World Journal of Agricultural Research, 2023, Vol. 11, No. 2, 59-67
Available online at http://pubs.sciepub.com/wjar/11/2/4
Published by Science and Education Publishing
DOI:10.12691/wjar-11-2-4

Efficacy of Biofertilizers and Farmyard Manure in Management of Late Blight (*Phytophthora infestans*) and Yield of Potato

Said Hassan Abdirahman[1,2,*], Mafurah J Joseph[1], Paul K Kimurto[1], Moses Nyongesa[3]

[1]Department of Crops, Horticulture, and Soils, Egerton University, 536-20115, Egerton, Njoro, Kenya
[2]Faculty of Agriculture & Environmental Science, Somali National University, Afgoie road, Mogadishu, Somalia
[3]Center Director, KARLO Tigoni, 388-00217, Limuru, Kenya
*Corresponding author: saeedhassan08@yahoo.com

Received May 22, 2023; Revised June 25, 2023; Accepted July 27, 2023

Abstract Seed potato with latent infection of *Phytophthora infestans* is implicated in the initiation and transmission of late blight early in cropping seasons. The disease is managed by extensive use of fungicides that has led to emergence of fungicide resistant strains resulting in chemical ineffectiveness and increased cost of late blight management. Biological agents offer a sustainable alternative in managing potato late blight. Field experiments were conducted to determine the efficacy of Biofertilizers (*Trichoderma asperellum* and *Bacillus subtilis*) and farm yard manure (FYM) on management of late blight in potatoes. Biofertilizers were applied through seed treatment and foliar applications. Some seed tubers were pre-treated with *Trichoderma asperellum* and *Bacillus subtilis* (1.0×10^7 CFU/mL) while others planted without any treatment and later on sprayed with the same concentration. FYM was applied two weeks prior to planting and incorporated into soil at the rate of 30 tons ha^{-1}. The susceptible variety of late blight (*Shangi*) was used. Result showed that FYM + *Trichoderma asperellum* and FYM + *Bacillus subtilis* were not significantly different ($P \leq 0.05$) in reduction of disease severity by 72.95% and 72.23%, and disease incidences by 74.12%, and 72. 23% while increased yields by 63.18% and 62.38%, respectively. In addition, the treatment combinations had lowest tuber infection of 12.24% and 14.60%, respectively, compared to the untreated control. The highest disease severity, incidence, tuber infection and lowest yield was observed on untreated and farmyard manure (FYM) only. Similarly, the results revealed that spraying and soaking methods were significantly different in yield and late blight severity. The yield was increased by 42% in treatments associated with the soaking method compared to the spraying method. The spraying method reduced disease severity by 11.42% leading to a 12.36% higher yield than the soaking method. The results suggest that seed treatment by spraying of *Trichoderma asperellum* and *Bacillus subtilis* and application of farmyard manure can manage to reduce late blight on potatoes while improving yield.

Keywords: *Bacillus subtilis, FYM, Late blight, Methods, Ridomil®, Trichoderma asperellum Soaking, Spray, Shangi*

Cite This Article: Said Hassan Abdirahman, Mafurah J Joseph, Paul K Kimurto, and Moses Nyongesa, "Efficacy of Biofertilizers and Farmyard Manure in Management of Late Blight (*Phytophthora infestans*) and Yield of Potato." *World Journal of Agricultural Research*, vol. 11, no. 2 (2023): 59-67. doi: 10.12691/wjar-11-2-4.

1. Introduction

Late blight (*Phytophthora infestans*) is a devastating potato disease that can wipe out an entire field. When the weather is humid it infects the crop, causing the foliage to die and the tubers to rot quickly. Late blight causes significant economic losses in potato production throughout the world. Research has demonstrated that late blight can be controlled under the right environmental conditions. Even when fungicides are used, the disease spreads quickly [1]. Reports indicated that field destruction due to late blight epidemics is relatively standard and the fungus is responsible for a global annual crop loss of US $ 12 billion [2]. In sub-Saharan Africa, late blight disease is one of the significant challenges for potato production and causes an estimated yield loss of 15 – 30% on smallholder farms [3]. In Europe, annual losses arising from control and damage costs are more than 1 billion USD [4].

In Kenya, yield and economic losses due to infection by late blight were computed using fungicide evaluation trial data in on-farm and on-station trials for 17 years between 1991 and 2007. The loss was estimated to be 22.6 to 80.9% estimated at KES 37,500 to I19,500 per hectare [5]. Late blight is probably the significant yield-reducing biotic stress worldwide, which has a tremendous impact on the yield and cost of potato production. High rainfall and temperature experienced in potato-growing regions

conducive to *P. infestans* result in a short life cycle that causes field defoliation within a week. [6]. Control of late blight requires multiple fungicide applications with a short interval regime. Multiple fungicide applications increase the cost of managing the disease more than any other input. Also, it harms humans and the environment, affects potato yield globally, and threatens the potato value chain [7]. Schemes for the management of late blight remain costly and unsustainable. The majority of the fungal populations have developed resistance to previously effective fungicides [8]. Pesticide use, particularly fungicide use, has skyrocketed, resulting in many health issues, including reproductive issues [9]. Furthermore, the pathogen is becoming increasingly resistant to fungicides because of its new aggressive nature, high mutation rate, and ability to co-evolve with the host [10]. More aggressive strains of the *P. infestans* have emerged in recent decades. These strains result from sexual reproduction, are resistant to a wide range of fungicides and have increased virulence. Although the public has expressed concerns about this heavy reliance on chemicals, building a fear that residues may remain in foodstuffs, environmentally friendly products for plant protection, also called biopesticides, still represent an insignificant portion of the overall pesticide market, which is dominated by synthetic chemicals [11].

Biofertilizers have the potential to restore biological activity, reduce farm inputs, and maintain ecological harmony. Bio-fertilizers have a variety of advantages, including increased nutrient and water uptake and the suppression of pests and pathogens, to promote soil properties and pest dynamics management. On the other hand, they could be used to induce defense mechanisms on potatoes early in the cropping season. Manure's varied nature in terms of nutrient quality and quantity and the slow release of nutrients, all available nitrogen is not leached. Therefore, manure has also been linked to the supply of additional beneficial microorganisms and their survival by providing a readily available cheap carbon and nitrogen source [12]. The use of beneficial bacteria as biofertilizers and biocontrol agents is gaining popularity in efforts to achieve sustainability, particularly in agriculture, forestry, and horticulture [13].

1.1. Description of Study Site

This study was conducted at the Center of Potato, Kenya Agricultural and Livestock Research Organization (KALRO), in Tigoni, Limuru (Kiambu County), in October 2020. The center is located at latitude 10°9'22"S and longitude 36°4'72"E, altitude of 2,300 m above sea level. The region experiences a bimodal precipitation pattern with an average precipitation of 1800 mm annually, and the temperature ranges between 10°C to 25°C [26]. The weather in this area is conducive for late blight development at any stage of potato growth. The experiment was conducted in a fallow field that had not been cropped with potatoes for the previous three years.

1.2. Land Preparation and Planting

Preparation of land was done by ploughing using mouldboard plough the the seed tubers of *Shangi* (Certified Primary Seed Generation) were obtained from KALRO, Tigoni. The sprouted tubers were 45 mm. *Shangi* variety yield ranges from 35 to 40 t ha^{-1} and takes 3 to 4 months to mature. However, the *Shangi* variety is susceptible to late blight, which is the most prevalent. The variety is the most grown in Kenya because it is suitable for making chips and home consumption. Planting was done in October 2021; the weeds and soil clods were removed before planting.

Diammonium Phosphate (DAP) at a rate of 500 kg ha^{-1} was applied and mixed with the soil in planting furrows at planting. Calcium ammonium nitrate (CAN) was used at a rate of 440 kg ha^{-1} after six weeks of planting. The planting season was short and rainy; however, it was not a humid cropping season. Greenhouse experiment was done and supplemental irrigation was done to promote the infection of pathogens.

1.3. Isolation and Inoculation of *Phytophthora infestans*

Thirty freshly blighted potato leaves (Plate 1a) were collected randomly from a potato crop at the Kenya Agricultural Livestock and Research Organization (KALRO), Tigoni. The leaves were surface sterilized by soaking them in 70% ethanol for 1 minute, then rinsing them with distilled water to remove excess ethanol and air drying them for 5 minutes. The surface-sterilized leaves were placed in a petri dish lined with wet (two drops of distilled water) serviettes to maintain humidity for the pathogen's survival. To stimulate sporulation, the Petri dishes were incubated at 18°C for 24 hours. Mycelia was carefully extracted with a sterilized hypodermal syringe without touching the leaf tissue and inoculated on pea agar with antibiotics rifampicin 50 g/mL. The inoculated PDA Petri dishes were incubated at 18°C for 5 days before being subcultured to increase the quantity of inocula. Mycelia was extracted from the pure culture by scrubbing with a sterilized spatula and placed in three Eppendorf tubes containing ten milliliters of distilled water. This was vortexed for 2 minutes at 3000 revolutions per minute (rpm) using an electric vortex (model VM-1000 of MRC Laboratory equipment company), filtered through a sterilized four-layered muslin cloth and incubated for 4 hours at 4°C to induce sporangia to release zoospores.

Identification and pathogenicity test was done on healthy potato seedlings and tuber slices of *Shangi* varieties using Koch's postulates [14]. Briefly, inoculum bulking was performed on *Shangi* on tuber slices. Inoculation was performed by placing 20 µl droplets of *P. infestans* sporangia suspension on healthy leaves (abaxial side) (Figure 1 a). Tubers were cleaned with sterilized distilled water and dipped in 70% ethanol for 10 seconds. They were rinsed with distilled water and then air-dried on the laboratory benches for 15 minutes. The tuber slices of 0.4 cm thickness (Figure 1 c) were cut transversely using sterilized surgical blades. From the inoculated leaves samples (Figure 1 b), a piece of the leaf with *P. infestans* lesion and healthy part was cut and placed on plastic dishes (15 x 12 x 5 cm) and incubated at room temperature 18 ± 2°C for 4 days in laboratory benches. The tuber slices were placed on the infected leaf piece in the plastic dishes and incubated for 7 days at room

temperature (18 ± 2°C) on laboratory benches [15]. Mycelia growth (Figure 1 d) was carefully picked from the upper side of the tuber slice with a sterilized hypodermic needle without touching the tuber and placed in 30 Eppendorf tubes containing 15 mL of sterilized distilled water. The suspension was vortexed for 2 minutes using an electric vortex and then incubated for 4 hours at 4°C to enhance sporangia and zoospore formation. The suspension was filtered through double folded cheesecloth and put in one litre bottle, which was incubated for 4 hours at 4°C. This was used in detached leaflet assay and field experiments.

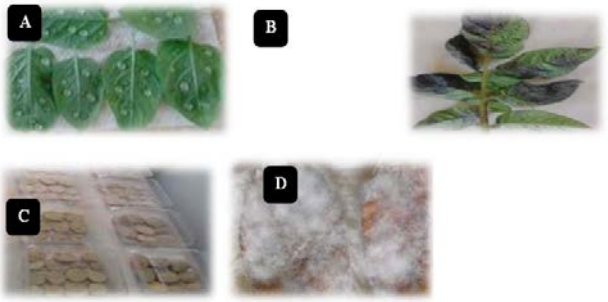

Figure 1. Isolation and bulking of *P. infestans*. (a) Freshly blighted leaves, (b) inoculated leaf tissue, (c) potato slices with *P. infestans* suspension for pathogen bulking (d) mycelial growth on potato slices

1.4. Seed Treatment with Biofertilizers

The seeds were cleaned to remove soil and entire tubers were cleaned with tap water and rinsed with pure distilled water. Then 5% sodium hypochlorite was used as surface sterilizer by dipping in it for 15 seconds. To remove excess alcohol, the tubers were rinsed with sterilized distilled water and air-dried in the shade for 15 minutes. Suspensions of 100% (1 x 10^7 CFU/mL) concentration of Manufacturer Recommended Rate (MRR) of *Trichoderma asperellum* and *Bacillus subtilis* and their combinations were used to inoculate the seed. Ridomil *Gold*® at 2 g L^{-1} was used a positive control. Three litres of each standardized suspension were prepared in a bucket that was changed after each seed treatment. Clean tubers were placed in a netted bag and dipped for 15 seconds in the *Trichoderma asperellum* and *Bacillus subtilis* concentrations and their mixture. The tubers were air-dried, incubated in a wooden store for 24 hours, and then inoculated with *P. infestans* by dipping in a zoospore suspension adjusted to 1 × 10^5 zoospores/ml.

1.5. Experimental Design and Planting

The treatments were laid out in a split-plot arrangement in a randomized complete block design with three replicates. The methods of application (Spraying and soaking) and treatments (farmyard manure, biofertilizers) were the main plot and subplot. The sub-sub plots measured 2.1 m × 2.1 m with crop spacing of 0.75 m × 0.3 m and a path of 1.5 m width between sub plots and 2 m between the main plots to avoid fungicide drifts. Farmyard manure (FYM) at 30t/ha was applied two weeks before planting. At the onset of rains, tuber seed was planted. The same treatments were applied as indicated (Table 1.1)

Table 1.1. Treatment combinations for Effect of biofertilizers and FYM on late blight management

Treatment	Description
T0	Water
T1	FYM
T2	Ridomil *Gold*®
T3	*T. asperellum*
T4	*B. subtilis*
T5	*T. asperellum* + *B subtilis*
T6	FYM + *T. asperellum*
T7	FYM + *B subtilis*

1.6. Field Inoculation and Fungicide Application

Whole field the entire field was artificially inoculated. Inoculation was done in the evenings with a calibrated hand sprayer and 150 ml of sporangia solution per m^2. This was done 18 Days After Emergence (DAE) on the outside rows to improve uniform disease spread and infection. To induce *P. infestans* infection, overhead irrigation was performed a day before inoculation and again two days later in the morning and late evening. Ridomil® application was used four days after appearance of the first late blight symptoms, which depicts the strategy used by the farmers. The knapsack sprayer was calibrated prior to every spraying of treatments application to deliver spray volume of uniform discharge. Spray drifts to neighboring plots were prevented using polythene paper. Furthermore, data were collected only in the inner rows.

1.7. Data Collection

Symptoms of sprout, stem, and foliage infection were monitored weekly. Late blight severity and incidence were taken weekly, starting at 16 days after emergence (DAE). Severity was determined by the proportion of diseased foliage on a scale of 0 to 5, with 0 representing healthy, 1 representing one fresh lesion (small circular water-soaked spot), 2 representing up to 25% lesion plus foliar blight, 3 representing up to 50% lesion, necrotic, foliar, and stem blight, 4 representing up to 75% lesion, necrotic, foliar, and stem blight, and 5 representing 100% defoliation [15] The results were summarized using the formula below to convert weekly disease scores to Area Under the Disease Progress Curve (AUDPC)

$$AUDPC = \sum_{i=1}^{n-1} \frac{y_i + y_i + 1}{2} X \left(t_i + 1 - t_i\right) \ldots x100. \quad (1)$$

Where y_i, t_i, and i^{th} represents an assessment of disease (percentage) at i^{th} observation, time (days) at i^{th} observation, and ith represent the total number of observations, respectively [16]. Disease incidence data (the number of plants showing late blight symptoms in every plot) were collected and changed to percentage disease incidence (PDI) was calculated using the formula below.

$$\text{PDI} = \frac{\text{Number of diseased plants}}{\textit{Total number of plant assessed}} x100 \quad (2)$$

Potato tubers were harvested from the inner rows of each plot when they reached maturity and inspected for tuber blight symptoms. According to the KALRO Tigoni potato grading system, tubers were graded as ware (>60 mm), seed (30 to 60 mm), and chatt (30 mm). The tubers in each grade 43 group were counted and weighed using a weighing scale and converted to tonnes per hectare. Tubers that seemed symptomatic and asymptomatic (10 samples) were cut transversely and incubated at 22 - 23°C for three weeks and inspected every third day for late blight symptoms to determine latent infection and estimate yield losses. The data were summarized using the formula below

$$\text{Tuber infected \%} = \frac{\text{Total number of infected tuber harvested from plot}}{\text{Total number of harvested tubers}} x100 \quad (3)$$

1.8. Data Analysis

The SAS software 9.2 version was used to analyze the collected data [17]. The Shapiro-Wilk test was used to determine the normality of data collected on growth, yield, and quality parameters. Outliers in the data were identified and removed.

$$W = \frac{(\sum_{i=1}^{n} \alpha_i x_{(i)})^2}{\sum_{i=1}^{n} (x_{(i)} - x)^2}. \quad (4)$$

where *X (i)* is the ordered random sample values; *Xi* is the smallest, *ai* are the constants generated from the means, variance, and covariance of the statistic sample of size from a normal distribution.

Model was

$$Y_{ijk} = \mu + R_i + M_j + B_k + MB_{jk} + \varepsilon_{ijkl} \quad (5)$$

where μ = Overall mean R_i = effect due to j^{th} effect of block/replication M_k = effect due to k^{th} methods of application RM_{jk} = effect due to interaction of j^{th} blocks and k^{th} methods of application B_l = effect to biofertilizers BM_{jk} effect due to interaction of l^{th} biofertilizers and k^{th} methods of application ε_{ijklm} = random error component.

The significantly different treatment means was separated using Tukey's Honest Significant Difference test to separate the treatment means.

The formula of Tukey's Honest is

$$R = q(a, p, f\, e) X \frac{\sqrt{MSE}}{r} \quad (6)$$

where $q\{a, p, f\, e\}$ is the studentized range, α is the level of significance, p is the number of treatments means, and fe is the error degrees of freedom.

The correlation analysis was made to determine the correlation between biofertilizers and disease incidence

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n\sum x_i^2 - (\sum x)^2 \left(n\sum y_i^2 - (\sum y_i)2\right.}} \quad (7)$$

where *r* is the estimate, *n* is the pairs of observations, *x* and *y* are the sample coefficients; in this case, disease severity will be the *x*, and yield is the y_i.

2. Result

2.1. Effects of Biofertilizers and Farmyard Manure on Late Blight and Yield

Methods and treatments significantly affected yield, AUDPC, and Disease Incidence ($p \leq 0.01$). Tuber Infection was affected by methods and treatments ($p \leq 0.05$) (Appendix E). Methods, mean yield, AUDPC, disease incidence, and tuber infection differed significantly. The combination of FYM + *Bacillus subtilis* and FYM+*Trichoderma asperellum* were more effective for controlling potato late blight than other treatments. In addition, FYM + *Trichoderma asperellum* had the lowest AUDPC (806.62) compared to untreated (2587.86). Regarding disease incidence the plant treated with FYM + *Bacillus subtilis and* FYM + *T. asperellum* had the lowest incidences of 16% and 17% respectively (Table 2.1).

The highest yield was recorded in plots treated with FYM + *T. asperellum* (26.95 t ha^{-1}) followed by FYM and *B. subtilis* (25.27 t ha^{-1}) while the untreated with water had the lowest yield (11.56 t ha^{-1}). The highest PTI of 60.81% was recorded in (water) followed by FYM at 50.25%. while the lowest was observed in plots treated with *and* FYM + *T. asperellum* at 12.24%, followed by FYM+*Bacillu subtilis* at 14.60% (Table 2.2).

Table 2.1. Effects of biofertilizers and farmyard manure on AUDPC and disease incidence

Treatments	AUDPC	% incidence
Water	2587.86a	61.83a
Ridomil *Gold*®	1289.52c	37.67d
FYM + *B subtilis*	833.48d	17.17e
T. asperellum	1247.48c	37.00d
FYM	2049.05b	51.50b
FYM + *T. asperellum*	806.62d	16.00e
T. asperellum + *B subtilis*	1211.64c	37.50c
B. subtilis	1266.52c	37.33c
LSD	129.94	1.30

Values are means; the means followed by the same letters are not significantly different according to the Least Significant Difference (LSD) test at a 5 % significance level.

Table 2.2. Effects of biofertilizers and farmyard manure on the tuber infection and yield

Treatments	%Tuber infection	Yield (t ha^{-1})
Water	60.81a	11.56f
Ridomil *Gold*®	35.19c	20.20d
FYM + *B. subtilis*	14.60e	25.27a
T. asperellum	34.74cd	21.38c
FYM	50.25b	13.27e
FYM + *T. asperellum*	12.24e	26.95a
T. asperellum + *B subtilis*	34.93cd	21.98c
B. subtilis	34.80d	21.37c
LSD	3.18	1.09

Values are means; the means followed by the same letters are not significantly different according to the Least Significant Difference (LSD) test at a 5 % significance level.

2.2. Effects of Biofertilizers and Farmyard Manure and Methods of Application on Late Blight and Yield

All the treatments were found at par with each other and recorded significantly low AUDPC values compared to untreated control in both methods (Spraying and Soaking (Figure 2.1). The spraying method had a higher yield and low AUDPC, disease incidence, and tuber infection than the soaking method.

All fertilizer treatments showed significant differences in yield, AUDPC, disease incidence, and tuber infection. The treatments significantly affected late blight and yield, but the response was dependent on the combinations. FYM + *Trichoderma asperellum* and FYM + *Bacillus subtilis* which were not significantly different, giving better disease control than untreated plots. In the Spraying method, FYM+*Trichoderma asperellum* and FYM + *Bacillus subtilis* reduced late blight severity by 72.95% and 72.55%, respectively with corresponding higher yields of 63.18% and 62.38%, respectively, compared to control (untreated plot). In addition, the lowest tuber infection and disease incidence were recorded in plots treated by FYM+*Trichoderma asperellum* and FYM + *Bacillus subtilis*. In the Soaking method, the highest reduction in disease severity compared with untreated control was observed with FYM+*Trichoderma asperellum* 64.62% followed by FYM + *Bacillus subtilis* at 59.83%. Also, the plots treated with FYM+*Trichoderma asperellum* and FYM + *Bacillus subtilis* showed the lowest tuber infection of 15.25 % and 17.99%, and disease incidence by 21.00% and 26.33%, respectively. (Table 2.3).

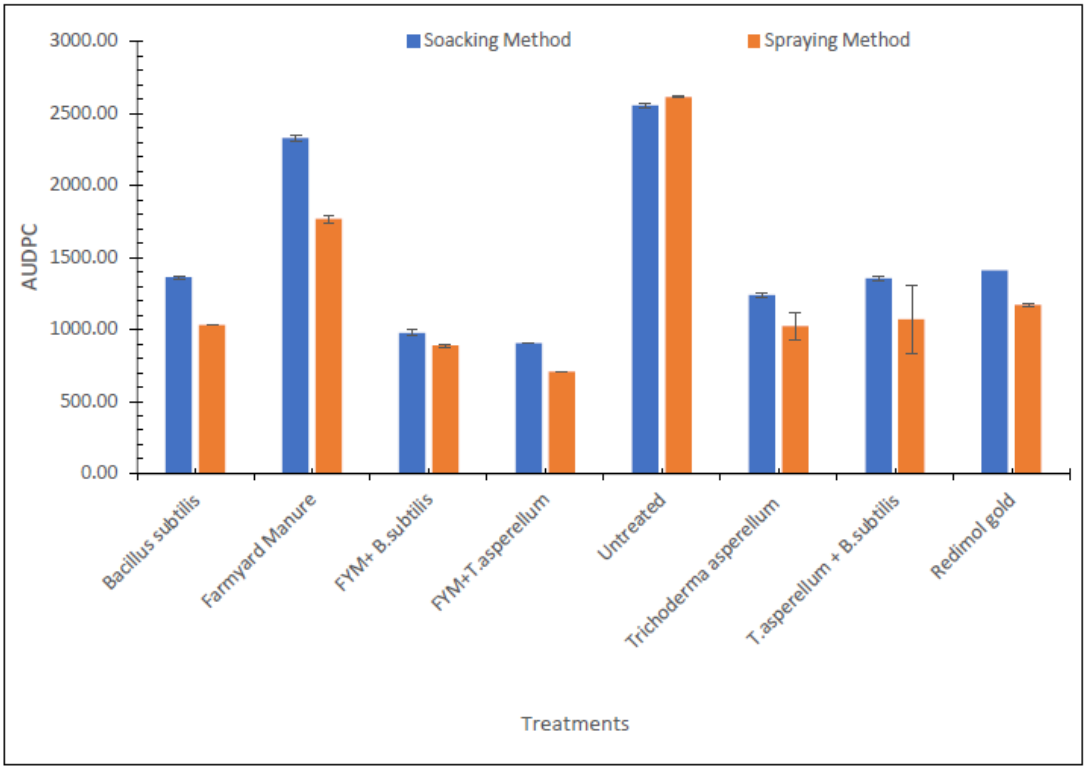

Figure 2.1. Effect of FY and biofertilizers with method of application on Area under the progressive disease curve (AUDPC)

Table 2.3. Effects of biofertilizers and farmyard manure and application methods on Late Blight and Yield

	SPRAYING			SOAKING		
Treatments	**Yield (t ha^{-1})**	**%Tuber infection**	**%Disease incidence**	**Yield (t ha^{-1})**	**%Tuber infection**	**%Disease incidence**
T4	8.46 ±0.70	29.80±0.36	33.67±0.88	6.29±0.83	40.58±0.43	45.00±0.58
T1	5.27±0.22	64.32±0.61	61.00±0.58	2.27±0.24	72.18±0.84	66.00±0.58
T7	13.80±0.68	11.22±0.67	20.00±0.58	18.86±0.52	17.99±0.87	26.33±0.88
T6	15.51±0.71	9.23±0.63	11.00±0.58	19.39±0.52	15.25±0.20	21.00±0.58
T0	4.34±0.04	73.37±0.59	71.33±0.88	2.10±0.56	88.25±0.63	70.33±0.88
T2	7.60±0.41	27.37±0.52	33.67±0.88	5.78±0.27	42.11±0.01	45.33±0.33
T3	8.72±0.37	28.16±0.40	32.00±0.58	6.23±0.29	41.70±0.39	45.00±0.58
T5	7.95±0.62	22.73±5.80	33.00±0.58	5.94±0.39	40.86±0.43	45.33±0.33

Values are means; the means followed by the same letters are not significantly different according to the Least Significant Difference (LSD) test at a 5% significance level. Key: T0: control (untreated) T1: Farmyard manure (FYM) T2: Fungicide (Ridomil *Gold*®) T3: *Trichoderma asperellum* T4: *Bacillus subtilis* T5: *Trichoderma asperellum* + *Bacillus subtilis* T6: FYM+ *Trichoderma asperellum* T7: FYM+ *Bacillus subtilis*

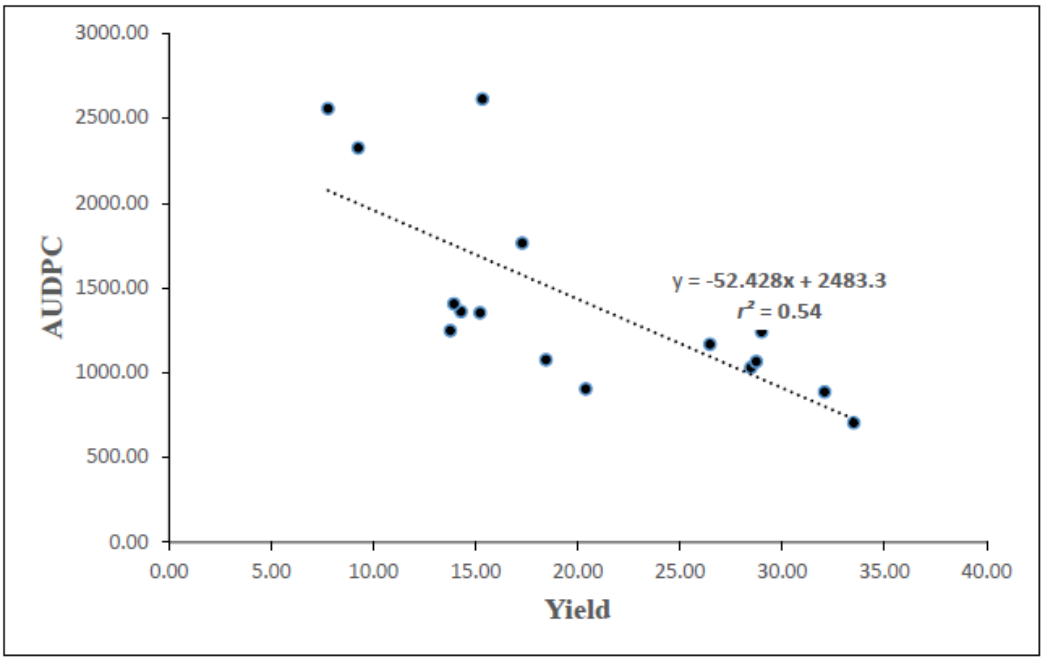

Figure 2.2. The relationship between tuber yield (t/ha) and Area under the progressive disease curve (AUDPC) of late blight

2.3. Pearson Correlation Coefficients (P-Values) of AUDPC and Yield

The linear regression analysis conducted for treatments versus untreated control revealed that the late blight severity in terms of AUDPC was inversely correlated with the yield of the potato crop in both methods (Figure 2.2). With increasing disease severity, there was a significant reduction in tuber yield. In both methods of disease management, the linear model showed negative correlation between disease severity and tuber yield in terms of tuber weight ($r^2 = 0.54$).

3. Discussion

Trichoderma and Mycorrhizae affected late blight management, crop growth, and yield were minimal when applied alone. Increases in the number of stems have been found to positively correlate with yield [18]. Higher stem count was observed when manure was used as carrier material than biochar. Further, it was observed that manure gave more yields than biofertilizers applied without a carrier. This could be attributed to the ability of manure to contain mineral nutrients, organic matter, and different microorganisms that enhance microbial consortium. Kumar *et al.* [19] found that soil application of FYM + seed treatment with bio formulation of *T. harzianum* + foliar spray of Mancozeb resulted in the lowest disease severity of early blight of tomato, which was 8.56 percent. Bansal *et al.* [20] found out that soil application of FYM and mustard cake + tuber treatment with *T. viride* + foliar spray with *T. viride* reduced late blight disease severity from 96.00% to 7.82%. The effect of integrated disease management (IDM) practices significantly reduced disease severity of late blight of potato as compared to control in warehouse condition. Soil application of FYM + Poultry Manure + Tuber treatment with *T. harzianum* as a foliar spray reduced disease severity.

Incorporation of bio-fertilizers in soil + tuber treatment with bio agents + foliar spray with bio formulation effectively managed late blight of potato. Effective control of late blight requires implementing an integrated disease management approach that has been reported by several researchers [11] [21]. Mishra *et al.* [22] found that seed treatment and soil application with bio-fertilizers of Azotobacter declined disease severity of spot blotch from 73.7% to 42.6% in wheat. An alternative to using microorganisms as a biocontrol method is to isolate the metabolites responsible for *P. infestans* inhibition and apply them directly to increase efficiency without establishing the antagonistic microorganism in the ecosystem. Several *in vitro* studies with *P. infestans* have demonstrated that metabolites produced by microorganisms can inhibit this oomycete. [23] [24] [25]

4. Conclusion

Potato is one of the most vulnerable solanaceous vegetables to the devastating disease of late blight and in severe cases, total crop failure is common. The situation can be overcome with proper management strategies. From seed treatment to harvesting, care must be taken. Biofertilizers (*Trichoderma asperellum* and *Bacillus subtilis*) and Farmyard Manure can effectively manage the disease as alternative fungicides. The results revealed that FYM + *Trichoderma asperellum* and FYM + *Bacillus subtilis* reduced disease severity by 68.79%, and 67.79% and disease incidence by 74.12%, and 72.23% of late blight respectively. Additionally, FYM + *Trichoderma asperellum* and FYM + *Bacillus subtilis* had highest tuber yield of 26.95 kg ha^{-1} and, 25.27 kg ha^{-1}) and lowest tuber infection of 12.24% and 14.60%, respectively. The results suggest foliar spray with *Trichoderma asperellum* and

Bacillus subtilis and combining farmyard manure in the soil reduced disease incidence under field conditions with high yield. The yield was reduced by 42% in treatments associated with the soaking method compared to the spraying method. The spraying method had 11.42% low disease severity, leading to a 12.36% higher yield than the soaking method. FYM and Biofertilizers are eco-friendly management of potato late blight in highlands. Whenever the incidences are severe, Seed treatment of these mixtures of FYM and Biofertilizers may be recommended.

Declarations

Funding: This study was funded by Transforming Africa Agricultural Universities to meaningfully contribute to African's Growth and development (TAGDev) Egerton project through RUFORUM and MasterCard foundation.

Conflict of interest: This is to inform that the authors have declared no conflicts of interest to declare relevant to the content of this article.

References

[1] Ghorbani, R., Wilcockson, S., & Leifert, C. (2005). Controlling late blight using Alternative treatments in organic potato: Antagonistic microorganisms and compost extracts for activity against *Phytophthora infestans*. *Potato research*, *48*(3), 181-189.

[2] Sundaresha, S., Kumar, S., Singh, B. P., Jeevalatha, A., Rawat, S., Mahota, A. K., & Sharma, T. R. (2015). Comparative genome analysis of Irish famine pathogen with Indian *Phytophthora infestans* isolate. In *3rd International symposium on Phytophthora: Taxonomy, genomics, pathogenicity, resistance and disease management. 9th-12th September*, 24-28.

[3] Ghislain, M., Byarugaba, A. A., Magembe, E., Njoroge, A., Rivera, C., Román, M. L., & Kiggundu, A. (2019). Stacking three late blight resistance genes from wild species directly into African highland potato varieties confers complete field resistance to local blight races. *Plant Biotechnology Journal*, *17*(6), 1119-1129.

[4] Majeed, A., Muhammad, Z., Ullah, Z., Ullah, R., & Ahmad, H. (2017). Late blight of potatoes (*Phytophthora infestans*) Fungicides application and related challenges. *Turkish Journal of Agriculture-Food Science and Technology*, *5*(3), 261-266.

[5] Kibiro, E. M. (2014). Management Of Potato Late Blight *(Phytopthora Infestans)* by Using Arbuscular Mycorrhizal Fungi. PhD Thesis, University Of Eldoret.

[6] Rekanović, E., Potočnik, I., Milijašević-Marčić, S., Stepanović, M., Todorović, B., & Mihajlović, M. (2011). Sensitivity of the *Phytophthora infestans* (Mont.) de Bary isolates to fluazinam, fosetyl-Al and propamocarb-hydrochloride. *Pesticidi i fitomedicina*, *26*(2), 111-116.

[7] Sharma, P., & Saikia, M. K. (2013). Chemical control of late blight of potatoes. *IOSR J Agric Vet Sci*, *2*, 23-36.

[8] Johnson, D. A., Cummings, T. F., & Hamm, P. B. (2000). Cost of fungicides used the potato management late blight in the Columbia Basin 1996 to 1998. *Plant Disease*, *84*(4), 399-402.

[9] Abell, A., Ernst, E., & Bonde, J. P. (2000). Semen quality and sexual hormones in greenhouse workers. *Scandinavian journal of work, environment & health*, 492-500.

[10] Kamoun, S., Furzer, O., Jones, J. D., Judelson, H. S., Ali, G. S., Dalio, R. J., & Govers, F. (2015). The top ten (10) oomycete pathogens in molecular plant pathology. *Molecular plant pathology*, *16*(4), 413-434.

[11] Axel, C., Zannini, E., Coffey, A., Guo, J., Waters, D. M., & Arendt, E. K. (2012). Ecofriendly control of potato late blight causative agent and the potential role of lactic acid bacteria: a review. *Applied microbiology and biotechnology*, *96*(1), 37-48.

[12] Jackson, K. M. (2022). Optimization of biofertilizers on potato blight, performance and farm returns using biochar and manure in combination with fertilizer. *East African Journal of Science, Technology and Innovation*, *3*.

[13] Muleta, D., Assefa, F., Börjesson, E., & Granhall, U. (2013). Phosphate-solubilising rhizobacteria associated with (*Coffea arabica* L.) in natural coffee forests of southwestern.

[14] Forbes, G. A. (2012). Using host resistance to manage potato late blight with particular reference to developing countries. *Potato Research*, *55*(3), 205-216.

[15] Forbes, G. A. (1997). Manual for laboratory work on *Phytophthora infestans* CIP Training Manual. International Potato Center (CIP), Lima, Peru.

[16] Simko, I., & Piepho, H. (2012). Analytical and theoretical: The Area Under the Disease Progress Stairs: Calculation, advantage and application. *Plant Pathology*, *102*(4), 381–389.

[17] Gomez, K.A., & Gomez A.A., (1983). Statistical procedures for agricultural research (2 ed.). John wiley & sons (Pp: 84-462). International rice research institute.

[18] Blauer, J. M., Knowles, L. O., & Knowles, N. R. (2013). Manipulating stem number, tuber set and size distribution in specialty potato cultivars. *American Journal of Plant Science*, *90*(5), 470–496.

[19] Kumar, S., Biswas, S. K., & Prakesh, H. G. (2018). Integrated disease management approaches for control of late blight of potato and enhancing the growth of potato. *Journal of Biological Control*, *32*(4), 264-269.

[20] Bansal, A., Biswas, S. K., & Kumar, S. (2021). Effect of Integrated Disease Managemnet practices on germination, growth parameters, yield and severity of late blight of potato caused by *Phytophthora infestans* (Mont.) de Bary.

[21] Kirk, W., Wharton, P., Hammerschmidt, R., Abu-el Samen, F., and Douches, D. (2013). Late blight. Michigan state university extension bulletin E-2945. East Lansing, MI. Available on: http://www.potatodiseases.org/ lateblight.html.

[22] Mishra Y, Biswas SK, Lal K, Naresh P, Sushree A, Kumar N. (20215). sustainable Integrated approach on control of early blight and their effect on tomato crop growth parameters, *The Bioscan 11*(1), 133-139.

[23] Hultberg, M., Bengtsson, T., & Liljeroth, E. (2010). The biosurfactant producing strain Pseudomonas koreensis 2.74 and its biosurfactant is suppressed late blight on potato. *BioControl*, *55*(4), 543-550.

[24] Son, S. W., Kim, H. Y., Choi, G. J., Lim, H. K., Jang, K. S., Lee, S. O., & Kim, J. C. (2008). Bikaverin and fusaric acid from Fusarium oxysporum show antioomycete activity against *Phytophthora infestans*. *Journal of applied microbiology*, *104*(3), 692-698.

[25] Yang, X., Qiu, D., Yang, H., Liu, Z., Zeng, H., & Yuan, J. (2011). Antifungal activity of xenocoumacin1 from *Xenorhabdus nematophilus* var. *pekingensis* against *Phytophthora infestans*. *Microbiology and Biotechnology International Journal*, *27*(3), 523-528.

[26] Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, C. (2006). Farm management handbook of Kenya-Natural conditions and farm management information, 2nd Edition. Volume II/B. Ministry of Agriculture, Nairobi.