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Original Paper

Assessing Inorganic Salts for Effective Management of Late Blight Disease in Potatoes

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***Abstract*— Potato in Ethiopia is the primary tuber crop, and late blight poses a significant challenge to its production. Field experiments were carried out in Meket and Wadla during the 2018 and 2019 growing seasons to assess the use of salts in controlling late blight and its cost-effectiveness management strategies. The study included seven treatments: sodium bicarbonate, sodium benzoate, sodium carbonate, potassium chloride, calcium chloride, a systemic fungicide containing Mefenoxam and Mancozeb, and a control treatment. The treatments were settled in a randomized complete block design with three replications. The study found that there were significant variations in disease levels, potato tuber yield, and yield components among different treatments. Application of salts were found to be effective in reducing late blight disease, leading to higher yields. Among salts, the highest total tuber yield (23.59 and 22.02 t ha^{-1}) was recorded from sodium bicarbonate at Meket and Wadla in 2019, respectively. The highest marginal rate of return (2,852%) was obtained from synthetic fungicide followed by 2,634% by sodium bicarbonate. Therefore, besides synthetic fungicide, foliar application of sodium bicarbonate can decrease potato late blight disease pressure and is advised to be considered as an alternative control measure.**

Keywords*— *late blight, percent severity index, potato, sodium bicarbonate, tuber yield

I. Introduction

Potato (Solanum tuberosum L.) is found under the Solanaceae family and is one of the most essential crops in the world [24] next to rice, wheat and maize [6]. In 1858, Schimper, a botanist from Germany, is recognized for bringing the potato crop to Ethiopia [23]. Potatoes could play an important role in ensuring access to food at the household level [29]. It serves as a source of income for smallholders, enhancing the economic viability of agricultural systems in developing nations. According to Food and Agriculture Organization's statistical database (FAOSTAT) [13] African potato production has continued expanding in the last seventeen years, rising from 14.7 million tons in 2001 to 25 million tons in 2017. Potato is one of the most preferred crops in Ethiopia for food consumption [32].

Potato is susceptible to over a hundred diseases caused by bacteria, fungi, viruses, or mycoplasmas [2]. Potato late blight (Phytophthora infestans (Mont.) de Bary) is a polycyclic disease that undergoes multiple reproductive cycles in a season, leading to a swift rise in disease prevalence once established in a field [2]. In the study area, potato tuber yield losses attributed to late blight ranges from 35.4% to 59.29% [4]. And also, under favorable environmental conditions, 50-70 % potato yield loss has occurred [16]. In Ethiopia, potato yield loss caused by late blight ranges between 29–100%, depending on the variety used [5].

Several management options for late blight disease have been developed and used. This includes cultural practices, the use of resistant varieties, and chemical controls [2]. According to Ashenafi et al. [4], spraying of fungicides like Tricyclazole, Mancozeb and Metalaxyl, Mancozeb and Propiconazole have reduced the development of late blight disease as compared with the untreated plot.

Several studies [19, 26, and 28] have discovered that salts such as potassium and sodium bicarbonates have the ability to manage various plant diseases. Inorganic salts, especially bicarbonates, were used to manage potato late blight disease on potato crops, which can suppress the disease's infestation [9, 11]. According to Nehal and Moktan, sodium bicarbonate application under field conditions significantly lowered the occurrence and severity of early blight by up to 34.7%, in comparison to the untreated control. The impact of inorganic salts on managing late blight disease has not been investigated in the study area, and its cost effectiveness is yet to be determined. The management strategies based on the use of inorganic salts can improve disease control in many potato growing areas [17]. Therefore, the proposed studies were conducted to evaluate the effect of inorganic salts on managing potato late blight disease and assess the cost-effectiveness in comparison with systemic fungicide.

II. Materials and Methods

A. Description of experimental site

The field experimentation was studied at Meket and Wadla Districts of North Wollo Zone for two consecutive years during

2018 and 2019 cropping seasons. The altitude of the trial field at Meket was 2898 m.a.s.l., located 11047'05'' North latitude to $38^0$40'46" East longitude. The study area's average annual temperature and rainfall range from 15°C to 17°C and 934 to 1342 mm, respectively. The average altitude of Wadla district is 2894 m.a.s.l., and located at $11^0$38'07'' North latitude to $38^0$44'24'' East longitude.

B. Experimental Design and Materials

The field trial was set up using a randomized complete block design (RCBD) with three replications. The experiment had seven treatments; five inorganic salts (Sodium bicarbonate (NaHCO3), Sodium benzoate (C7H2O2Na), Sodium carbonate (NaCO3), Potassium Chloride (KCL) and Calcium chloride (CaCl2)), one synthetic fungicide Mefenoxam and Mancozeb (Ridomil Gold MZ 68 WG; Syngenta Crop Protection LLC, North Carolina, USA) and unsprayed treatment used as a control check. Each salt (3.5 kg/ha) and synthetic fungicide at a rate of 2.5 kg/ha [1] were applied as foliar treatments three times, with ten-day intervals between applications, starting the first spray after the initial symptoms of late blight disease appeared.

The experiment utilized plots measuring 3m x 3m in length and width. The plots measured four rows, with a plant spacing of 30cm and a row spacing of 75cm. Plots and blocks were separated by 1.0m and 1.5m, respectively. To prevent the drift of fungicides and salts, plastic sheets were employed during application.

C. Disease Data Collected

Disease severity was measured from ten randomly tagged plants per plot for data collection. Assessments were conducted at least five times at seven-day intervals, beginning with the onset of the disease, using a standard 0-9 severity scale, where 0 = no disease, 1 = <10%, 3 = 10-20%, 5 = 20-30%, 7 = 30-60%, and 9 = >60% of the leaf surface affected by lesions [27]. The severity grades were then converted into a percentage severity index (PSI) for analysis [31].

$$PSI = \frac{Snr}{Npr+Msc} \, x \, 100 \quad ......(1)$$

Where: Snr = sum of numerical ratings, Npr = total number of plants assessed, Msc = maximum score of the scale.

The area under the disease progress curve (AUDPC) was calculated for each treatment combination from the assessment of disease severity using the following formula [7].

$$AUDPC = \sum_{i=1}^{n-1} 0.5\,(x_{i+1} + x_i)(t_{i+1} - t_i) \quad ......(2)$$

In this equation, 'n' denotes the total number of assessments, 'ti' indicates the time of the ith assessment in days from the initial assessment date, and 'xi' represents the percentage of disease severity at the ith assessment. AUDPC is expressed in percent-days, as severity (x) is measured in percentages and time (t) is measured in days.

The disease progress rate (r) was calculated by using the linearized logistic model. The disease progress rate was determined from the initial disease assessment to each subsequent assessment interval using a linear logistic model [7, 30], and the calculated value was analyzed.

$$r = \left(ln\frac{Y}{1-y}\right) - \left(ln\frac{Y_0}{1-Y_0}\right)/t \quad ......(3)$$

Where r is disease progress rate, ln = Natural logarithm, Yo is initial disease severity, Y is the final disease severity and t is the duration of the epidemic.

D. Yield and Yield Component Data Collected

The yield loss of potato tubers caused by late blight disease was determined as a percentage reduction in yield of untreated treatments compared to the most protected treatment, using the following formula [25]:

$$RPYL = \frac{YP-YT}{YP} \, x \, 100 \quad ......(4)$$

Relative percent yield loss (RPYL) was calculated by comparing the yields of treated plots (YT) with the yield of the maximum protected plot (YP), i.e., treatment with the fungicide.

Percentage yield increase (PYI) is calculated using the formula proposed by [18]:

$$PYI = \frac{\text{tuber yield of a fungicide treated plot} - \text{yield of control plot}}{\text{yield of control plot}} \, x \, 100 \quad ......(5)$$

E. Cost-benefit Analysis

The cost-benefit analysis for each treatment was calculated separately, and the marginal rate of return was assessed by considering the variable costs associated with each treatment [8]. The analysis encompassed variable input costs such as expenses for chemicals and labor for spraying, as well as fixed costs including the price of potato seeds and agronomic practices.

F. Data Analysis

Data on disease, yield, and yield component parameters were analyzed using Analysis of Variance (ANOVA) for each dataset through GenStat version 18.0 software [14]. Treatments mean separation was done by using Duncan's multiple range test.

III. Results and Discussion

A. Disease Assessment

The analysis of variance revealed a significant difference between treatments "range test at P≤0.05 probability" regarding AUDPC and percentage severity index in the Meket and Wadla districts during the 2018 and 2019 cropping seasons. In the 2018 season, initial signs of potato late blight appeared 55 days after planting (DAP) in Meket and 59 DAP in Wadla. In 2019, the first symptoms were observed at 59 DAP in Meket and 61 DAP in Wadla. Disease assessments commenced at 60 DAP in Meket and 63 DAP in Wadla during the 2018 season, while in 2019, assessments began at 62 DAP in Meket and 64 DAP in Wadla.

B. Percentage Severity Index (PSI)

The PSI significantly differed among treatments at Meket and Wadla districts in the 2018 and 2019 production years. In 2018 from the final PSI (89 DAP) of Meket, the maximum (88.33%) and minimum (25%) PSI was scored from control and sodium bicarbonate treated plots, respectively. And also, at Wadla the maximum (91.67%) PSI was scored from unsprayed control and the minimum (26.67 and 28.33%) PSI was scored from synthetic fungicide and sodium bicarbonate treated plots, respectively (Table 1 and 2).

Moreover, in 2019 at Meket the lowest (7.33%) final PSI (90 DAP) was recorded from synthetic fungicide -treated plots and 55% from sodium bicarbonate-treated plots. The highest (81.33%) PSI was scored from control plots at Meket in 2019 (Table 3). Similarly, at Wadla the highest (70.33%) PSI was scored from untreated control plots in 2019 cropping season. And also, the lowest (14%) PSI were scored from synthetic fungicide treated plots at Wadla in 2019 cropping season (Table 4).

Salts vary significantly in their effectiveness for managing potato late blight across different locations and years. Variance analysis revealed that sodium bicarbonate is the most effective management option, followed by sodium carbonate. The use of fungicides, including synthetic options and Mancozeb, has reduced the progression of late blight compared to untreated plots [1, 4]. This study aligns with [11] previous research indicating that sodium bicarbonate treatment led to maximum inhibition of late blight. Additionally, sodium bicarbonate effectively reduced the severity of early blight by 21.3% [22]. Inorganic salts, particularly bicarbonates, have been shown to manage potato late blight, suppressing disease infection by 17% [9].

C. Disease Progress Rate (DPR)

Data analysis of the DPR indicated significant differences among the treatments. The highest DPR of 0.0377 and 0.0295 units per day was calculated on the control plot at Meket and Wadla in 2019 cropping season, respectively (Table 3 and 4). Whereas at Meket location, the lowest (0.0038 and 0.0224) DPR were calculated from synthetic fungicide and sodium bicarbonate treated plots in 2019 cropping season (Table 3). Similarly, at Wadla the lowest (0.0050 and 0.0205) DPR were calculated from synthetic fungicide and sodium bicarbonate treated plots in 2019 cropping season (Table 4). These results align with those of [20], who indicated that the use of fungicides reduced late blight infection more effectively than in the control plots.

TABLE I. EFFECT OF INORGANIC SALTS ON MEAN YIELD, YIELD COMPONENT AND DISEASE PARAMETERS AT MEKET IN 2018

Treatment	PSI at 89DAP	AUDPC in %-days	PH (cm)	MKY (t ha $^{-1}$)	UMKY (t ha $^{-1}$)	TY (t ha $^{-1}$)
$NaHCO_3$	25.00^{a}	460.8^{a}	52.00	21.41^{a}	0.34^{a}	21.75^{a}
$C_7H_2O_2Na$	41.67^{a-c}	927^{cd}	43.33	18.58^{bc}	0.26^{ab}	18.83^{bc}
$NaCO_3$	48.33^{bc}	863^{c}	44.00	19.39^{ab}	0.55^{b}	19.94^{ab}
KCl	55.00^{c}	1085de	47.67	18.35^{bc}	0.38^{b}	18.73^{bc}
$CaCl_2$	56.67^{c}	1160^{e}	57.33	16.17^{c}	0.89^{b}	17.06^{c}
synthetic fungicide	33.33^{ab}	647^{b}	51.67	21.68^{a}	0.39^{b}	22.07^{a}
Control	88.33^{d}	1627^{f}	52.00	17.76^{bc}	0.26^{b}	18.01^{bc}
GM	49.8	968	49.7	19.05	0.439	19.49
CV (%)	18.3	9.9	16.2	7.3	49	7.5
Sig (0.05)	***	***	NS	**	**	**

*Where: Ns= Not significant at p<0.05; **= Significant at p<0.01; ***=Significant at p<0.001; GM= Grand mean; CV = Coefficient of Variation; PH= Plant height; MKY= Marketable yield; UMKY= Unmarketable yield; TY= Total tuber yield; PSI= Final percentage index; AUDPC= Area under disease progress curve;*

D. Area under Disease Progress Curve (AUDPC)

Significant ($p<0.05$) differences were observed in the area under the disease progress curve at all locations during the 2018 and 2019 cropping seasons. In 2018 maximum (1627.5%-days) AUDPC values were calculated from untreated control plots at Meket (Table 1). At Wadla 2018 main cropping season minimum (449%-days) AUDPC was scored from synthetic fungicide treated plot followed by sodium bicarbonate (577.5%-days) and maximum (1516%-days) AUDPC was calculated from the unsprayed control plot (Table 2). In 2019 cropping season at Meket the highest (1975%days) and lowest (423%-days) AUDPC was calculated from untreated control and synthetic fungicide treated plots, respectively (Table 3). Similarly, at Wadla the highest (1995%days) and lowest (502%-days) AUDPC was calculated from untreated control and synthetic fungicide treated plots, respectively (Table 4).

This result further supports the results of [26], who found that inorganic salts like baking soda (sodium bicarbonate) might reduce fungal infection through direct inhibition of spore germination and growth. Similarly, salts like sodium and potassium bicarbonate were performed highest antifungal activity against potato dry rot, tomato leaf spot and grape gray mold [19]. Baking soda (NaHCO3) or KHCO3 could significantly inhibit (95%) the mycelial growth of Fusarium species [15].

E. Plant Height

The use of salts and fungicides on foliage may have enhanced plant height by minimizing foliage loss due to disease, enabling the plant to sustain its physiological functions. The analysis of variance indicated there wasn't a significant difference at ($p<0.05$) between treatments on potato plant height at Meket district in both 2018 and 2019 cropping season (Table 1 & 3). But analysis of plant height showed a significant difference ($p<0.05$) at Wadla district in 2018 and 2019 cropping season (Table 2 & 4). The tallest (55cm) and shortest (43.33cm) plant height were obtained from plots treated with calcium chloride and sodium carbonate at Wadla in 2018, respectively (Table 2). In 2019 cropping season, the tallest (58cm) and shortest (42.33cm) plant height were obtained from plots treated with synthetic fungicide and untreated control, respectively at Wadla (Table 4). The current study is supported by [12] findings, which indicated that the highest (53.13cm) plant height was observed in the treatment where Ridomil was applied.

TABLE II. EFFECT OF INORGANIC SALTS ON MEAN YIELD, YIELD COMPONENT AND DISEASE PARAMETERS AT MEKET IN 2018

Treatment	PSI at 91DAP	AUDPC in %-days	PH (cm)	MKY (t ha $^{-1}$)	UMKY (t ha $^{-1}$)	TY (t ha $^{-1}$)
$NaHCO_3$	28.33^{a}	577 ^{a}	51.00^{ab}	19.38^{ab}	0.90^{b}	20.27^{ab}
$C_7H_2O_2Na$	45.00^{b}	787 ^{b}	45.00^{bc}	16.70^{b-d}	0.63^{b}	17.00^{bc}
$NaCO_3$	46.67^{b}	927 ^{b}	43.33^{c}	16.61^{bc}	0.51^{b}	17.11^{bc}
KCl	61.67^{c}	1114 ^{c}	48.30^{a-c}	12.3^{cd}	4.44^{a}	16.74^{bc}
$CaCl_2$	60.00^{c}	1213 ^{c}	55.00^{a}	12.15^{d}	4.44^{a}	16.59^{bc}
synthetic fungicide	26.67^{a}	449 ^{a}	52.00^{a-c}	21.27^{a}	0.37^{b}	21.64^{a}
Control	91.67^{d}	1516.7 ^{d}	51.00^{a}	12.60^{cd}	3.52^{a}	16.12^{c}
GM	51.43	940.8	49.38	15.8	2.1	17.9
CV (%)	8.6	9.7	7.2	14.5	31.4	10.8
Sig (0.05)	***	***	**	**	***	**

*Where: Ns= Not significant at p<0.05; **= Significant at p<0.01; ***=Significant at p<0.001; GM= Grand mean; CV = Coefficient of Variation; PH= Plant height; MKY= Marketable yield; UMKY= Unmarketable yield; TY= Total tuber yield; PSI= Final percentage index; AUDPC= Area under disease progress curve;*

F. Days to Physiological Maturity

Applying salts and fungicides could increase the potato's maturity date and potato tuber yield. The analysis of variance revealed a significant difference (p<0.05) among the treatments on days to maturity at Meket and Wadla in 2019 main cropping season (Table 3 & 4). The longest (104.3) and shortest (96.7) days to maturity was obtained from plots treated with synthetic fungicide and unsprayed control plot respectively at Meket (Table 3). Similarly, at Wadla the longest (106.3) and shortest (99) days to maturity were obtained from plots treated with Synthetic fungicide and unsprayed control plot respectively (Table 4). The foliar application of Ridomil fungicide delayed (104.3 days) the physiological maturity of potatoes by reducing disease pressure [1].

TABLE III. EFFECT OF INORGANIC SALTS ON MEAN YIELD, YIELD COMPONENT AND DISEASE PARAMETERS AT MEKET IN 2019

Treatment	PSI at 90DAP	DPR	AUDPC in %-days	PH (cm)	DM (days)	ATW (g)	MKY (t ha^{-1})	UMKY (t ha^{-1})	TY (t ha^{-1})
$NaHCO_3$	55.00^{b}	0.0224^{ab}	1213^{c}	37.27	101.00^{ab}	43.95^{ab}	22.68^{ab}	0.92^{cd}	23.59^{ab}
$C_7H_2O_2Na$	74.33^{ab}	0.0366^{b}	1815^{ab}	38.13	101.30^{ab}	39.12^{bc}	13.69^{bc}	1.83^{b}	15.52^{bc}
$NaCO_3$	69.33^{ab}	0.0327^{b}	1554^{bc}	38.13	100.00^{bc}	34.95^{bc}	18.18^{bc}	1.52^{bc}	19.70^{abc}
KCl	71.67^{a}	0.0333^{b}	1648^{ab}	39.80	102.30^{ab}	38.94^{bc}	16.13^{bc}	1.82^{b}	17.95^{bc}
$CaCl_2$	63.33^{ab}	0.0275^{ab}	1406^{bc}	40.27	99.30^{bc}	28.30^{bc}	13.50^{bc}	1.25^{bcd}	14.75^{bc}
Synthetic fungicde	7.33^{c}	0.0038^{a}	423^{d}	41.40	104.30^{a}	58.11^{a}	27.97^{a}	0.57^{d}	28.54^{a}
Control	81.33^{a}	0.0377^{b}	1975^{a}	35.93	96.70^{c}	25.60^{c}	11.05^{c}	2.85^{a}	13.90^{c}
GM	60.33	0.0277	1433.25	38.7	100.71	38.43	17.6	1.54	19.14
Sig (0.05)	***	**	***	ns	*	**	*	***	*
CV (%)	18.6	29.7	15.3	10.2	2	21.3	28	28.4	25.2

*Where: Ns= Not significant at p<0.05; **= Significant at p<0.05; **= Significant at p<0.01; ***=Significant at p<0.001; GM= Grand mean; CV = Coefficient of Variation; DM= Days to maturity; PH= Plant height; ATW= Average tuber weight; MKY= Marketable yield; UMKY= Unmarketable yield; TY= Total tuber yield; PSI= Final percentage index; DPR= Disease progress rate; AUDPC= Area under disease progress curve;*

G. Average Tuber Weight

There was significant difference (p<0.005) among treatments with regard to average tuber weight at both locations in 2019 cropping season (Table 3 & 4). The highest (58.11gm) average tuber weight was recorded on Synthetic fungicide treated plots followed by sodium bicarbonate at Meket (Table 3). Similarly, at Wadla the highest (57.31 g) average tuber weight was obtained from Ridomil treated plots (Table 4). On the other hand, the lowest (25.6 and 26.37 g) average tuber weight was recorded from unsprayed control plot, at Meket and Wadla, respectively. At both locations, sodium bicarbonate sprayed plots showed significant difference among different salts and unsprayed control plot. The present study agree with [1] research, who found that the highest tuber weights were achieved in all varieties treated with Ridomil fungicide.

H. Marketable Tuber Yield

The analysis of marketable yield had shown significant difference (p<0.05) between treatments at Meket and Wadla locations in 2018 and 2019 cropping seasons. At Meket, the maximum (21.68 t ha^{-1}) and minimum (16.17 t ha^{-1}) marketable yield was found from Synthetic fungicide sprayed plot and calcium chloride sprayed plot respectively in 2018 (Table 1). In the same year of 2018 at Wadla district the highest (21.27 t ha^{-1}) marketable tuber yield of potato was recorded from Synthetic fungicide plot followed (19.38 t ha^{-1}) by sodium bicarbonate and the lowest (12.15 t ha^{-1}) tuber yield was recorded from calcium chloride sprayed plot (Table 2).

Moreover, in 2019 cropping season at Meket the highest (27.97 t ha^{-1}) marketable tuber yield of potato was recorded from Synthetic fungicide plot followed (22.68 t ha^{-1}) by sodium bicarbonate and the minimum (11.05 t ha^{-1}) tuber yield was obtained from unsprayed control plot (Table 3). Similarly, the maximum (25.87 t ha^{-1}) marketable potato tuber yield was recorded from Synthetic fungicide sprayed plots followed (21.11 t $ha^{-1)}$ by sodium bicarbonate and the minimum (12.81 t ha^{-1}) marketable yield was obtained from unsprayed plots, at Wadla district (Table 4). The present experiment showed that among salts foliar application of sodium bicarbonate could increase the marketability of potato yield than other salts and unsprayed control plots. Foliar application sodium bicarbonate could increase (30.7%) potato tuber yield under field condition [22]. Ans also, [21] emphasized that implementing an effective fungicide application strategy significantly contributed to achieving a high yield of potato tubers.

TABLE IV. EFFECT OF INORGANIC SALTS ON MEAN YIELD, YIELD COMPONENT AND DISEASE PARAMETERS AT WADLA IN 2019

Trt	PSI at 92DAP	DPR	AUDPC in %-days	PH (cm)	DM (days)	ATW (g)	MKY (t ha^{-1})	UMKY (tha^{-1})	TY (t ha^{-1})
$NaHCO_3$	47.67^{b}	0.0205^{bc}	1282^{c}	52.87^{ab}	102.30^{bc}	51.94^{ab}	21.11^{ab}	0.92	22.02^{ab}
$C_7H_2O_2Na$	59.33^{ab}	0.0237^{bc}	1634^{b}	50.73^{abc}	99.70^{cd}	31.90^{c}	14.35^{bc}	1.33	15.69^{bc}
$NaCO_3$	45^{b}	0.0175^{b}	1301^{c}	49.87^{abc}	102.00^{cd}	38.37^{bc}	17.46^{bc}	1.13	18.59^{bc}
KCl	56^{ab}	0.0233^{bc}	1446^{bc}	47.87^{bc}	104.30^{ab}	40.47^{abc}	16.99^{bc}	0.83	17.82^{bc}
$CaCl_2$	53.67^{b}	0.0213^{bc}	1336^{c}	52.33^{ab}	101.30^{bcd}	33.93^{c}	14.32^{bc}	1.25	15.57^{bc}
Synthetic fungicide	14.00^{c}	0.0050^{a}	502^{d}	58.93^{a}	106.30^{a}	57.31^{a}	25.87^{a}	0.40	26.27^{a}
Control	70.33^{a}	0.0295^{c}	1995^{a}	42.33^{c}	99.00^{d}	26.37^{c}	12.81^{c}	1.29	14.10^{c}
GM	49.43	0.0201	1356.6	50.7	102.14	40.04	17.56	1.02	18.58
Sig (0.05)	***	***	***	*	**	*	*	ns	*
CV (%)	16.6	18.5000	10.8	9.5	1.6	22.8	22.1	36.9	20.8

*Where: Ns= Not significant at p<0.05; *= Significant at p<0.0; 5**= Significant at p<0.01; ***= Significant at p<0.001; GM= Grand mean; CV = Coefficient of Variation; DM= Days to maturity; PH= Plant height; ATW== Average tuber weight; MKY= Marketable yield; UMKY= Unmarketable yield; TY= Total tuber yield; PSI= Final percentage index; DPR= Disease progress rate; AUDPC= Area under disease progress curve;*

I. *Unmarketable Tuber Yield*

The analysis of variance revealed that unmarketable potato tuber yield indicated significant difference (p<0.05) between treatments at all locations except at Wadla in 2019. The highest (0.89 t ha^{-1}) unmarketable tuber yield was scored from plots sprayed with calcium chloride and the lowest (0.26 t ha^{-1}) from Sodium benzoate and control plots at Meket in 2018 (Table 1). In 2018 at Wadla the highest (4.44 t ha^{-1}) and lowest (0.37 t ha^{-1}) unmarketable tuber yield was recorded from calcium chloride and Synthetic fungicide treated plot in 2018 respectively (Table 2). In 2019 cropping season at Meket the highest (2.85 t ha^{-1}) unmarketable tuber yield was scored from unsprayed control plot and the lowest (0.57 t ha^{-1}) from Synthetic fungicide application plots (Table 3). This result is supported by [1], who reported that the highest unmarketable tuber yield (3.04 t ha^{-1}) occurred in the untreated plot of Jalene variety.

J. *Total Tuber Yield*

The current study indicated a statistically significant difference (p<0.05) in total tuber yield among treatments across all locations during the 2018 and 2019 main cropping seasons. The highest total tuber yields of 22.07 and 21.64 t ha-1 were recorded from plots treated with Synthetic fungicide in Meket and Wadla, respectively, during the 2018 cropping season (Table 1 & 2). In contrast, the lowest (17.06 and 16.12 t ha^{-1}) total tuber yield was obtained from plots treated with calcium chloride and unsprayed control plot at Meket and Wadla respectively in 2018 cropping season (Table 1 & 2). Moreover 2019 cropping season at Meket the maximum (28.54 t ha^{-1}) total tuber yield was recorded from Synthetic fungicde sprayed plot followed by sodium bicarbonate (23.59 t ha^{-1}) and the minimum (13.9 t ha^{-1}) from unsprayed control plots (Table 3). In addition to that in the same year at Wadla the maximum (26.27 t ha^{-1}) and minimum (14.1 t ha^{-1}) total tuber yield was recorded from Synthetic fungicide treated and unsprayed control plot in 2019 respectively (Table 4). In the current research, results were consistent with those of [22], showing that in field conditions, the application of calcium chloride and sodium bicarbonate led to the highest potato tuber yield. The present study is similar to [3] research result indicated that, the highest yields were obtained from plots treated with Victory 72 WP followed by Ridomil gold.

K. *Abbreviations and Acronyms*

The analysis of relative yield loss assessment and percentage yield advantage were calculated from the average total tuber yield of Meket and Wadla in 2019 cropping season. Yield loss was calculated for all treatments relative to the yield of maximum protected plot of Synthetic fungicde foliar application. The result of yield loss differed among plots treated with salts. Losses were particularly higher in unsprayed plots than in treated plots with Ridomil and sodium bicarbonate (Table 5). Relatively the lower losses were obtained from plots sprayed with Synthetic fungicde and sodium bicarbonate. The highest (48.91%) relative total potato tuber yield loss was obtained from unsprayed control plots followed by 44.68% yield loss from plots treated with calcium chloride (Table 5). However, total tuber yield losses were reduced by all fungicide treatments as compared to the unsprayed control plots. According to (Ashenafi et al.) [4] Research report, from his result the maximum potato tuber yield losses 54.79% was obtained from unsprayed Jalene variety.

Percentage yield advantage study was considered from all treatments as compared with the untreated control plots. The result of percentage yield advantage had shown differences among treatments. Maximum (95.75%) yield advantage was attained from plots treated with Synthetic fungicde fungicide and also followed by 62.89 and 36.75% yield increase was found from plots of sodium bicarbonate and sodium carbonate salts respectively (Table 5). According to Nehal and Mokhtar [22] research result maximum yield increment was obtained from plots treated with both at calcium chloride and sodium bicarbonate.

TABLE V. RELATIVE YIELD LOSS AND PERCENTAGE YIELD INCREASE FOR BOTH LOCATIONS IN 2019

Treatment	Total tuber yield (t ha^{-1})	Relative yield loss (%)	Percentage yield increase (%)
$NaHCO_3$	22.81	16.79	62.89
$C_7H_2O_2Na$	15.61	43.06	11.46
$NaCO_3$	19.15	30.14	36.75
KCl	17.89	34.74	27.75
$CaCl_2$	15.16	44.68	8.29
Ridomil	27.41	0.00	95.75
Control	14.00	48.91	0.00

L. Cost-benefit Analysis

A straightforward cost-benefit analysis was conducted for each treatment using the partial budget analysis formula (CIMMYT, 1988) to evaluate the profitability of managing potato late blight with various salts and Ridomil fungicide. Average marketable tuber yield of Meket and Wadla was used from 2019 main cropping season (Table 6). Partial budget analysis indicated that Synthetic fungicde treated plots showed the maximum net benefit (2075505 ETB ha^{-1}) and marginal rate of return (2852%) as compared with other salts. Moreover, among salts maximum (163615 ETB ha^{-1}) and minimum (91645 ETB ha^{-1}) net benefit was found from sodium bicarbonate and calcium chloride respectively (Table 6). Percentage marginal rate of return had shown difference among salt treatments from which maximum (2634.3%) percentage marginal rate of return was obtained from sodium bicarbonate followed (1533.59%) by sodium carbonate. These indicated that by application of sodium bicarbonate; for every 1 Ethiopian birr (ETB) invested for sodium bicarbonate foliar spray, there was 1 ETB and had gotten an additional of 26.34 ETB. Whereas minimum (408.38%) percentage marginal rate of return was obtained from sodium benzoate.

The findings of this study are supported by the results reported by [21]; fungicide applications were giving high yield and maximum marginal rate of return (MRR). Similarly to the findings of [5], it is crucial to use a lower dosage of Ridomil and potato varieties with moderate resistance in order to effectively manage potato late blight, ultimately leading to an increase in the production and profitability of high-quality potato tubers.

TABLE VI. PARTIAL BUDGET ANALYSIS OF SALTS AND SYNTHETIC FUNGICDE FUNGICIDE FOR THE MANAGEMENT OF LATE BLIGHT IN 2019.

TRT	MTY	AMTY (Y* 0.9)	PP/Kg	GB/ha	TIC	MC	NB	MNB	MRR%
$NaHCO_3$	21.9	19705.5	10	197055	33440	3280	163615	86405	2634.30
$C_7H_2O_2Na$	14.02	12618	10	126180	33860	3700	92320	15110	408.38
$NaCO_3$	17.82	16038	10	160380	33405	3245	126975	49765	1533.59
KCl	16.56	14904	10	149040	33475	3315	115565	38355	1157.01
$CaCl_2$	13.91	12519	10	125190	33545	3385	91645	14435	426.44
Synthetic fungicde	26.92	24228	10	242280	34730	4570	207550	130340	2852.08
Control	11.93	10737	10	107370	30160	0	77210	0	0.00

Where: MTY= Marketable tuber yield, AMTY= Adjusted marketable tuber yield, PP=Price per kg, GB=Gross benefit, TIC=Total input cost, MC=Marginal cost, NB=Net benefit, MNB=Marginal net benefit, MRR=Marginal rate of return

IV. CONCLUSION AND RECOMMENDATION

Inorganic salt and synthetic fungicide analysis revealed dramatic differences in late blight control as well as the yield of potatoes. Synthetic fungicide performed best with the lowest disease severity (7.33–14%) and the highest tuber yield. Among all the inorganic salts, sodium bicarbonate ($NaHCO_3$) performed best with the lowest disease severity, the highest yield, as well as the highest marginal rate of return (MRR = 2634.33%), i.e., for each 1 ETB invested it returned an additional 26.34 ETB.

It would be recommendable to use sodium bicarbonate as a cost-effective option for the management of late blight where synthetic fungicide application is limited. Further research would be important in determining how sodium bicarbonate would be integrated into spray programs with synthetic fungicides and its applicability in organic-scale potato production.

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