EISSN: 2707-0425

East African Journal of Science, Technology and Innovation, Vol. 3 (Special issue): February 2022

Optimization of biofertilizers on potato blight, performance and farm returns using biochar and manure in combination with fertilizer

[1*]KILONZI M J., [1]PWAIPWAI P., [1]NYONGESA W M

[1]Kenya Agricultural and Livestock Research Organization (KALRO) Tigoni, P.O BOX 338-0217, Limuru, Kenya

***Corresponding author:** kilonzijack@gmail.com

Abstract

Bio-fertilizers form a valuable interaction tool with soil dynamics in improving crop yield despite their inferior yield compared to inorganic fertilizers. However, optimizing bio-fertilizers using carrier material and combination with inorganic fertilizer while minimizing detrimental effects associated with chemicals is not fully comprehended. Field experiment was conducted to study effects of Mycorrhizae and Trichoderma optimization using manure and biochar (carrier) in combination with Diammonium Phosphate (DAP) applied at 50 %, 75% and 100% (500 kg ha^{-1}) the recommended rate on late blight, growth, yield and farm income. A survey was also conducted to establish fertilizer usage by potato farmers. The most widely used fertilizer was DAP. Plots without fertilizer recorded the highest late blight severity (RAUDPC of 0.45), lowest height (39.37 cm), stem count (2.81) and yield (0.29 t ha-1) followed by plots with 50% DAP. Yield observed from DAP rates differed significantly ($P \le 0.05$). However, there was no significant difference among combinations of biofertilizer with 75% and 100% of DAP. Trichoderma and Mycorrhizae increased yield by 74%, 70% and 71% respectively relative to control. Manure on average improved Trichoderma and Mycorrhizae effects on late blight, stem count and yield by 55%, 56% and 76% respectively while biochar improved by 50%, 51% and 75% respectively. Combination of DAP (75% and 100% rates) and biofertilizer had significant increase in net farm returns. Conversely, higher marginal rate of return was observed in plots with mycorrhizae and manure as carrier. Improved yield and net income from biofertilizer plots could be attributed to their low costs and less bulky. Manure as carrier material provided additional nutrients support, stable environment and more micro-organism resulting in microbial consortium build up. Bio-fertilizers combined with carrier material in combination with chemical fertilizers improved yield and farm net income, thereby could be an alternative to conventional production.

Keywords: *Biofertilizer; Mycorrhizae; Trichoderma; Diammonium; Phosphate*

Received: 28/10/21
Accepted: 13/12/21
Published: 16/02/22

Cite as: *Kilonzi et al., (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(Special Issue).*

Introduction

In response to the demand for food in the midst of biotic stress challenges and human population growth increase, promotion of key food crops has gained attention worldwide. One of the most important food crop capable of improving human livelihood is potato (*Solanum tuberosum*) (Devaux and Ortiz, 2014). The crop has received much attention throughout the world recently due to its ability to yield higher per unit area as compared to cereal crop thereby contributing to food security and improved farm income. Contrariwise, potato production continues to face numerous production challenges including biotic and abiotic stresses thereby plummeting yield (Pandey *et al.*, 2017). To overcome the challenges and the need to increase potato yield, efforts have been geared in the use of chemical products extensively. Late blight caused by the oomycetes, *Phytophthora infestans* is one of the major disease of potato whose management relies on extensive use of fungicides (Taylor *et al.*, 2013). Subsequently, this has raised concerns on pesticides residue and nitrates deposits (Norris and Congreves, 2018) as potato tuber is usually harvested and marketed immediately after harvest and therefore safety of the product need to be assured. Moreover, soil health is jeopardized in this degraded environment ultimately influencing agricultural productivity and sustainability of ecosystem functions. Therefore, the need to develop viable technologies is inevitable.

One of the vital techniques is sustainable improvement of soil fertility and health in crop fields each cropping season. However, this has not been the case, instead, farmers rely on the use of chemical fertilizers. Excessive application of phosphatic and nitrogenous fertilizer has aggravated decline in organic matter, mineralization and accelerate acidification of soil jeopardizing nutrients availability (Divya and Belagali, 2012). Consequently, the historical unprecedented long-term effects, distress soil microbial population structure and diversity thus destructing soil biological processes. For instance, long term application of nitrogen fertilizer has impacted on soil quality including soil pH and microbes survival and multiplication including bacterial communities involved in the nutrient mineralization thereby reducing nitrogen cycling process (Coolon and Herman, 2013). Recently, Yan *et al.* (2020) reported that, bacterial communities declined in soil over fertilized compared to under less fertilized field. Conversely, chemical fertilizers cannot be avoided owing to their ability to release sufficient amount of nutrients within crop growing period, even though can be substantially reduced.

Additional tool with the capacity to improve soil fertility and health is bio-fertilizers, which potentially restore biological activities, minimize farm inputs and maintain ecological harmony. The bio-fertilizers have multiple benefits including improvement of nutrient and water uptake and suppress pests and pathogens (Hol and Cook, 2005). In addition, the fungi contribute to disease management and improve on nutrients uptake (Martínez-Medina and Pascual, 2011). However, farmers' uptake and also their effectiveness in improving yield is at parity. The ability of Mycorrhizal and Trichoderma to promote soil properties and pest dynamics management could be tapped to induce defence mechanisms on potato early in the cropping season.

The major challenges attributed to manure and biochar are their variability nature in terms of nutrients quality and quantity, their difficult in application and reduce possibility of mechanization (Bateman and Carliell-Marquet, 2011). The slow release of nutrients allied to manure is expedient in the combination since all the nitrogen available is not leached (Pang and Letey, 2000). Manure has also been associated with supplying additional beneficial micro-organism and supporting their survival by providing available cheap source of carbon and energy (Chakraborty *et al.*, 2011). This twofold distinctive practice has received less attention in providing crop protection and fertility service.

Therefore to reduce negative effects of the chemical fertilizers and taking advantage of their faster release of nutrients and in sufficient quantities (Mugo *et al.*, 2020; Coolon *et al.*, 2013) while optimizing the benefits of manure and biofertilizer, combining the triads could be sustainable alternative in managing soil productivity. Further, benefits and cost associated with combination of chemical fertilizers and bio-fertilizers to improve farm income has received less attention. We therefore, aimed at building up literature pertaining benefits accrued in the combination of optimized bio-fertilizers with chemical fertilizers in integrated crop management program to provide sustainable alternative recommendation.

Materials and Methods

Study Area

The study was conducted at Kenya Agricultural and Livestock Research Organization (KALRO) Tigoni, in Limuru, Kiambu County from October 2020 to July 2021. The Centre is located at latitude 10° 9′ 22″ south and longitude 36° 4′ 72″ east and situated at an altitude of 2300 m above sea level.

Survey on Fertilizer use

A survey was conducted using randomly selected farmers to determine type of fertilizer commonly applied and rates adopted by potato growers of Nyandarua County alongside other objectives. A total of 59 farmers were interviewed using structured questionnaire loaded in Open Data Kit (ODK) application based on agro-ecological zone using Cochran formula;

$$n = \frac{NZ^2 \frac{\alpha}{2} pq}{e^2(N-1) + Z^2 \frac{\alpha}{2} 2pq}$$

Where n, N, Z, p, q and e refer to sample size, population size, Z value (area under normal curve), proportion of attribute present in the population, p-1 and precision level desired (95%) respectively.

Late Blight Management

Late blight was managed by applying Mistress® (cymoxanil 40% + 60% mancozeb) at bi-weekly interval contrary to manufacturer's recommendation (spray weekly) uniformly to determine contribution of bio-fertilizers to late blight management.

Treatment Applications

Mycorrhizae (2 kg ha^{-1}) and Trichoderma (2 L ha^{-1}) were dissolved in distilled water and mixed thoroughly with biochar and manure as carrier material added at a rate of 2 t ha^{-1} and 5 t ha^{-1} respectively. The materials were incubated at room temperature (18 ± 2 °C) for 24 hours. The mixture was then aired dried to about 30% moisture content and applied around the seed. Following survey results, Diammonium Phosphate (DAP) was used in this experiment. The fertilizer was applied and mixed with soil before planting at a rate of 250, 375 and 500 kg ha^{-1} separately representing 50%, 75% and 100% the manufacturers recommended rate (MRR) respectively. Manure as fertilizer was applied at a rate of 20 t ha^{-1}.

Experimental Design

Treatments were laid in randomized complete block design in split plot arrangement with three replications. Treatments namely: DAP fertilizer applied at rates of 100%, 75% and 50% the manufacturers recommended rate separately were the main plot while manure, Mycorrhiza, Trichoderma, Mycorrhiza + Trichoderma, biochar + Mycorrhiza, manure + Mycorrhiza, manure + Trichoderma and Trichoderma + biochar were subplots. Negative controls in the main plot were treatments with no DAP while in the sub-plot were without biofertilizer respectively. Positive control were plots with DAP alone. Subplots measured 3 x 3 m with a path measuring 2 m in width.

Data Collection

Weather variables including rainfall, temperatures and relative humidity were collected in the short and long rain seasons from KALRO Tigoni weather station located about 100 m from the field experiment. Emergence, height measurement and stem number were taken at 30, 45 and 60 days after emergence. Severity was evaluated on the basis of the proportion of disease on foliage using a scale of 0 to 5 and converted to weekly disease scores then to Relative Area Under Disease Progress Curve (RAUDPC) as described by Simko and Piepho (2012). At maturity, potato tubers were harvested from the inner rows of each plot and graded as marketable size (>30 mm) and weighed. Weight was converted to tonnes per hectare.

Cost Benefit Analysis

Partial budgeting was used to calculate Marginal Rate of Return (MRR). Costs that applied uniformly to all treatments were not considered (Halloran *et al.*, 2013). Costs that varied among treatments included manure costs, biochar costs, bio-fertilizers and fertilizer application wage. Potato prices were based on prices at harvesting when packed in 100 kg bags valued at farm gate price. The yield data was adjusted by 10% to approximately match field yield obtained by farmers (Muchiri *et al.*, 2017).

Data analyses; Data was analysed using SAS software and means separated using Tukeys Honest significant difference (p≤0.05). Economic analyses were conducted using partial budgeting in Kenya Shillings (Kes). Marginal rate of return (MRR) was calculated using the formula below;

$$MRR = \frac{DNI}{DIC}$$

Where DNI refer to difference net income while DIC refer to difference in cost

Results

Choice of Fertilizer Usage in Potato Production

From the survey, results reveal that, about 65% of the farmers in Nyandarua use DAP fertilizer followed by NPK at 21%. Other fertilizer included Baraka, Yara and manure whose score was below 10% (Figure 1). In addition, only 8% of farmers applied fertilizer based on soil testing report whilst majority (76%) apply fertilizer using conventional (blanket application) rate of 500 kg ha^{-1} (Figure 2).

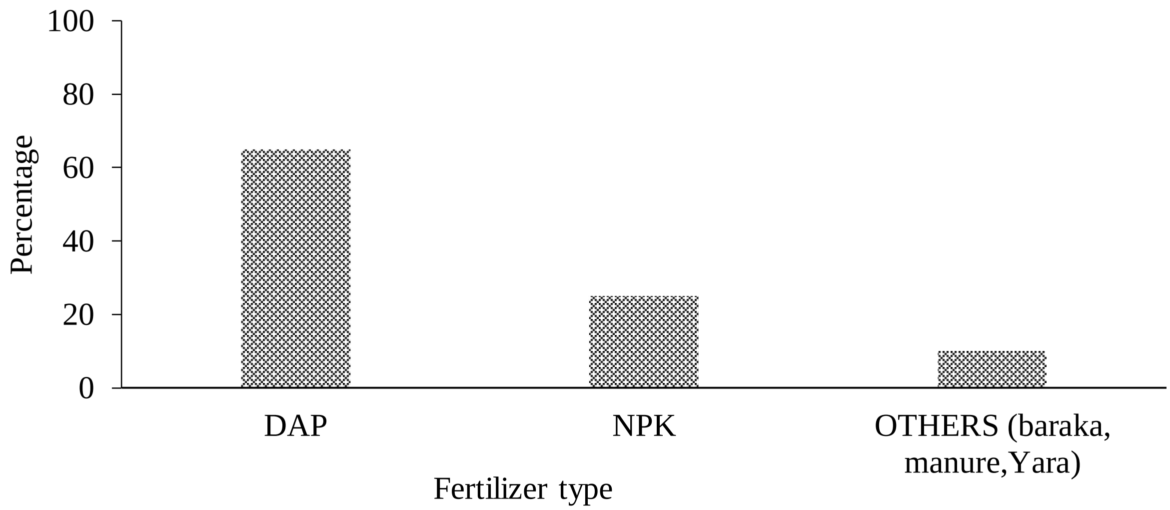

Figure 1. Choice of fertilizer use

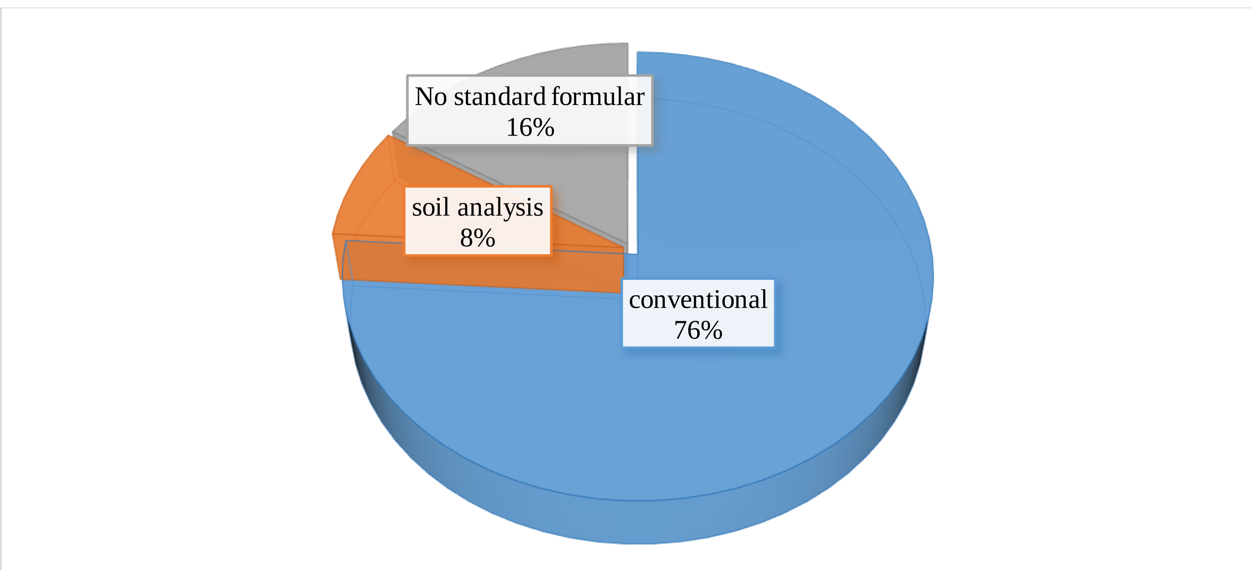

Figure 2. Fertilizer rate of application

Late blight Symptomatology

Relative Area Under Disease Progress Curve (RAUDPC) showed that nutrition played a key role in late blight management. Results indicated that, plots that had no DAP generally had the highest disease score of up to 0.45 while plots supplied with 100% and 75% DAP rate had the least score. On the other hand, plots fertilized with DAP only had the highest late blight score followed by manure, Mycorrhizae and Trichoderma in that order. DAP applied at 75% and 100% rate in combination with biofertilizer in carrier material had the lowest disease score (average 0.25) and did not differ significantly. Optimizing bio-fertilizers by incubating with manure and biochar improved late blight management by 25% cumulatively when compared to biofertilizers applied without carrier material (

Effects of DAP and Bio-Fertilizers on Crop Growth

Effect of DAP on crop growth

Application of DAP had no significant influence on potato seed emergence. Results suggest that plots that were not fertilized with DAP were not significantly different from those supplied with the fertilizer. Conversely, DAP increased height and stem count significantly. This was demonstrated by the unfertilized plots that recorded the lowest score followed by half the rate of DAP. Height and stem count observed in plots fertilized using full dose and ¾ rate did not vary significantly. Following the height and stem observations, yield unexpectedly had different trajectory where all the treatments differed in yield score significantly (Table 1).

).

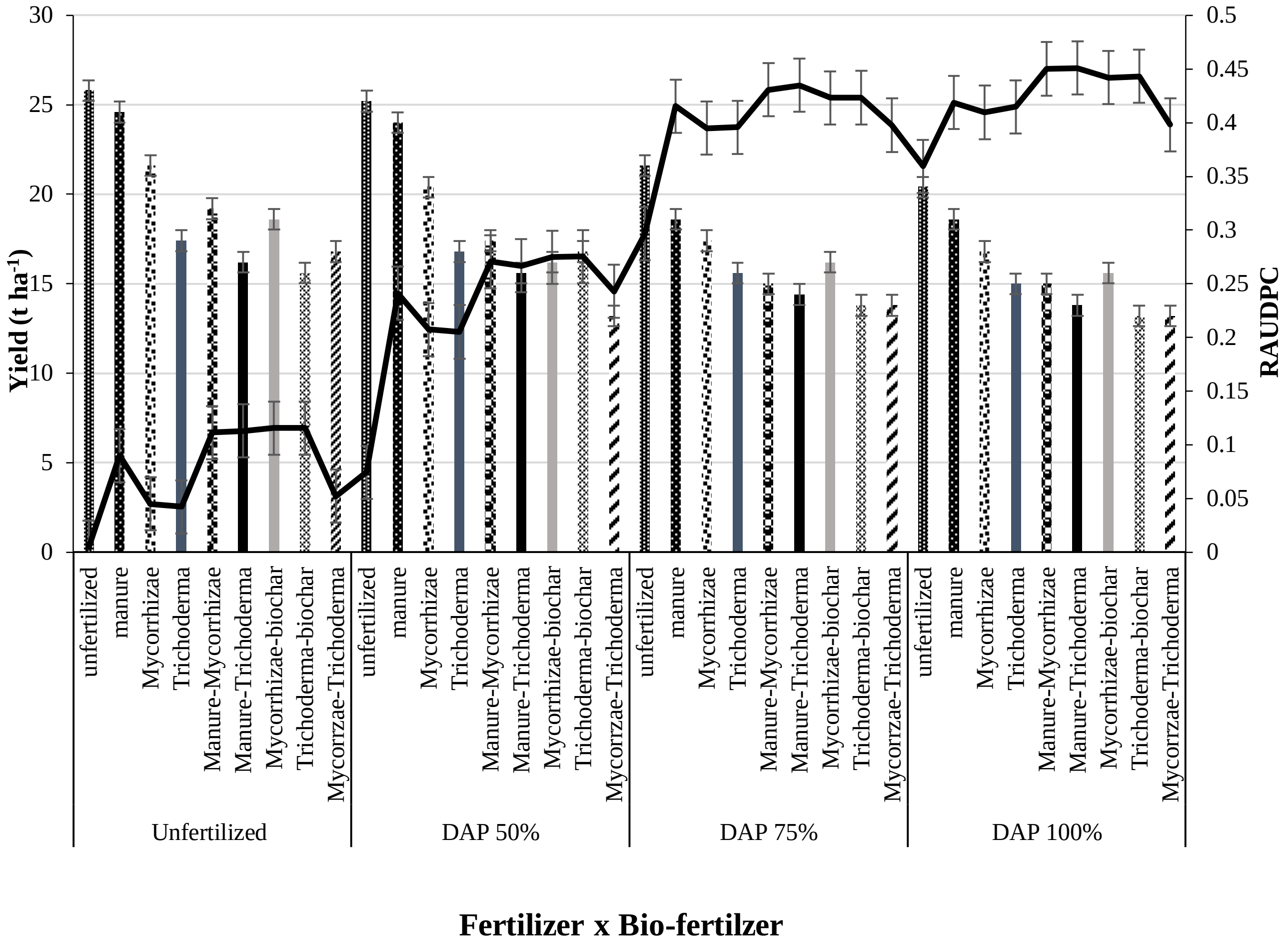

Figure 3. Effect of fertilizer and biofertilizer on late blight and yield

Effects of DAP and Bio-Fertilizers on Crop Growth

Effect of DAP on crop growth

Application of DAP had no significant influence on potato seed emergence. Results suggest that plots that were not fertilized with DAP were not significantly different from those supplied with the fertilizer. Conversely, DAP increased height and stem count significantly. This was demonstrated by the unfertilized plots that recorded the lowest score followed by half the rate of DAP. Height and stem count observed in plots fertilized using full dose and ¾ rate did not vary significantly. Following the height and stem observations, yield unexpectedly had different trajectory where all the treatments differed in yield score significantly (Table 1).

Table 1. Effects of DAP on potato crop growth and yield

DAP rate (kg ha^{-1})	Emergence (%)	Height (cm)	Stem	Yield (t ha^{-1})
Unfertilized	96.67a	39.37a	2.81a	4.60a
250	97.22a	46.11b	3.74b	13.72b
375	98.00a	62.00c	3.78c	24.08c
500	98.52a	66.63c	3.81c	25.25d
HSD ($p \leq 0.05$)	2.014	3.762	0.274	0.619
CV%	2.88	9.86	10.79	5.11

Effects of bio-fertilizers on crop growth

Plots without biofertilizer had the lowest emergence percentage compared to other plots. Emergence was not significant different among the bio-fertilizers. Similarly, same results trend were observed on stem count. However, combination of bio-fertilizers with manure and biochar had the highest yield score compared to single treatment application (Table 2). Concomitantly, the highest height measurements were observed in all bio-fertilized plots. A higher gradient of growth was observed in plots with biofertilizer mixed with manure and biochar. Mixing Trichoderma and Mycorrhizae contributed to increase in height (
Figure 4).

Table 2. Effects bio-fertilizers on stem and yield of potato

Biofertilizer	Emergence (%)	Stem	Yield (t ha^{-1})
Unfertilized	90.9a	1.8a	4.56a
Trichoderma	98.8b	3.3b	15.86b
Mycorrhizae	98.5b	3.5b	15.87b
Mycorrhizae -Trichoderma	97.8b	3.6b	16.36bc
Manure	97.7b	3.4b	17.48bc
Biochar-Trichoderma	97.8b	3.6b	18.85c
Manure-Trichoderma	98.2b	4.1b	18.99c
Biochar- Mycorrhizae	98.2b	3.6b	18.83c
Manure-Mycorrhizae	98.8b	4.2b	18.94c
HSD($p \leq 0.05$)	3.673	0.499	1.129
CV%	2.88	10.79	5.11

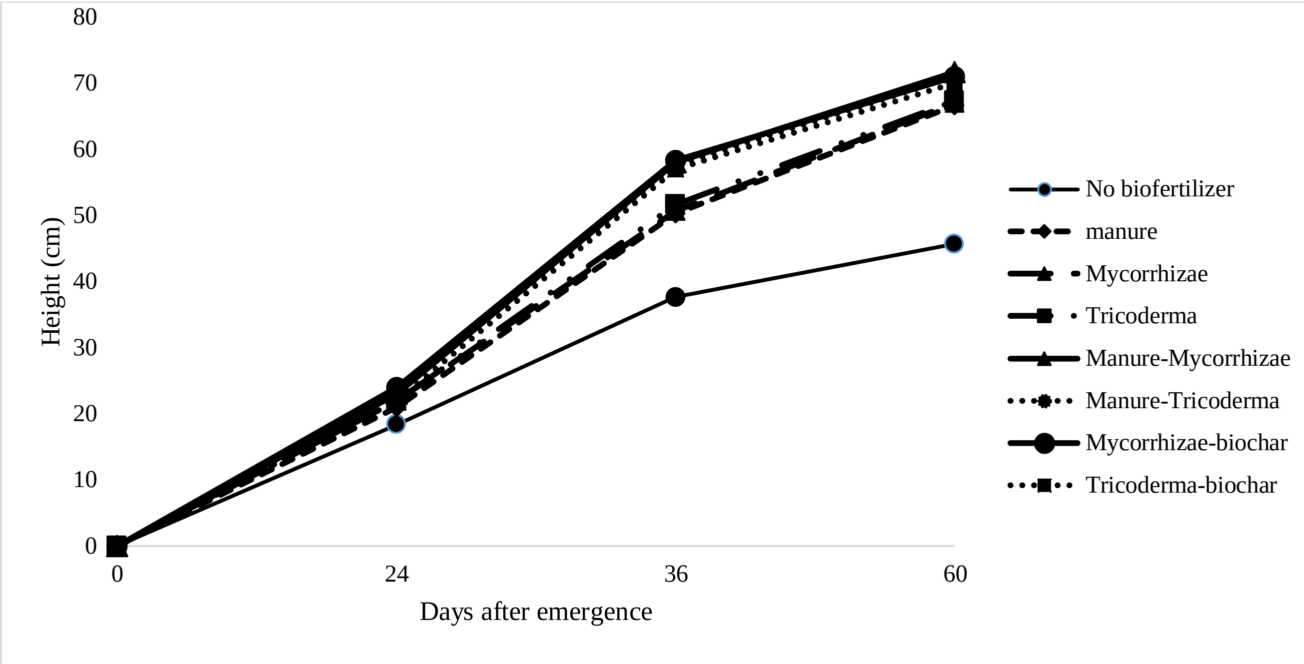

Figure 4. Effect of biofertilizer on crop height in the growing period

Comparison between Manure and Biochar as Carrier Material

Results in Table 4 reveals that carrier material had significant effect on crop growth and yield of potato during the cropping season. Mixing bio-fertilizers with carrier materials had no significant effect on emergence. Contrary, stem count and height data indicate that biochar and manure contributed to increased crop growth. The highest score was observed in plots in which bio-fertilizers were combined with manure as carrier material. Similarly, yield data were in tandem with the same trend.

Table 3. Effects of carrier material on biofertilizer in crop growth and yield

Biofertilizer	Emergence (%)	Height (cm)	Stem	Yield (t ha^{-1})
Unfertilized	98.00a	45.67a	1.8a	4.56a
Manure	98.00a	66.67b	3.0b	25.13c
Trichoderma	99.33a	67.33b	4.0c	24.58c
Mycorrhizae	97.33a	67.00b	3.0b	24.89c
Biochar-Trichoderma	99.33a	70.00b	4.0c	26.59c
Biochar- Mycorrhizae	98.67a	71.00b	4.0c	26.52c
Manure-Trichoderma	98.00a	71.00b	4.7e	27.06c
Manure-Mycorrhizae	98.67a	71.67b	4.6e	27.01c
Mycorrhizae -Trichoderma	99.30a	69.33b	3.7d	23.89b
HSD ($p \leq 0.05$)	0.740	6.979	0.454	1.934
CV%	6.67	3.61	1.58	2.64

Effects of DAP and Bio-fertilizers on Yield and Yield Loss

Results in Table 5 suggests that, yield from full and ¾ DAP dose in combination with bio-fertilizers recorded the highest yield. Combination of DAP with bio-fertilizers and manure had significantly ($P \leq 0.05$) higher yield than plots with bio-fertilizers alone. Similarly, plots with DAP alone had inferior yield than when DAP was combined with bio-fertilizers and manure. On the other hand, yield observed in plots with manure alone was lower than plots with DAP. Optimizing bio-fertilizers with manure and biochar resulted to higher yield than when the bio-fertilizers were applied without carrier material. Optimal yield was observed when Mycorrhizae and Trichoderma were mixed with carrier material and DAP at ¾ rate was applied. Furthermore, reduction of DAP rate resulted to decline in yield even when combined with bio-fertilizers and manure (

Effects of DAP and Bio-Fertilizers on Crop Growth

Effect of DAP on crop growth

Application of DAP had no significant influence on potato seed emergence. Results suggest that plots that were not fertilized with DAP were not significantly different from those supplied with the fertilizer. Conversely, DAP increased height and stem count significantly. This was demonstrated by the unfertilized plots that recorded the lowest score followed by half the rate of DAP. Height and stem count observed in plots fertilized using full dose and ¾ rate did not vary significantly. Following the height and stem observations, yield unexpectedly had different trajectory where all the treatments differed in yield score significantly (Table 1).

). Data on yield loss suggests that, the highest forfeiture was in plots in which DAP at 75% and 100% was applied. Biochar and manure mixing with bio-fertilizers contributed to reduction in yield loss.

Economic Analysis

The highest returns were observed in plots with DAP at full dose followed by ¾ dose and correspondingly, high total variable cost. The lowest costs were observed in all plots without DAP. Application of Mycorrhizae and Trichoderma was less costly compared to other treatments. Biochar as carrier material had lower return than manure due to its high cost. The cost of DAP also disadvantaged combination strategy with biofertilizers in plots where full and ¾ DAP dose were combined with the bio-fertilizers. Even though, higher yield was observed from plots supplied with full and ¾DAP rate plots, MRR and net benefit ratio suggested that, Mycorrhizae mixed with manure as carrier but with no DAP was unpredictably more profitable. In general, mycorrhizae and Trichoderma with manure as carrier had the highest MRR.

Table 4. Effects of combining chemical fertilizer and biofertilizer on yield and farm returns

DAP Rate	Biofertilizer	Yield (t ha^{-1})	Yield Loss (%)	Adj. Yield (t ha^{-1})	Wages (Kes)	Costs (Kes)	TVC (Kes)	NB (Kes)	MRR
No DAP	Unfertilized	0.29		0.26	0	0	0	5,200	
	Manure	5.40	94.6	4.86	1,200	12,000	13,200	97,200	6.97
	Trichoderma	2.54	88.6	2.29	600	2,400	3,000	45,800	13.53
	Mycorrhizae	2.70	89.3	2.06	600	1,600	2,200	41,200	16.36
	Biochar-Tric	6.93	95.8	6.24	600	12,400	13,000	124,800	9.20
	Biochar-Myc	6.94	95.8	6.24	600	11,600	12,200	124,800	9.80
	Manure-Tric	6.78	95.7	6.10	1,200	5,400	6,600	122,000	17.70
	Manure-Myc	6.68	95.7	6.01	1,200	4,600	5,800	120,200	19.83
	Myc -Tric	3.13	90.7	2.82	600	4,000	4,600	56,400	11.13
250 kg ha^{-1}	No biofertilizer	4.47	93.5	4.02	600	14,000	14,600	80,400	5.15
	Manure	14.47	98.0	13.02	1,800	12,000	13,800	260,040	18.47
	Trichoderma	12.31	97.6	11.08	1,200	16,400	17,600	221,600	12.30
	Mycorrhizae	12.44	97.7	11.20	1,200	15,600	16,800	224,000	13.33
	Biochar-Tric	16.52	98.2	14.87	1,200	26,400	27,600	297,400	10.59
	Biochar-Myc	16.48	98.2	14.92	1,200	25,600	26,800	298,400	10.94
	Manure-Tric	16.01	98.2	14.41	1,800	19,400	21,200	288,200	13.35
	Manure-Myc	16.23	98.2	14.61	1,800	18,600	20,400	292,200	14.07
	Myc -Tric	14.57	98.0	13.11	1,200	19,000	20,200	262,200	12.72
375 kg ha^{-1}	No biofertilizer	17.85	98.4	16.07	600	21,000	21,600	321,400	14.64
	Manure	24.93	98.8	22.44	1,800	33,000	34,800	448,800	12.75
	Trichoderma	23.74	98.8	21.37	1,200	23,400	24,600	427,400	17.16
	Mycorrhizae	23.70	98.8	21.33	1,200	22,600	23,800	426,600	17.71
	Biochar-Tric	25.40	98.9	22.86	1,200	33,400	34,600	457,200	13.06
	Biochar-Myc	25.39	98.9	22.85	1,200	32,600	33,800	457,000	13.37
	Manure-Tric	26.09	98.9	23.48	1,800	26,400	28,200	469,600	16.47
	Manure-Myc	25.84	98.9	23.26	1,800	25,600	26,400	465,200	17.42
	Myc -Tric	23.86	98.8	21.47	1,200	25,000	26,200	429,400	16.19
500 kg ha^{-1}	No biofertilizer	21.56	98.7	19.40	600	28,000	28,600	388,000	13.38
	Manure	25.13	98.8	22.62	1,800	40,000	41,800	452,400	10.70
	Trichoderma	24.89	98.8	22.40	1,200	30,400	31,600	448,000	14.01
	Mycorrhizae	24.58	98.8	22.12	1,200	29,600	30,800	442,400	14.19
	Biochar-Tric	26.59	98.9	23.93	1,200	40,400	41,600	478,600	11.38
	Biochar-Myc	26.52	98.9	23.87	1,200	32,000	33,200	477,400	14.22
	Manure-Tric	27.06	98.9	24.35	1,800	33,400	34,200	487,000	14.09
	Manure-Myc	27.01	98.9	24.31	1,800	32,600	33,400	486,200	14.40
	Myc -Tric	23.89	98.8	21.50	1,200	32,000	33,200	430,000	12.80

Key; Biochar-Tric, Biochar-Myc, Manure-Tric, Manure-Myc, Myc -Tric represented biochar + Trichoderma, biochar + Mycorrhiza, manure + Trichoderma, manure + Mycorrhiza and Mycorrhiza + Trichoderma respectively while Adj., TVC and NB referred to adjusted, Total Variable Costs and Net benefits respectively

Discussion

Crop growth and yield depend on cumulative effects of the crop's genetic make-up and interactions with environment including human, edaphic, climatic and biotic factors. Previous studies have reported that, the use of organic fertilizer gave similar results as that of inorganic fertilizers (Singh, *et al.*, 2017). However, this study found that bio-fertilizers alone gave lower yield than conventional method where DAP was applied at 500 kg ha^{-1} in the short run. In addition, earlier experiments focused on evaluating this fertilizers independently without focusing on their synergistic benefits (Rosen and Bierman, 2008) while those attempted to combine organic and inorganic fertilizers failed to explore vectoring mechanism of biofertilizers as elucidated in this study. Nonetheless, Alori and Babalola (2018) showed that, use of organic fertilizers would result to healthy crop products and improve on soil productivity in the long term. Furthermore, most of bio-fertilizers are less costly and environmentally friendly.

Chemical fertilizers and bio-fertilizers had no significant effects on emergence. This could be due to the fact that, potato tubers had sufficient food to nourish emerging sprouts. Results from unfertilized plots suggest that late blight contributed to yield loss owing to deficiency of key nutrients that contribute to crop growth vigour, resistance to pests and metabolites formation. Nutrition including use of calcium (Seifu, 2017), phosphorous (Liljeroth *et al.,* 2016) and chemical fertilizers in combination with fungicide (Majeed *et al*., 2017) have shown to contribute to late blight disease management. Late blight spores would develop very rapidly in leaves that possess lower concentrations levels of calcium and phosphate in their cell walls. Further, Mycorrhizae and Trichoderma improved late blight management possibly through enhanced induced crop resistance (Shoresh and Mastouri, 2010). The results are also in tandem with Kilonzi *et al.* (2020) who reported the effects of *T. asperellum* on late blight when combined with Ridomil®. Therefore elevating contribution of Trichoderma and Mycorrhizae as biofertilizer in managing crop diseases remain imperative.

Trichoderma and Mycorrhizae effects on late blight management, crop growth and yield were minimal when applied alone. Increase in the number of stems has been found to have positive correlation with yield (Blauer and Knowles, 2013). 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 carrier. This could be attributed to the ability of manure to contain mineral nutrients, organic matter and additional micro-organisms that enhance microbial consortium. This is a valuable attribute for the bio-fertilizers other than been harboring microbes protecting them from harsh environment (Zhen *et al.*, 2014). Similar results were also observed by (Celik and Kilic, 2004). Studies have indicated that micro-organisms solubilize and mineralize nutrients making them readily available to the crop thereby promoting growth (Singh *et al*., 2017). Combination of manure and DAP at full and ¾ dose resulted into higher yields. Chemical fertilizers provide right amount of nutrients within a short time while manure take a longer period to break down and supply nutrients (Jilani *et al.*, 2007). Biochar on the other hand, consists of inert material (mainly carbon) with no release of microbes and nutrients but beneficial in harbouring bio-fertilizers and providing them with energy. These key aspects were significant and demonstrated in this study. Use of manure improves physical, chemical and biological properties of soil and increase microbial biomass which subsequently increase nutrient mineralization and cycling thereby providing a balanced nutrients at later stage of crop growth (Pang and Letey, 2000). Therefore, combining the two would be more beneficial to crop production and soil performance.

Higher returns were observed in plots where DAP at 100% and 75% rate were combined with biofertilizer mixed with carrier material which corresponded with higher yield thereby offsetting additional costs. Lower marginal rate of return revealed in plots with 75% and 100% DAP rate and also in combination with manure was due to high cost of DAP and higher cost of labour for applying manure. On the contrary, Mycorrhizae and Trichoderma mixed with manure had the highest MRR. This could be explicated by the low cost of the bio-fertilizers as compared to manure and optimized effects when mixed. Previous studies suggested that half dose of NPK combined with bio-fertilizers had higher net farm income than individual bio-fertilizer (Al Rubaye *et al.*, 2019). This was contrary to our findings where the yield observed in half rate chemical fertilizer combined with bio-fertilized was much lower than recommended rate. The present study concludes that optimizing bio-fertilizers with manure could increase yield and farm returns.

Even though the present study elucidates that, use of manure and biochar as carrier material improved crop growth and performance, there is need to explore the actual interaction between the biofertilizer and manure. The role of chemical fertilizer in promoting efficacy of biofertilizer remains unclear. An on-farm based research would be useful in confirming the value of optimizing bio-fertilizers. Manure and bio-fertilizers play key role in managing soil ecosystem integrity which ultimately balance biological cycles in the long term while minimizing the use chemical fertilizer aid in recovering short term costs. Therefore, optimizing bio-fertilizers is imperative in integrated soil nutrition management.

Conclusion and recommendations

Reducing DAP to 75% and 50% the recommended rates resulted in declined yield compared to recommended rate. Bio-fertilizers and manure when applied singly had lower yield compared to plots that had DAP only. The combined use of DAP at 75% rate along with bio-fertilizers significantly managed late blight symptoms while promoting crop growth that ultimately increased yield. Further, manure as carrier material performed better than biochar in optimizing Trichoderma and Mycorrhizae activities. Higher economic returns were observed when bio-fertilizers were optimized using manure. Therefore, use of optimized bio-fertilizers alongside chemical fertilizers provide a sustainable crop production technology.

Acknowledgement

We take this opportunity to acknowledge Peace Kambua (Masinde Muliro University of Science and Technology) and Samuel Ng'ae (Embu University) for their assistance in data collection and entry. Thanks to Kenya Agricultural and Livestock Research Organization (KALRO) Tigoni for funding the project.

References

Al Rubaye, A. T., Abdul-Ratha, H. A., & Hadown, H. A. (2019). Effect of local and imported biofertilizers on growth and yield of potato. *Iraqi Journal of Agricultural Sciences*, *50*(1), 431–445.

Alori, E. T., & Babalola, O. O. (2018). Microbial inoculants for improving crop quality and human health in Africa. *Frontiers in Microbiology*, *9*(SEP), 1–12. https://doi.org/10.3389/fmicb.2018.02213

Bateman, A., Van Der Horst, D., Boardman, D., Kansal, A., & Carliell-Marquet, C. (2011). Closing the phosphorus loop in England: The spatio-temporal balance of phosphorus capture from manure versus crop demand for fertiliser. *Resources, Conservation and Recycling*, *55*(12), 1146–1153. https://doi.org/10.1016/j.resconrec.2011.07.004

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. https://doi.org/10.1007/s12230-013-9317-0

Celik, I., Ortas, I., & Kilic, S. (2004). Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. *Soil and Tillage Research*, *78*(1), 59–67. https://doi.org/10.1016/j.still.2004.02.012

Chakraborty, A., Chakrabarti, K., Chakraborty, A., & Ghosh, S. (2011). Effect of long-term fertilizers and manure application on microbial biomass and microbial activity of a tropical agricultural soil. *Biology and Fertility of Soils*, *47*(2), 227–233. https://doi.org/10.1007/s00374-010-0509-1

Coolon, J. D., Jones, K. L., Todd, T. C., Blair, J. M., & Herman, M. A. (2013). Long-Term nitrogen amendment alters the diversity and assemblage of soil bacterial communities in tallgrass Prairie. *PLoS ONE*, *8*(6). https://doi.org/10.1371/journal.pone.0067884

Devaux, A., Kromann, P., & Ortiz, O. (2014). Potatoes for sustainable global food security. *Potato Research*, *57*(3), 185–199. https://doi.org/10.1007/s11540-014-9265-1

Divya, J., & Belagali, S. L. (2012). Effect of Chemical Fertilizers on Physico-Chemical characteristics of agricultural soil samples of. *The Ecoscan 6*, *6*, 181–187.

Halloran, J. M., Larkin, R. P., Defauw, S. L., Olanya, O. M., & He, Z. (2013). Economic potential of compost amendment as an alternative to irrigation in Maine potato production. *American Journal of Plant Science*, *4*, 238–245. https://doi.org/10.4236/ajps.2013.42031

Hol, W. H. G., & Cook, R. (2005). An overview of arbuscular mycorrhizal fungi-nematode interactions. *Basic and Applied Ecology*, *6*(6), 489–503. https://doi.org/10.1016/j.baae.2005.04.001

Jilani, G., Akram, A., Ali, R. M., Hafeez, F. Y., Shamsi, I. H., Chaudhry, A. N., & Chaudhry, A. G. (2007). Enhancing crop growth, nutrients availability, economics and beneficial rhizosphere microflora through organic and biofertilizers. *Annals of Microbiology*, *57*(2), 177–184. https://doi.org/10.1007/bf03175204

Kilonzi J. M., Mafurah, J. J., Nyongesa, M. W. & Kibe, A. M. (2020). Efficacy of *Trichoderma asperellum* seed treatment and Ridomil® application in managing late blight on potato. *World Journal of Agricultural Research*, *9*(2), 42–52. https://doi.org/10.5539/jas.v12n7p32

Liljeroth, E., Lankinen, Å., Wiik, L., Dhar, D., Alexandersson, E., & Andreasson, E. (2016). Potassium phosphite combined with reduced doses of fungicides provides efficient protection against potato late blight in large-scale field trials. *Crop Protection*, *86*, 42–55. https://doi.org/10.1016/j.cropro.2016.04.003

Majeed, A., Muhammad, Z., Ullah, Z., Ullah, R., & Ahmad, H. (2017). Late Blight of Potato (*Phytophthora infestans*) I: Fungicides Application and Associated Challenges. *Turkish Journal of Agriculture -Food Science and Technology*, *5*(3), 261–266. https://doi.org/10.24925/turjaf.v5i3.261-266.1038

Martínez-Medina, A., Roldán, A., & Pascual, J. A. (2011). Interaction between arbuscular mycorrhizal fungi and *Trichoderma harzianum* under conventional and low input fertilization field condition in melon crops: Growth response and Fusarium wilt biocontrol. *Applied Soil Ecology*, *47*(2), 98–105. https://doi.org/10.1016/j.apsoil.2010.11.010

Muchiri, F. N., Narla, R. D., Olanya, O. M., Nyankanga, R. O., & Ariga, E. S. (2017). Efficacy of fungicide mixtures for the management of *Phytophthora infestans* (US-1) on potato. *Phytoprotection*, *90*, 19–29. https://doi.org/10.7202/038983ar

Mugo, J. N., Karanja, N. N., Gachene, C. K., Dittert, K., Nyawade, S. O., & Schulte-Geldermann, E. (2020). Assessment of soil fertility and potato crop nutrient status in central and eastern highlands of Kenya. *Scientific Reports*, *10*(1), 1–11. https://doi.org/10.1038/s41598-020-64036-x

Norris, C. E., & Congreves, K. A. (2018). Alternative management practices improve soil health indices in intensive vegetable cropping systems: A review. *Frontiers in Environmental Science*, *6*(50), 1–18. https://doi.org/10.3389/fenvs.2018.00050

Pandey, P., Irulappan, V., Bagavathiannan, M. V., & Senthil-Kumar, M. (2017). Impact of combined abiotic and biotic stresses on plant growth and avenues for crop improvement by exploiting physio-morphological traits. *Frontiers in Plant Science*, *8*(April), 1–15. https://doi.org/10.3389/fpls.2017.00537

Pang, X. P., & Letey, J. (2000). Organic farming challenge of timing nitrogen availability to crop nitrogen requirements. *Soil Science Society of America Journal*, *64*(1), 247–253. https://doi.org/10.2136/sssaj2000.641247x

Rosen, C. J., & Bierman, P. M. (2008). Potato yield and tuber set as affected by phosphorus fertilization. *American Journal of Potato Research*, *85*(2), 110–120. https://doi.org/10.1007/s12230-008-9001-y

Seifu, Y. W. (2017). Reducing severity of late blight (*Phytophthora infestans*) and Improving potato (*Solanum tuberosum* L.) Tuber Yield with pre-harvest application of Calcium nutrients. *Agronomy*, *69*(7), 1–11. https://doi.org/10.3390/agronomy7040069

Shoresh, M., Harman, G. E., & Mastouri, F. (2010). Induced systemic resistance and plant responses to fungal biocontrol agents. *Annual Review of Phytopathology Phytopathology*, *48*, 21–43. https://doi.org/10.1146/annurev-phyto-073009-114450

Simko, I., & Piepho, H. (2012). Analytical and theoretical plant pathology. The Area Under the Disease Progress Stairs : Calculation , Advantage and Application. *Extra*, *102*(4), 381–389.

Singh, M., Biswas, S. K., Nagar, D., Lal, K., & Singh, J. (2017). Impact of bio-fertilizer on growth parameters and yield of potato. *International Journal of Current Microbiology and Applied Sciences*, *6*(5), 1717–1724. https://doi.org/10.20546/ijcmas.2017.605.186

Taylor, P., Nyankanga, R. O., Wien, H. C., Olanya, O. M., & Ojiambo, P. S. (2013). Farmers' cultural practices and management of potato late blight in Kenya Highlands : implications for development of integrated disease management. *International Journal of Pest Management*, *50*(2), 37–41. https://doi.org/10.1080/09670870410001691812

Yan, G., XinG, Y., Han, S., Zhang, J., Wang, Q., & MU, C. (2020). Long-time precipitation reduction and nitrogen deposition increase alter soil nitrogen dynamic by influencing soil bacterial communities and functional groups. *Pedosphere*, *30*(3), 363–377. https://doi.org/10.1016/S1002-0160(19)60834-9

Zhen, Z., Liu, H., Wang, N., Guo, L., Meng, J., Ding, N. & Jiang, G. (2014). Effects of manure compost application on soil microbial community diversity and soil microenvironments in a temperate cropland in China. *PLoS ONE*, *9*(10). https://doi.org/10.1371/journal.pone.0108555