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**Article**

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# Response of *Solanum tuberosum* L to different soil amendments and foliar sprays in the control of *Phytophthora infestans* in Kisii, Kenya

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**Abstract**

Irish potato (*Solanum tuberosum* L.) is an important crop grown globally especially in Kenya. However, poor yields in Kisii County are due to late blight disease which is rampart in the region. Depletion of the beneficial soil microbes and excessive use of inorganic fungicides have led to the resistance of late blight disease pathogen *(Phytophthora infestans)* raising alarm for alternative treatments as counter measure. Hence, the current research focused to investigate the efficacy of different soil amendments and foliar sprays in controlling late blight in Irish potato. The experiment was laid in a Randomized Complete Block Design in three replications for two planting seasons. Three-week-old healthy Irish potato plants in the field plots were inoculated with $1x10^7$ spores/ml suspension of the re-isolated fungal mycelia. Data collected on disease incidences and marketable yield were subjected to analysis of variance using statistical Analysis Software and treatment means separated using Turkey's test at $P < 0.05$. Disease incidence was low (2.1395) in the experimental plot treated with Di- Ammonium Phosphate fertilizer and vermiliquid foliar spray while highest (5.444) in the control experimental plot. Marketable tuber yield was recorded highest (70.3 tons/ha) with a yield percentage increase of (92.7%) in the experimental plot treated with Di-Ammonium Phosphate and sprayed with vermiliquid foliar spray but lowest (36.5 tons/ha) in the control plot. Therefore, integrating DAP fertilizer with vermiliquid foliar spray was taken as the best treatment of controlling late blight disease in Irish potatoes.

**Keywords** – Di- Ammonium Phosphate (DAP) – Soil microbes – Vermicompost manure – Vermiliquid foliar spray

## Introduction

Irish potato is the second most important food and cash crop after maize in Kenya. It plays an important role as a staple food among small scale farmers as well as alleviates poverty through income generation. Approximately one million farmers grow potato in Kenya, while over 2.5 million Kenyans are employed along the potato value chain either directly or indirectly (Okello et al. 2017, Kevin et al. 2018). Despite its importance, potato production is constrained by soil degradation, lack of quality certified seeds, as well as pest and disease management among other factors (Were et al. 2013, Kevin et al. 2018). The inherently high soil acidity proposed by Muthoni & Nyamongo (2009) exacerbates the situation in the region. Therefore, this necessitates the

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amending of the soils so as to increase the soil pH in the Irish potato growing regions. Late blight disease caused by the fungus *P. infestans* (Mont.) de Bary (Volk 2001) has been identified as the major cause of low Irish potato yields to farmers in Kenya (Muthoni & Nyamongo 2009, Arora et al. 2014, Daniel 2019). The disease causes serious crop losses of up to 22% and hence it has become a major concern to many scientific researchers (Lung'aho & Kabira 1999, Mosley et al. 2000, Forbes & Landeo 2006, Fry 2008).

For a long time, farmers in Kenya more so Kisii County have not earned as much as they should from the cultivation of Irish potatoes (Kirumba et al. 2004). Statistics indicate that the yield per acre is reducing despite farmers increasing acreage in the production of potatoes (CIP 2010, FAO 2018) and this implies that either the production technology being used is getting obsolete or not being used efficiently (FAOSTAT 2020). This yield constraint has been attributed to among other factors, poor nutrient management strategies, inadequate cropping systems, accelerated soil erosion rates and high cost of inorganic fertilizers and fungicides. On the other hand, fertilizer applications in Kenya is mainly blanket and is often below the recommended rates resulting in adequate amount of nutrients which cannot meet the potato growth requirement (Muthoni & Nyamongo 2009, James et al. 2020). Therefore, this study aimed to assess different soil amendments to restore soil fertility and also to determine a viable foliar spray that can eradicate the fungal spores of *P. infestans* appropriately.

## Materials & Methods

In this research, the common *shangi* variety of Irish potato in the market but not commonly grown in Kisii region was identified and selected to establish its level of resistance to late blight disease and yield production. The methodology used to achieve this objective has been discussed under the following sub-headings; Isolation and identification of *P. infestans,* collection of experimental materials, Construction of vermibeds and vermicomposting, Field soil sampling, land preparation and planting, application of foliar sprays, data collection on disease incidences, yield and analysis. The set-up of the experiment was done at Kenya Agricultural and Livestock Organization (KALRO) – Kisii Centre with all laboratory experiments including soil analysis.

### Isolation and identification *of P. infestans*

The infected Irish potato leaves from each farm and variety were picked randomly and used to isolate *P. infestans*. Infected leaves were washed under running tap water and rinsed five times. Leaf surfaces were sterilized by dipping in 70% ethyl alcohol for 30 seconds and blot dried on a paper towel for quick removal of alcohol according to Drenth & Sendall (2001). Small, fresh and recently infected leaf piece measuring 2mm x 3mm were excised from the edge of actively growing lesion using a sterilized scalpel and placed in each petri-dish containing solidified potato dextrose agar (PDA). The Petri dishes were sealed using a foil and then incubated at $18^{0}$C for fourteen days in a germinating chamber. The petri-dishes were examined regularly for the growth of mycelium, sporangia and their morphological characteristics. The mycelium and sporangia were isolated and mounted on a sterile microscope slide and observed with medium power objective lens. Identification of the fungus was based on symptomatology, pure culture assessment, pathogenicity and microscopy test using objective lens of (x40). Pathogenicity test was evaluated using universal protocol (Koch's postulates) by foliar spraying of 3-week-old healthy Irish test potato plants with the prepared fungal isolate of $10^{7}$ spores / ml. The control plants were kept without fungal isolate inoculation. The artificially inoculated plants were then observed for disease symptoms after 10 days which is the incubation period of the fungus. The infected leaves from the test plants were randomly sampled and *P. infestans* re-isolated by growing the isolates again on fresh PDA which obtained same culture characteristics that were exactly similar to the mother culture. Flooding of the pure sporulating culture petri-dishes was done to obtain a suspension which was serial diluted to obtain a concentration of $1x10^{7}$spores/ml. This concentration was used to inoculate the 3-week-old healthy Irish potato experimental plants by use of a hand sprayer.

**Collection of Materials**

Coffee husks were obtained from Coffee Research – Kisii centre. Vegetable remains were collected from Daraja Mbili Market within Kisii municipality. The certified seed potato tubers of *Shangi* variety were bought from Agricultural Development Corporation (ADC) – Molo centre. *Eisenia fetida* earthworms were collected from Bondo in Siaya County while the cow dung used in pre- decomposition was obtained from the livestock unit in KALRO- Kisii. Di-Ammonium Phosphate fertilizer (18%N, 46%, $P_2O_5$) and Milthane fungicide powder were obtained from Josmo Agrovet in Kisii town.

**Preparation of vermicompost, vermiliquid, compost manure and compost tea**

Five vermibed units were constructed using sand, concrete, bricks and cement measuring 4m x 4m x 2m. The vermibeds were fixed with plastic pipes at the back to facilitate the drainage of the vermiliquid in line with (Munroe 2004). A 25cm layer of broken pebbles were placed at the bottom of each vermibed followed by a 25cm layer of coarse sand. A 20-30cm layer of loamy soil was placed on the top of the filter bed followed by a 25cm layer of sawdust mixed with chopped cardboards to act as a bedding material for the earthworms. Vegetable remains and coffee husks were pre- decomposed with cow dung for 20 days in a separate pit measuring 6m x 3m x 4m. These remains were then transferred into the vermibeds to the brim according to Sudha & Kapoor (2000). One kilogram of the earthworms - about 100 earthworms was placed at the top of the four vermibeds while the $5^{th}$ vermibed was left out to prepare compost manure and compost tea. Favourable conditions were maintained (Moisture at 75%; Temperature at 15-25$^{o}$C and pH of 5.7). The units were monitored regularly to prevent infestation of earthworm pests such as ants, rats, birds and snakes. The vermibeds were covered with iron sheets to prevent the earthworms from direct sunlight and rainfall. The vermicomposting process was carried out for 4 months.

**3.8 Vermicompost, compost manure and field soil analysis**

Soil sampling was done before planting and analysis conducted at KALRO- Kisii branch. The samples were taken randomly using a soil auger 3-inch in diameter in a zig-zag pattern from the entire experimental field before planting. Ten soil samples were taken from the top soil layer to a depth of 20 cm and composited in a bucket to represent the site. The soil was broken into small crumbs and thoroughly mixed. From this mixture, a composite sample weighing one kg was filled into a plastic bag for transportation to the soil laboratory for analysis. The soil colour was assessed using Munsell soil colour chart (FAO 2006), soil bulky density was determined using a hand –held soil sampling tube (Schmidhalter 2005), soil pH was obtained using a pH meter (FAO 2006), electrical conductivity (EC) was determined using EC meter at a temperature of 25$^{o}$C and expressed in micro-siemens per centimeter ($dsm^{-1}$) as recommended by Richards (1994), soil texture was assessed using a simple hand method of rolling the wetted soil into ball ribbons as recommended by USDA (1999), Dalgliesh & Foale (2005). The chemical content of the soil was determined using various methods. Total N was determined according to the USDA soil protocols (1999, Mangale 2016), available P was determined by extraction with 0.5M Sodium bicarbonate ($NaHCO_{3)}$ according to the methods of Olsen et al. (1954), exchangeable potassium was determined with a flame photometer after extraction with 0.5 ammonium acetate according to Hesse (1971) while organic carbon of soil was determined by the Walkley & Black (1934).

Samples of vermicompost and compost manure were taken randomly from the entire harvested bags. The samples were broken into small crumbs and prepared for determining chemical properties. The colour was determined using Munsell colour chart. The samples were air-dried and sieved through a 2mm sieve and analyzed for soil pH using a pH meter, electrical conductivity (EC), total N, available P, exchangeable K. organic matter and organic carbon were analyzed using similar procedures for field soil analysis above protocols as recommended by USDA (1999), Dalgliesh & Foale (2005), Estefan et al. (2013).

**Land Preparation and Planting**

Land for experimental plots was ploughed to a fine tilt and all weeds eliminated. Experimental plots measuring 2m x 1m were demarcated. Vermicompost and compost manure were applied on the plots 7 days before the final preparation at the rate of 10 kg per plot as per the treatment. The mixing of soil with vermicompost and compost was done manually using a jembe and spade in the field plots according to Rashidul et al. (2013). Ridges were dug on the demarcated experimental plots measuring 75cm apart with intra row spacing of 30cm. The planting holes were made to a depth of 10cm. Di-Ammonium Phosphate (18%N, 46%, $P_2O_5$) fertilizer was applied at a rate of 10g per hole which translates to 90Kg N $ha^{-1}$ as recommended by Lung'aho & Kabira 1999, Mosley et al. 2000, MOA 2018. Irish potato seed tubers that had sprouted were used as planting materials. The seed tubers were placed with the "eyes" facing upwards and the holes covered with light soils as recommended by Greenlife (2018). Guard rows were established around the experimental plots. Earthing up was executed two times throughout the entire growing period, one at 30 days and another at 60 days after planting.

**Application of Vermiliquid, Milthane fungicide and Compost tea**

The vermiliquid and compost tea collected were diluted at the ratio of 1:10 v/v with tap water and sprayed at a rate of 1 litre per plot as per the treatment as recommended by Munroe 2004, Mandic et al. 2011. The extracts were sprayed using a knapsack sprayer and done twice monthly until the Irish potatoes matured according to Ingham 2000, Scheuerell & Mahaffee 2002, Rashidul et al. 2013. The milthane fungicide was prepared by dissolving 20 grams of milthane fungicide in 20 litres of water, mixed thoroughly before spraying using a knapsack sprayer twice monthly for three months according to Mosley et al. 2000, Forbes & Landeo 2006, Rahman et al. 2008.

**Data Collection and Analysis**

Disease scoring was done on a scale of 1-9 according to Rahman et al. 2008. This was done to determine the intensity of the disease and was achieved by measuring of the length of lesions in identified and marked leaves of Irish potato plants in the field plots. The length of the lesions was measured in centimeters and recorded. The scoring was done weekly for a period of 7 weeks in season 1 and 5 weeks in season 2.

The zero - rating scale was not applied in this research as it referred to situations where rating could not be made. Scale 1 and 2 was applied to plants with minimum symptoms hence showing the highest level of resistance to late blight disease. Plants with moderate symptoms scored 3 and 4 implying that they have moderate resistance to disease while scale 5, 6 and 7 was reserved for plants with intense symptoms. The highest scores were 8 and 9 which were reserved for plants with severe symptoms and even death of the plants. These plants showed the highest level of susceptibility to late blight disease.

In addition to the disease incidence score, the average yield of the marketable Irish potato tubers was determined. Harvesting was done during the month of August and December for season 1 and 2 respectively. During the last 2 weeks to harvesting, the potatoes were dehaulmed to facilitate the skin of the tubers to harden and minimize bruising. The Irish potatoes were harvested separately from each plot. The health and infected Irish potato tubers per plot treatment were harvested in kilograms by weighing balance (Salter Model 323, capacity 2000). An average weight of Irish potato per treatment was obtained and records made. The average weight in kilograms was expressed in tons per hectare (tons/ha) for subsequent analysis. The total number of tubers per plant from control treatments was weighed in kilograms. The tubers were graded into ≥ 4cm in diameter as marketable size tubers and < 4cm in diameter as non - marketable tuber sizes.

**Results**

**Isolation and identification of *P. infestans***

Assessment of the laboratory culture plates revealed white, lumpy and fluffy colonies of mycelium. Microscopy test using a light microscope with objective lens (X40) revealed the ellipsoid and lemon-shaped sporangia with small pedicel sporangiophores. The isolates were fast - growing and covered the 9cm laboratory culture plate within 7-10 days. Plate 1 below show the results of the pathogenicity tests carried out to confirm the identity of *P. infestans* isolates from the laboratory. Plate 2 below show the small sunken, dark-green and water-soaked spots that were first observed appearing on the upper side of the leaves after inoculation with *P. infestans* spores.

The spots enlarged, coalesced and formed large area that later became necrotic or black during moist conditions as shown in Fig. 2. During the wet and humid weather, powdery and white mycelium growths were observed on the lower sides of the leaves but disappeared during the hot weather. These particular lesions and characteristic symptoms observed are features of the Oomycete fungus of *P. infestans* which cause late blight disease in Irish potatoes.

**Fig. 1** – Lesions on inoculated leaves.

**Fig. 2** – Water soaked lesions on the leaves.

**Preparation of vermicompost, vermiliquid, compost manure and compost tea**

Mature vermicompost manure turned to be black, odourless and crumbly as shown in Fig. 3 below. It is similar to the soil found in deciduous woodlands and mixed forests. Vermicompost contains earthworm cocoons that increase the population and activity of earthworm in the soil. A total of 1000kg of vermicompost and 300 kg of compost manure were harvested from the vermibeds. Vermiliquid is a dark concentrated liquid obtained from earthworm vermibeds as shown in Fig. 4 below. 20 litres of vermiliquid was collected and stored in an open plastic container in a cool and dark place to avoid anaerobic fermentation.

**Fig. 3** – Sample of Vermicompost manure

**Fig. 4** – Sample of Vermiliquid spray

The chemical soil analysis result of vermicompost and compost manure was shown in Table 1.

**Table 1** Vermicompost and compost manure chemical analysis

| **Fertility manure results** | **Vermicompost Value** | **Compost Value** | **Class** |
|---|---|---|---|
| Ph | 9.0 | 8.8 | Alkaline |
| Electrical cond.µs/cm | 0.08 | 0.09 | Low |
| Organic carbon % | 42 | 40 | High |
| Total nitrogen % | 1.7 | 1.5 | Moderate |
| Phosphorous ppm | 5 | 3 | Low |
| Manganese % | 1.4 | 1.1 | Moderate |
| Magnesium (ppm) | 4.5 | 0.8 | Very low |
| Potassium (ppm) | 10.2 | 5.1 | Low |

The results indicate that vermicompost and compost manure are alkaline in nature with pH values of 9.0 and 8.8 respectively. Vermicompost and compost manures have high organic carbon content of (42%) and (40%) respectively. In terms of other soil nutrients, vermicompost manure has higher nitrogen content of (1.7%), phosphorous of (5 ppm), manganese (1.4%), magnesium (4.5 ppm) and potassium (10.2 ppm). On the contrary, compost manure has low percentage of nitrogen and manganese of (1.5%) and (1.1%) respectively as compared to vermicompost manure. Phosphorous and magnesium are low with (3 ppm) and (0.8 ppm) respectively as compared to those of vermicompost.

The result of the chemical field soil analysis is shown in Table 2.

**Table 2** Field soil fertility results

| Fertility results | Value | Class | Critical level |
|---|---|---|---|
| Soil Ph | 4.9 | Acidic | 5.5 |
| Electrical conductivity µS/cm | 1.0 | Moderate | 1.6 |
| Organic carbon % | 10 | Moderate | 25 |
| Phosphorus(ppm) | 17 | Deficient | 30 |
| Total nitrogen% | 0.12 | Low | 2.5 |
| Sulphur % | 3.0 | Adequate | 4.5 |
| Magnesium(ppm) | 2.6 | Very low | 30 |
| Potassium(ppm) | 7.8 | Very low | 20 |

The soil analysis report in Table 2 above indicates that the soil pH was acidic and hence suitable for the growth of Irish potatoes that require a soil pH range of 4.5-8.5. This result agreed with Muthoni & Nyamongo (2009) findings in their review on the constraints of ware Irish potato in Kenya that the soils are more acidic in the growing regions due to the inorganic fertilizers that are frequently used. Irish potatoes perform well in loose loamy and sandy loam soils that are well drained and aerated and rich in organic matter. The field soil was low in Total nitrogen (0.12%), Magnesium (2.6ppm) and potassium (7.8 pmm). Therefore, the field soil should be amended with fertilizer or soil manure that supplements the deficit soil nutrients.

**Effect of the treatments on the experimental plots**

Fig. 5 below illustrates the severity of late blight disease in the plot treated with (compost manure + compost tea) as compared to the plot treated with (vermicompost + milthane fungicide) as shown in Fig. 6.

**Fig. 5** – Irish potato plants treated with CM/CT.

**Fig. 6** – Irish potato plants treated with VC/MF.

It can be evidenced from Fig. 6 above that the Irish potato plants in treatment VC/MF which were artificially inoculated with *P. infestans* and planted with vermicompost manure and plants sprayed with milthane fungicide survived the severity of the pathogen as compared to Irish potato plants grown on treatment CM/CT which were treated with compost manure as a soil amendment and plants sprayed with compost tea as presented in Fig. 5 above. Most Irish potato plants dried up before maturity leaving the land plain. Disease incidence scores in the field for the two planting seasons in Table 3, indicate evidence of significant difference in disease score of *Shangi* variety among some treatments in the two seasons. There was significantly (P<0.0001) high disease score in the control (CO) and CM/CT (Compost manure + compost tea) of 5.444 and 4.4630 respectively as compared to DAP/VL (DAP + Vermiliquid spray) and DAP/MF (DAP + milthane spray) of 2.1395 and 2.4444 respectively on average.

There was no significance difference (P<0.0001) between treatments DAP/VL and DAP/MF in the two seasons hence this result depicts equal efficacy between the two foliar sprays. Further the results show that there was no significant difference among treatments VC/VL, VLD/VL, VC/MF and VLD/MF in all seasons. This result further indicates that the two foliar sprays can equally control late blight disease in Irish potatoes despite the soil amendment used.

**Table 3**: Mean disease incidences in the experimental plots for the two seasons

| Treatment | Season 1 | Season 2 | Average | % Disease control compared to control |
|---|---|---|---|---|
| CO | 4.8159a | 6.0370a | 5.444a | 0 |
| CM/CT | 3.9630b | 4.9630b | 4.4630b | 18.0 |
| VC/MF | 2.9630d | 4.6667cb | 3.8148c | 29.0 |
| VLD/VL | 3.7037cb | 4.0000c | 3.8519c | 29.3 |
| VLD/MF | 2.7778ed | 4.7037b | 3.7407c | 31.3 |
| VC/VL | 2.0000ef | 4.8148cb | 3.4074c | 37.4 |
| DAP/MF | 2.0000ef | 2.7407d | 2.4444d | 55.1 |
| DAP/VL | 1.6250f | 2.4444d | 2.1395d | 60.7 |
| Mean | 3.1071 | 4.2963 | 3.6632 | |
| SE | 2.9992 | 1.600 | 1.93 | |
| CV% | 49.0 | 29.4 | 37.3 | |
| LSD | 0.8725 | 0.6788 | 0.5407 | |
| P-value | <0.0001 | <0.0001 | <0.0001 | |

Mean figures in the column with different letters are significantly different (P<0.0001)

It is evident from the results that there is a significant difference in disease incidence scores in the field among the treatments. Treatment CM/CT (Compost manure and compost tea) had significantly (P<0.0001) higher disease score of (4.4630) as compared to all other treatments except the control (5.4444). This result explains the low efficacy of compost tea to control late blight disease in Irish potatoes. Treatment DAP/VL had the lowest disease scores at (2.1395) with a percentage disease control of 60.7% while treatment DAP/MF had a disease incidence mean score of (2.4444) with a percentage disease control of 55.1%. The two treatments had no significant difference (P<0.0001) in terms of disease incidence mean score. On the contrary, treatment CM/CT recorded high disease incidences mean score of (3.8148) but lower than the CO (5.444) with the lowest percentage disease control of 18.0%. There was no significance difference (P<0.0001) among treatments VLD/VL, VC/MF, VLD/MF and VLD/VL which had higher disease incidence mean scores of (3.8519), (3.8148), (3.7407) and (3.4074) respectively with percentage disease control of (29.3%), (29.0%), (31.3%) and (37.4%) respectively.

The disease incidences scores were significantly (P<0.0001) higher in season 2 (4.2962) as compared to season 1 (3.1071). This result can be attributed to the high rainfall amount experienced during the second season in the region. The heavy and extended rains experienced during the season enabled a cool and humid weather which facilitated the development and progression of late blight disease.

The results in Table 4, indicate that there is evidence of significant difference (P<0.0001) in the marketable Irish potato tubers harvested among the various experimental treatments and between the two seasons. For instance, treatment DAP/VL recorded high marketable tuber yields of (70.33tons/ha) on average with a percentage yield increase of 92.7% while CM/CT recorded low yields of (40.3tons/ha) with percentage yield increase of 10.5%. This result was followed by treatment DAP/MF which produced (65.08tons/ha) with a percentage yield increase of 78.3%. Treatment VC/VL produced 60.25onst/ha with a percentage yield increase of 65.1% while treatment VC/MF produced (54.8tons/ha) with a percentage yield increase of 50.2%. This result agrees with Kevin et al. (2018) earlier findings which realized that vermicompost manure gave better yields of 30% more than the normal compost manure. VLD/VL treatment recorded a yield of (44.35tons/ha) with a percentage yield increase of 21.5% while VLD/MF treatment recorded a yield of (49.83tons/ha) with a percentage yield increase of 36.5%. This result indicates the possibility of vermiliquid being used as an organic fertilizer since it contains nutrients that can sustain the growth of Irish potato and recommendable yields. The results further indicate that there were high average marketable tuber yields of *Shangi* variety of Irish potatoes in season 1 (53.92 tons/ha) as compared to season 2 with a mean score of (51.46 tons/ha).

**Table 4** Mean scores of marketable tubers yields for the two seasons in tons/ha

| Treatment | Season 1 | Season 2 | Average yield | % yield increase compared to control |
|---|---|---|---|---|
| DAP/VL | 72.333a | 68.333a | 70.333a | 92.7 |
| DAP/MF | 68.000b | 62.1667b | 65.0833b | 78.3 |
| VC/VL | 62.333c | 58.1667c | 60.250c | 65.1 |
| VC/MF | 55.333e | 54.333d | 54.833d | 50.2 |
| VLD/MF | 50.333e | 49.333e | 49.8333e | 36.5 |
| VLD/VL | 45.333f | 43.333g | 44.333f | 21.5 |
| CM/CT | 40.333g | 40.333g | 40.333g | 10.5 |
| CO | 37.333h | 35.6667h | 36.500h | 0 |
| Mean | 53.9167 | 51.4583 | 52.6875 | |
| SE | 0.081845 | 0.0892 | 0.0856 | |
| CV% | 0.53061 | 0.5806 | 0.3450 | |
| LSD | 0.501 | 0.5233 | 0.56 | |
| P-Value | <0.0001 | <0.0001 | <0.0001 | |

Mean figures in the column with different letters are significantly different (P<0.0001)

## Discussion

Vermicompost and compost manure soil analysis result (Table 1) indicate that the organic manures have high organic carbon content of (42%) and (40%) respectively. High organic carbon content improves soil texture, structure and water retention. Results from field soil analysis (Table 2) indicate low levels of electrical conductivity (1.0µS/cm) which implies that the field soil contained low available nutrients which were supplemented by the application of D.A.P fertilizer and organic manures. Nitrogen supply influences tuber bulking rate and time of tuber growth, Potassium plays an important role in increasing tuber size and quality while phosphorous enhances root development, tuber set and also promotes tuber maturity. The organic carbon percentage of the field soil was low with (10%) and this result agrees with earlier findings of Muthoni & Nyamongo (2009) which established that one of the constraints of Irish potato production in Kenya is due to low availability of soil nutrients and organic carbon content. The nutrient content in the field soil was low in terms of phosphorous (17ppm), total nitrogen (0.12%), manganese (1.54%), magnesium (2.6 ppm) and potassium (7.8 ppm). Irish potato is a heavy feeder crop with regard to the primary nutrients (N, P and K). For instance, to attain tuber yield of 48 tons/ha, potato tubers remove 47.6 Kg N, 24 Kg P, 103.4 Kg K and 5Kg S while the haulm requires 31.8 Kg N, 8.2 Kg P, 47.6 Kg K and 3.2 Kg S as proposed by (Burton 2018, James et al. 2020). These nutrient amounts can only be supplied through fertilizer application and therefore the importance of amending the soils with the recommended different soil amendments to enhance the soil nutrient level.

Disease incidences of late blight disease (Table 3) were high in season 2 (4.2963) as compared to season 1(3.1071) and this is attributed to the high rainfall experienced in the region during the month of October- December that created a cool and humid environment which facilitates the spread, development and progression of the disease. Integration of DAP fertilizer with vermiliquid organic foliar spray (Table 4) gave the highest marketable tuber yield of (70.3tons/ha) with a percentage yield increase of (92.7%) with a disease control of 60.7%. This result agreed with Chaichi et al. (2018) findings on the effect of vermiliquid on Faba Bean growth and yield which indicated that 10% vermiliquid was a useful fertilizer which improved yield when used as a foliar fertilizer. DAP/MF treatment scored 55.1% disease control and 78.3% increase in marketable yields. The other treatments such as VC/VL, VC/MF, VLD/MF, VLD/VL and CM/CT followed with disease control and increase in marketable yields of (37.4%; 65.1%), (29.0%; 50.2%), (31.3%; 36.5%), (29.3%; 21.5%) and (18.0%; 10.5%) respectively from Tables 3 and 4 above. This result indicates evidence of vermiliquid organic foliar spray having beneficial microbial activity on the fungal spores of *P. infestans* in Irish potato reducing the disease incidences in the field. This study result agrees with the findings of Govindarajan & Prabakaran (2012) which confirmed that vermiliquid contains bacterial compounds that inhibit the growth of bacteria and fungi. On the other hand, vermiliquid is highly efficient in not only essential nutrients for plants but also carbohydrates, proteins, lipids and amino acids which are also important factors for plant growth as confirmed by Ansari (2008), Ansari & Sukhraj (2010).

Chaichi et al. (2018) proposes that vermiliquid contains several phytohormones or molecules that present hormone- like effects which explain the effect of increased yields observed in various crops grown using vermiliquid. On the contrary, compost tea performed poorly as a foliar spray in the control of late blight disease in Irish potatoes with the least disease control of 18.0%. This result indicates that vermiliquid has more microbial activity as compared to normal compost tea. In terms of soil amendments, D.A.P fertilizer gave the highest marketable tuber yields and this is because it contains high amounts of N, P, K which are key limiting nutrients to potato production according to the earlier findings of James et al. (2020). Vermicompost manure performed fairy good with marketable yield of 60.3tons/ha translating to a percentage yield increase of (65.1%) when sprayed with vermiliquid foliar spray and a yield of 54.833tons/ha with a percentage yield increase of (50.2%) when sprayed with milthane fungicide. This result agrees with the findings of Kevin et al. (2018) which indicated that vermicompost was equally effective in increasing the potato growth by (39.2–46.5%) compared to the untreated control. Normal compost manure did not significantly differ ($P<0.0001$) from the untreated control and only registered a yield increase of (10.5%). Vermiliquid soil drench when used as a soil amendment indicated a percentage yield increase of (36.5%) when sprayed with milthane fungicide and (21.5%) when sprayed with vermiliquid foliar spray. These yields obtained are much lower compared to percentage yield increases obtained by use of D.A.P fertilizer and vermicompost manure. This result agrees with Abbasi et al. (2002) earlier findings which established that organic soil amendments used in their study were not able to give high yields compared with the chemical fertilizer of Di-Ammonium Phosphate.

## Conclusion

The research study sought to establish the effect of different soil amendments and foliar sprays on controlling late blight disease in Irish potatoes. The results obtained indicate that there is evidence of significant difference ($P<0.0001$) in disease score amongst the treatments and between the two seasons. There were significantly ($p<0.0001$) low disease incidence scores in treatment containing D.A.P fertilizer and vermiliquid foliar spray. It was also noted that season 2 had significantly ($p<0.0001$) high disease score as compared to season 1. The research findings have indicated that integration of D.A.P fertilizer with vermiliquid foliar spray has significant effect in managing late blight disease and marketable yields in the field. It can thus be concluded that a nutrient sustainable soil amendment together with an efficient foliar spray and seasons that do not favor disease development can be taken as one way of managing late blight disease in Irish potato farms in Kisii region.

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## References

Ansari AA. 2008 – Effect of vermicompost and vermiwash on the productivity of spinach (*Spinacia oleracea*), Onion (*Allumcepa*) and Potato (*Solanum tuberosum* L.). World J. Agric. Sci. 4(5), 554–557.

Ansari AA, Sukhraj K. 2010 – Effect of vermiwash and vermicompost on soil parameters and productivity of Okra (*Abelmoschus esculentus* in Guyana. Africa Journal of Agricultural Research. 5(14), 1794–1798.

Arora RK, Sharma S, Singh BP. 2014 – Late blight disease of potato and its management. In Potato journal. 41(1) 16–40.

Burton A. 2018 – Influence of Solution Management Techniques on Nutrient Use Efficiency in Hydroponically Grown Salad-type Plants. Proquest Journal.

Chaichi W, Djazouli Z, Zebib B, Merah O. 2018 – Effect of Vermicompost Tea on Faba Bean Growth and Yield. Compost Science & Utilization, Taylor & Francis. 26(4), 279–285. Doi 10.1080/1065657X.2018.1528908

CIP. 2010 – (International Potato Center) Annual report. The International Potato Centre, Lima, Peru. https://cipotato.org/about/annualreport/ (Accessed on August 12, 2019).

Dalgliesh N, Foale M. 1998 – Soil matters: monitoring soil water and nutrients in dry land farming. Agricultural Production Systems Research Unit, Cranbrook Press: Toowoomba).

Drenth A, Sendall B. 2001 – Practical Guide to Detection & Identification of *Phytophthora.* CRC forTropical plant protection Brisbane. 1, 20–27.

Estefan G, Sommer R, Ryan J. 2013 – Methods of soil, plant, and water analysis: a manual for the West Asia and North Africa region. Third Edition. (International Centre for Agricultural Research in the Dry Areas: Beirut).

FAO. 2006 – Guidelines for soil description, 4th Edition. (FAO: Rome). Available at http://www.fao.org/docrep/019/ a0541e/a0541e.pdf (Accessed on July 3, 2021).

FAO. 2018 – International year of the potato 2008. http://www.potato 2018.org/en/world/Africa.html (Accessed on April 20, 2020).

FAOSTAT. 2020 – Food and Agricultural Organization of the United Nations Statistics. Potato Production in Kenya. http://www.fao.org/faostat/en/#data/QC (Accessed on July 26, 2019).

Forbes GA, Landeo JA. 2006 – Late blight in Gopaji. PK, SN, Eds. Handbook of Potato Production, improving and post-harvest management. Bingamton, NY: Hawart Press. 279–320.

Fry W. 2008 – 'Phytophthora Infestans' 'The Plant Destroyer' Molecular Plant Pathology. 9 (3): 385. Doi 10.1111/j.1364-3703.2007.00465.x

Govindarajan B, Prabakaran V. 2012 – Antimicrobial activity of vermiwash of *Eisenia fetida* (earthworms). GTRP Int. J. Bio. Techno. 3(3), 15–16.

Houba VJG, Temminghoff EJM, Gaikhorst GA, Van Vark W. 2000 – Soil Analysis Procedures Using 0.01 M Calcium Chloride as Extraction Reagent. Commun Soil Sci *Plantanal* 31, 1299–1396.

Ingham E. 2000 – The Composting Tea Brewing Manual. Unisun Communications, Corvallis, Oregon, PP. 67.

James NM, Nancy NK, Charles KG, Klaus D et al. 2020 – Assessment of soil fertility and potato crop nutrient status in central and eastern highlands of Kenya. Scientific reports (2020) 10: 7779. Doi 10.1038/s41598-020-64036-x (Accessed February 10, 2020).

Kevin NJ, Lenah N, Amos AOM, Samuel N et al. 2018 – Response of potato to different soils and fecal matter fertilizers. African journal of Agricultural research 13 (36): 1880–1887.

Kirumba W, Kinyae P, Muchara M. 2004 – Irish Potato Market. Survey promotion of Private Sector Development in Agriculture. GTZ/MOA.

Kiiya WW, Mureithi JG, Kiama JM. 2006 – Improving Production of Irish Potatoes in Kenya. The Use of green manure legumes for soil fertility improvement. In development and upscaling of green manure legumes Technologies in Kenya. JG Mureithi, CKK Gacheru, JW Wamuongo and Eilitta M. (eds) KARI, 2006.

Lung'aho C, Kabira JN. 1999 – A guide to growing potatoes. Kenya Agricultural Research Institute, National Potato Research Centre, Tigoni.

Mandic L, Djukic D, Beatovic J, Javovic Z et al. 2011 – Effect of different fertilizers on the microbial activity and productivity of soil under potato cultivation. Afri. J. Biotechno; 10 (36): 6954–6960.

Mangale N. 2016 – Manual for Integrated Soil Fertility Management in Kenya.

MOA. 2018 – (Ministry of Agriculture) National Policy on Potato Industry. Policy Returns to Revitalize the Potato Industry. Contentuploads/2019/01/AGRICULTURAL-SECTOR-TRANSFORMATION and GROWTH-STRATEGY.pdf.

Mosley AI, Vanes J, McMorran S, Yilma. 2000 – Principles of potato production. available at http://oregonstate.edu/potatoes/css322Webnotes.html (Accessed December 17, 2020).

Munroe G. 2004 – Manual of On-Farm Composting and Vermiculture; Organic Agriculture Centre of Canada. Retrieved from http://www.allthingsorganic.ca/pdf/Vermiculture-Farmers Manual-gm.pdf (Accessed on August 16, 2019).

Muthoni J, Nyamongo DO. 2009 – A Review of constraints to Ware Irish Potatoes Production in Kenya. Journal of Horticulture and Forestry. Vol 1(17), pp. 098–102. http://www.academicjournals.org/jhf (Accessed onMay 7, 2020).

Okello JJ, Yuan Z, Norman K, Sylivester O et al. 2017 – Productivity and food security effects using certified seed potato: the case of Kenya's potato farmers. Agriculture and food security 6–25.

Olsen SR, Cole CV, Watanabe FS, Dean LA. 1954 – Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular, Washington, DC: US Department of Agriculture 939: 19.

Greenlife. 2018 – Potato Farming, Crop Protection Africa. https://www.greenlife.co.ke/potato-Farming (Accessed on June 4, 2020).

Rahman MM, Dey TK, Ali M, Khalequzzaman KM, Hussein MA. 2008 – Control of late blight disease of potato by using new fungicides. Int. J. Sustain crop prod. 3(2): 10–15.

Rashidul I, Chhoa M, Hossain I, Meah B. 2013 – Organic Management: An alternative to control Late Blight of Potato and tomato caused by Phytophthora infestans. International journal of Theoretical and Applied sciences, 5(2): 32–42.

Richards LA. 1954 – Diagnosis and improvement of saline and alkali soils. Agricultural Handbook No. 60. (United States Department of Agriculture: Washington D. C.).
Available at https://www.ars.usda.gov/ARSUserFiles/20360500/hb60_pdf/hb60complete.pdf (Accessed on August 2020).

Scheurells J, Mahaffee WF. 2002 – Compost Tea Principles and Prospects for plant Disease control. Compost Sci. utilize. 10: 313–338.

Schmidhalter U. 2005 – Development of a quick on-farm test to determine nitrate levels in soil. Journal of Plant Nutrition and Soil Science 168, 432–438.

Sudha B, Kapoor KK. 2000 – "Vermicomposting" of crop residues and cattle dung with *Eisenia fetida.* Bioresource Technology.73, 95–98.

USDA. 1999 – Soil quality test kit guide. United States Department of Agriculture. (USDA: Washington (D.C.). Availableat: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044790.pdf (Accessed on July 10, 2021).

Volk. 2001 – *Phytophthora infestans*, Cause of late blight of potato and the Irish potato famine. http://bioweb.uwlax.edu/bio203/s2007/benrud_jaco/index_files/Page365.html (Accessed on July 5, 2020).

Walkley A, Black IA. 1934 – An Examination of the degtjareff for determining soil organic matter and a proposed chromic acid titration method. Soil Science 37: 29–38.