

Evaluation of Horticultural Practices for Sustainable Tomato Production in Eastern Uganda

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Abstract. Tomato cultivars (Heinz 1370, MT 56, and Nuru F1), fungicide application (\pm), staking (\pm), and mulching (\pm) were tested for their effect on yield, disease severity, and gross margin in tomato production in the Kamuli District of Uganda. Treatments were arranged in a randomized complete block design with a factorial and split-plot arrangement in field plots in two growing seasons during 2013. Total and marketable fruit number, marketable fruit weight, gross margin, and disease severity, assessed using the area under disease progress curve, were measured. Disease-resistant and open-pollinated ‘MT 56’ in combination with fungicide application and soil mulch provided the highest marketable fruit number and marketable fruit weight and had a positive gross margin in the first growing season. A combination of ‘MT 56’ and treatments without applying fungicide and soil mulch resulted in the only positive gross margin in season two. Application of fungicides reduced disease severity (early blight, *Alternaria solani* Sorauer) for all cultivars in season one and for ‘Heinz 1370’ and ‘Nuru F1’ in season two, but did not affect disease severity for ‘MT 56’ in the second season. Using soil mulch reduced the severity of early blight disease, but decreased the gross margin when purchased. Staking did not affect yield, disease severity of plants, and decreased the gross margin. Cultivar MT 56 had the highest gross margin and marketable fruit and least disease severity, and seeds should be made available to small-landholder tomato farmers in Uganda to enhance their sustainable livelihoods.

Tomato (*Lycopersicon esculentum* Mill.) is the most widely grown vegetable crop in Uganda, and is popular in the diets of Ugandan citizens. Tomato is cultivated primarily by farmers who own 2 ha or less of land (Karungi et al., 2011). Tomatoes contribute to a farm income in Uganda of \approx 250 USD per hectare in each growing season at yields of 7.125 t (Sonko et al., 2005), but their production is challenged by various factors. Pests include insects such as aphids (*Myzus persicae* Sulzer), fruit worms (*Helicoverpa armigera* Hubner), mites (*Tetranychus evansi* Baker & Pritchard), and thrips (*Frankliniella occidentalis* Pergande), and diseases, such as bacterial wilt (*Ralstonia solanacearum* Smith), early blight (*Alternaria solani* Sorauer), and late blight [*Phytophthora infestans* (Mont.) de Bary]. Fungicides and insecticides have been used to manage tomato pests (Akemo et al., 2001; Tumwine et al., 2002b). Additional limitations include lack of improved cultivars and inadequate information on sustainable horticultural practices (Akem et al., 2000;

Anastacia et al., 2011; Kasenge et al., 2002; Ssekya, 2006; Tumwine, 1999; Tumwine et al., 2002a). Potential disease-resistant or tolerant cultivars (Akem et al., 2000; Fayad et al., 2013; Schreinemachers et al., 2017) and cultural practices such as mulching and staking have been identified to assist in disease management (Akemo et al., 2001). However, the sustainability of cultural practices for tomato production among rural small-landholder farmers has not been studied extensively in Uganda.

The objective of this work was to determine sustainable practices for producing tomatoes in the Kamuli District of Uganda by evaluating cultivars and use of fungicide, staking, and mulching and their impact on yield, disease severity, and gross margin. Evaluating horticultural practices for sustainable tomato production will enable small-landholder farmers to benefit from increased farm income and personal consumption.

Materials and Methods

Production of seedlings

On 22 Apr. 2013, tomato seeds of ‘Heinz 1370’, ‘MT 56’, and ‘Nuru F1’ were planted and seedlings raised in transplant boxes (0.6 m long \times 0.4 m wide \times 0.1 m deep), which contained steam-sterilized soil. Dried elephant grass was placed on top of the boxes to maintain soil moisture and hand watering was

done as often as required to enable germination. On 4 May, the elephant grass was removed from the top of the box and a shade structure (1.07 m high) with elephant grass on its roof was built directly over the boxes. Victory fungicide (Mancozeb and metalaxyl) (Invectra Agro Ltd, Limassol, Cyprus) was applied by spraying the seedlings once per week at recommended label rates. After \approx 4 weeks, which occurred 4 May through 1 June in season one and 1 Sept. through 31 Sept. in season two, the shade was removed from above the boxes to allow the transplants to harden off, and hardened seedlings were transplanted into research plots.

Research plots

Field experiments were established and maintained in 2013 in season one, April to August, and in season two, September to December, in the Kamuli District of Uganda on land of the Nakanyonyi Primary School (lat. 0°56' 34.4" N, long. 33°02' 19.6" E). In each growing season, the plots were on different but similar sites at the primary school. The Kamuli District receives a bimodal rainfall that ranges between 900 and 1500 mm annually, with two growing seasons. March to May/June is the period when most of the rains are received (first growing season) and in August to October is when additional rains are received (second growing season) but are less than the first season (Kamuli District Local Government, 2011). Supplemental hand watering was used in each season during transplant establishment, and weekly thereafter if rainfall of $<$ 2.5 cm was received.

The field experiment was laid out in a randomized complete block design with a factorial and split-plot arrangement of treatments. Main plot treatments included three cultivars (Heinz 1370, Nuru F1, and MT 56), two levels of fungicide application (fungicide and no fungicide), two methods of plant training (staked and not staked), and a split plot of two levels of soil mulching (mulched and without mulch). Raised bed plots measuring 9.8 m long, 0.91 m wide, and 0.30 m high were prepared using manual tillage and tomato seedlings transplanted into plots. The 9.8-m-long raised beds had 16 plants spaced 0.60 m apart with the split plot having eight plants mulched and eight plants not mulched. A distance of 0.60 m was between the raised beds.

Soil type

The soil at Nakanyonyi Primary School is provisionally identified as “Nakanyonyi” series. It is formed from a biomantle of weathered granite and ash over pedogenic laterite on a very gently undulating plain ($<$ 1% slope). It is well drained with moderately low water-holding capacity. The limitation in water-holding capacity is the extensive laterite present at \approx 50 to 75 cm depth. The Nakanyonyi series is tentatively classified as a shallow, coarse-loamy, kaolinitic, isothermic Cumulic Hapludoll (C.L. Burras, personal communication).

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Soil fertility

In 2013 before each growing season, seven random samples were taken from different locations of the field, gravel removed by hand, and samples ground into finer particles. Equal quantities from each sample were mixed together thoroughly to make one representative sample per field, which was submitted to the Soil, Water and Plant Analytical Laboratory, College of Agriculture and Environmental Sciences, Makerere University, Kampala, Uganda, for analysis. Fertilizer (Invectra Agro Ltd, Limassol, Cyprus) was added in both seasons at Nakanyonyi Primary School to achieve uniform and optimal fertility across plots before treatment application using amounts based on Iowa State University soil test result interpretations (A. Nair, personal communication). Soil pH was 4.8 in season one and 5.6 in season two. Calcium carbonate was applied at a rate of 19,054.47 kg·ha⁻¹ in season one and 11,208.51 kg·ha⁻¹ in season two. In both seasons, a fertilizer formulation of 26N–20.1P–49.8K was applied at rates of 146, 224, and 224 kg·ha⁻¹ of N–P–K to maintain tomato growth and development.

Cultivars

Tomato cultivars included the following: Heinz 1370, a locally grown and determinate cultivar that was bred for processing; MT 56, a determinate and improved selection that was bred at Makerere University, Kampala, and is resistant to tomato bacterial wilt (Karungi et al., 2011); and Nuru F1, selected as a determinate, early-maturing F1 hybrid (East African Seed Company, 2016).

Pesticides

All pesticides were applied with a plastic backpack sprayer to the plots receiving the fungicide treatment. Pesticide treatments used in both growing seasons included two products containing systemic fungicides, Ridomil (metalaxyl) and Victory (Mancozeb and metalaxyl), one contact fungicide of Dithane M-45 (Mancozeb). Two insecticides, Thionex (endosulfan 35% emulsifiable concentrate) and Methomex (methomyl 90% soluble powder) (Invectra Agro Ltd), also were applied to all plots, but were not part of treatments. Products containing systemic fungicides were applied once every 2 weeks and were alternated in successive applications on different weeks. Contact fungicide and the insecticides were each applied weekly. The spray regimen followed label recommendations.

Staking

Tomato plants were tied to a trellis between stakes on 11 July and 5 Aug. during the first season and 22 Oct. and 12 Nov. in season two. Sisal twine was used to support plants growing between the wooden, 1.5-m-long stakes. Pruning of tomato plants was not used in the experiment to avoid disease spread among treatments.

Mulching

Dried elephant grass was applied to the soil surface of mulched plots at a depth of

0.1 m. To prevent pestiferous termite damage to the mulch, Pyrinex (chlorpyrifos) (Invectra Agro Ltd) was applied at label rates over the top of the mulch one time, as soon as mulch was placed on treatment plots.

Weeding

Hand weeding was completed every 3 weeks, and all weeds were removed from the plots.

Harvesting

Fruits were harvested twice a week starting 29 July through 10 Aug. in season one and 25 Nov. through 16 Dec. in the second season, 2013. Yield data were collected from all the eight plants in each subplot. Marketable (suitable for the market) fruits were counted and weighed. There is no standard grade of tomatoes in Uganda; tomatoes were classified and counted as nonmarketable fruits when exhibiting a split surface and/or insect or disease damage.

Labor

Hand labor was used for all activities. The time in minutes for fungicide application, staking, and mulching was recorded across all cultivars and was included in the calculation of the gross margin.

Disease severity

Weekly observations of the leaves of all eight plants per subplot for early and late blight and bacterial wilt symptoms were collected after all treatments had been applied to plots. The percentage of leaves attributed to disease was recorded for each subplot. These values were then used to calculate the area under the disease progress curve (AUDPC). The formula used to calculate the AUDPC was $\sum_{i=1}^{N_i-1} [(X_{i+1} + X_i)/2] [t_{i+1} - t_i]$; where X_i = the percentage of the leaves damaged at i^{th} week, t_i = the time in days after appearance of the disease at i^{th} week, N = the total number of observations (Madden et al., 2007).

Gross margin

Variable costs were calculated using the current input prices and labor costs (Engindeniz, 2007). Variable costs of tomato production included all inputs and labor directly related to treatments, including seeds of cultivars, fungicides, stakes, and mulch. The total production costs are the sum of the fixed costs and variable costs. For this experiment, we did not include the fixed costs because the goal was to determine the costs incurred for each treatment. Costs of practices that were assumed to be equal for all plots and were not included in the calculation of gross margin included labor and inputs of land preparation, germination, transplanting, fertilizer, insecticides used on tomato plants, and watering. Transportation of locally available inputs (mulch and stake) to the research site also were not included in the gross

margin. The costs that accrued from using the different treatments were calculated by dividing the overall cost of the treatment by the number of plots that received the treatment. To determine the gross production (revenue) for the different treatments, the average price of fresh tomatoes (kg) in the town of Kamuli at the time of harvest was multiplied by the fruit weight (kg per plot). Average price was determined in each season by making price inquiries in the local, primary town market and interviewing all sellers of fresh tomatoes ($n = 26$). The gross margin that accrued from use of the different treatments was determined by the difference between the gross production value and the cost incurred (Engindeniz, 2007).

Data analysis

Results for yield variables, AUDPC values, and gross margin were analyzed as a randomized complete block and a split-plot design using PROC MIXED routine of the SAS program (SAS Institute, 2011). Differences between least-square means of treatments were determined using LS MEANS statements and defining custom orthogonal contrasts between LS MEANS across cultivars. Significance of these differences was determined based on Tukey's adjustment for multiple comparisons.

Results

Interactions occurred among the main effects of cultivar, growing season, fungicide application, and mulching (Table 1). Therefore, data were analyzed and are presented within cultivar and growing seasons for fungicide application and mulch. There was no interaction of the main effect of staking.

Cultivar

In season one, cultivar MT 56 yielded more total fruits than Nuru F1 and Heinz 1370 by 42 and 73 respectively, whereas Nuru F1 yielded more than Heinz 1370 by 31 fruits (Table 2). In season two, 'Nuru F1' yielded more than 'Heinz 1370' and 'MT 56' by 57 and 34 fruits, respectively, whereas 'MT 56' also produced more fruit (23) than 'Heinz 1370'.

Marketable fruit number in season one showed cultivar MT 56 out-yielded Nuru F1 and Heinz 1370 by 21 and 43 fruits respectively, whereas Nuru F1 yielded more than Heinz 1370 by 22 marketable fruits. In the second season, 'MT 56' produced 14 more marketable fruits than 'Heinz 1370', whereas 'Nuru F1' out-yielded 'MT 56' and 'Heinz 1370' by 14 and 29 fruits, respectively.

In the first season, 'MT 56' marketable fruits weighed more than 'Nuru F1' and 'Heinz 1370' by 1.91 and 2.30 kg/subplot, respectively. In season two, 'MT 56' and 'Nuru F1' fruits weighed more than 'Heinz 1370' by 1.98 and 1.33 kg, respectively. Cultivar MT 56 had a positive gross margin (profit) of 0.67 (USD) per plot of eight plants, whereas Nuru F1 (–1.64 USD) and Heinz 1370 (–1.19 USD) produced negative gross

Table 1. Four-way analysis of variance of main effects for total and marketable fruit number, marketable fruit weight, gross margin, and early blight severity assessed by area under the disease progress curve (AUDPC) of tomato research in Kamuli District, Uganda.

Treatment	Total fruit number (no./subplot ^z)	Marketable fruit number (no./subplot)	Marketable fruit wt (kg/subplot)	Gross margin (USD/subplot)	AUDPC (per subplot ^y)
Cultivar					
Cultivar * fungicide	0.0143 ^x	0.0271	0.1798	0.1798	0.8613
Cultivar * stake	0.7680	0.6925	0.3724	0.3724	0.1113
Cultivar * mulch	0.2798	0.2258	0.1273	0.1273	0.8077
Cultivar * GS ^w	<0.0001	<0.0001	0.0300	0.0392	<0.0001
Fungicide application					
Fungicide * stake	0.1291	0.6665	0.6436	0.6436	0.0602
Fungicide * mulch	0.9705	0.5977	0.2886	0.2886	0.8531
Fungicide * GS	0.8908	0.3874	0.3568	0.0516	0.0278
Staking					
Stake * mulch	0.2363	0.4309	0.0759	0.0759	0.0766
Stake * GS	0.8443	0.9232	0.8322	0.2364	0.2631
Mulching					
Mulch * GS	0.1597	0.0502	0.0973	<0.0001	0.1509

^zSubplots had eight plants, row length of 4.9 m, and represent all harvests per season in 2013.

^yAUDPC = area under the disease progress curve was calculated using $= \sum_{i=1}^{N_i-1} [(X_{i+1} + X_i)/2][t_{i+1} - t_i]$; where X_i = the percentage of the leaves damaged at i^{th} week, t_i = the time in days after appearance of the disease at i^{th} week, N = the total number of observations.

^x P value of interaction effect between main effects as determined by Tukey's adjustment for multiple comparisons.

^wGS = growing seasons 1 (May to Aug. 2013) and 2 (Sept. to Dec. 2013).

Table 2. Comparisons of cultivar for total and marketable fruit number, marketable fruit weight, gross margin, and early blight severity assessed by area under the disease progress curve (AUDPC) of tomato plants in Kamuli District, Uganda.

Cultivar	Total fruit no.		Marketable fruit no.		Marketable fruit wt		Gross margin		AUDPC	
	Growing season ^z		Growing season		Growing season		Growing season		Growing season	
	1	2	1	2	1	2	1	2	1	2
	(no./subplot ^z)		(no./subplot)		(kg/subplot)		(USD/subplot ^z)		(per subplot ^w)	
Heinz 1370	50	21	16	9	1.21	0.77	-1.19	-1.35	3323	1275
MT 56	123	44	60	24	3.60	2.76	0.67	0.18	3154	729
Nuru F1	81	78	39	38	1.68	2.10	-1.64	-1.11	3424	1174
Comparisons^y										
Heinz 1370 vs. Nuru F1	-31	-57	-22	-29	NS	-1.33	NS	NS	-101	NS
Heinz 1370 vs. MT 56	-73	-23	-43	-14	-2.30	-1.98	-1.86	-1.53	169	546
Nuru F1 vs. MT 56	-42	34	-21	14	-1.91	NS	-2.31	-1.30	270	444

^zGrowing seasons 1 (May to Aug. 2013) and 2 (Sept. to Dec. 2013).

^ySubplots had eight plants, row length of 4.9 m, and represent all harvests per season in 2013.

^xData obtained in Uganda Shillings and converted to US dollars (1 USD = 2500 Uganda Shillings in 2013).

^wAUDPC = area under the disease progress curve was calculated using $= \sum_{i=1}^{N_i-1} [(X_{i+1} + X_i)/2][t_{i+1} - t_i]$; where X_i = the percentage of the leaves damaged at i^{th} week, t_i = the time in days after appearance of the disease at i^{th} week, N = the total number of observations.

^vOrthogonal comparison value within a column is the difference of all treatment combination means among cultivars within a growing season at $P \leq 0.05$; NS = not significant.

margins (loss) in the first season. The pattern was consistent in season two, with 'MT 56' producing a positive gross margin of 0.18 USD, whereas 'Nuru F1' and 'Heinz 1370' produced a negative gross margin of -1.11 USD and -1.35 USD, respectively (Table 2).

The AUDPC of cultivar Nuru F1 was 101 and 270 higher than that of Heinz 1370 and MT 56, respectively, whereas the AUDPC of Heinz 1370 was 169 higher than that of MT 56 in season one. In season two, the AUDPC of cultivar MT 56 was 546 and 444 lower than that of Heinz 1370 and Nuru F1, respectively (Table 2).

Horticultural practices within cultivars

'Heinz 1370'. Total and marketable fruit number and marketable fruit weight did not differ for treatments in each season (Table 3). The highest gross margin was from subplots that did not receive applications of fungicide and soil mulch but it did not differ from those

receiving fungicide and without mulch in both seasons. All gross margins were negative (loss); in seasons one and two, the lowest gross margins were from subplots receiving fungicides and mulch but did not differ from subplots with fungicide and without mulch and subplots of no fungicide and mulch.

'Nuru F1'. In season one, there were no differences among treatments for total and marketable fruit number, marketable fruit weight, and gross margin (Table 3). In season two, application of fungicides and soil mulch yielded the highest total fruit number (136), marketable fruit number (72), and marketable fruit weight (4.25 kg). Subplots that did not receive fungicide and with or without mulch had lower total fruit number than the subplots with fungicide and with or without mulch. All gross margins were negative in seasons one and two, but subplots that did not receive fungicide and mulch had the higher gross margins and did not differ from fungi-

cide and mulch and fungicide and no mulch. The least gross margin came from mulched subplots that did not receive fungicide and did not differ from subplots that received fungicide and mulch and fungicide and no mulch.

'MT 56'. Total fruit number and gross margin in season one and total and marketable fruit number and marketable fruit weight in season two were not different among treatments (Table 3). In the first season, subplots with application of fungicides and mulch had the highest marketable fruit weight (6.21 kg), compared with all other treatments, and marketable fruit ($n = 92$), which did not differ from treatments of fungicide and no mulch and no fungicide with mulch. Subplots without fungicides and mulch produced the lowest fruit weights (1.28 kg), but were not different from subplots without fungicide and with mulch, and plots with fungicide and no mulch. In season

two, subplots in which fungicides and mulch were not applied produced a positive gross margin (profit) of 1.61 USD per subplot of eight plants and did not differ from subplots with fungicide applied and no mulch applied (0.40 USD). Applications of fungicide and soil mulch produced the least gross margin but did not differ from treatments without fungicide and with mulch, and with fungicide and without mulch.

Positive gross margins (profits) were received for all treatments of 'MT 56' when the mulch was obtained locally (not purchased) and only labor for its cutting and application included in the calculation of the gross margin (Table 4).

In season one, the break-even price for MT 56 (0.55 USD) was below the Kamuli average price (0.80 USD), and the break-even yield (4.34 kg) was below the actual yield received from experimental plots (marketable fruit weight) (6.21 kg), resulting in positive gross margins received by cultivar MT 56 (Table 5).

In informal visits with tomato sellers in the local market, vendors were more inclined

to purchase and sell cultivars with a Roma or plum appearance because of expecting a longer shelf life. Sensory characteristics of flavor and overall taste of the fresh fruit were not considered by sellers because almost all fresh tomatoes are cooked in stews before consumption in the Kamuli District.

No significant interactions occurred between staking and growing season, and seasons were combined for total and marketable fruit number, marketable fruit weight, and gross margin. Staking did not affect total and marketable fruit number and marketable fruit weight; all gross margins were negative (losses) and a higher gross margin was obtained from plots that were not staked (-0.51 USD) compared with those that were staked (-0.96 USD).

AUDPC

Interactions occurred among the main effects of cultivar, fungicide application, and growing season for AUDPC. There was no interaction for the main effects of staking and mulching. Data are presented within cultivar and growing seasons for fungicide

application (Table 6). Application of fungicides to 'Heinz 1370' and 'Nuru F1' subplots resulted in a lower AUDPC in the first and second seasons compared with subplots that did not receive fungicides. In 'MT 56', the AUDPC for subplots receiving fungicide was lower (2904) than nonfungicide (3404) in season one. However, in the second season, subplots that received fungicide did not differ from the subplots that did not receive fungicide.

Significant interactions did not occur between growing seasons for AUDPC, and staking and mulching values are presented as a combination of both seasons (Table 7). The AUDPC was not different for staked and unstaked subplots, but mulching the soil reduced AUDPC.

Discussion

Tomato production is an important enterprise for small-landholder farmers in rural Uganda because tomatoes are a source of income and nutrition and are consumed widely by Ugandans. Challenges of inadequate

Table 3. Total and marketable fruit number, marketable fruit weight, and gross margin of three tomato cultivars grown with or without fungicide application and soil mulch in the Kamuli District, Uganda.

Treatments within cultivar	Total fruit no.		Marketable fruit no.		Marketable fruit wt		Gross margin	
	Growing season ^z		Growing season		Growing season		Growing season	
	1	2	1	2	1	2	1	2
	(no./subplot ^y)		(no./subplot)		(kg/subplot)		(USD/subplot ^x)	
Heinz 1370								
Fungicide (+), mulch (+)	60 a ^{w, v}	30 a	24 a	16 a	1.70 a	1.18 a	-2.42 b	-2.62 b
Fungicide (+), no mulch (-)	65 a	20 a	17 a	10 a	1.43 a	0.86 a	-1.46 ab	-0.82 ab
No fungicide (+), mulch (+)	50 a	20 a	19 a	8 a	1.36 a	0.67 a	-0.61 ab	-1.88 b
No fungicide (-), no mulch (-)	25 a	15 a	5 a	5 a	0.33 a	0.37 a	-0.26 a	-0.07 a
Nuru F1								
Fungicide (+), mulch (+)	104 a	136 a	57 a	72 a	2.71 a	4.25 a	-2.44 a	-0.99 ab
Fungicide (+), no mulch (-)	74 a	91 b	35 a	41 b	1.41 a	2.20 b	-2.30 a	-0.58 ab
No fungicide (+), mulch (+)	87 a	44 c	37 a	24 bc	1.60 a	1.16 b	-1.26 a	-2.32 b
No fungicide (-), no mulch (-)	57 a	43 c	26 a	15 c	1.01 a	0.80 b	-0.54 a	-0.56 a
MT 56								
Fungicide (+), mulch (+)	151 a	41 a	92 a	24 a	6.21 a	3.13 a	1.13 a	-1.11 b
Fungicide (+), no mulch (-)	118 a	37 a	63 a	24 a	3.46 b	2.46 a	0.11 a	0.40 ab
No fungicide (-), mulch (+)	136 a	55 a	60 ab	26 a	3.46 b	2.89 a	1.01 a	-0.16 b
No fungicide (-), no mulch (-)	88 a	43 a	24 b	21 a	1.28 b	2.54 a	0.45 a	1.61 a

^zGrowing seasons 1 (May to Aug. 2013) and 2 (Sept. to Dec. 2013).

^ySubplots had eight plants, row length of 4.9 m, and represent all harvests per season in 2013.

^xGross margin was calculated by subtracting the costs of seeds of cultivar, fungicides, and mulch, and labor for applying fungicides and mulch from the revenue accrued. Data obtained in Uganda Shillings and converted to US dollars (1 USD = 2500 Uganda Shillings in 2013).

^wMean separation within a cultivar and column by Tukey-Kramer ($P \leq 0.05$); means followed by the same letter within a cultivar and column are not different from one another.

^vTotal fruit number represents the quantity of fruits harvested per subplot. Marketable fruit is the number of fruits suitable for the market. Marketable fruit weight is the kilograms of the marketable fruit per subplot.

Table 4. Gross margin of 'MT 56' tomatoes (USD/subplot^z) calculated with respect to fungicide and soil mulch.

Treatment within 'MT 56'	Gross margin ^y		Gross margin	
	Growing season ^x		Growing season	
	1	2	1	2
	With labor and cost of purchased mulch		With labor and without cost of purchased mulch	
Fungicide (+), mulch (+)	1.13 a ^w	-1.11 b	2.10 a	0.61 a
Fungicide (+), no mulch (-)	0.11 a	0.40 ab	0.11 a	0.40 a
No fungicide (-), mulch (+)	1.01 a	-0.16 b	1.99 a	1.56 a
No fungicide (-), no mulch (-)	0.45 a	1.61 a	0.45 a	1.61 a

^zSubplots had eight plants, row length of 4.9 m, and data represent all harvests per season in 2013.

^yThe gross margin was calculated by subtracting the costs of 'MT 56' seeds and fungicides and labor to apply fungicides and mulch with and without the cost of purchased mulch from the revenue accrued. Data obtained in Uganda Shillings and converted to USD (1 USD = 2500 Uganda Shillings in 2013).

^xGrowing seasons 1 (May to Aug. 2013) and 2 (Sept. to Dec. 2013).

^wMean separation within a column by Tukey-Kramer ($P \leq 0.05$); means followed by the same letter within columns are not different from one another.

Table 5. Marketable fruit weight, cost of seed, mulch, and fungicide application, and break-even analysis for three tomato cultivars grown in two seasons in the Kamuli District, Uganda.

Cultivar	Marketable fruit wt		Costs ^y											
			Plus mulch				Variable cost		Break-even yield ^w					
	Growing season ^z		Seed		Growing season		Growing season		Growing season					
	1	2	1	2	1	2	1	2	1	2				
	(kg/subplot ^x)		Growing season		(USD/subplot)		Growing season		(USD/subplot)		Growing season		(kg/subplot)	
Heinz 1370	1.70	1.18	0.16	0.16	1.17	2.05	2.07	1.14	3.42	3.36	2.01	2.85	4.28	4.2
Nuru F1	2.71	4.25	1.00	1.00	1.17	2.05	2.07	1.14	4.25	4.19	1.57	0.98	5.32	5.2
MT 56	6.21	3.13	0.21	0.21	1.17	2.05	2.07	1.14	3.47	3.41	0.55	1.09	4.34	4.2

^zGrowing seasons 1 (May to Aug. 2013) and 2 (Sept. to Dec. 2013).

^yCosts were calculated by dividing the overall cost of the treatment by the number of subplots that received the treatment. Data obtained in Uganda Shillings and converted to US dollars (1 USD = 2500 Uganda Shillings in 2013).

^xBreak-even price = variable cost ÷ fruit weight.

^wBreak-even yield of marketable fruit weight = variable cost ÷ price (Kamuli average price = 0.80 USD/kg).

^vSubplots had eight plants and a row length of 4.9 m.

Table 6. Early blight severity assessed by area under disease progress curve (AUDPC) of three tomato cultivars grown with or without fungicide application and in the Kamuli District, Uganda.

Treatment within cultivar	AUDPC	
	Growing season ^z	
	1	2
Heinz 1370	Per subplot ^y	
Fungicide (+)	3,141 b ^{x,w}	1,083 b
No fungicide (-)	3,505 a	1,468 a
Nuru F1		
Fungicide (+)	3,210 b	1,007 b
No fungicide (-)	3,638 a	1,341 a
MT 56		
Fungicide (+)	2,904 b	634 a
No fungicide (-)	3,404 a	825 a

^zGrowing seasons 1 (May to Aug. 2013) and 2 (Sept. to Dec. 2013).

^ySubplots had eight plants, row length of 4.9 m, and represent all AUDPC values per season in 2013.

^xMean separation by Tukey-Kramer ($P \leq 0.05$); means followed by the same letter within columns are not different from one another.

^wAUDPC = area under the disease progress curve was calculated using = $\sum_{i=1}^{N_i-1} [(X_{i+1} + X_i)/2][t_{i+1} - t_i]$;

where X_i = the percentage of the leaves damaged at i^{th} week, t_i = the time in days after appearance of the disease at i^{th} week, N = the total number of observations.

information about horticultural practices of tomato production for eastern Uganda formed the basis for this investigation. Cultivars, fungicide application, staking, and mulching were tested for their impact on tomato yield variables, disease severity, and gross margin.

Interactions between growing season and cultivar were expected because the Kamuli District has two growing seasons and receives a bimodal rainfall with most of the rains received in season one (March through May/June), and less rains received in season two (August through October) (Kamuli District Local Government, 2011). In addition, the cultivars used in this study genetically were different.

Cultivar MT 56 yielded higher than Nuru F1 and Heinz 1370 and had a higher gross margin in season one owing to the least early

Table 7. Early blight severity assessed by area under disease progress curve (AUDPC) of tomatoes grown with or without staking or soil mulch in the Kamuli District, Uganda in two growing seasons.^z

Treatment	AUDPC (per plot ^v)
Staking	
Stake (+)	2,172 a ^{x,w}
No stake (-)	2,188 a
$P \leq 0.05$	NS
Mulching	
Mulch (+)	2,167 b
No mulch (-)	2,192 a
$P \leq 0.05$	0.0002

^zGrowing seasons combined: 1 (May to Aug. 2013) and 2 (Sept. to Dec. 2013).

^ySubplots had eight plants, row length of 4.9 m, and represent all AUDPC values across two growing seasons in 2013.

^xMean separation by Tukey-Kramer ($P \leq 0.05$); means followed by the same letter within column and treatment (staking and mulching) are not different from one another. NS = not significant.

^wAUDPC = area under the disease progress curve was calculated using = $\sum_{i=1}^{N_i-1} [(X_{i+1} + X_i)/2][t_{i+1} - t_i]$;

where X_i = the percentage of the leaves damaged at i^{th} week, t_i = the time in days after appearance of the disease at i^{th} week, N = the total number of observations.

blight disease (lowest AUDPC) and a higher number of marketable fruit, resulting in a higher marketable fruit weight. A higher marketable fruit weight together with a lower cost of seed compared with 'Nuru F1' increased the gross margin for 'MT 56'. Preliminary cultivar trials in the Kamuli District also found MT 56 to be among the highest-yielding cultivars (G.R. Nonnecke and S.M. Tusiime, unpublished data). 'Nuru F1' yielded more than 'MT 56' in the second season possibly because 'Nuru F1' can grow and yield well in a season that does not receive as much rainfall.

'Heinz 1370' produced the least total and marketable fruit number because of more early blight disease that reduced fruit production. Baliyan and Madhava (2013) reported 'Heinz 1370' as a low-yielding cultivar, a finding that is similar to our results, and 'Heinz

1370' was similar to 'Nuru F1' in terms of marketable fruit weight (season one) and gross margin (season two).

A high AUDPC value is associated with more disease, and in both seasons 'MT 56' had the least AUDPC. Some genetic tolerance to early blight might exist, although 'MT 56' was bred for resistance against primarily bacterial wilt (Asimwe et al., 2013; Karungi et al., 2011). 'Nuru F1' had the highest disease in season one but was not different from 'Heinz 1370' in the second season. 'Nuru F1' may have been selected for yield components and not disease tolerance. Our data agree with Maršić et al. (2005), who reported Heinz 1370 to be more susceptible to disease compared with the other cultivars, and Baliyan and Madhava (2013) who found Heinz 1370 was susceptible to various pests including diseases of early and late blight.

Because Heinz 1370 is not a high-yielding cultivar (Baliyan and Madhava, 2013; Tudzarov, 1996), all gross margins were negative (a loss) in both seasons when fungicides and mulch were used, and the lower yields below the break-even yield could not offset the input costs incurred.

Application of fungicides and use of soil mulch in the second season produced the highest total and marketable fruit number and marketable fruit weight in 'Nuru F1' (Table 2), agreeing with Akemn et al. (2000), who found an increase in tomato yields with the use of Dithane M45. The overall gross margins were negative (loss) because the higher cost of 'Nuru F1' seeds increased the total cost and the yield obtained was below the break-even yield, therefore revenues obtained could not offset the high input costs.

'MT 56' subplots that received fungicide and mulch yielded the highest marketable fruit and weight in season one, primarily because fungicides and mulch decreased disease, reduced the number of nonmarketable fruits, and increased marketable fruit number and weight. These results are consistent with Fontem (2003), who found higher yields in tomato plots that received fungicides compared with those that did not receive any fungicides because of a reduction in early blight disease. Keinath et al. (1996)

reported a 38% increase in tomato fruit weight when fungicides were applied. Also, mulching could have lessened the problems associated with disease infection (reducing splash and contact between plant leaves and soil), improved tomato plant growth, reduced soil erosion (Erenstein, 2002), weeds (Campiglia et al., 2010), and leaching of nutrients (Olasantan, 1999), and improved the soil's physical environment (soil moisture, temperature) (Erenstein, 1999; Hapaala et al., 2014). Higher gross margin was achieved in plots without costs incurred from fungicides, stakes, and mulch. Also, 'MT 56' seeds did not cost as much as the 'Nuru F1' hybrid seed.

Fungicide applications reduced early blight disease for 'Heinz 1370' and 'Nuru F1' in the first and second seasons and for 'MT 56' in the first season. Earlier studies by Fontem (2003) and Sood and Sharma (2004) found low early blight severity with the use of fungicides compared with no fungicide use. However, in season two when less rainfall typically occurs, the 'MT 56' subplots that received fungicide did not differ from the subplots without fungicide application in terms of early blight disease. In both seasons, total and marketable fruit number and marketable fruit weight did not differ between staked and unstaked plots, in agreement with Tewari and Vishunavat (2012). In contrast, earlier studies (Huxley, 1962; Wurster and Nganga, 1970), found that staking reduced tomato yields, whereas a later study (Karungi et al., 2011) indicated that the staking increased yields. In our study, the purchase of materials and labor associated with staking reduced gross margin without the benefit of increased marketable fruit.

Soil particles may contain infective fungal spores, such as early blight (Wharton and Kirk, 2007). We found reduced disease in this study when mulch was used, possibly because it lessened soil splash onto the lower leaves of the tomato plants. Mulching acts as a barrier and prevents the fungal spores from moving to plants from the soil surface. A hairy vetch residue applied as mulch decreased early blight of tomato (Mills et al., 2002).

Study Limitations

'MT 56' tomato officially has not been released in the Ugandan horticulture industry and availability of seeds may be a concern for Ugandan tomato growers. Prices used for tomatoes, inputs, and market sales can differ, and these will affect gross margin results. Additional factors not researched and that may limit tomato yield include low soil fertility, inconsistent rainfall, and lack of extension services on horticultural production and management topics to assist small-landholder farmers.

Conclusions

In this study, factors that helped prevent early blight disease infection and spread provided the best gross returns. These in-

cluded the use of disease-tolerant MT 56 tomato cultivar and fungicide application in season one, and disease-tolerant MT 56 in season two. If soil mulch is available locally and does not have to be purchased, it should be used in both seasons. Staking of determinate cultivars was not beneficial. Postharvest handling and consumer acceptance of new disease-tolerant cultivars should be determined for marketplace acceptance.

Implementation of a national seed policy is needed to ensure a reputable and certified seed industry in Uganda to distribute improved tomato cultivars and provide access by small-landholder farmers. Cultivar MT 56 could be profitable for farmers if its seed is available. Because small-landholder farmers lack access to open-pollinated cultivars that are disease tolerant and an improved seed distribution system in Uganda, further research to develop or determine additional disease-tolerant tomato cultivars for Uganda's climate and soil and distributed throughout an efficient and affordable seed system will assist small-landholder farmers increase sustainable production and their rural livelihoods.

In Uganda, reliable soil quality and climate data of all districts are not available. Efforts are needed to provide accurate weather information and site-specific soil maps for the Kamuli District. These data are needed to help small-landholder farmers and extension agents plan appropriate agricultural outreach programs, determine integrated pest management strategies, and make informed production decisions to sustainably produce tomatoes for Ugandan markets.

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