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Late blight (*Phytophthora infestans*) control in Tomato (*Solanum lycopersicon*) in Tanzania

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ABSTRACT

Between 2011 and 2018 surveys and tests have been carried out to determine current practices in tomato cultivation and to find out how late blight control in tomato can be improved in Tanzania. Surveys were organized and implemented by Wageningen University and Research together with Rijk Zwaan Afrisem in the framework of the Sevia (Seeds for Expertise and Vegetables in Africa) project. The tests and some other surveys have been done in commission of Sevia by Sokoine University of Agriculture and TARI Tengeru. In this article the results of these activities are described.

INTRODUCTION

Tomato originated from South America and was introduced into Europe in the 16th Century and later to East Africa by colonial settlers in the early 1900s (Wamache, 2005). In Tanzania tomato is under a total of almost 25,000 hectare one of the most important vegetable crops in terms of acreage (Table 1). In the period between 2012 and 2017 data was collected from 50 tomato fields located in Babati, Arusha, Moshi, Bagamoyo and Lushoto (Table 2). It revealed that with a profit of over 5 million shilling (approximately 2,000 euro) per hectare tomato is quite profitable. Roughly half of the costs are material costs while the other half is spent on labour. In terms of cost share only 6% is spent on crop protection while trellis costs are high with over 12% of the total cost.

Table 1. *Acreage of vegetable crops in Tanzania*

Crop	Regional zone					
	Central	North East	North West	South East	South West	Mean
Amaranths	736	856	1054	848	317	3811
Bitter Aubergine	1009	858	870	165	265	3167
Cabbage	1495	1681	1836	320	324	5656
Carrot	281	326	82	89	31	809
Chillies	601	880	726	732	287	3226
Cucumber	96	431	282	887	7	1703
Egg Plant	60	142	139	84		425
Ginger	93	1261	108	71	102	1635
Okra	1027	1383	1495	3204	987	8096
Onion	2528	1747	1046	1072	2381	8774
Pumpkins	580	38	607	480	56	1761
Radish	713	175	146	73	118	1225
Spinach	955	685	349	1105	325	3419
Tomatoes	7491	5047	6526	3751	1879	24694
Turmeric	478	133	313	41	175	1140
Watermelon	200	132	1167	1861	72	3432
Mean	18343	15775	16746	14783	7326	72973

Source: Compiled data from Regional reports from the NATIONAL SAMPLE CENSUS OF AGRICULTURE 2007/2008

Table 2. *Crop balance sheet for tomato*

Parameter	Quantity	Unit	Unit price	Unit	Total	Share in total costs
Yield	13,648	kg/ha	566	TSh/kg	7,729,668	
Land ploughing / bed making					22,477	0.9
Seeds	450	g	519	TSh/g	233,664	9.4
Fertilizers					351,392	14.2
Crop protection					143,467	5.8
Herbicides					1,488	0.1
Irrigation fuel					121,609	4.9
Trellis					313,629	12.7
Transport costs					4,864	0.2
Other costs					865	0.0
Total material costs					1,193,455	48.3
Hired labour	1030	hr	1243	TSh/hr	1,279,950	51.7
Family labour	783	hr				
Profit					5,256,263	

REGISTERED FUNGICIDES AND AVAILABILITY OF FUNGICIDES TO CONTROL LATE BLIGHT

In Tanzania the Tropical Pesticides Registration Institute (TPRI) under the ministry of Agriculture is responsible for the registration of pesticides. They publish the registered, either full with a renewable registration for five years or provisional with a two year non-renewable registration, pesticides in the Gazette. According to the latest Registered plant protection substances for use in the United Republic of Tanzania (URT), Issue of October, 2018 a total of 425 products are registered of which 275 products representing 80 single or combinations of active ingredients (A.I.) are allowed for use in tomato. To control late blight in tomato a total of 188 products with 38 different single or combinations of A.I. are registered (Table 3). In Tanzania mainly contact fungicides (e.g. chlorothalonil, copper, mancozeb, propineb and sulphur) are registered providing 51% of the total registered fungicides with efficacy against late blight. Next to those products almost 20% of the registered late blight fungicides contain metalaxyl or a related active ingredient belonging to FRAC code group 4. In principle it can therefore be concluded that more than sufficient fungicides are registered to control late blight and at the same time prevent resistance build-up of the pathogen. However, based on surveys conducted to agro dealers only a limited range of active ingredients are available to farmers to buy (Everaarts *et al.*, 2011 and Everaarts *et al.*, 2014). The reason for this is that farmers are not asking for other products since they are not aware of them, while agro shop owners are not putting more expensive fungicides on the shelf as farmers are mostly asking for cheaper products mainly those containing metalaxyl.

Table 3. *Number of products per active ingredient or combination of active ingredients of formulated products registered in 2018*

Active ingredient(s)	Full registration	Provisional registration	Mode of action(s) FRAC code
carbendazim	9		1
carbendazim + tebuconazole	1		1+3
carbendazim + chlorothalonil	0	1	1
chlorothalonil	28	1	M5
copper based	14	1	M1
cymoxanil + mancozeb	4		27+M3
cymoxanil + copper oxychloride	1		27+M1
cymoxanil+ cyazofamid	1		27+21
cymoxanil + mancozeb + dimethomorph	1		27+M3+40
dimethomorph	1		40
dimethomorph + mancozeb	3		40+M3
dimethomorph + chlorothalonil	2		40+M5
dimethomorph + prochloraz	1		40+3
ethaboxam	1		22
famoxadone + cymoxanil	1		11+27
folpet	2		M4
fosetyl-al	5		P7
fosetyl-al + mancozeb	1		P7+M3
fosetyl-al + fenamidone	1		P7+11
mancozeb	33		M3
benalaxyl + mancozeb	0	1	4+M3
iprovalicarb +mancozeb	1		40+M3
mancozeb + sulphur	1		M3+M2
mancozeb + copper sulphate	1		M3+M1
mandipropamid + difenoconazole	1		40+3
metalaxyl + mancozeb	34		4+M3
metalaxyl+ triadimefon	0	1	4+3
probineb	3		M3
cymoxanil + propineb	3		27+M3
propineb + fluopicolide	1		M3+43
propamocarb	4		28
propamocarb + fosetyl -al	1		28+P7
propamocarb + fluopicolide	1		28+43
propamocarb + fenamidone	1		28+11
pyrimethanil	3		9
sulphur	14		M2
tetraconazole + chlorothalonil	1		3+M5
thiophanate methyl	3		1

CURRENT FUNGICIDE APPLICATION PRACTICES IN TOMATO

Tomato production in the United Republic of Tanzania is hampered by several factors and average yield is between 10 to 20 ton/ha. One of the major constraint is Late Blight caused by the oomycete *Phytophthora infestans*. In order to prevent losses caused by this pathogen farmers mainly rely on the use of fungicides. Common fungicides used are mancozeb and metalaxyl based ones (De Putter *et al.*, 2017). In the dry season when less rainfall is expected farmers tend to apply just a couple of mancozeb sprays. In the rainy season farmers spray more frequently with mancozeb/metalaxyl based fungicides (Table 4). Since farmers are afraid that fungicides will be washed off the crop, they avoid spraying before expected rain but spray immediately after rain even when using products with contact fungicides only. The fungicides are applied by using knapsack sprayers with 15- 17 l content. Nozzles are not maintained and while spraying applicators are not wearing proper PPE. In the best case they wear wellingtons with some makeshift rain coat (Figure 1).

Table 4. *Typical spray schedules of tomato farmers in Moshi Region, 2015*

Variety	Kipato F1		Kipato F1			Rio Grande (OP)		
Yield	37 t/ha		28 t/ha			11 t/ha		
Season	date	activity/spray	Season	date	Activity/spray	Season	date	Activity / spray
						wet	3-apr	mancozeb + metalaxyl
						wet	13-apr	mancozeb + metalaxyl
dry	7-jul	transplanting	wet	25-dec	transplanting	wet	27-apr	transplanting
dry	16-jul	mancozeb + metalaxyl	wet	2-jan	sulphur	dry	2-mei	mancozeb
dry	4-aug	mancozeb + metalaxyl	wet	16-jan	sulphur	dry	8-mei	mancozeb
dry	15-aug	mancozeb + metalaxyl	wet	27-jan	sulphur	dry	24-mei	mancozeb + fosetyl-al
dry	19-aug	mancozeb + metalaxyl	wet	20-feb	1st harvest	dry	31-mei	mancozeb + fosetyl-al
dry	25-aug	mancozeb + metalaxyl	wet	28-feb	sulphur	dry	14-jun	mancozeb
dry	8-sep	1st harvest	wet	9-mrt	sulphur	dry	22-jun	mancozeb
dry	10-sep	mancozeb	wet	16-mrt	last harvest	dry	28-jun	mancozeb
dry	20-okt	last harvest				dry	5-jul	mancozeb
						dry	19-jul	mancozeb + metalaxyl
						dry	26-jul	mancozeb + metalaxyl
						dry	28-jul	1st harvest
						dry	7-aug	mancozeb + metalaxyl
						dry	24-aug	mancozeb
						dry	18-sep	last harvest

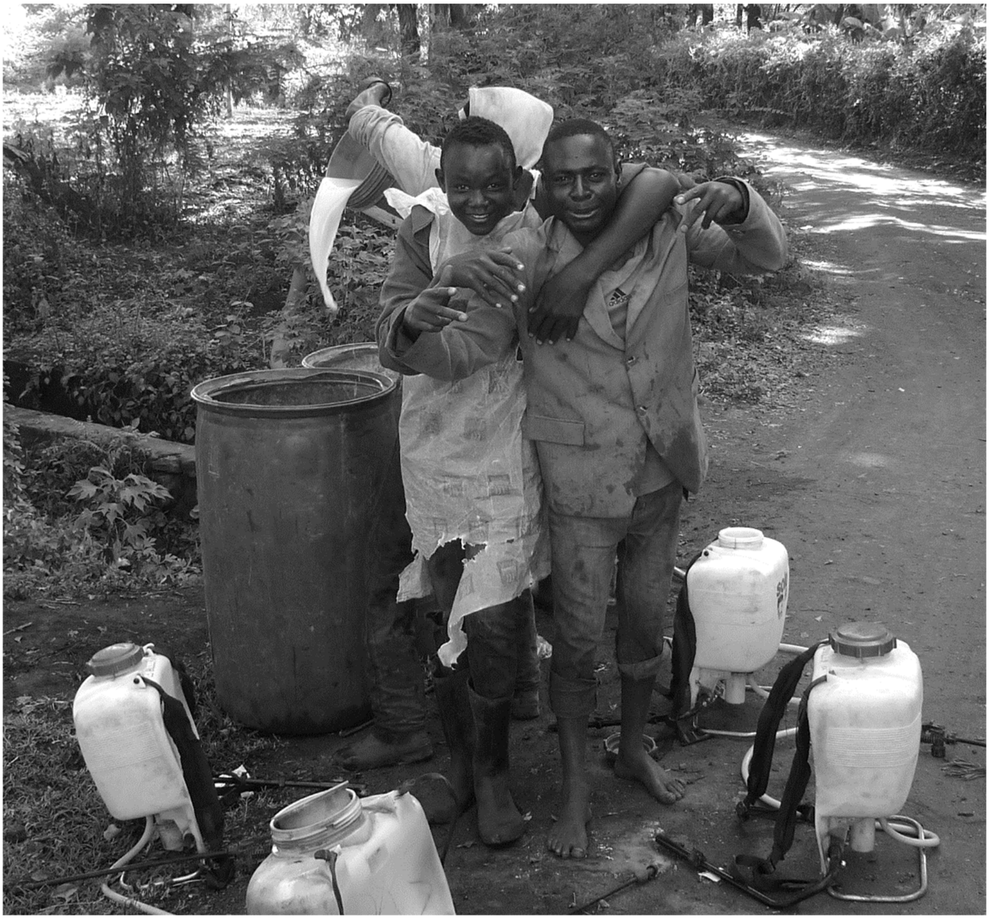

Figure 1. *Pesticide applicators in Tanzania, the person left has some plastic cover and wears boots, while the person right has no foot wear at all*

Since farmers frequently use products containing the phenylamide metalaxyl or the related active ingredient mefenoxam, more than the recommended 2 times a season, resistance of *P. infestans* against this active ingredient is suspected (FRAC pathogen risk list). The current recommendation is to limit phenylamide use to 2 to 4 consecutive sprays and to apply only in the early or the active growing stage of the crop (FRAC phenylamide general recommendation).

RESISTANCE OF *P. INFESTANS* TO METALAXYL OR METALAXYL-M

To find out if resistance of *P. infestans* against metalaxyl/mefenoxam is present a test was done by Sokoine Agriculture University in Morogoro. Tomato and potato fields from six regions (Mbeya, Njombe, Iringa, Morogoro, Tanga and Arusha) were inspected for late blight disease in April to June 2017. From the infected fields, leaves with infected fresh, nicely sporulating lesions on the leaflets were sampled. A total of 63 leaf samples were collected for processing, culturing and identification at the Sokoine University of Agriculture (SUA) Plant Pathology laboratory and for *Phytophthora infestans* DNA analysis by using FTA cards. The FTA card analysis was carried out by James Hutton Ltd., Dundee, United Kingdom. From each sample four leaf discs taken at the edge from the infected part were placed between potato slices of the *P. infestans* susceptible potato variety Akira. After the potato slices surfaces were sterilized a leaf disc was placed underneath a slice in a sterile petri dish. After mycelia became visible on the upper side of the potato slice mycelium was transferred to a petri dish with a Pea V8 ampicillin agar medium. Tests were performed with the fungicides Ridomil Gold MZ 68 WG (Metalaxyl-m 40 g/kg + Mancozeb 640 g/kg) (Syngenta Crop Protection, Switzerland) and Ivory M72 (Metalaxyl-m 80 g/kg + Mancozeb 640 g/kg) (Arysta Life Science, France). The test was done in three replicates per fungicide and concentration for each *P. infestans* isolate. Petri dishes were filled with 25 ml double-distilled water containing fungicide with a calculated concentration of 0, 0.001, 0.01, 0.1, 1, 10 and 100 mg/l metalaxyl-m. Per isolate leaf discs of either tomato (var. Tanya) or potato (var. Arika) were taken from greenhouse reared plants. The discs were placed upside down in the petri dish with a given metalaxyl-m concentration. Three hours after placing the discs in the petri dish 30 ul droplets with 20,000 spores/ml were put in the center on the floating leaf discs. The petri dishes where then placed for six days at 20^{o}C in the light on a bench. Mycelium growth was visually observed in percentage of affected leaf area (Figure 2 and 3). On all tested isolates in tomato the affected leaf area was more than 50%. Samples collected from fields in Arusha showed a dose response effect. The overall conclusion is that resistance is present since even at the highest concentration tested more than 50% of the leaf disk surface was affected by mycelium growth.

Analysis of the FTA cards showed that most of the isolates were either US-1 or 2-A1 and one possible 13-A2 isolate, but doubtful since the DNA material collected was not conclusive enough for an accurate analyze.

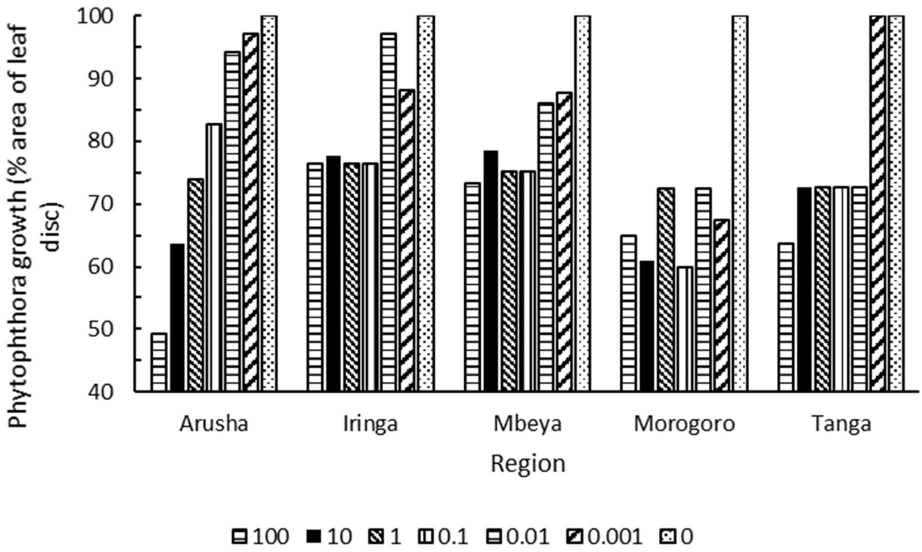

Figure 2. *Effect of Ivory M72 on P. infestans growth on tomato leaf disks*

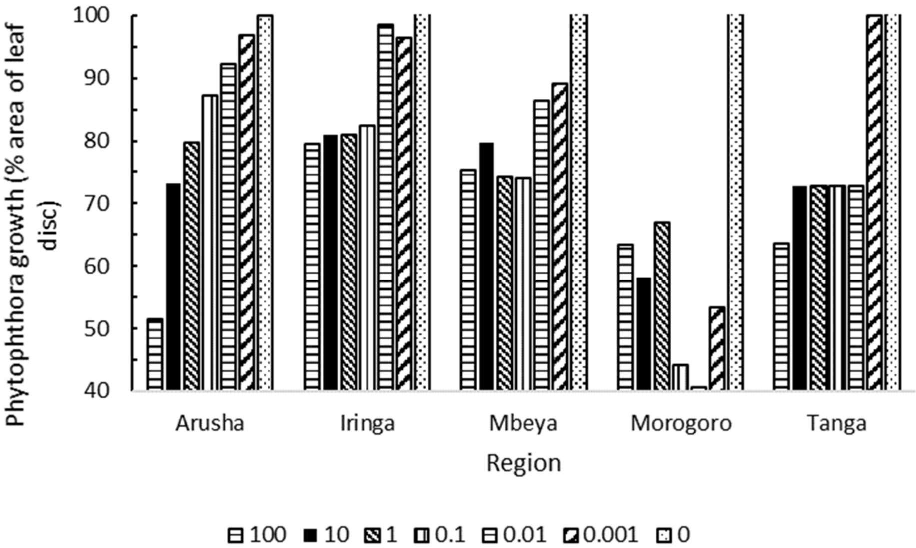

Figure 3. *Effect of Ridomil Gold on P. infestans growth on tomato leaf disks*

EFFECT OF FUNGICIDES AND ADJUVANTS ON THE INCIDENCE OF *P. INFESTANS* IN TOMATO

To prevent resistance proper use of fungicides is essential but also application technique is an important factor to achieve an optimal control *of P. infestans*. Currently farmers are not adding adjuvants to their fungicide sprays. In 2017 a test was carried out by Tanzania Agricultural Research Institute (TARI) Tengeru, Arusha to determine the effect of two different adjuvants: Aquawet 15 SL (nonylphenol ethoxylate) (Osho Chemical Ltd.) and Silwet Gold (Heptamethyl Trisilozane 84% And Polyakylene Oxide 16%) (Arysta Life Science) with three different fungicides: Ebony 80 WP (mancozeb 80%) (Balton Tanzania Ltd.), Milraz 76 WP (propineb 70% + cymoxanil 6%) (Bayer) and Victory 72 WP (mancozeb 64% + metalaxyl 8%) (Sineria Industries Tanzania).

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Each plot measured 2 m wide by 4 m long. Planting of tomato var. Tanya was done at a spacing of 60 cm x 50 cm. Fungicides were sprayed at the label recommended rates every 14 days. Tomato was grown in line with good agricultural practices.

During the experiment disease incidence was observed in week 9 after planting. Disease was rated on a scale of 1 to 9 as described by Gwary and Nahunnaro (1998) in which 0 = 0% (no disease), 1 = when 10% of leaf area is affected; 3 = 10 - 20% of leaf area affected; 5 = 20 – 30% of leaf area affected; 7 = 30 – 60% of leaf area affected; 9 = over 60% lesion area of the whole leaf affected. Then the rating scales were converted into percentage severity index (PSI) for analysis of disease severity using the formula: PSI = (Sum of individual numerical rating/Total number of assessed x maximum score in scale) x 100.

Marketable yield was recorded for all harvest periods based on local criteria. Based on yield and an estimated market price of 500 Tsh and input costs the net benefit and benefit cost ratio was calculated.

With adjuvants it seems the disease rating is lower as compared to the applications with the respective fungicides without adjuvants applied (Table 5). The highest yield was present with Milraz 76WP, where the yield increased to approximately 30 t/ha when adding an adjuvant to the spray solution. Difference in yield between Ebony, only mancozeb, and Victory, mancozeb plus metalaxyl, is negligible. When adding Aquawet to those fungicides yield increased to 18 t/ha with Ebony but only to 5 t/ha with Victory. The reason for a more or less similar results between Victory and Ebony might be related to possible metalaxyl resistance. This would imply that only the mancozeb component in Victory was effective in preventing late blight just like with Ebony. The reason that adjuvants didn't improve the efficacy of Victory might be due to an already good formulation of this product.

Table 5. *Effect of adjuvant sprayed with fungicides of tomato yield*

Treatment	Disease rating	Marketable yield (tons/ha)	Net benefit (Tsh x 1,000/ha)	Benefit/cost ratio
Ebony 80	19.3 a	72.0 b	33,828	3.1
Ebony 80+Aquawett	5.7 a	90.2bc	36,884	3.5
Ebony 80+Silwet	4.3 a	75.8 b	29,513	2.5
Milraz 76	19.0 a	80.8 b	37,334	3.1
Milraz 76+Aquawet	3.3 a	109.7 c	45,709	4.0
Milraz 76+Silwet	3.7 a	110.7 c	46,064	4.0
Victory 72	20.3 a	77.3 b	36,163	3.3
Victory 72 +Aquawet	4.3 a	81.8 b	32,333	2.8
Victory 72 + Silwet	8.3 a	81.7 b	32,168	2.7
Control	100.0 b	10.0 a	-2,653	0.7
CV (%)	51.6	26.62		
LSD	19.4	20.66		
F-test	***	**		

Means followed by same letter(s) in the column do not differ (P>0.05)

EFFECT OF SPRAY STRATEGIES ON THE INCIDENCE OF P. INFESTANS IN TOMATO

In the period of April till July 2018 control of late blight in tomato (open pollinated var. Tanya) with three different commonly used fungicides combined with fixed or flexible (depending on rain conditions) spray intervals of the fungicides against the tomato late blight was tested. The test in a complete randomized block design with three blocks was done at TARI Tengeru near Arusha, Tanzania. Each plot contained 32 plants planted at 50 x 60 cm. Ebony 80WP (Mancozeb 80%), Victory 72WP (Mancozeb 64% + Metalaxyl 6%) and Milraz 76 WP (Propineb 70% + Cymoxanil 6%) were sprayed at their recommended label rates. Ebony was sprayed in a fixed calendar spray frequency of 7 or 14 days to resemble farmer's practice. The timing of the applications of the other treatments depended on the climatic conditions and crop stage (Table 6) Ebony was sprayed at a set interval per crop stage, 7 or 14 days at the long interval or 3 and 7 days at the short interval strategy. In case of moist (rainy) conditions the interval was interrupted with a stronger product. In one strategy Milraz was chosen while in the other strategy Victory was chosen.

Table 6. *Strategies in the experiment*

Strategy	Crop stage	Spray frequency (rain = when precipation exceeds 5 mm/day)
7	0 – end	standard every 7 days spray with Mancozeb
14	0 – end	standard every 14 days spray with Mancozeb
flex long	0-30 days	Normal 14 day interval but if it rains between 7 – 14 days, spray the next day after the rain day and start again with a 14 day interval.
	31-60 days	Normal 7 days interval but If it rains after 4 days spray next day and start again with 7 day interval
	60-90 days	Normal 14 days interval If it rains after 7 days spray a day after rain and start with 14 days interval
flex short	0-30 days	Start with 7 days interval. If it rains after 4 days spray a day after rain and start with 7 days interval
	31-60 days	Start with 4 days interval. If it rains after 2 days spray a day after rain and start with 4 days interval
	61-90 days	Start with 7 days interval. If it rains after 4 days spray a day after rain and continue with 7 days interval

Based on the climatic conditions and crop growth the final applied number of fungicide applications are presented in Table 7.

Table 7. *Actual applied fungicides per strategy*

Treatment code	Strategy	Mancozeb	Milraz	Victory
T1	Control	0	0	0
T2	14 day Mancozeb	7	0	0
T3	7 day Mancozeb	14	0	0
T4	Flex long Mancozeb only	11	0	0
T5	Flex short Mancozeb only	18	0	0
T6	Flex long Mancozeb/Milraz	8	2	0
T7	Flex short Mancozeb/Milraz	14	4	0
T8	Flex long Mancozeb/Victory	7	0	3
T9	Flex short Mancozeb/Victory	15	0	3

Severity of late blight was recorded on the basis of 1-6 rating scales as described by Gwary and Nahunnaro (1998). where scale 1=trace to 20% leaf infection, 2=21-40% leaf infection, 3=41-60% infection, 4=61-80 infection, 5=81-99% infection, 6=100% leaf infection or the entire plant defoliation and then the rating scales were converted into percentage severity index (PSI) for the analysis of disease severity using the formula: Percentage Severity index = sum of individual numerical rating/Total number of assessed x maximum score in scale x 100.

Based on total marketable yield of all harvest periods, market price of 400 Tsh/kg, costs of inputs and labour, the net benefit of each treatment was calculated as well as the benefit cost ratio.

Disease severity with the calendar spray strategy was higher than the ones from the flexible strategies (Table 8). No significant differences were observed in disease severity between the flexible strategies. In terms of marketable yield it is clear, especially for the flexible strategies that shortening the interval gave the highest yield and best economic performance. Between the fungicides selected in the strategy no big differences were seen, although it seems that a more stronger active ingredient, e.g. cymoxanil or metalaxyl, gave slightly better results than applying mancozeb only as in treatment T4 and T5.

Table 8. *Disease severity, yield and net benefit of the different strategies tested in 2018*

Treatment	Disease Severity week 10	Weight of marketable yield (ton/ha)	Weight of non marketable yield (ton/ha)	Net benefit (Tsh x 1,000/ha)	Benefit cost ratio
T1 Control	5.0 a	0.8 b	0.8 d	320	-0.9
T2	2.7 ab	20.4 b	7.0 abc	8,160	0.3
T3	4.3 a	5.9 b	2.9 cd	2,360	-0.6
T4	1.7 b	23.7 b	5.3 abcd	9,480	0.5
T5	1.0 b	58.0 a	9.4 ab	23,200	2.6
T6	1.3 b	20.8 b	4.0 bcd	8,320	0.2
T7	1.0 b	67.0 a	7.3 abc	26,960	3.0
T8	0.3 b	27.8 b	4.0 bcd	11,120	0.7
T9	0.3 b	75.3 a	10.2 a	30,120	3.4
CV (%)	68.4	49.7	52.7		
LSD	2.3	28.6	5.2		
F-test	**	***	*		

Means in the same column followed by the same letter (s) are not significantly different according to Duncan's multiple range test at 0.05 level of significance

CONCLUSIONS

Tomato production in Tanzania faces a lot of challenges of which a proper late blight control is one. In principle more than a sufficient number and range of fungicides are registered for use in tomato to control late blight. However, in agro shops only a few products are available mainly mancozeb and metalaxyl based products. As a result farmers also use a lot of those products only with the risk of causing resistance among the *Phytophthora infestans* pathogens present in Tanzania. A test conducted by Sokoine University of Agriculture showed that this is highly likely the case already. From the most common available fungicides it also seems that products containing metalaxyl are not so effective. When adding adjuvants to fungicides their efficacy is improved. Finally it appears that a more interactive spray strategy considering crop stage and climate is more effective than a standard 7 or 14 days interval. A shorter interval in this case is more economic than maintaining longer intervals even though two times more applications are used.

In order to improve late blight control, farmers should receive more training on proper use of fungicides where attention is paid to strategy and application technologies. Moreover, agro shop owners should also receive information on efficacy of fungicides and resistance risks when no proper control strategy is implemented by farmers. In this way a wider range of products can become available at outlets.

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