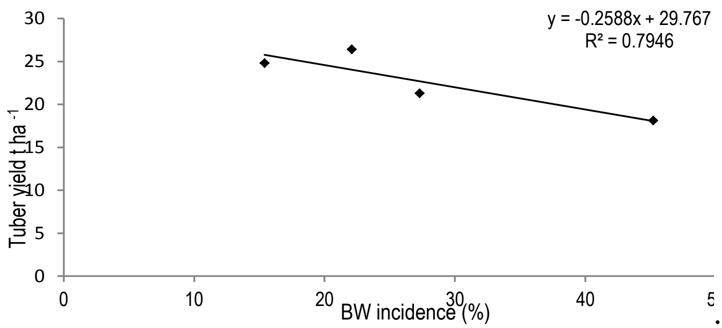

Figure 4. Relationships between potato tuber yield and incidence of bacterial wilt in one season rotation using beans, cabbage, carrot and mono crop potato at Shashemene, 2011-2013 cropping season.

Two-season rotation: Days to onset of BW were not affected by the different rotation treatments. However, after the onset of wilt at 40 days after planting, disease progress with the mono crop control was fast, and mean incidence at 91 days after planting was the highest (68.5%)which was significantly (P < 0.05) different as compared to the incidences under rotations, which were below 46.4% (Figure 5). The progress of the disease in treatments under rotation was very slow until 70 days after planting (DAP) and was below 12 % incidence. But after 78 DAP the progress of the disease on potato-carrot-carrot-potato, potato-carrot-beans-potato and potato-beans-beans-potato was relatively faster compered to potato-cabbage-cabbage-potato and potato-cabbage-carrot-potato rotation treatments.

Two season rotation effect on the incidence of the disease and tuber yield is presented in Table 6. Mean BW incidence was as high as 40.3 % with the range of 14.0 % to 81.1 % (Table 6). The treatments have shown significant differences among each other and to the control treatment. The lowest and statically significant ($p<0.05$) incidence of the disease was recorded when cabbage followed cabbage or when it was considered in the rotation before beans and carrot. Whereas, carrot - beans, .carrot - carrot and beans-beans had significantly highest disease incidence compared to the cabbage based rotation system but reduced the disease significantly compared to the mono crop potato.

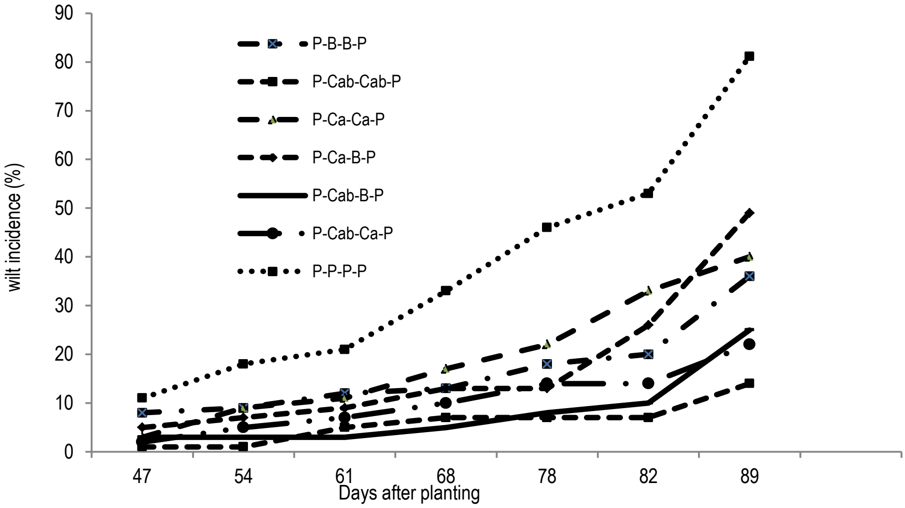

Figure 5. Two seasons' rotation of potato with beans (B), cabbage (Cab), carrot (Ca), and mono crop potato (P) effect on the progress of the disease.

The mono crop potato had significantly ($p<0.05$) highest disease incidence (81.1 %) and cabbage-cabbage had the lowest (14.0%) but the rest of the treatments had in the range of 22.0 % to 49.4% incidence and the values are statistically differ among each other. Mean percentage of latently infected tubers was 38.7 %. The lowest (23 %) was recorded in cabbage-cabbage whereas the highest (77.3 %) being in mono crop potato and the rest of the treatments had in the range of 25.0 % to 53.3%. However, carrot-carrot and cabbage – carrot had significantly higher per cent of latently infected tubers compared to beans-beans, cabbage-cabbage, carrot-beans and cabbage-beans. The highest per cent of latently infected tubers in mono-crop susceptible variety is not often expected because infected tubes of susceptible potato varieties rot still when they are in the field and the possibility to carry the inoculum of the pathogen as latent not expected. But as it happened in this experiment even susceptible varieties can act as a carrier of the pathogen without promoting rotting at field level which probably may depend on the amount of inoculum of the pathogen in the tuber at the age where the crop reached to senescence.

Mean marketable tuber yield increased when potato was rotated with beans, cabbage and carrot. Significantly ($p<0.05$) highest marketable potato tuber yield (29.27 t ha^{-1})and per cent increase (154 %) was recorded after rotations with beans – beans followed by cabbage - beans(27.4 t ha^{-1}) with 138 % increase and the lowest (11.5 t ha^{-1})tuber yield was obtained in mono cropped potato treatment. This may probably be, in crop rotations grain legumes serve as N2- fixing plants which can reduce the mineral N fertilizer demand and improve soil fertility. Mayer et al., 2003 reported that any crop that comes after pulses like beans often give more yield because of the ability of the crop to fix free nitrogen from the air which increases the availability of the element to the plant and improve soil fertility. The rest of the treatments gave within the range of 18.9 t ha^{-1} to 27.4 t ha^{-1} and 64.5 7 to 138.0% yield advantage over and above the mono crop control treatment and were differ significantly.

Table 6. Effect of two-season rotation on bacterial wilt incidence and potato yields at Shashemene, 2010 - 2014 seasons h

Treatment	BW incidence (%)	Latent infection%	Marketable tuber yield (t ha^{-1})	% increase
Potato - Beans - Beans - potato	36.4 (5.81 d)*	25.0c	29.27a **	154.52
Potato - Cabbage - Cabbage - Potato	14.0 (3.28 g)	23.0c	20.73bc	80.27
Potato - Carrot - Carrot - Potato	40.3 (6.32c)	53.3b	18.92bcde	64.57
Potato - Carrot– Beans - Potato	49.4 (7.01b)	36.7c	20.15bc	75.21
Potato – Cabbage - Beans – Potato	25.2 (4.89e)	30.0c	27.37ab	138.00
Potato – Cabbage - Carrot – Potato	21.9 (4.52 f)	48,3b	20.7bcd	80.00
Potato - Potato - Potato - Potato	81.1 (8.96 a)	77.3a	11.5f	-
Mean	40.26	38.74	20.97	98.76
CV %	9.1	8.4	7.6	

** Square root values. **Means followed by same letters in columns are not significantly different at 5% probability level*

Some crop species seem to reduce the loss attributed to the disease and the relation of potato yield (Y) and wilt incidence (X)is given by Y= -0. 0.177x + 28.019 ($R^2 = 0.4597$). The regression of marketable tuber yield (t ha -1) over bacterial wilt incidence (%) under rotation clearly indicated that yield significantly ($p=0.05$) decreased with increase in wilt incidence (Figure. 6)

The study suggested that bacterial wilt control can be improved if the extension is supported by sessions based on crop phenology because disease control largely depends and needs knowledge about the pathogen. As farmers acquired knowledge about the pathogen, they can change their views and understood the causative agent of bacterial wilt, as it was observed in this research work, and the likely hood of exercising the control technologies increased. In general the FFS extension approach warranted for knowledge transfer and intensive technology development such as bacterial wilt of potato. However integrated BW control practices that farmers are willing to adopt should be supported by advanced pathogen detection techniques like serology so that the risk of latently infected tubers to new areas minimized. Crop rotation with non-host crop such as one season rotation potato with cabbage and two seasons rotation with the presence of cabbage in the system reduced the disease incidence in moderately BW infected soils.

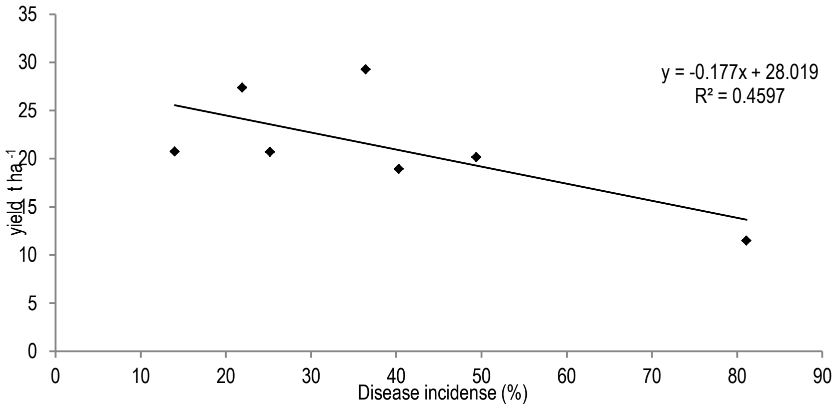

Figure 6. Relation of disease incidence over tuber yield in two season rotation potato with beans, carrot and cabbage with different configurations.

The availability of such research should be considered to be part of an integrated bacterial wilt control where the disease is a threat and cabbage exists in the given cropping system. We strongly suggest that for areas with a BW problem, crop rotation be considered as an important component of an integrated control option to get significant impact in pathogen reduction in the soil and concurrently to reduce the amount of latent infection in tubers which has vital role in the dissemination of the disease to new un polluted areas by the pathogen.

References

Allen E. J., O'Brien, P.J. and Firman D.1992.Seed tuber production and management.*In*: Harris, P.M. (Ed.), The Potato Crop. The scientific basis for improvement.Second edition.Champman and Hall, London, UK. Pp247-291

Bang, S.K. and Wiles, G.C. 1995. Control of bacterial wilt (Psuedomonassolanacearum) in potato by crop rotation. *In*: SAPRAD on the Third Year of Phase III. Rasco, Jr. E.T. and Aromin, F.B (Eds.), pp. 103-106 .Selected Research Papers Vol 1.South Asian Program for Potato Research. Manila, Philippines.

Barton, D., Smith, J. and Murimi, Z.K. 1997. Socio-economic inputs to 'biological control of bacterial wilt diseases of potato in Kenya'. ODA RNRRS Crop protection: R66292 (NR International: ZA0085), 22 pp.

Bekele Kassa and Abebe Chindi. 2013. Seed Tuber Cycle and Latent Infection for the Spread of Potato Bacterial Wilt *Ralstonia solanascearum* (Smith) a major threat for Seed Production in Ethiopia. Asian Journal of Plant Pathology 7 (2): 74-83, 2013

BekeleKassa and Berga Lemaga.2001. Effect of preceding crop, potato varieties and post emergence cultivation (Hilling) on the incidence of bacterial wilt. *In*: Rot crops in 21st Century. Proceedings of the 7th Triennial Symposium Canadian journal of Microbiology 29: 433-440

BekeleKassa and EshetuBekele, 2008. Potato Disease Management: Root and Tuber Crops the Untapped Resources. *In:*GebremedhinWoldegiorgis, EndaleGebre and BergaLemaga (eds). Ethiopian Institute of Agricultural Research. Addis Ababa, Ethiopia, pp 79-95.

BekeleKassa, Gebremedhin W/Giorgis, FasikaKelemwork, AwelMela, O.M Olanya. P.T.Ewell, R.El-Bedewy and O.Ortiza. 2002. Integrated potato late blight management: Experience of farmers Field School (FFS) in Dendi District. Pp56-67.*In*: GemechuKeneni, YohannesGojjam, KifluBedane, ChilotYirga and AsgelilDibabe (eds.).Towards Farmers'Participatory Research: Attempts and achievements in the Central Highlands of Ethiopia. Proceedings of Client oriented Research Evaluation Workshop, 16-18 October 2001, Holetta Agricultural Research Center, Holetta, Ethiopia

BekeleKassa. 1996. Incidence and Distribution of Major Potato Diseases in 1993 & 1994 off-Season in Central Ethiopia. *In*: Abstract of the 4th Annual Conference of the Crop Protection Society of Ethiopia, (CPSE) 18-19 May 19, Addis Ababa, Ethiopia. p 15.

CIP, 1995. Program Report for 1993-1994. International Potato Center (CIP, Lima, Peru.Combination of rotation and resistance to control of bacterial wilt (*Psuedomonassolanacearum*) in Rwanda.Pp 100-101. EAPR Abstracts.Tenth Triennial Conference of European Association for Potato Research, Aolborg, Denmark.

Elphinstone, J.G. and Aley, P. 1992.Integrated control of bacterial wilt of potato in the warm tropics of Peru. *In*: Bacterial wilt Proceedings No 45. Hartman, G. L. and Hayward, A.C. (Eds.), pp. 276-283. Kaoshuing, Korea.

Ephrem Debebe Zegeye, Amutha Santanam, Bekele Kassa, Dereje Gorfu and Mesfin Tesera. 2011. Bio control activity of *Trichoderma viridi*, and *Pseudomonas fluorescens* aginest *Phytophthora infestans* under green house condition. Journal of Agricultural Technology . vol.7(6):1589-1602. ISSN 1686-9141

FAO-CIP. 1995. Potatoes in the 1990s; Situation and prospects for the world potato economy, FAO (Food and Agricultural Organization), Rome 39 pp.

French, E.R. 1994. Strategies for integrated control of bacterial wilt of potatoes.*In*: Hayward, A,C. and G.L. Hertman (eds,). Bacterial wilt: The disease and its causative agent, *Pseudomonas solanacearum*. CAB International U.K. 288 p

Gallangher, K. 1993. Farmers field school (FFS): A group extension process based on adult none formal education methods. Global IPM Facility Secretariat, FAO, Rome, 7 pp.

Gildemacher, P., Dimpo , P., Kinyae, P., Wakahiu, M., Nyongessa, M. and Zschocke, T. 2007. Select the best: positive selection to improve farm seed potatoes. Trainers manual International Potato Centre, Lima, Peru 108 pp.

Graham, J., Jones, D.A., and Lloyd, A.B.1979. Survival of *Pseudomonas Solansearum* race III I n plant debris and in latently infected potato tubers. Phytopathology: 69 1100-1103

Granada, G.A. and L. Sequeira.1983.Survival of *Pseudomonas solanacearum* in soil, rhizosphere, and plant roots.Canadian Journal of Microbiology (29):433–440.

Gunadi, N., Chujoy, E. Kusmana, M., Surviani, I., Gunawan, O. S. and Sinung- Basuki. 1998. Effect of crop rotation patterns on *Ralstoniasolanacearum* population in the soil. Potato reseach in Indonesia. Results in working paper series, CIP/RIV. pp. 56-61.

Habtamu Kefalegne, Alemayehu Chala, Bekele Kasaa and GBG Pananjay K.Tiwari. 2012.Evaluation of different potato variety and fungicide combinations for the management of potato late blight (Phytophthora infestans) in southern Ethiopia. International Journal of Life Sciences Vol.1 No. 1, 2, 2012.8-15

Hayward, A.C. 1991. Biology and Epidemiology of bacterial wilt caused by *Pseudomonas solanacearum*.Annu. Rev. Phytopathology 29: 65-87.

Jackson, M.T. and González, L.C. 1981. Persistence of *Pseudomonas solanacearum* (Race 1) in a naturally infested soil in Costa Rica. Phytopathology 17: 690-693.

Jan W. Low, Ian Barker, Meredith Bonierbale, Charlie Crissman, Greg Forbes, BergaLemaga, and Sylvie Priou. 2008. Potato Disease Management: Root and Tuber Crops the Untapped Resources. *In: GebremedhinWoldegiorgis ,EndaleGebre and BergaLemaga (eds.). Ethiopian Institute of* Agricultural Research. Addis Ababa, Ethiopia,

Kelman, A.1998. One hundred and one years of research on bacterial wilt. Pages1-5 *In*: Bacterial Wilt: Molecular and Ecological Aspects (Eds. prior, P. Allen, C. and Elphinston, J.) INRA Editions, Paris and Springer Germany.

Kishore, V., Sunaina, V. and Shekhawat, G.S. 1994.Relative effectiveness of various crop rotations on incidence of potato bacterial wilt. *In*: Proceedings of Potato: Present and future. Shekawat, G.S., Khurana, S.M. P., Pandey, S.K. and Chandla, V.K. (Eds.), pp.184-187.Indian Potato Association. Shimla, India.

Kloos, J.P., Fernandez, B.B., Tumapon, A.S. and Villanueva, L. 1991. Effects of crop rotation on incidence of potato bacterial wilt caused by *Psuedomonassolanacearum* E.F. Smith. Asian Potato Journal 2:1-3.

Lemaga Berga, Kakuhenzire, R. Kassa Bekele, Ewell, P.T., and PriousS. 2005. Integrated control of potato bacterial wilt in Eastern Africa: The experience of Highlands initiative. Pp145-158.*In*; Bacterial Wilt Disease and the *Ralstonia solanascarum* Spicies Complex. (Eds) Allen C., Prior P., and Hayward , A.C. APS press, St. Paul, Minnesota USA, 510 pp.

Lloyd, A. B. 1976. Bacterial wilt in cold- temperature climate of Australia. In: Planning Conference and Workshop on ecology and Control of bacterial wilt caused by *Psuedomonassolanacearum.* North Carolina state University, Raleigh, North, Carolina. pp. 134 -135.

Low, J.W. 1997. Potato in southwestern Uganda.Threats to sustainable production. African Crop Science Journal 5:295-412.

Lung'aho, C., Lemaga, B., Nyongesa, M., Gildemacher, P., Kinyae, P., Demo, P and Kabir, J. 2007.omercial and seed potato production in eastern and central Africa. Kenya Agricultural Institute. 140pp.

Mayer, J., F. Buegger, E.S. Jensen, M. Schloter and J. Heb. 2003. Residual nitrogen contributionNazreth Agricultural Research Centre progress report, 1993).

Ortez, O., Fano, H., Winters, P., Thiele G., UNda, V.J., and Hakiza, J.J. 1999. Understanding farmers response to late blight (LB): Evidence from the base line study in Peru, Bolivia, Ecuador and Uganda. In: Proceedings of the global initiative on late blight, A threat to global food security. Crissman.

Rueda, J.L. 1990. Seed potato improvement under bacterial wilt (*Pseudomonas solanacearum* E.F. Smith) pressure: An integrated approach. PhD Thesis, University of Reading, U.K. 266 p

SAS Institute Inc. 2003. SAS/STAT, Guide for personal computer version 9.1 SAS Institute, Inc. carry, NC, USA.

Scott, G.J., Rosegrant, M.W., and Ringler , C.2000. Global projections for root and tuber crops in the year 2020. Food Policy 25, 561-597. .

Sumaina, V., Kishore, V. and Shekhawat, G.S. 1989.Latent survival of Pseudomonas solanacearum in potato tubers and weeds. Journal of Plant Diseases and Protection 96:361-364.

Tusiime, G., E. Adipala, F. Opio, and A.S. Bhagsari.1996b. Occurrence of *Pseudomonas solanacearum* latent infection in potato tubers and weeds in highland Uganda. African Journal of Plant Protection 6:108–118.

Van de Fliert, E. & Braun, A.R. 1999.Farmer Field School for integrated Crop Management of Sweet Potato.Field Guides and Technical Manual. International Potato Centre, Regional Office for East, S.E. Asia and the Pasfic, Borgor, Indonesia, 101 pp.

Vander Zaag, P. 1986. Potato production under *Pseudomonas solanascearum* conditions; Sources and management of planting materials . In Persely, G.J. (ed). Bacterial wilt disease in Asia and South Pasfic.ACIAR Proceedings 13, Canberra. P. 84-88

Verma, R.K. and Shekhawat, G.S. 1991. Effect of crop rotation and chemical soil treatment on bacterial wilt of potato. Indian Phytopathology 44:5-8.

YaynuHiskias. 1989. Characteristics of isolates of *Pseudomonas solanacearum* in Ethiopia. Ethiopian Journal of Agricultural Science.11:7-13