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Association between Soil Acidity and Bacterial Wilt Occurrence in Potato Production in Ethiopia

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Abstract: Soil acidity is one of the main constraints to crop production worldwide. In Ethiopia, the problem of soil acidity has been increasing. Currently, more than 40% of cultivated land in the country has a soil pH < 5.5. Recently, bacterial wilt (caused by *Ralstonia solanacearum*) has become a serious problem, reaching epidemic levels in some of the major potato growing districts in the country. However, it is currently unknown if the current outbreak of bacterial wilt in potato production is associated with soil acidification or not. To examine the association between bacterial wilt and soil acidification, we conducted a field survey and field experiments and detected and characterised *R. solanacearum* strains. The study showed that 50% of potato fields were very strongly acidic (pH 4.5–5.0) and bacterial wilt incidence was higher in potato fields with low soil pH. The field experiments indicated that lime application significantly increased soil pH ($p < 0.001$) and reduced bacterial wilt incidence ($p < 0.001$). The more lime was applied, the stronger the positive effect on soil pH and the stronger the reduction in bacterial wilt incidence. Bacterial wilt incidence was on average 10.8% under 12 t/ha lime application, while it was about 40% in control plots (without lime) after 90 days. All *R. solanacearum* strains isolated from the symptomatic potato plants were Phylotype II. Our findings show that the current outbreak of bacterial wilt in Ethiopia is associated with soil acidification. They add to the understanding of the risk factors for bacterial wilt in potato. Aside from farm hygiene, sanitation and cultural practices, addressing soil acidification using lime needs to be considered as an additional component of an integrated package to deal with bacterial wilt in potato under acidic soil conditions.

Keywords: bacterial wilt; genetic diversity; lime; soil acidification; soil pH

Citation: Tafesse, S.; Braam, C.; van Mierlo, B.; Lemaga, B.; Struik, P.C. Association between Soil Acidity and Bacterial Wilt Occurrence in Potato Production in Ethiopia. *Agronomy* **2021**, *11*, 1541. https://doi.org/10.3390/agronomy11081541

Academic Editor: John Hammond

Received: 18 June 2021
Accepted: 14 July 2021
Published: 31 July 2021

1. Introduction

Potato is an important food and nutrition security crop for Ethiopians, and it is grown by close to four million smallholder farmers [1]. Bacterial wilt, caused by a soil-borne pathogen (*Ralstonia solanacearum*), has recently become a serious constraint to potato production in Ethiopia, jeopardising food security efforts [2,3]. The disease has spread widely in the last few years. Previous studies showed that the occurrence of bacterial wilt seemed more prominent in some potato growing districts than in other areas [3–5]. Causes of variation in disease incidence among the districts remain unclear. However, cool highlands that have historically been known to be free from bacterial wilt are now being affected by the disease [2,6,7].

Studies have shown that free movement of latently infected seed potato contributed to the spreading of the disease in Ethiopia [6]. Limited knowledge among farmers and the

lack of a coordinated action among the various actors in the country's potato production system constrained effective management of the disease [8,9]. Furthermore, poor quality of seed produced and marketed by seed potato cooperatives has contributed to the spreading of the disease [10]. The interdependency among seed and ware potato farmers (e.g., sharing of farm tools and labour sharing) coupled with the infectiveness of the existing seed potato quality assurance system in Ethiopia has also made it difficult to manage the outbreak of the disease [10,11]. Apart from this knowledge about the primary social conditions facilitating the spreading of the disease, there is very little knowledge on biophysical factors that could explain the outbreak of the disease in the country.

Many studies have shown that about 40% of the arable land in Ethiopia is currently covered by acidic soils (pH < 5.5), and the problem of soil acidity has been increasing in the country [12,13]. The problem of soil acidity is aggravated in Ethiopia mainly because of the complete removal of crop residues from crop fields, overgrazing and high rainfall that washes basic cations and organic matter away through soil erosion and leaching [14–16]. Long-term application of acid-forming inorganic fertilisers like urea and diammonium phosphate (DAP) have also considerably contributed to soil acidification in the country [12,15,17,18]. According to several studies, the problem of soil acidity is rampant in high rainfall areas of the western, northwestern, southwestern and southern parts of Ethiopia [12,13,19,20]. In contrast, the northern and eastern parts of the country have alkaline soils [13,21].

Soil pH affects various chemical and biological processes in the soil. Solubility and availability of plant nutrients such as calcium, magnesium, phosphorous, potassium and trace metals depend on soil pH [22]. Many studies have shown that the activities of different soil microorganisms are strongly influenced by soil pH [23–25]. In particular, Bååth and Arnebrant [26] and Hartman et al. [27] reported the effect of soil pH on the abundance and diversity of bacteria. There are plant-growth-promoting (beneficial) and -pathogenic (harmful) bacteria in the soil. Beneficial bacteria (e.g., *Pseudomonas fluorescens*, *Bacillus pumilis*, *Bacillus cereus*) supply nutrients to plants, enhance plant growth and protect plants from various pathogens [28–31]. Plant-pathogenic bacteria (e.g., *Xanthomonas oryzae*, *Ralstonia solanacearum)* have harmful effects on plants and cause significant economic losses [30,32,33].

The knowledge about the relationship between *Ralstonia solanacearum* and soil acidity is limited. Recent research has shown that *Ralstonia solanacearum*, which causes bacterial wilt in tobacco, has been found to be more serious under acidic soil conditions [34]. Furthermore, the same research showed that acidic conditions are conducive to the expression of virulence genes of the pathogen while the expression of a resistance gene is restrained in tobacco [34]. Growth and antagonistic activity of the antagonistic bacteria *Bacillus cereus* and *Pseudomonas fluorescens* were also suppressed at pH < 5.5 [30,34,35].

In this paper, we describe our efforts to study the relationship between soil acidity and incidence of bacterial wilt in potato production in Ethiopia. Our study was designed with the main objective of understanding the extent of soil acidification in major potato growing districts in Ethiopia and to elucidate whether there is an association between the occurrence of bacterial wilt and soil acidification. We also tested through field experiments liming as a management method to decrease soil acidity and thus suppress the pathogen in the context of smallholder potato growers in Ethiopia. Moreover, since knowledge of the genetic diversity of the pathogen is important to control the disease, the study also aimed to detect and characterise *Ralstonia solanacearum* strains in seed and ware potatoes. The specific objectives of this study were:

1. To determine the extent to which soil acidification is a problem in major potato growing districts in Ethiopia.
2. To assess the extent of bacterial wilt incidence in potato fields and its relationship with soil acidity.
3. To examine the effect of different levels of lime application on soil acidity and the incidence of bacterial wilt.

4. To detect and characterise *Ralstonia solanacearum* strains in potato fields.

2. Materials and Methods

2.1. Soil Sampling and Bacterial Wilt Incidence Survey in Potato Fields

Soil samples were collected (0–20 cm) from 147 randomly selected potato fields to determine the status of soil acidity in seven potato growing districts (Wolmera, Meta Robi, Ada'a Barga, Dendi, Jeldu, Ambo and Wonchi) in the central highlands of the country. Soil pH analysis was done in a suspension of 1:2.5 soil:water at Ambo University Chemistry Laboratory. An assessment of bacterial wilt incidence was also carried out. Three quadrants (about 5 m × 5 m each) were selected from each field, with disease incidence assessed as the percentage of wilted plants of the total number of plants in the three quadrants.

2.2. Field Experiments

2.2.1. Site Description and Experimental Design

To examine the effect of soil amelioration using lime on bacterial wilt incidence, field experiments were conducted at three sites in Wolmera district in the Oromia regional state of Ethiopia during the main potato growing season (June to October) of 2018. Over the past two decades, this district has served as a hub for seed potato production. The sites were Bakaka, Gaba Robi and Wolmera Choke. The soil type at each site is a well-drained nitisol. Initial soil pH was determined. Details of the experimental sites are presented in Table 1.

Table 1. Description of experimental sites.

Experimental Site	Location		Altitude(m)	Soil pH	Soil Texture (%)		
	Latitude	Longitude			Sand	Silt	Clay
Bakaka	09°06′28.8″ N	038°28′3.1″ E	2521	5.22	50	30	20
Gaba Robi	09°07′33.8″ N	038°26′39.3″ E	2592	4.81	47.5	30	22.5
Wolmera Choke	09°06′13.2″ N	038°31′55.5″ E	2459	4.58	57.5	30	12.5

At each of the three sites, an experiment was conducted in a randomised complete block design with five treatments, replicated three times. The five treatments included a control (no lime), lime at 3 t/ha, lime at 6 t/ha, lime at 9 t/ha and lime at 12 t/ha. Lime was obtained from Guder Lime Factory, Oromia, Ethiopia. Individual plot size was 3 m × 3 m. The different quantities of lime were mixed with the soil one day before potato plants were planted. The number of plants per plot was 40 (i.e., a plant density of 44,444 plants per ha). Before the plots were treated, soil samples were collected from each site and initial pH and soil texture were assessed. Changes in soil pH were monitored by collecting and analysing soil samples from each plot on 30, 60, 90 and 120 days after treatment.

2.2.2. Inoculation

To examine the effect of lime on bacterial wilt incidence under different soil pH conditions, permission was obtained from Wolmera District Office of Agriculture to inoculate the plots with *Ralstonia solanacearum*. Each plant in each plot was inoculated with 10 mL of a bacterial suspension (10^8 CFU/mL) of the local *Ralstonia solanacearum* strain (WA36; Phylotype II). The bacteria were cultivated on modified semi-selective media (M-SMSA) [36]. An isolated colony was transferred to a 250 mL Erlenmeyer flask and incubated in a rotary shaker. Dilution of bacterial suspension was performed using distilled water and the suspension was adjusted to 10^8 CFU/mL. Dilution was checked by measuring optical density (OD600 nm) with a spectrophotometer. The inoculation was carried out by drenching at the base of each potato plant after 30 days of planting (Figure 1). Disease development was monitored weekly and the final bacterial wilt incidence (percentage of wilted plants over total number of plants per plot) was calculated 90 days after inoculation.

Figure 1. Field experiment. (**A**) Inoculation of each plant by drenching, (**B**) Bacterial suspension prepared for inoculation in Erlenmeyer flasks, and (**C**) Experimental plots at one of the sites (Wolmera Choke).

2.3. Detection and Characterisation of Ralstonia solanacearum

2.3.1. Potato Tuber Sampling

Potato tuber samples were collected from symptomatic plants from nine major potato growing districts (the seven districts mentioned above and two additional ones). Three tubers were taken from a selected potato plant with wilting symptoms. A total of 135 samples were collected, including from most of the potato fields from where soil samples were collected, in collaboration with an expert from Holeta Agricultural Biotechnology Research Centre and agricultural extension workers from the districts.

2.3.2. Isolation of *Ralstonia solanacearum* Strains and DNA Extraction

Isolation of *Ralstonia solanacearum* strains was performed at the National Agricultural Biotechnology Research Centre, Holeta, Ethiopia. Each potato tuber sample was washed with tap water and the surface was disinfected using 70% ethanol. Strips along the vascular ring were then removed from each potato tuber, added into an extraction buffer and placed on a shaker for 15–20 min to allow the release of bacteria. Streaking of bacterial

suspensions was done on modified semi-selective media (M-SMSA) [37] and purification of *R. solanacearum* colonies was done on tetrazolium chloride (TZC) agar medium [38]. DNA was extracted from presumptive *Ralstonia solanacearum* pure cultures using the DNeasy Blood and Tissue kit (supplied by QIAGEN).

2.3.3. Detection and Identification of *Ralstonia solanacearum*

To identify the bacterial isolates, a *Ralstonia solanacearum* species-specific universal primer pair (759/760) was used for polymerase chain reaction (PCR) amplification [39] at the Laboratory of Phytopathology, Wageningen University and Research, Wageningen, the Netherlands. PCR cycling conditions were run with initial denaturation at 95 °C for 15 min, followed by 30 cycles of 94 °C for 30 s, 59 °C for 1 min, 72 °C for 1 min, and a final extension at 72 °C for 10 min. PCR products were checked through electrophoresis using agarose gel.

2.3.4. Phylotype Identification

Phylotype identification was done following a protocol described by [40]. Multiplex PCR amplification was done using *Ralstonia solanacearum* species complex (RSSC)-specific universal primer and phylotype-specific primers (Table 2). PCR cycling conditions were initial denaturation during 9 min at 96 °C; 30 cycles of 1 min at 95 °C, 1 min at 70 °C, 2 min at 72 °C, and final extension of 10 min at 72 °C. Examination of PCR products was conducted by electrophoresis using 1% agarose gel stained with ethidium bromide. A known Phylotype I strain (PD 7123), *Ralstonia pseudosolanacearum*, was used as a positive control. This representative strain was obtained from the National Plant Protection Organisation (NPPO) of the Netherlands.

Table 2. List of primers used for multiplex PCR.

Primer	Primer Sequence (5′ to 3′)	Specificity	Amplicon Size (bp)	Reference
759F	GTCGCCGTCAACTCACTTTCC	Universal *R.-solanacearum*-specific primer	280	[39]
760R	GTCGCCGTCAGCAATGCGGAATCG		Reverse	
Nmult21:1F	CGTTGATGAGGCGCGCAATTT	Phylotype I	144	
Nmult21:2F	AAGTTATGGACGGTGGAAGTC	Phylotype II	372	
Nmult23:AF	ATTACSAGAGCAATCGAAAGATT	Phylotype III	91	[40]
Nmult22:InF	ATTGCCAAGACGAGAGAAGTA	Phylotype IV	213	
Nmult22:RR	TCGCTTGACCCTATAACGAGTA	All phylotypes	Reverse	

2.4. Data Analysis

A correlation analysis was conducted to evaluate the relationship between pH and incidence of bacteria wilt in potato fields (%). A scatter plot graph was constructed using the ggplot2 R package.

In order to assess how lime affected the soil pH, a linear regression analysis was performed using the R statistical package (version 3.6.1) [41]. Similarly, to determine the effect of lime application on bacterial wilt incidence, a linear regression analysis was done. Furthermore, multiple comparisons of the means were performed using the least significant difference method (LSD) after analysis of variance (ANOVA). Graphs were drawn using the ggplot2 package of R.

3. Results

3.1. Soil Acidity Status in Potato Fields

We assessed the proportions of the 147 potato fields that fell in different soil pH ranges. The pH values in the sampled potato fields ranged from 4.40 to 5.94. The highest proportion (50%) of the potato fields was very strongly acidic (pH 4.5–5.0), followed by strongly acidic (pH 5.1–5.5; 30%), as indicated in Figure 2. Only 11% of the fields were moderately acidic (pH 5.6–6.0), while 9% were extremely acidic (3.5–4.4) and none were neutral or alkaline. These findings show the wide prevalence of soil acidity in these potato fields.

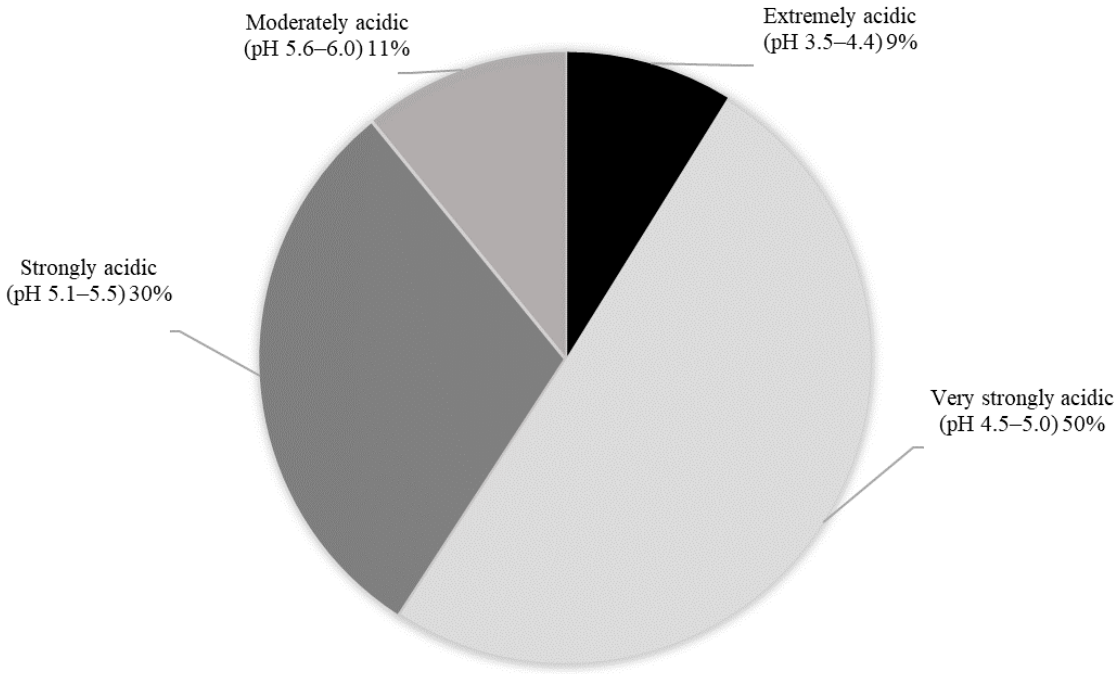

Figure 2. Proportion of soil pH ranges in sampled potato fields (n = 147).

3.2. Correlation between Soil Acidity and Bacterial Wilt Incidence

The incidence of bacterial wilt in 147 seed and ware potato fields in the central highlands of the country ranged from 0.0 to 19.7%. As indicated in Figure 3, we found a negative correlation between soil pH and bacterial wilt incidence (R = −0.27, $p = 9 \times 10^{-4}$).

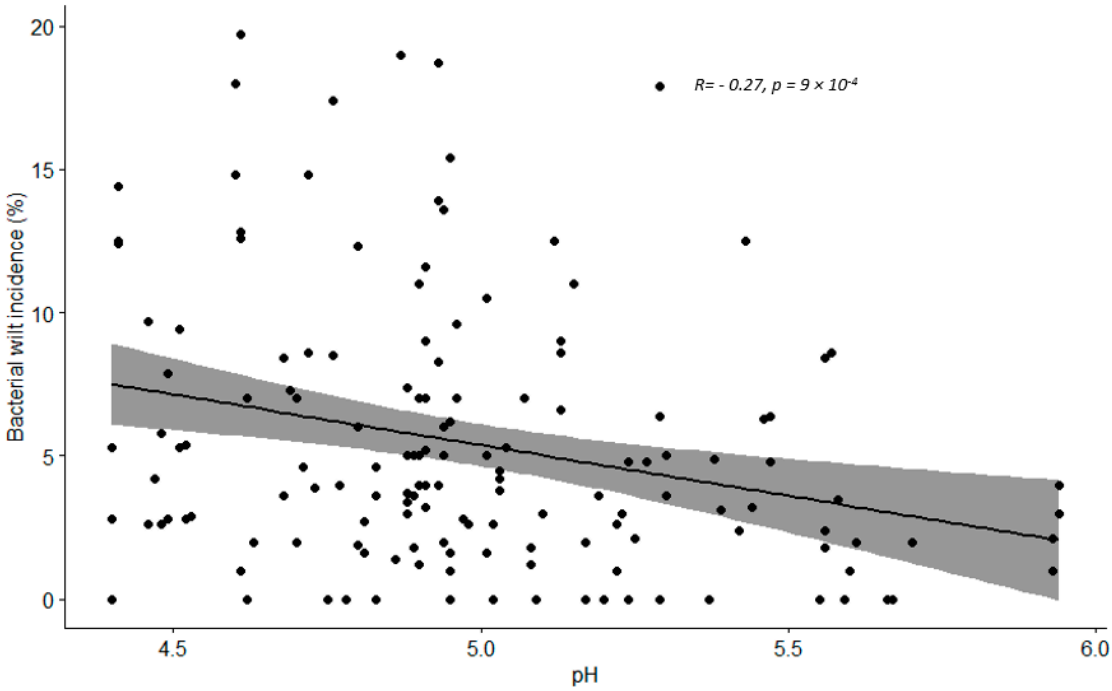

Figure 3. Correlation between soil acidity and bacterial wilt incidence in different potato fields. Each point indicates an observation of soil pH and bacterial wilt incidence from a different potato field.

3.3. Effect of Lime on Soil pH Value

The application of lime significantly affected soil pH in the field experiment: the more lime was applied, the higher the pH value of the soil became (Figure 4). The regression analysis showed that the factors of time and location were not significant in accounting for variation in pH (data not shown).

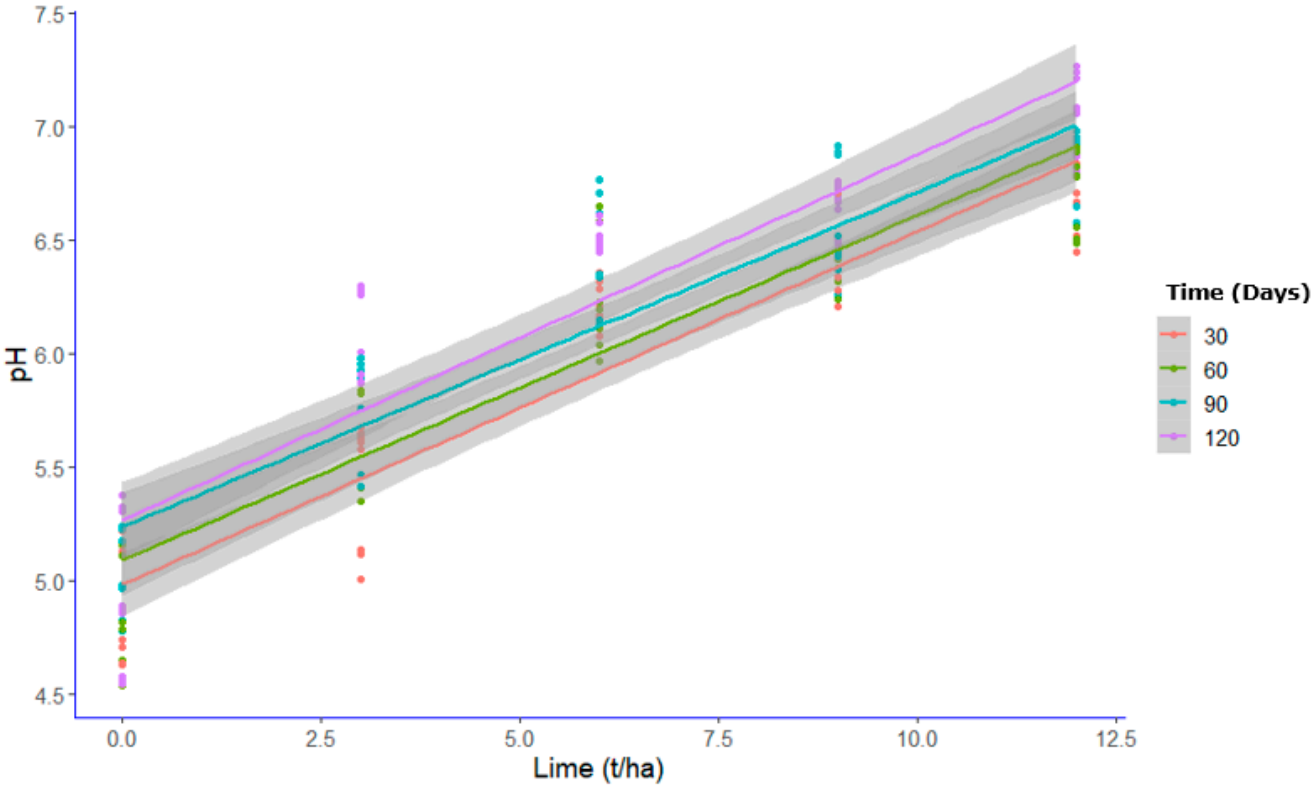

Figure 4. Linear regression curves showing highly significant positive relationships between soil pH and lime application for different dates of measurement (R = 0.93, $p < 2.2 \times 10^{-16}$ after 30 days, R = 0.91, $p < 2.2 \times 10^{-16}$ after 60, 90 and 120 days).

3.4. Effect of Lime on Bacterial Wilt Incidence

Bacterial wilt incidence was explained significantly by lime application rate in the field experiment. A separate linear regression analysis considering bacterial wilt incidence as a dependent variable and lime rate as an independent variable is depicted in Figure 5. The bacterial wilt incidence was reduced by an increase in lime application rate. This effect was stronger when the assessment was done later, because the increase in bacterial wilt incidence over time was stronger at lower rates of lime application (data not shown). Location was not significant in explaining the variation in the incidence of bacterial wilt. Bacterial wilt incidence on average was 10.8% under 12 t/ha lime application, while it was about 40% in control plots (without lime) after 90 days of inoculation. Furthermore, analysis of variance followed by mean separation indicated there was no statistically significant variation between the lime application rates of 12 t/ha and 9 t/ha. However, there was significant variation between the lime application rates of 6 t/ha and 3 t/ha (Table 3).

Table 3. Effects of different lime application rates on bacterial wilt incidence (values in the same column followed by the same letter do not differ significantly ($p < 0.05$)). The values are averaged over the three locations.

Lime Treatments	Bacterial Wilt Incidence after 90 Days
Control	39.4 ± 8.46 [a]
3 t/ha	31.4 ± 6.26 [b]
6 t/ha	23.6 ± 7.24 [c]
9 t/ha	12.5 ± 3.95 [d]
12 t/ha	10.8 ± 4.33 [d]

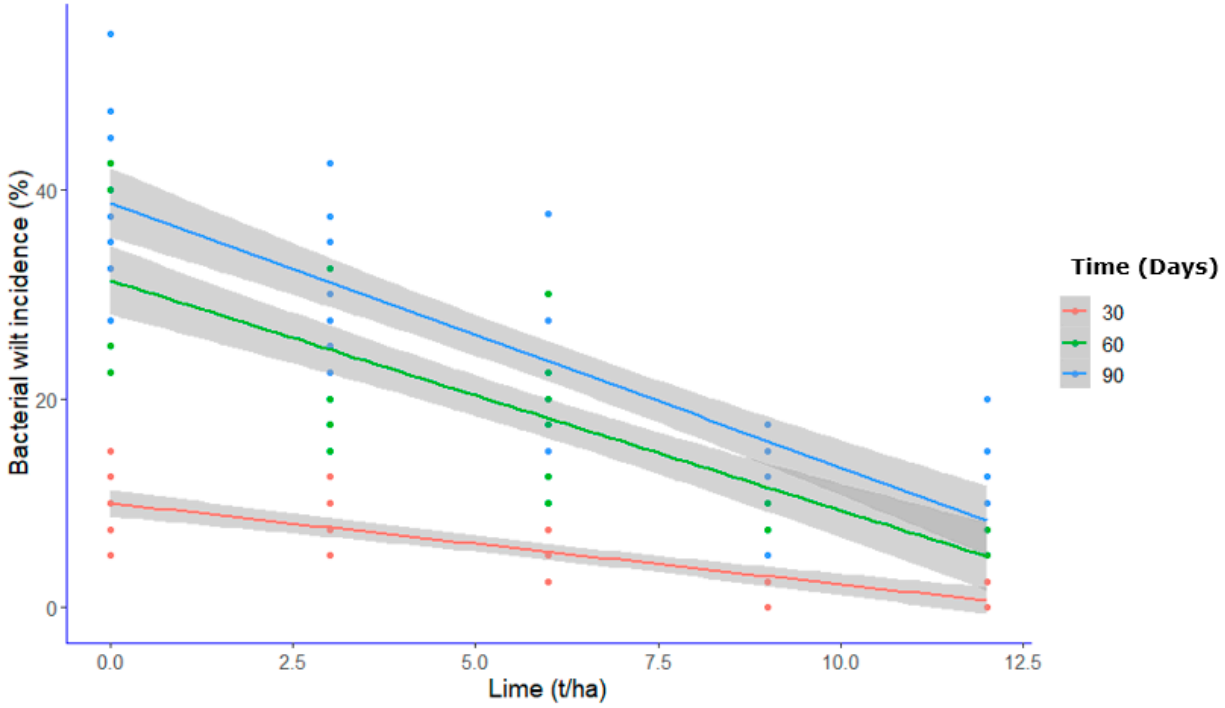

Figure 5. Linear regression curves showing highly significant negative relationships between bacterial wilt incidence and lime application for three dates of disease observation after inoculation (R = −0.80, $p = 2.8 \times 10^{-11}$ for time after 30 days; R = −0.84, $p = 8.8 \times 10^{-13}$ for time after 60 days; R = −0.87, $p = 1.74 \times 10^{-14}$ for time after 90 days).

3.5. Phylotype Identification of Ralstonia solanacearum Isolates

Bacterial isolates from samples collected from the various potato fields were confirmed to be *Ralstonia solanacearum* by PCR amplification using the *Ralstonia* species complex (RSSC) universal primer pair (759/760). PCR amplification yielded a single 280-bp fragment. All *Ralstonia solanacearum* isolates that gave a positive PCR reaction using the universal primer pair were identified as Phylotype II using multiplex PCR based on the amplicon size (Figure 6).

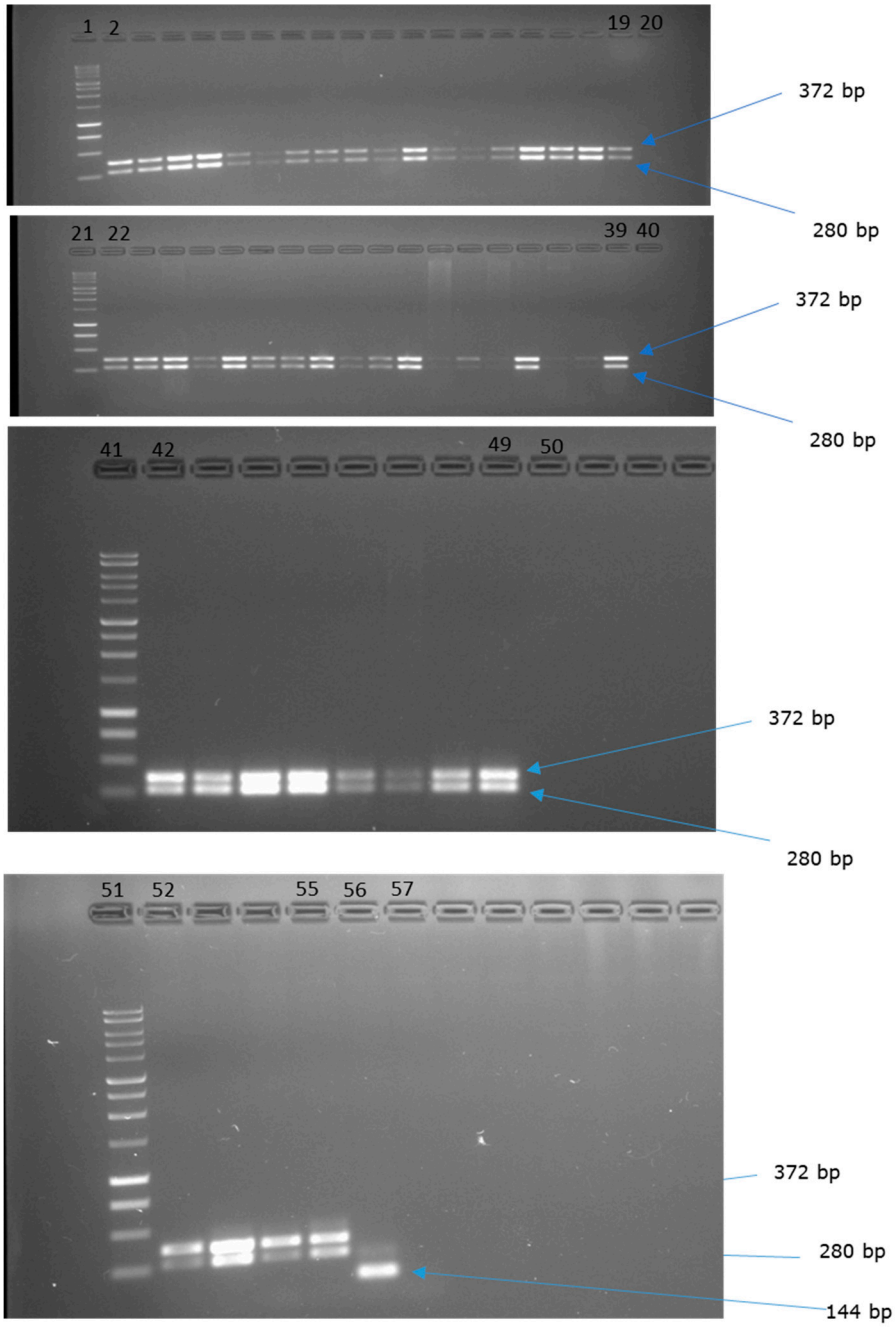

Figure 6. Detection and identification of *Ralstonia solanacearum* strains. Lanes 1, 21, 41 and 52: molecular marker (100 bp); Lanes 20, 40, 50 and 57: negative control; Lanes 2–19, 22–39, 42–49 and 52–55: isolates of this study; Lane 57: Phylotype 1 (PD 7123) positive control).

4. Discussion

4.1. Extent of Soil Acidity in Major Potato Growing Areas

The results of this study show that the extent of soil acidity in potato fields in the central highlands of Ethiopia is worrisome (Figure 2). All investigated potato fields had low soil pH values. The findings observed in this study mirror those of previous assessments that have indicated the pervasiveness of soil acidity in arable lands in Ethiopia [13,21,42]. The high soil acidity could be due to improper use of acid-forming fertilisers and soil erosion or leaching that washes away the basic cations calcium, magnesium, sodium and potassium [14,15,22]. When basic cations are leached or washed away by soil erosion, acidic cations (hydrogen and aluminium) replace them, causing soil acidity [22,43].

4.2. Association between Soil Acidity and Bacterial Wilt Incidence

This study showed a weak negative association (R = −0.27) between bacterial wilt incidence and the soil pH (Figure 3). Highly acidic potato fields had a higher incidence of bacterial wilt in most samples. The occurrence of bacterial wilt depends on various conditions, such as whether the seed is infected or not. It can also depend on whether the pathogen has previously infested the crop field or not. In addition to these and other risk factors, potato fields with lower pH values seemed to have a higher incidence of the disease (higher number of wilted plants per field) than those with relatively higher soil pH values. A previous study conducted to investigate the epidemiology of the disease in the Ethiopian potato production system showed that the incidence of the disease reached an epidemic level in some districts such as Chencha [6]. This study indicated that bacterial wilt incidence reached more than 96% in some potato fields in this district. Another recent study indicated that this district receives high rainfall [44], which could be one of the leading causes of soil acidification via the leaching of basic cations. Furthermore, a recent soil acidity map (Figure 7) developed by the Ethiopian Agricultural Transformation Agency shows that the soil acidity problem is rampant in arable lands of the Chencha district [13].

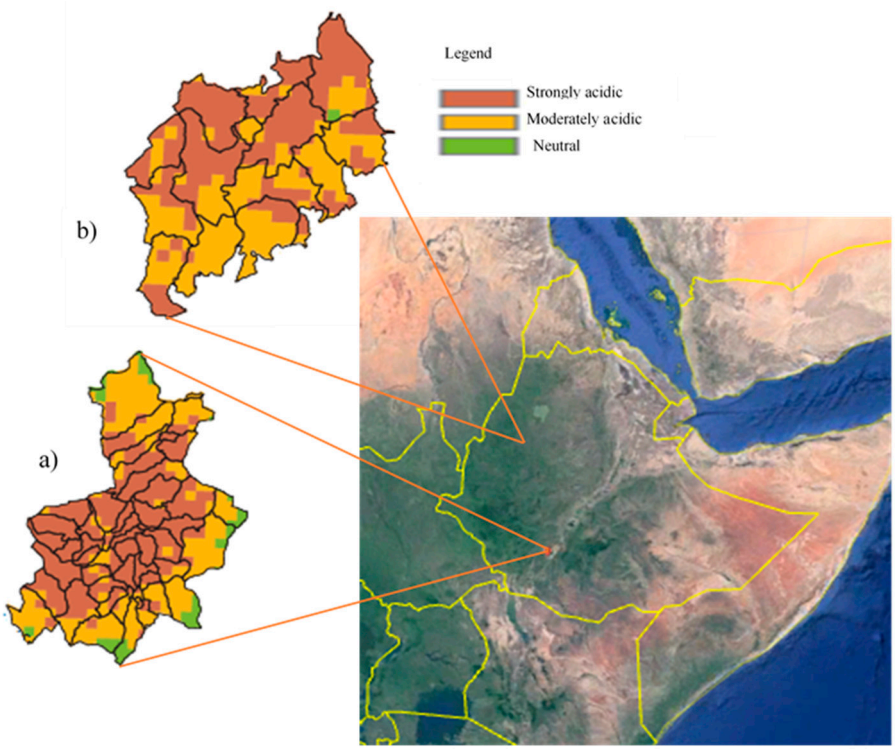

Figure 7. Map of soil pH for (**a**) Chencha district (Southern Nations, Nationalities, and Peoples' Regional State, Ethiopia), and (**b**) Guagusa Shikudad district (Amhara Regional State, Ethiopia). Reproduced with kind permission from the Ethiopian Agricultural Transformation Agency [13].

Likewise, in the Amhara region, one of the major potato growing areas that has been severely affected by bacterial wilt, soil acidity is also a serious problem. For instance, the soil pH map indicated in Figure 7 for Guagusa Shikudad, one of the potato growing districts in the region, shows that most of the district is strongly acidic [13]. Furthermore, a previous study reported a severe incidence of bacterial wilt in this district [4].

A key reason why bacterial wilt incidence is more severe in some potato fields than in other ones might thus be the soil acidity status of the potato fields. Moreover, across different parts of the country, the current serious incidence of the disease seems to be intensified by the wide spread of soil acidification in high rainfall areas in the country. Overall, it looks like the bacterial wilt problem in the country is most severe in areas affected most by soil acidity and which receive high rainfall.

4.3. Liming Reduces Bacterial Wilt Incidence

The field experiments showed that application of lime at different rates significantly increased soil pH (Figure 4). The highest change in soil pH was observed under 12 t/ha of lime (Figure 4). Our results confirm other studies showing that liming is an effective and common practice to ameliorate soil acidity [22,45,46]. Lime has immediate and residual effects on soil acidity. Due to the low solubility of lime in water, its residual effects can last for years [42,46–48]. Thus, unlike fertilisers, lime should not be applied every year, since its benefits persist for more than five years [47,49].

The findings of this study show that liming reduced bacterial wilt incidence under all rates of lime application (Figure 5; Table 3). Bacterial wilt incidence was only 10% under 12 t/ha, compared to about 40% under the unlimed plot (Table 3). Since *Ralstonia solanacearum* is (also) a soil-borne pathogen, soil chemical and biological properties affect its growth and development. This result is in line with the findings of recent studies. Li et al. [34] reported that *Ralstonia solanacearum* can survive well under acidic soil conditions. Furthermore, this study has shown that the growth of the antagonistic bacteria *Pseudomonas fluorescens* and *Bacillus cereus* are suppressed under acidic soil conditions. Likewise, Shen et al. [35] and Wu et al. [50] reported suppression of bacterial wilt incidence and reduction in abundances of *Ralstonia solanacearum* through lime application in field conditions. The finding of this study also align with other many studies that have shown that soil pH is one of the key factors determining the composition of the soil microbial community [24,30,51].

Potato is an acid-tolerant crop and grows well under acidic soil conditions (pH 4.5–6.0). Hence, farmers in the highly acidic highlands of Ethiopia can expand potato production as it is a good alternative to cereals, which are sensitive to acidic soil conditions. However, if bacterial wilt is not controlled well, acidic conditions can intensify disease incidence, resulting in considerable yield loss. Therefore, dealing with soil acidity could help to reduce the impact of the disease in areas affected by soil acidification and sustain potato production, as revealed by this study.

4.4. Detection and Characterisation of Ralstonia solanacearum Strains

The results of this study revealed low genetic diversity among the *R. solanacearum* strains affecting potato in Ethiopia, although further phylogenetic analysis is needed using more samples through partial endoglucanase (egl) sequences, based on the protocol developed by Fegan and Prior [40]. All strains belonged to Phylotype II (Figure 6). This finding confirms previous studies that reported *Ralstonia solanacearum* strains isolated from potato as Phylotype II [5,6]. Furthermore, many studies conducted in East African countries have reported *Ralstonia solanacearum* isolated from potato mainly as Phylotype II [52,53]. However, according to the previous classification of the *R. solanacearum* species complex, Phylotype II is composed of strains mainly from America [39]. Phylotype II strains are maintained to be *R. solanacearum* by a recent work that revised the taxonomy of the *R. solanacearum* species complex [54]. Studies show that Phylotype II strains are cold-tolerant [55,56]. The wide occurrence of this phylotype in the warm climate of Ethiopia and in other East African countries shows the adaptability of the pathogen to various environmental conditions and its ability to cause damage worldwide. Moreover, these findings show that similar strains of *Ralstonia solanacearum* spread in the country and in the East African region, threatening the potato industry.

These findings of this study confirm the wide spread of this disease across different potato growing districts in Ethiopia. Abdurahman et al. [6] suggested that this spread was caused by the uncontrolled movement of latently infected seed tubers. Large nongovernmental organisations and government offices of agriculture usually purchase and distribute seed potato without knowing whether the seed is infected or not, because they do not have reliable means to check seed health. This necessitates strengthening of the capacity of seed potato cooperatives to become effectively involved in quality declared seed production through a robust monitoring system. Improving farmers' knowledge and practices through

experiential and social learning approaches should be prioritised to foster collective action involving both seed and ware potato growers [57]. Developing quarantine systems could also support efforts to control the disease in the country's smallholder potato production. In particular, strengthening regional-level seed quality control laboratories is needed to be able to detect latent infection of *Ralstonia solanacearum* using a standard protocol for the pathogen [58] and to limit further spread of the disease through the distribution of infected seed potatoes.

5. Conclusions

The Phylotype II of the pathogen *Ralstonia solanacearum* has spread widely throughout Ethiopia, probably because it can adopt to diverse environmental conditions. The findings of this study show the association between the occurrence of bacterial wilt across major potato growing areas in Ethiopia and soil acidification. Improvement of soil acidity using lime may significantly reduce the incidence of the disease. While soil acidity by itself is a serious constraint to potato production due to its effect on the availability of plant nutrients even though potato is relatively acid-tolerant, it also affects the productivity by enhancing the incidence of bacterial wilt. Hence, ameliorating soil acidity urgently requires attention from various actors in the country's potato production system because dealing with soil acidity is a prerequisite for the effective management of bacterial wilt. Integrating the application of lime as part of the existing extension services to manage bacterial wilt could be a promising strategy and benefit potato farmers. Future studies need to explore further how lime application affects the population of *Ralstonia solanacearum* and the diversity of soil microbial population in acidic soils over periods of years.

Author Contributions: S.T. and P.C.S. initiated and designed the study. Data collection was conducted by S.T. Laboratory analysis was carried out by S.T. and C.B. Data analysis was done by S.T. and P.C.S. with input by B.v.M. Manuscript was prepared by S.T. with input and editing by P.C.S., B.v.M. and B.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Interdisciplinary Research and Education Fund (INREF) of Wageningen University, and the CGIAR Research Program on Roots, Tubers and Bananas (RTB) and supported by CGIAR Trust Fund contributors.

Data Availability Statement: Data may be made available after request.

Acknowledgments: The authors would like to thank Laurens Deurhof, Adeba Tilahun, Doni Hinsene, and Gert Kema for the technical support during laboratory work.

Conflicts of Interest: The authors declare no conflict of interest.

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