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Effect of Field Treatment with Selected Soil Amendments on Bacterial Wilt Incidences in Tomatoes, Capsicum and Potatoes

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Authors' contributions

This work was carried out in collaboration amongst all authors. Author EKK did Ralstonia solanacearum isolates collection, carried out field experiment, analyzed data and prepared the first draft. Author ZMK provided the working experimental design for treatment and guided (supervised) the activity. Authors JMM and POO provided general guidance on the experiment and edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this study was to establish the effect of field treatment with selected soil amendments on bacterial wilt incidences in Tomatoes, Capsicum and Potatoes.
Study Design: The study was laid out as randomized complete block design (RCBD) in split plot arrangement for two seasons in the field.
Place and Duration of Study: The experiment was conducted at the experimental plots at KARLO-NARL, Kabete Nairobi County between July, 2017- September, 2017 and between November, 2017- January, 2018.
Methodology: The three choice crops of interest (potatoes, tomatoes and capsicum) were inoculated with prepared pure bacterial isolates; 18 (2T-Kiambu-Low Land), 71(2A-Nyeri-Low Land), 67 (2A-Nyeri-High Land), 83 (2T-Kirinyaga-Highland) and MX (18/71/67/83). A plot measuring 66 m

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by 28.5 m was marked, cleared, ploughed, harrowed and demarcated into 150 plots each measuring 2.4 m x 3.75 m. Spacing of the host crops of interest: potato - (Tigoni variety), tomato (Caj variety) and capsicum (Califonia Wonder) was carried out at 75 cm between the rows and 30 cm within the rows. The treatments were Chalim^{TM}, Super-hydro-grow polymer + Metham sodium, Metham sodium, Metham sodium & Orange peel, Super-hydro-grow polymer, Brassica tissues, Chalim^{TM} + Super-hydro-grow polymer, Brassica tissue + Orange peel, Metham sodium + Super-hydro-grow polymer and Control (no amendments).

Results: Significant differences ($P \leq 0.05$) were revealed in the bacterial wilt incidences in tomatoes, capsicum and potatoes between control and all the soil amendments used in season 1 and 2 in the five *R. solanacearum* isolate from Kenyan highlands and lowlands. The Brassica tissue + Super-hydro-grow polymer was superior in reducing bacterial wilt incidences in tomatoes, capsicum and potatoes in the field in all the *R. solanacearum* isolates from Kenyan highlands and lowlands both in season 1 and 2.

Conclusion: The findings showed that organic and inorganic soil amendments could serve as a viable control of bacterial wilt in solanaceous crops caused by *R. solanacearum in the* field. We recommend the use of Brassica tissue + Super-hydro-grow polymer soil amendment in the control of bacterial wilt incidences in the field on solanaceous crops.

Keywords: Bacterial wilt; incidences; Ralstonia solanacearum; field; soil amendments.

1. INTRODUCTION

Ralstonia solanacearum, the causal agent of bacterial wilt disease, is considered one of the most destructive bacterial pathogens due to its lethality, unusually wide host range, persistence and broad geographical distribution [1]. The bacteria infect over 50 plant families and causes bacterial wilting of more than 250 plant species [2,3]. *R. solanacearum* widely distributed in tropical, subtropical, and temperate regions of the world, is a complex species with considerable diversity [4]. *R. solanacearum* was described as a species complex due to its diversity and the variability of the strains aggressiveness in different hosts [5]. The strains that can cause disease below 20ºC are considered a threat to agriculture in temperate areas and some countries have placed quarantine measures naming it as a select agent [6].

Ralstonia solanacearum invades plant roots through wounds or emergence points of lateral roots [7]. Root exudates released from wounds initiate the bacteria's' chemotactic mediated swimming toward the roots [8]. It invades the vascular vessels and grows systemically in the plant [9]. Plants infected by *R. solanacearum* appear shrunk with severe leaf epinasty while still freshly green. When the plant stem is vertically split, vascular discoloration can be observed, while lateral sections are dipped in water, the bacteria can be seen streaming. In order to cause infection, the *R. solanacearum* must be able to utilize the host resources to ensure successful multiplication inside the plant tissue amidst the plant defense mechanisms [5]. Stems exhibiting vascular browning are usually filled with very high concentrations of bacteria [10], which can be observed as a thick, milky stream oozing out of cut stems immersed in water [11].

The host pathogen interaction is greatly influenced by the environment [12]. *R. solanacearum* strains have varying abilities to survive in different climatic zones [13]. Most plant pathogens of a given species are active within a limited range of temperature. However, some strains are virulent across a wider range due to adaptive and perhaps evolutionary pressures. Introduction of such strains to new crop zones could be economically devastating [14]. *R. solanacearum* survives in soil by feeding on dead plant debris and shows an unusual ability of surviving in a nutrient depleted environment [15]. It was shown that strains of *R. solanacearum* can be altered based on soil type, its texture, pH and moisture content [16]. During heavy rainfall on infested soil, water runoff contaminates rivers which are the sources of irrigation water [17].

Bacterial wilt control in various pathosystems has been possible through use of a combination of diverse methods such as host resistance, biofumigation, fertiliser application, soil solarisation, biological control, chemical control, and other cultural practices and integrated disease management schemes [18,19]. Cultural practices such as fallowing and crop rotation are ineffective since the bacterium is able to endure harsh conditions and survive for a long time in soil [20,21]. Breeding of crop cultivars with suitable resistance is regarded as a key approach for integrated management of bacterial wilt. Remarkable progress has been achieved in developing resistant cultivars for some economically important crops in China including peanut [22], tobacco [23], potato [24], tomato [25], pepper [26], and eggplant [27].

Soil amendments are widely used in agriculture to increase soil pH and are considered to have positive effects on soil health and plant growth. Moreover, the use of soil amendments as an alternative for bacterial wilt control has been studied. Li and Dong [28] demonstrated that rock dust (CaO) additions under greenhouse conditions can effectively control tomato bacterial wilt by raising the soil pH and Ca content. A study showed that rice straw biochar application could reduce the incidence and severity of tobacco bacterial wilt disease [29]. Studies on soil chemical composition and how soil amendment can be done to hamper invasion would be useful. Bacterial wilt of tobacco can also be suppressed by supplementation of mineral nutrients like calcium and molybdenum [30]. Yadessa et al. [16] proposed amending top soil with coco peat, farmyard manure and compost to control *R. solanacearum*. The objective of the study was to establish the effect of field treatment with selected soil amendments on bacterial wilt incidences in Tomatoes, Capsicum and Potatoes.

2. MATERIALS AND METHODS

2.1 Study Area

The experiment was conducted at the experimental plots at KARLO- NARL, Kabete, near Nairobi, about 8 km Northwest of Nairobi at 36° 41'E and 01° 15'S and an altitude of 1737 Metres Above Sea Level (MASL). The rainfall is bimodal; the average received ranging from 600 to 2000 mm per year. The area is reliable and favorable for agricultural activities, with the April-July period receiving 60% and October-November 40% of precipitation. It has two crop growing periods with a total of 150-214 days. The mean annual temperature ranges from 18.0ºC to 21.9ºC. Soils at KARLO, Kabete, are dominated by humic Nitisols [31] with a clay texture and are known locally as Kikuyu Red Loam. The laboratory work was carried out at (KARLO-NARL), Kenya Agricultural Research and Livestock Organization-National Agricultural Research laboratories.

2.2 Eperimental Design and Treatments

The experiment was carried out between July, 2017- September, 2017 and between November, 2017- January, 2018 and was replicated three times for the two seasons. The experiment was laid out in randomized complete block design (RCBD) in split plot arrangement in the field. A plot measuring 66 m by 28.5 m was marked, cleared, ploughed, harrowed and demarcated into 150 plots each measuring 2.4 m x 3.75 m. Spacing of the host crops of interest: potato - (Tigoni variety), tomato (Caj variety) and capsicum (Califonia Wonder) was carried out at 75 cm between the rows and 30 cm within the rows. The treatments were Chalim™, Superhydro-grow polymer and Metham sodium, Metham sodium, Metham sodium + Orange peel, Super-hydro-grow polymer, Control, Brassica tissue, Chalim™ + Super-hydro-grow polymer, Brassica tissue + Orange peel and Metham sodium + Super-hydro-grow polymer. All agronomic practices including, watering, fertilization, weeds, pests and disease control were well managed.

2.3 Preparation of Plot Soil Amendments

Fresh leaves of cabbage plant residues were finely chopped and incorporated into the soil at a depth of 20 cm, at the rate of 3969 g per 2.4 m x 3.75 m plot (4355.56 kg/ha), The inoculated soil was thoroughly mixed with the finely chopped cabbage plant residue, ensuring that all the residues were well incorporated in the soil. Freshly dried finely chopped peels of orange plant residues were incorporated into the soil at a depth of 20 cm, at the rate of 3969 g per 2.4 m x 3.75 m plot (4355.56 kg/ha). The inoculated soil was thoroughly mixed with the finely chopped orange peels residues; ensuring that all the residues were well incorporated in the soil. Metham sodium, a chemical fumigant was applied in 12 plots of 2.4 m x 3.75 m at the rate of 200 ml/m^2 i.e. (1800 ml in 9 L of water). This was the positive control. This was done in each of the 6 furrows where each furrow received 1800 ml of the mixture (10.800 L), approximately 2000 L/ha. The sprayed furrows were thereafter covered with soil awaiting three weeks to the planting of the test crops. Chalim™ effect was assessed in the inoculated field after application at the rate of 227.81 g per 2.4 m x 3.75 m plot (250 kg/ha). Super-hydro-grow polymer was applied in 12 plots of 2.4 m x 3.75 m at the rate of 200 ml/m^2 using knap-sack sprayer. Combination of Chalim™ + Super-hydro-grow polymer was applied at the rate of 227.81 g per 2.4 m x 3.75 m plot (250 kg/ha) and 2.4 m x 3.75 m at the rate of 200 ml/m^2 respectively. Metham sodium + Super-hydro-grow polymer was applied in a 2.4 m x 3.75 m plot at the rate of 200 ml/m^2 and 3969 g per 2.4 m x 3.75 m plot (4355.56 kg/ha). Metham sodium + Orange peel treatment was applied in a 2.4 m x 3.75 m at the rate of 200 ml/m^2 and Orange peel rate of 3969 g per 2.4 m x 3.75 m plot (4355.56 kg/ha). Brassica tissue + Orange peel treatment were applied at a rate of 3969 g per 2.4 m x 3.75 m plot (4355.56 kg/ha) and Orange peel at a rate of 3969 g per 2.4 m x 3.75 m plot (4355.56 kg/ha) respectively. Pre-determined concentrations of all the amendments were applied per furrow and the crop of interest planted.

2.4 Field Inoculation

The positively identified potato tubers and stems of capsicum and tomato were used to isolate *R. solanacearum*. The five pure bacterial isolates were 18 (2T-Kiambu-Low Land), 71(2A-Nyeri-Low Land), 67 (2A-Nyeri-High Land), 83 (2T-Kirinyaga-Highland) and MX (2T-L/2A-L/2A-H/2T-H (18/71/67/83). Potato tuber stems and infected tomato and capsicum plants were cut above the soil level and the cut surfaces were suspended in test tube containing clean water. Bacterial strains were routinely cultured in CPG agar (CPG broth with 15 g of agar/litre) media. These strains were easily distinguished on the basis of colony morphology and colour by using the South Africa semi-selective medium (SMSA-E) at KARI-NARL bacteriology laboratory. Pure bacterial was harvested (30 plates per plant sample) into a 5 L of sterile distilled water to make composite bacterial inoculate to be sprayed in 24 plots (208.3 ml). Each plot was sprayed evenly with a mixture of 208.3 ml of the concentrated inocular topped with distilled water to 15 L mark of knapsack sprayer. All the plots were inoculated with *R. solanacearum* isolates 18, 71, 67, 83 and MX to a level of approximately 7.5×10^7 Colony forming unit (CFU) per plot. Three plots were used as negative controls for the experiment where the plants were planted directly without any soil amendments other than DAP fertilizer and agrosober gel. Metham sodium, a known fumigant was used as a positive control. Randomized complete split plot design was used in the field layout.

2.5 Data Collection and Analysis

Three choice crops (tomato, capsicum and potato) were used. The plants were rated weekly, each Wednesday for bacterial wilt disease incidence from the 18th day after planting where wilted plants were uprooted upon total foliage wilt and recorded though only the incidence at 4th, 7th and 10th weeks after planting (WAP) was considered for evaluation. Plants with visible symptoms (wilted leaves) were recorded as diseased plants. Bacterial wilt incidence was assessed as percentage of wilted plants within each treatment. It was calculated in accordance with the formula provided by Getachew et al. [32].

$I = NPSWS/NPPT \times 100$; where I = wilt incidence, NPSWS = number of plants showing wilt symptoms, and NPPT = number of plants per treatment.

For proper key diagnostic identification of *R. solanacearum* in the field and to distinguish bacterial wilt from vascular wilts caused by fungal pathogens, bacterial wilt symptoms was identified by visual observation of typical bacterial wilt disease symptoms such as wilting, vascular discoloration, bacterial streaming in glass of water and browning of the vascular bundles of the tuber. Milky white strands containing bacteria and extracellular polysaccharide was oozed out from the cut ends of the xylem. The diseased samples were brought to the laboratory and subjected aseptically for detection and confirmation of *R. solanacearum*.

2.6 Data Analysis

Data that was obtained from effect of field treatment with selected soil amendments on bacterial wilt incidences in Tomatoes, Capsicum and Potatoes was statistically analyzed by statistical package for social sciences (SPSS) software for Windows, ver. 23 (SPSS, IBM, USA). Chi-square was done to measure the strength of associations between variables. A p-value of <0.05 was considered to be statistically significant.

3. RESULTS AND DISCUSSION

3.1 Influence Selected Soil Amendments on Field Disease Incidence on Capsicum

The results of incidences of bacterial wilt on Capsicum grown on the field for season 1 and 2 are shown by Figs. 1 and 2 respectively. Significant differences (*P*≤0.05) were revealed in the bacterial wilt incidences in Capsicum between control and all the soil amendments used in season 1 and 2 except for MS+SHG in the five *R. solanacearum* isolate from Kenyan highlands and lowlands. The mean disease index for control and soil amendments; MS+SHG, BT, MS, CM+OP, BT+OP, BT+SHG, CM+SHG, CM and MS+OP for season 1 and 2 were as follows; 7.977, 7.667, 2.6, 4.133, 5.067, 0.867, 0.6, 2.6, 5, 6.267 and 5.022, 5.133, 1.933, 1.8, 2.4, 0.8, 0.067, 2, 1.6, 2.667 Respectively.

The Brassica tissue + Super-hydro-grow polymer was superior in reducing bacterial wilt incidences in capsicum in the field in all the *R. solanacearum* isolates from Kenyan highlands and lowlands both in season 1 and 2. This concur with the findings of Kago et al. [33] that established that the Brassica tissue + Super-hydro-grow polymer was superior in reducing bacterial wilt incidences in capsicum in the greenhouse in all the *R. solanacearum* isolates from Kenyan highlands and lowlands both in season 1 and 2. Brassica species produce glucosinolates which are nematocidal and biocidal. Plant materials, usually added in compost amendments, represent a reservoir of effective chemotherapeutants and can provide valuable sources of natural pesticides [34]. The use of cabbage plant residue in the control of

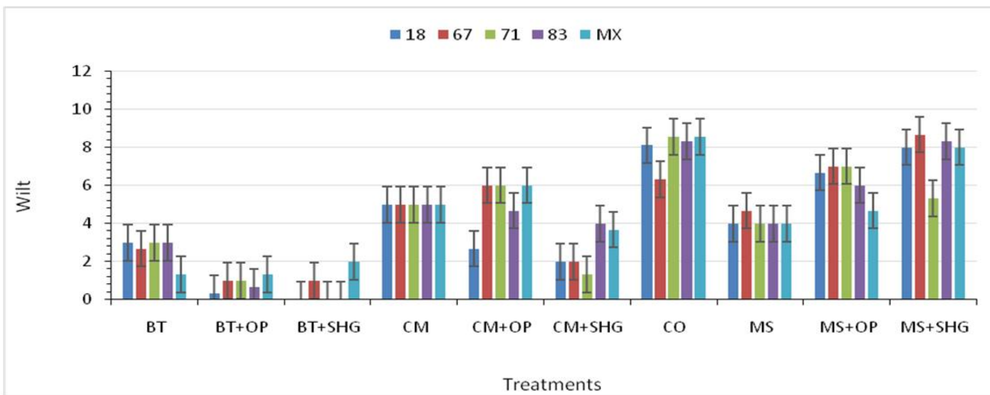

Fig. 1. Field bacterial wilt incidence in capsicum season 1

BT-Brassicae Tissue, BT+OP - Brassica tissue+ Orange peel, BT+SHG- Brassicae Tissue+ Super hydro-grow polymer, CM-Chalim^{TM}, CM+OP- Chalim^{TM}+ Orange peel, CM+SHG- Chalim^{TM}+ Super-hydro-grow polymer, MS- Metham sodium, Ms+ OP-Metham sodium+ Orange peel, MS+SHG- Metham sodium+ Super-hydro-grow polymer: 18 (2T-Kiambu-Low Land), 71(2A-Nyeri-Low Land), 67 (2A-Nyeri-High Land),83 (2T-Kirinyaga-Highland) and MX (2T-L/2A-L/2A-H/2T-H(18/71/67/83)

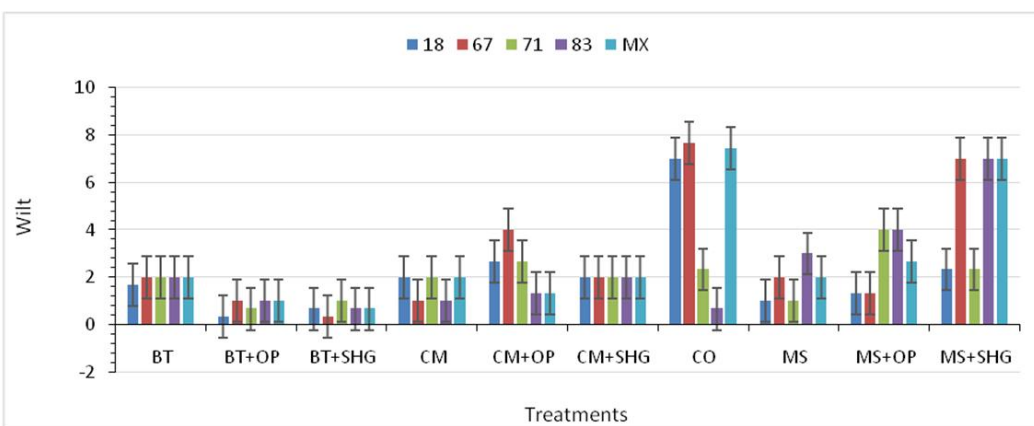

Fig. 2. Field bacterial wilt incidence in capsicum season 2

BT-Brassicae Tissue, BT+OP - Brassica tissue+ Orange peel, BT+SHG- Brassicae Tissue+ Super hydro-grow polymer, CM- Chalim^{TM}, CM+OP- Chalim^{TM}+ Orange peel, CM+SHG- Chalim^{TM}+ Super-hydro-grow polymer, MS- Metham sodium, Ms+OP- Metham sodium+ Orange peel, MS+SHG- Metham sodium+ Super-hydro-grow polymer: 18 (2T-Kiambu-Low Land), 71(2A-Nyeri-Low Land), 67 (2A-Nyeri-High Land),83 (2T-Kirinyaga-Highland) and MX (2T-L/2A-L/2A-H/2T-H(18/71/67/83) bacterial wilt has been conducted and reported to be effective in a study by Kirkegaard [35]. This is attributed to its anti-microbial properties that facilitate its effectiveness. There are different mechanisms reported through which Brassica controls the disease amongst which the release of sulphur compounds and isothiocyanates [36]. In addition, brassicaceous materials have been reported to have allellopathic effects as well as biofumigation effects to soil biota that includes plant parasitic nematodes [37,38,39].

The use of Brassica tissue to control *R. solanacearum* is an organic soil amendment. Previous experiments demonstrated the successful application of organic matter against bacterial wilt in greenhouses and in the field. For example, in a greenhouse experiment, when the freshly cut aerial parts of pigeon pea (*Cajanus cajan*) and crotalaria (*Crotalaria juncea*) were incorporated at concentrations of 20–30% and incubated for 30 d, they completely suppressed tomato bacterial wilt 45 d after the inoculation [40]; however, the application rate of this organic matter was high and, thus, not feasible for farmers. Thymol oil derived from a thyme plant reduced bacterial wilt by 65% in the fall 2002 tomato cultivation and by 82% in fall 2003 tomato cultivation at an application rate of 0.72% in the field [41]. Reports are also available on the use of several plant by-products, which possess antimicrobial properties on several pathogenic bacteria and fungi [42]. Satish et al. [43] reported antimicrobial properties of leaves of such plants as Lawsonia inermis, Aloe vera, neem (Azardirachta indica) and Mimosa pudica. Ganiyu et al. [44] and Popoola et al. [45] reported bactericidal properties of neem, mango (Mangifera indica) and siam (Chromolaena odorata) trees.

3.2 Influence Selected Soil Amendments on Field Disease Incidence on Potatoes

The results of incidences of bacterial wilt on Potatoes grown on the field for season 1 and 2 are shown by Figs. 3 and 4 respectively. Significant differences (*P*≤0.05) were revealed in the bacterial wilt incidences in potatoes between control and all the soil amendments used in season 1 and 2 in the five *R. solanacearum* isolate from Kenyan highlands and lowlands. The mean disease index for control and soil amendments; MS+SHG, BT, MS, CM+OP, BT+OP, BT+SHG, CM+SHG, CM and MS+OP for season 1 and 2 were as follows; 8.955, 8, 3, 3.867, 5.667, 1, 0, 2, 4.8, 7, and 6.867, 5.6, 2, 2.4, 3.467, 0.533, 0.067, 2, 2.6, 3.2 Respectively. These results indicate the suppressive effect of organic and inorganic treatments used in this study.

MS+SHG and MS+OP soil amendment had antagonistic effect in the control of *R. solanacearum* as opposed to when MS was used alone. Pesticides such as algicide (3-[3-indolyl] butanoic acid), fumigants (metam sodium, 1,3-dichloropropene, and chloropicrin), and plant activators generating systemic resistance on the tomato (validamycin A and validoxylamine) have been used to control bacterial wilt. The combination of methyl bromide, 1,3-dichloropropene, or metam sodium with chloropicrin significantly reduced bacterial wilt in the field from 72 % to 100 % and increased the yield of tobacco and the tomato. The yield of the pesticide-treated tomato was 1.7- to 2.5-fold higher than that of the untreated control [46,47].

The Brassica tissue + Super-hydro-grow polymer was superior in reducing bacterial wilt incidences in capsicum in the field in all the *R. solanacearum* isolates from Kenyan highlands and lowlands both in season 1 and 2 but was not significantly different with Brassica tissue + Orange peel in season 2. This concur with the findings of Kago et al. [33] that established that the Brassica tissue + Super-hydro-grow polymer was superior in reducing bacterial wilt incidences in potatoes in the greenhouse in all the *R. solanacearum* isolates from Kenyan highlands and lowlands both in season 1 and 2. According to Bonilla et al. [48], the effect of organic amendments on soil suppressiveness was often related to a general suppression mechanism. The input of organic matter may lead to an increase in total microbial biomass and activity in soil, causing the inhibition of the pathogen by competition for resources or through other direct forms of antagonism. No specific microorganism is responsible for general suppression, but all microbiota cooperate in the generation of an environment hostile for disease development [48].

3.3 Influence Selected Soil Amendments on Field Disease Incidence on Tomatoes

The results of incidences of bacterial wilt on Tomatoes grown on the field for season 1 and 2 are shown by Figs. 5 and 6 respectively.

Significant differences ($P \leq 0.05$) were revealed in the bacterial wilt incidences in tomatoes between control and all the soil amendments used in season 1 and 2 in the five *R. solanacearum* isolate from Kenyan highlands and lowlands. The mean disease index for control and soil amendments; MS+SHG, BT, MS, CM+OP, BT+OP, BT+SHG, CM+SHG, CM and MS+OP for season 1 and 2 were as follows; 9, 8, 3, 4, 5.6, 1, 0, 2, 5, 7 and 7.267, 3.267, 2, 2.2, 3.2, 0.667, 0.667, 2, 1.8, 2.4 respectively. These results indicate the suppressive effect of organic and inorganic treatments used in this study.

The degradation of organic matter in soil can directly affect the viability and survival of a pathogen by restricting available nutrients and releasing natural chemical substances with varying inhibitory properties [49]. Carbon released during the degradation of organic matter contributes to increasing soil microbial activity and thereby enhances the likelihood of competition effects in the soil [49]. The Brassica tissue + Super-hydro-grow polymer was superior in reducing bacterial wilt incidences in capsicum in the field in all the *R. solanacearum* isolates from Kenyan highlands and

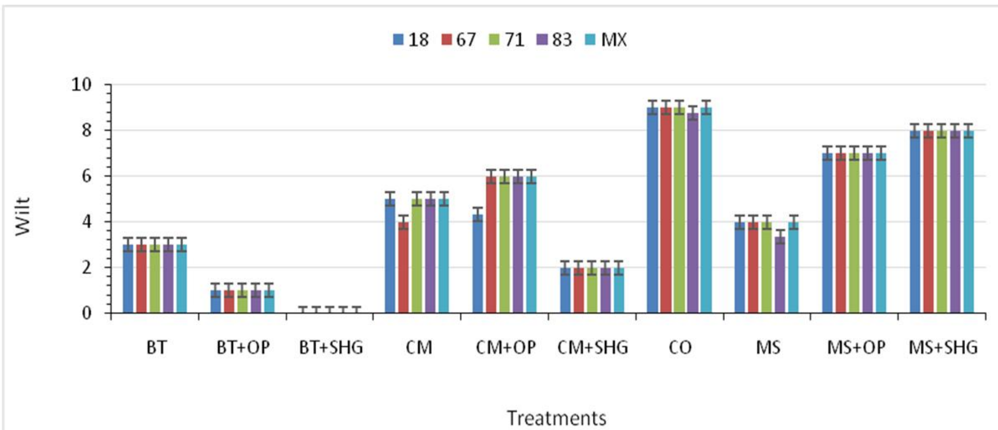

Fig. 3. Field bacterial wilt incidence in potatoes season 1

BT-Brassicae Tissue, BT+OP - Brassica tissue+ Orange peel, BT+SHG- Brassicae Tissue+ Super hydro-grow polymer, CM- Chalim^{TM}, CM+OP- Chalim^{TM}+ Orange peel, CM+SHG- Chalim^{TM}+ Super-hydro-grow polymer, MS- Metham sodium, Ms+OP- Metham sodium+ Orange peel, MS+SHG- Metham sodium+ Super-hydro-grow polymer: 18 (2T-Kiambu-Low Land), 71(2A-Nyeri-Low Land), 67 (2A-Nyeri-High Land),83 (2T-Kirinyaga-Highland) and MX (2T-L/2A-L/2A-H/2T-H(18/71/67/83)

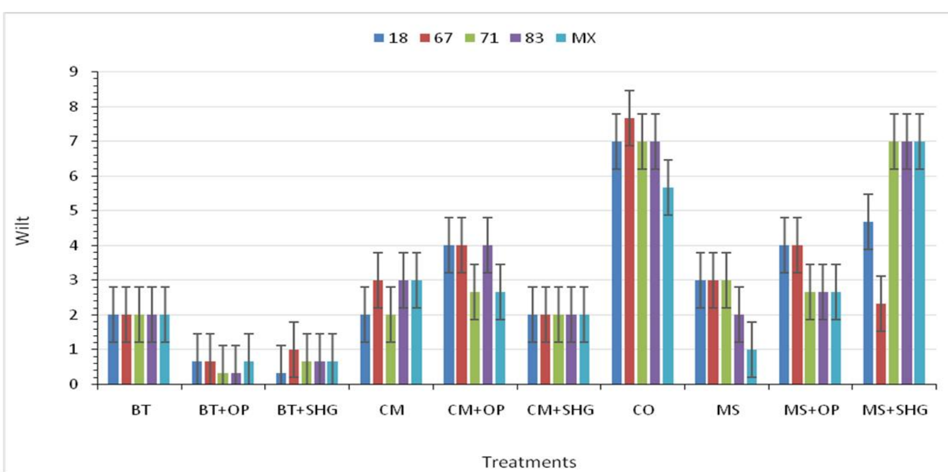

Fig. 4. Field bacterial wilt incidence in potatoes season 2

BT-Brassicae Tissue, BT+OP - Brassica tissue+ Orange peel, BT+SHG- Brassicae Tissue+ Super hydro-grow polymer, CM- Chalim^{TM}, CM+OP- Chalim^{TM}+ Orange peel, CM+SHG- Chalim^{TM}+ Super-hydro-grow polymer, MS- Metham sodium, Ms+OP- Metham sodium+ Orange peel, MS+SHG- Metham sodium+ Super-hydro-grow polymer: 18 (2T-Kiambu-Low Land), 71(2A-Nyeri-Low Land), 67 (2A-Nyeri-High Land),83 (2T-Kirinyaga-Highland) and MX (2T-L/2A-L/2A-H/2T-H(18/71/67/83)

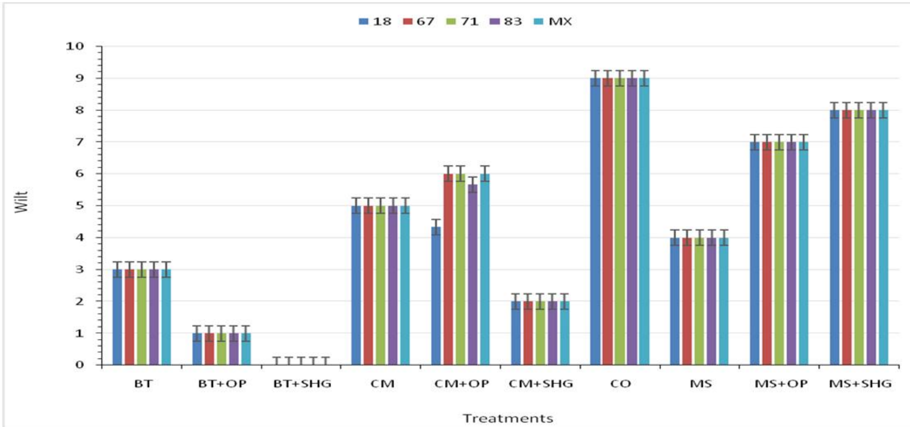

Fig. 5. Field bacterial wilt incidence in Tomatoes season 1

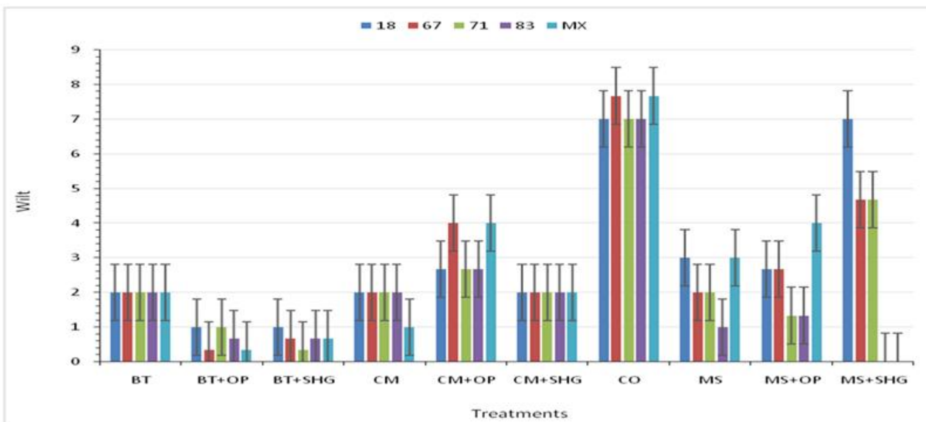

Fig. 6. Field bacterial wilt incidence in tomato season 2

lowlands both in season 1 and 2 but was not significantly different with Brassica tissue+ Orange peel in season 2. This concur with the findings of Kago et al. [33] that established that the Brassica tissue + Super-hydro-grow polymer was superior in reducing bacterial wilt incidences in potatoes in the greenhouse in all the *R. solanacearum* isolates from Kenyan highlands and lowlands both in season 1 and 2. Several previous studies reported that bacterial wilt was suppressed by plant residues derived from, *e.g.* chili (*Capsicum annum*) [50], Chinese gall (*Rhus chinensis*) [51], clove (*Szygyum aromaticum*) [52], cole (*Brassica* sp.) [35,53,54]. Organic fertilizer and biochar amendments are promising alternatives to suppress bacterial wilt by increasing the soil pH, electric conductivity, organic carbon and nitrogen availability and microbial activities [55,56,57,58]. MS+ SHG was able to effectively control 83 and MX isolates in season 2 as opposed to isolates 18, 67 and 71 in the same season. This study concurs with a study by Meng [15] that established that different *R. solanacearum* strains have different levels of aggressiveness and subsequently different breeding lines differ in their levels of resistance.

Chalim™ soil amendment drastically reduced the disease incidence in season 2. Previous studies revealed that the application of fertilizers reduced the incidence of bacterial wilt. Calcium (Ca) is the most well-known fertilizer to suppress disease. Increased Ca concentrations in plants reduced the severity of bacterial wilt as well as the population of *R. solanacearum* in the stems of the tomato [59,60]. Furthermore, an increase in Ca uptake by tomato shoots correlated with lower levels of disease severity [60,61]

Higher disease incidence recorded in tomato compared to capsicum and potato may be an indication that this pathogen is more virulent on this crop that may have led to the subsequent wilting of more tomato crops relative to those of potato and capsicum. Similar findings have been reported by Hsu et al.[62] in a study carried on perilla plants in Taiwan where strains of bacterial wilt pathogens obtained from tomato, potato, capsicum and other plants were observed to cause wilting and browning symptoms on inoculated plants although when the strain from perilla was inoculated on tomato, wilting and death was recorded. In addition all the strains from perilla were virulent on potato, tomato and capsicum plants [62].

4. CONCLUSION

In conclusion, our findings showed that organic and inorganic soil amendments could serve as a viable control of bacterial wilt in solanaceous crops caused by *R. solanacearum in the* field. Brassica tissue + Super-hydro-grow polymer was superior in reducing bacterial wilt incidences in selected solanaceous crops in all the *R. solanacearum* isolates from Kenyan highlands and lowlands both in season 1 and 2. The study recommends the use of Brassica tissue + Super-hydro-grow polymer soil amendment in the control of bacterial wilt as it is eco-friendly, increases soil organic content and Brassica tissues are readily available. The data presented in this study substantiate the findings that, various *R. solanacearum* isolates from both the Kenyan highland and lowland are causing bacteria wilt disease in various important solanaceous crops grown in the country.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Wei Y, Moreno CC, Gongora TJ, Wang K, Sang Y, Duran R, Macho AP. The *Ralstonia solanacearum* csp22 peptide, but not flagellin-derived peptides, is perceived by plants from the Solanaceae family. Journal Plant Biotechology. 2018; 1–14.
2. Salgon S, Raynal M, Lebon S, Baptiste JM, Daunay MC, Dintinger J, Jourda C. Genotyping by sequencing highlights a polygenic resistance to *Ralstonia pseudosolanacearum* in eggplant (*Solanum melongena L.*). International Journal of Molecular Sciences. 2018; 19(2):1–24.
Available:https://doi.org/10.3390/ijms19020
3. Macho AP, Jiang G, Wei Z, Xu J, Chen H, Zhang Y, She, X, Ding, W, Liao B. Bacterial wilt in China: History, current status, and future perspectives. Frontier. Plant Science. 2017;8:1549.
DOI: 10.3389/fpls.2017.01549
4. Genin S, Denny TP. Pathogenomics of the *Ralstonia solanacearum* species complex. Annual Review Phytopathology. 2012;50: 67–89.
5. Peeters N, Guidot A, Vailleau F, Valls M. *Ralstonia solanacearum*, a wide spread bacterial plant pathogen in the post genomic era. Molecular Plant Pathology. 2013;1-11.
DOI:10.1111/mpp.12038
6. EPPO. Diagnostic protocols for regulated pests; *Ralstonia solanacearum*.pp. 2004; 173-178.
7. Yao J, Allen C. The plant pathogen *Ralstonia solanacearum* needs aerotaxis for normal biofilm formation and interactions with its tomato host. Journal of Bacteriology. 2007;189(17):6415-6424.
8. Belena A, Biosca EG, Lopez MM. On the life of *Ralstonia solanacearum*, a destructive plant bacterial pathogen. Formatex. 2010;267-279.
9. Schell MA. Control of virulence and pathogenicity genes of *Ralstonia solanacearum* by an elaborate sensory network. Annual Review of Phytopathology. 2000;38:263-292.
10. Vasse J, Frey P, Trigalet A. Microscopic studies of intercellular infection and protoxylem invasion of tomato roots by *Pseudomonas solanacearum*. Molecular Plant Microbe Interaction. 1995;8:241-251.
11. Moorman GW. Bacterial Wilt - *Ralstonia solanacearum*. Penn State Extension; 2014.
Available:http://extension.psu.edu/plant-disease-factsheets/all-fact-sheets/ralstonia

12. Gilbert GS, Parker IM. Rapid evolution in a plant-pathogen interaction and the consequences for introduced host species. Evolutionary Applications. 2010;144-156. DOI: 10.1111/j.1752-4571. 2009.00107
13. Chandrashekara NK, Prassanakumar MK, Deepa M, Vani A, Nazir A, Khan A. Prevalance of races and biotypes of *Ralstonia solanacearum* in India. Journal of Plant Protection Research. 2012;52(1): 53-58.
14. Bocsanczy A, Achenbach CM, Mangravita A, Chow M and Norman DJ. Proteomic comparison of *Ralstonia solanacearum* strains reveals temperature dependent virulence factors. BMC Genomics; 2014. DOI: 10.1186/1471-2164-15-280
15. Meng F. The virulence factors of the bacterial wilt pathogen *Ralstonia solanacearum*. Journal of Plant Pathology and Microbiology; 2013.
DOI: 10.4172/21577471.1000168
16. Yadessa GB, van Bruggen AHC, Ocho FL. Effects of different soil amendments on Bacterial Wilt caused by *Ralstonia solanacearum* and on the yield of tomato. Journal of Plant Pathology. 2010;92(2): 439-450.
17. Adebayo OS, Kintomo AA, Fadamiro HY. Control of bacterial wilt disease of tomato through integrated crop management strategies. International Journal of Vegetable Science. 2009;15:96-105.
18. Getachew A, Chemeda F, Seid A, Wydra K. Effects of soil amendment on bacterial wilt caused by *Ralstonia solanacerum* and tomato yields in Ethiopian Journal of Plant Protection Research. 2011;51(1):72–76.
19. Singh AK, Singh RK, Singh AK, Singh VK, Rawat SS, Mehta KS, Kumar A, Gupta MK, Thakur S. Bio-mulching for ginger crop management: Traditional ecological knowledge led adaptation under rainfed agroecosystems. Indian Journal Tradition Knowledge. 2013;13(1):111–122.
20. Tahat MM, Sijam K. *Ralstonia solanacearum*: The bacterial wilt causal agent. Asian Journal of Plant Science. 2010;9:385-393.
21. Ouyang X, Chao Z, Bai Z, WY, Chen Q, Tian M. Preliminary study on grafting cultivation of tobacco with eggplant. Hunan Agriculture. Science. 2015;1:25–26.
DOI: 10.16498/j.cnki.hnnykx.2015.05.010
22. Liao J, Zhou X, Xia Y, Liu K, Li Q, Dong Y, Jiang H. Quantitative trait locus analysis of late leaf spot resistance and plant type related traits in cultivated peanut (*Arachis hypogaea* L.) under Multi-environments. PLoS One. 2016;11(11):e0166873.
Available:https://doi.org/10.1371/journal.pone.0166873
23. Liu F, Wei A, Wang L, Liu H, Zhu X, Liang Y. Riboflavin activates defense responses in tobacco and induces resistance against *Phytophthora parasitica* and *Ralstonia solanacearum*. Physiology Molecular Plant Pathology. 2010;74:330–336.
24. Deng R, Deng K, He T, Lei Z, and Chen E. Progresses of main diseases resistance breeding in potato. Southwest China Journal of Agricultural Science. 2014;27: 1337–1342.
25. Yin G, Wang X, Zhang Y, Pan G, Yang Q. Research progress on tomato bacterial wilt and resistance breeding in China. Journal Yunnan Agriculture. University. 2005;20: 163–167.
26. Dang F, Lei Y, Guan D, Wang Z and He S. Identification and evaluation of resistance to bacterial wilt in pepper. Plant Science. Journal. 2013;31:378–384.
DOI: 10.3724/SP.J.1142.2013.40378
27. Li W, Lv L, Wei C. Research advance in bacterial wilt resistance of eggplant. Guangdong Agricultural Science. 2014;41: 91–94.
28. Li J-G, Dong Y-H. Effect of a rock dust amendment on disease severity of tomato bacterial wilt. Antonie Van Leeuwenhoek. 2013;103:11–22.
Available:https://doi.org/10.1007/s10482-012-9781-4
29. Zhang C, Lin Y, Tian X, Xu Q, Chen Z, Lin W. Tobacco bacterial wilt suppression with biochar soil addition associates to improved soil physiochemical properties and increased rhizosphere bacteria abundance. Applied Soil Ecology. 2017; 112:90–96.
Available:https://doi.org/10.1016/j.apsoi1.2016.12.005
30. Zheng S, Ding W, Du G, Yang L, Liu X, Zhang Y. Control efficacy and action mechanism of mineral nutrition on tobacco bacterial wilt. Science. Agriculture Sin. 2014;47:1099–1110.
31. Food Agriculture Organization (FAO). Soil map of the world, Revised Legend. World Soil Resources Report. 1990:60.

32. Getachew A, Chemeda F, Seid A, Kerstin W. Effects of soil amendment on bacterial wilt caused by *Ralstonia solanacearum* and tomato yields. Ethiopia Journal of Plant Protection Research. 2011;51(1). DOI: 10.2478/v10045-011-0013-0
33. Kago EK, Kinyua ZM, Maingi JM, Okemo PO. Control of *Ralstonia solanacearum* on Selected Solanaceous Crops in Greenhouse by Selected Soil Amendments. Journal of Agriculture and Ecology Research International. 2019; 19(2):1-12.
(Article no.JAERI.50531)
ISSN: 2394-1073
34. Termorshuizen AJ, van Rijn E, van der Gaag DJ, Alabouvette C, Chen Y, Lagerlöf J, Malandrakis AA, Paplomatas EJ, Rämert B, Ryckeboer J. Suppressiveness of 18 composts against 7 pathosystems: variability in pathogen response. Soil Biology and Biochemistry. 2007;38:2461–2477.
35. Kirkegaard J. Evaluating biofumigation for soil-borne disease management in tropical vegetable production. Australian Centre for International Agricultural Research; 2005. Available:http://aciar.gov.au/project/SMCN/2000/114
36. Walters D. Disease control in crops: Biological and environmentally friendly approaches. Blackwell publishing limited, Australia; 2009.
37. Bailey KL, Lazarovits G. Suppressing soil borne diseases with residue management and organic amendments. Soil Tillage. 2003;72:69-180.
38. Gruver LS Weil RR, Zasada IA, Sardanelli S, Momena B. Brassicaceous and rye cover crops altered free-living soil nematode community composition. Applied Soil Ecology. 2010;45:1–12.
39. Schonfeld JA, Gelsomino LS, Van Overbeek A, Gorissen KS, Van Elsas JD. Effects of compost addition and stimulated solarisation on the fate of Ralstonia solanacearumbiovar 2 and indigenous bacteria in soil. FMES Microbiology of Ecology. 2003;43:63-74.
40. Cardoso SC, Soares ACF, Brito ADS, Laranjeira FF, Ledo CAS, dos Santos AP. Control of tomato bacterial wilt through the incorporation of aerial part of pigeon pea and crotalaria to soil. Summa Phytopathology. 2006;32:27–33. [Google Scholar]
41. Ji P, Momol MT, Olson SM, Pradhanang PM. Evaluation of thymol as biofumigant for control of bacterial wilt of tomato under field conditions. Plant Disease. 2005;89: 497–500. [Google Scholar].
42. Helsey RM, Gorham BK. Antimicrobial effects of plant extracts on Streptococcus mutans, Candida albicans, Trichophyton rubrumand other micro-organisms. Letters in Applied Microbiology. 1992;14:136–139.
43. Satish S, Raveesha KA, Janardhana GR. Antibacterial activity of plant extracts on phytopathogenic Xanthomonas campestris pathovars. Applied Microbiology. 1999;28: 145–150.
44. Ganiyu SA, Popoola AR, Babalola OA, Ayo-John E. Effects of compost amendments on bacterial diseases and yield of tomato. In: Aiyelaagbe IOO, Adetunji MT, Osei SA (eds), Organic agriculture and the millennium development goals: proceedings of the 1st West African Summit and 4th National Conference on Organic Agriculture. Abeokuta, Nigeria. Nigeria: WANOART Publishers. 2008;180–183.
45. Popoola AR, Ganiyu SA, Babalola OA, Ayo-John EI. Effects of tillage methods, varieties and compost amendments on bacterial leaf spot, leaf speck and fruit yield of two tomato varieties. Nigerian Journal of Plant Protection. 2011;25:127–138.
46. Fortnum BA, Martin SB. Disease management strategies for control of bacterial wilt of tobacco in the southeastern USA. In: Prior P, Allen C, Elphinsone J, editors. Bacterial Wilt Disease: Molecular and Ecological Aspects. Springer; Heidelberg, New York. [Google Scholar]. 1998;394–402.
47. Santos BM, Gilreath JP, Motis TN, Noling JW, Jones JP, Norton JA. Comparing methyl bromide alternatives for soil-borne disease, nematode and weed management in fresh market tomato. Crop Prot. [Google Scholar]. 2006;25:690–695.
48. Bonilla N, Gutierrez-Barranquero JA, de Vicente A, Cazoria FM. Enhancing soil quality and plant health through suppressive organic amendments. Diversity. 2012;4:475–491.
49. Bailey KL, Lazarovits G. Suppressing soil-borne diseases with residue management and organic amendments. Soil Tillage

Research. 2003;72:169–180. [Google Scholar].

50. Teixeira FR, Lima MCOP, Almeida HO, Romeiro RS, Silva DJH, Pereira PRG, Fontes EPB, Baracat-Pereira MC. Bioprospection of cationic and anionic antimicrobial peptides from bell pepper leaves for inhibition of Ralstonia solanacearum and Clavibacter michiganensis sp. michiganensis growth. Phytopathology. [Google Scholar]. 2006; 154:418–421.
51. Yuan G-Q, Li Q-Q, Qin J, Ye Y-F, Lin W. Isolation of methyl gallate from Toxicodendron sylvestre and its effect on tomato bacterial wilt. Plant Disease. 2012; 91:1143–1147. [Google Scholar]
52. Amorim EPD, De Andrade FWR, Moraes EMD, Da Silva JC, Lima RD, De Lemos EFP. Antibacterial activity of essential oils and extractions of the development of Ralstonia solanacearum in banana seedlings. Revista Brasileira de Fruticultura. [Google Scholar]. 2011;33: 392–398.
53. Katafiire M, Adipala E, Lemaga B, Olanya M, El-bedewy R. Management of bacterial wilt of potato using one-season rotation crops in southwestern Uganda. In: Allen C, Prior P, Hayward AC, editors. Bacterial Wilt Disease and the Ralstonia solanacearum Species Complex. American Phytopathological Society Press; St Paul, MN. [Google Scholar]. 2005;197–204.
54. Posas MB, Toyota K, Islam TMD. Inhibition of bacterial wilt of tomato caused by Ralstonia solanacearum by sugars and amino acids. Microbes Environ. [Google Scholar]. 2007;22:290–296.
55. Wei Z, Yang X, Yin S, Shen Q, Ran W, Xu Y. Efficacy of *Bacillus*-fortified organic fertiliser in controlling bacterial wilt of tomato in the field. Applied. Soil Ecology. 2011;48:152–159.
DOI: 10.1016/j.apsoil.2011.03.013
56. Zhang P, Wei Z, Zhu Z, Gao X, Deng K, Ran W. Effect of a bio-organic fertilizer on microbial flora and *Ralstonia solanacearum* population in rhizosphere soils of continuous cropping tomato and pepper. J. Nanjing Agriculture University. 2013;36:77–82.
57. Liu L, Sun C, Liu S, Chai R, Huang W, Liu X. Bioorganic fertilizer enhances soil suppressive capacity against bacterial wilt of tomato. Plos One. 2015;10:e0121304.
DOI: 10.1371/journal.pone.0121304
58. Gu Y, Hou Y, Huang D, Hao Z, Wang X, Wei Z. Application of biochar reduces *Ralstonia solanacearum* infection *via* effects on pathogen chemotaxis, swarming motility, and root exudate adsorption. Plant Soil. 2016;415:269–281.
DOI: 10.1007/s11104-016-3159-8
59. Yamazaki H, Hoshina T. Calcium nutrition affects resistance of tomato seedlings to bacterial wilt. Horticultural science. [Google Scholar].1995;30:91–93.
60. Yamazaki H, Kikuchi S, Hoshina T, Kimura T. Calcium uptake and resistance to bacterial wilt of mutually grafted tomato seedlings. Soil Science Plant Nutrition. 2000;46:529–534. [Google Scholar]
61. Yamazaki H, Ishizuka O, Hoshina T. Relationship between resistance to bacterial wilt and nutrient uptake in tomato seedlings. Soil Science Plant Nutrition. 1996;42:203–208. [Google Scholar]
62. Hsu ST, Hong WF, Tzeng KC, Chen CC. Bacterial wilt of perilla caused by Pseudomonas solanacearum and its transmision. Plant diseases. 1993;77:674-677.

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