Chapter 13
Impacts of Transboundary Crop Diseases on Sustainable Crop Production: The Case of Maize Lethal Necrosis (MLN) in Africa

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Abstract More than half of the world's population relies on wheat, maize, and rice for their daily dietary energy. In 2019, the daily per person average calorie intake was 2,963 kilocalories (kcal), in which the share was more than 18.2% (538 kcal) for wheat, 5.4% (159 kcal) for maize, and 18.3% (542 kcal) for rice. It is projected that by 2050, the total global population is expected to reach between 8.9 and 10.6 billion from 7.8 billion in 2020. Thus, it will be imperative to produce more wheat, maize, and rice to ensure the food security of the world's burgeoning population. While it is imperative to produce more food, the emergence and re-emergence of lethal crop diseases and their spread from the epicenters to new regions continuously threaten crop yield, farmers' income, and the world's food security. For example, the emergence of maize lethal necrosis (MLN) in Africa has generated a credible threat to global and African food security. This study quantified MLN-induced maize production loss in Kenya, DR Congo, and Tanzania. Applying the time-series projection method, this study estimates that the loss in maize production due to MLN was 442 thousand tons in Kenya, nearly 12 thousand tons in DR Congo, and 663 thousand tons in Tanzania. As more pest- and disease-related crop losses are expected due to the changes in global climate, this study concludes by suggesting that it is imperative to invest more in research and development of disease-resistant crop varieties globally to ensure food and nutrition security, particularly in the global south.

13.1 Introduction

Currently, an estimated 821 million people—10.9% of the world's population—do not have enough to eat (FAO et al. 2019). At the same time, 149.2 million children

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below five years old are stunted, 45.4 million are wasted, 38.9 million are overweight, and more than 40% of all men and women (2.2 billion people) are obese or overweight (Development Initiatives 2021a). By 2050, the global population is expected to reach between 8.9 billion to 10.6 billion people, and an estimated 2 billion people will face hunger under the business-as-usual scenario (UN 2019). Cereals like wheat, rice, and maize are the major dietary energy sources in many emerging economies in Sub-Saharan Africa, Latin America, and Asia, where most undernourished people live. To eliminate hunger by 2030 as per the United Nations (UN) Sustainable Development Goals (SDGs), more cereals and nutrition-enriched cereals, in particular, must be supplied to food-insecure countries in Asia and Africa. A few projections indicate that it will be imperative to supply 70–110% more food by 2050 to ensure global food security (FAO 2009; Tilman et al. 2011). The question as to how to supply more food comes to the fore.

One of the important ways to produce more food, particularly quality food, is by minimizing the pest- and disease-induced crop production losses. Due to pests and diseases, loss in crop production has been present since the dawn of human civilization. In the last three decades, however, the world has witnessed an unprecedented emergence, re-emergence, and globalization of lethal pests and diseases of crops, which have threatened the sustainability of the global food system (Bhattacharya 2017; Bueno-Sancho et al. 2017; Mehrabi and Ramankutty 2019; Pennisi 2010; Singh et al. 2019; Wellings 2007). For example, the re-emergence of a more aggressive variant of stem or black rust in wheat, known as UG99, in Uganda, Kenya, Ethiopia, Yemen, Syria, Iran, Afghanistan, Pakistan, and India (Beddow et al. 2015; Singh et al. 2019; Yahyaoui et al. 2008); the emergence of wheat blast in Bangladesh (Islam et al. 2016) and Zambia (Tembo et al. 2020); desert locust infestation in the Horn of Africa (Devi 2020; Salih et al. 2020); and maize lethal necrosis (MLN) in Kenya (Wangai et al. 2012), Ethiopia, Uganda, Tanzania, Rwanda, and the DR Congo (CIMMYT 2020). The ever-increasing trade and travel in a globalized world and global warming due to climate change are the major contributing factors to the globalization of crop pests and diseases (Anderson et al. 2004; Deutsch et al. 2008; Savary et al. 2019).

While there is a consensus about the destructive impacts of pests and diseases of crops on sustainable crop production, there is no consensus on the size and severity of the crop damage induced by pests and diseases. For example, assuming a 10% loss in cereal production due to pests and diseases, Marlatt (1904) estimated that in 1904, the monetary value of production loss in cereals in the USA was USD 200 million. Cramer (1967) stressed that the total loss in wheat and maize were 23.9% and 34.8% in 1964–65. Oerke et al. (1994) calculated that the actual global loss in wheat and maize due to pests and diseases were 34% and 38.3%, respectively. Using the latest data and dividing the crop production area into 19 regions, based on the crop production intensity and conditions, Oerke (2006) estimated that the total loss in crop production due to weeds, pests, and diseases are 28.1% for wheat, 31.2% for maize, and 37.4% for rice. Using the expert solicitation method, Savary et al. (2019) estimated that global annual crop losses due to pests, diseases, and weeds are 21.5% in wheat, 22.5% in maize, and 30% in rice.

Importantly, crop loss due to pests and diseases is country- and region-specific. Due to the advent of modern technology, improved agronomic practices, and seeds, such as hybrid and transgenic seeds, agricultural production and intensity have been evolving considerably in the twenty-first century. This suggests conducting country- and crop-specific case studies to quantify the economic loss in crop production due to pests and diseases. This study aims to estimate the loss in maize production in Kenya, DR Congo, and Tanzania due to the outbreak of MLN.

MLN is a disease in maize caused by the combination of maize chlorotic mottle virus (MCMV) and any of the viruses belonging to the Potyviridae family (Mahuku et al. 2015). The disease can destroy maize yield by 100% in a severe case. MLN was first reported in Peru in 1974 (Castillo and Hebert 1974; Hebert and Castillo 1973) and in the USA in 1976 (Niblett and Claflin 1978). Later, the disease was reported in several countries in the Americas, Asia, and Africa (Teyssandier et al. 1983). For a detailed list of the countries affected by MLN, please see Boddupalli et al. (2020). In 2011, for the first time in history, MLN was first reported in southwestern Kenya (Wangai et al. 2012), and by 2013, this lethal maize disease had spread to all maize-cultivating areas of Kenya (CIMMYT 2022b). In DR Congo, MLN emerged in 2013 (Lukanda et al. 2014), and in Tanzania, MLN was first reported in 2012 (CIMMYT 2022a) (Fig. 13.1). Using FAOSTAT (2022a) data and applying the time-series estimation procedure, this study demonstrated that the loss in maize production due to MLN outbreak in the sampled countries, where maize is a major staple food, was significant.

The case is worth investigating for two important reasons. First, it is imperative to develop and scale-out improved agronomic practices and resistant and resilient crop varieties, to minimize the loss in crop production due to pests and diseases. To develop and scale-out resistant varieties and improve agronomic practices, it is necessary to ensure adequate international donor agencies' financial support for research and development. However, to convince donors and international development agencies,
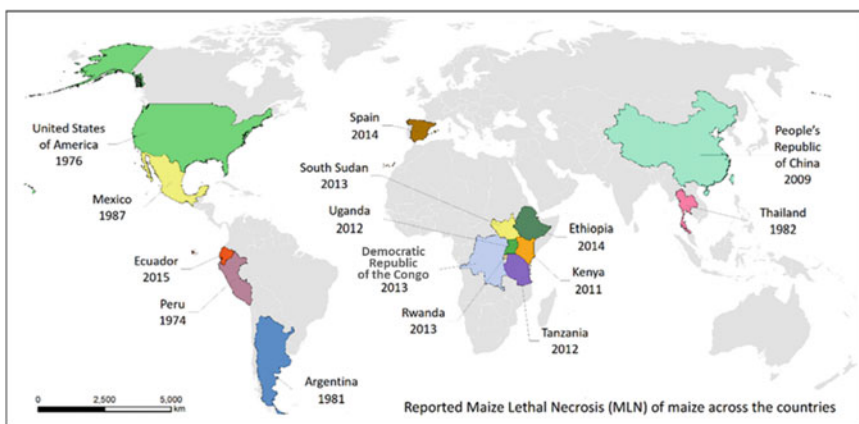

Fig. 13.1 MLN-affected countries in the world and year of emergence

it is necessary to showcase the loss in crop production based on country-, crop-, and disease-specific cases.

Second, maize is the most produced crop in the world. In 2019, total production in the world was around 765 million tons for wheat and 749 million tons for rice; but maize production was 1,141 million tons, and the crop was cultivated in 166 countries (FAOSTAT 2021a). Globally, 66% of the total wheat and 82% of the total rice produced is consumed as food (FAOSTAT 2021b). In the case of maize, less than 13% of total maize in the world is used as food, and nearly 59% is used as feed. The world's yearly per capita maize consumption is 19 kg, and maize supplies 159 kcal of the daily dietary energy requirement per person (FAOSTAT 2021b). Maize in Africa, however, is the major staple food. More than 66% of the total maize produced in Africa is consumed as food (FAOSTAT 2021b). The yearly average maize consumption in Africa is more than 43 kg per person, and maize supplies 383 kcal of the daily dietary energy requirement. Among the sampled countries, 99% of maize produced in Kenya is used as food, 84% in DR Congo, and 57% in Tanzania (FAOSTAT 2021b). As maize is the major food item, outbreaks of the devastating MLN have generated severe havoc on the food security of the sampled countries, where the food security situation is already precarious. The economic quantification of the loss in maize production due to the MLN outbreak in the three sampled countries demonstrates that the loss was significantly large. This study strongly urges international research organizations and donor agencies to extend support to mitigate the problem to ensure food security and income of the smallholder farmers in Kenya, DR Congo, and Tanzania.

Studies on quantifying loss in maize production due to the MLN outbreak in Africa are few. Gitonga and Snipes (2014) estimated that in 2014, 60,000 ha of maize area in Kenya was affected by MLN, which was 9% of the country's total maize area, with an estimated production loss of USD 50 million. Using qualitative information collected through focused group discussion in Kenya, De Groote et al. (2016) estimated a loss of 0.5 million tons of maize worth USD 187 million. Mahuku et al. (2015) reported up to 90% (equivalent to 126 thousand tons) loss in maize yield in Kenya in 2012 in the affected fields, valued at USD 52 million. The novelty of the current study is that it is based on real production data that are matched with the real-time outbreak of MLN in the sampled countries. Moreover, it is based on a simple time-series estimation process, which is relatively easy to understand.

The rest of the study is organized as follows. Section 13.2 presents materials and methods, Sect. 13.3 includes descriptive findings, Sect. 13.4 presents the simulation results, and Sect. 13.5 includes the conclusion and policy implications.

13.2 Materials and Methods

13.2.1 Data

To quantify the economic impacts of MLN on maize production in Kenya, DR Congo, and Tanzania, this study relied on the FAOSTAT dataset—an online web portal of the Food and Agriculture Organization of the United Nations (FAOSTAT 2022a). Maize is the major food item in the sampled countries. In 2019, the total domestic supply of maize (domestic production + imports) in Kenya was 8 million tons, of which 91% (7.28 million tons) was consumed as food (FAOSTAT 2021b). In DR Congo in 2019, the domestic supply of maize was 2.25 million tons, of which 80% (1.8 million tons) was consumed as food (FAOSTAT 2021b). In Tanzania in 2019, the total domestic supply of maize was 5.33 million tons, of which 61% (3.24 million tons) was consumed as food (FAOSTAT 2021b). To quantify the maize production loss due to the MLN outbreak in the sampled countries, this study used the area, production, and yield of maize in the sampled countries.

13.2.2 Estimation Process: Predicting Maize Yield

The MLN emerged for the first time in Kenya in 2011 (Wangai et al. 2012); in Tanzania in 2012 (CIMMYT 2022a); and in DR Congo in 2013 (Lukanda et al. 2014). To assess the loss in maize production due to the MLN outbreak, the per ha yield loss was estimated as follows:

$$E(y_l) = E\left(\overline{\overline{y}}_e\right) - y_{ta}$$

where $E(y_1)$ is the estimated yield loss per ha (ton/ha), $E\left(\overline{\overline{y}}_e\right)$ is the predicted (expected) yield, and y_{ta} is the actual yield of maize in the MLN-affected year. Total production loss ('000 tons) due to MLN (Q_1) was calculated as:

$$Q_1 = E(y_l) \times A_{ta}$$

where A_{ta} is the total maize area (hectares or ha) in the MLN-affected year. The economic valuation of maize production loss is calculated as: $Q_1 \times$ producers' price of maize (USD/ton) in the MLN-affected year.

13.2.3 Maize Yield Prediction: Specifying the Autoregressive Integrated Moving Average (ARIMA) Estimation Process

To predict the maize yield $(\bar{\bar{y}}_e)$ in Kenya, DR Congo, and Tanzania, this study employed univariate time-series analysis applying the autoregressive integrated moving average (ARIMA) estimation method developed by Box and Jenkins (1976). Symbolically,

$$(yield)_t = \beta_0 + \sum_{i=1}^{p} \beta_i (yield)_{t-1} + \sum_{j=1}^{q} \alpha_i u_{t-j} + u_t$$

where yield is the actual maize yield (ton/ha) in year $t(= 1961–2020)$, p is the number of lags of the dependent variable (maize yield), q is the number of lags of the error term u_t, and t is the year ($t = 1961–2020$).

To apply the ARIMA method, a series must be stationary. To check the stationarity, the augmented Dickey-Fuller test procedure was applied. The unit root test statistics result is presented in Table 13.1. In the case of Kenya and Tanzania, a simple natural log of the yield turned the series stationary. In the case of the maize yield data for DR Congo, the first difference of the natural log form of the maize yield variable rejects the null hypothesis of the presence of the unit root in the data, making the data stationary.

We tabulated and graphed autocorrelations and partial autocorrelations to determine the number of lags (p) of the dependent variable and the number of lags (q) of the error term. The model that provided better prediction power for Kenya was ARIMA (1, 0, 4); ARIMA (2, 1, 1) for DR Congo; and ARIMA (1, 0, 3) for Tanzania.

Table 13.1 Augmented Dickey-Fuller test for unit root (H0: Random walk without drift, $d = 0$)

Sampled countries	Kenya	DR Congo	Tanzania
Dependent variable	ln (maize yield)	d2.ln (maize yield)	ln (maize yield)
Constant	0.14*** (0.04)	0.002 (0.003)	0.07* (0.04)
ln (yield)$_{t-1}$	−0.32*** (0.09)		−0.31*** (0.09)
d.ln (yield)		−1.23*** (0.13)	
No. of observations	59	58	59
Z(t)	−3.34**	−9.50***	−3.27**
MacKinnon approximate p-value for Z(t)	0.01	0.00	0.02
Dickey-Fuller critical value of Z(t) 5%	−2.92	−2.92	−2.92

Note Values in parentheses are standard errors. *, **, and *** indicate significance at 10%, 5%, and 1% level, respectively

13.3 Descriptive Findings

The temporal changes in maize area (million ha), production (million tons), yield (tons/ha), and net export (export–import, '000 tons) in the sampled countries are shown in Table 13.2. The yearly maize consumption per capita (in kg) and the daily dietary energy intake from maize in the sampled countries are also presented.

In Kenya, maize is the major staple food and a major source of livelihood for millions of smallholder farmers. Over the years, the maize area and maize production have consistently increased in Kenya, as illustrated in Table 13.2. However, maize yield in Kenya oscillated between 1.2 and 1.8 tons/ha during 1961–2020. Therefore, the growth in maize production has mainly come from area expansion than a productivity gain. Interestingly, although maize is the major staple food of Kenya, the consumption of maize has been showing a declining trend. In 1961, the yearly per capita maize consumption in Kenya was 112 kg, which supplied 972 kcal of the daily dietary energy per person, 43% of the total daily calorie intake of a person in Kenya (1,149 kcal). In 2019, the yearly per capita maize consumption reduced to 74 kg, equivalent to 642 kcal dietary energy or 29% of the total dietary energy intake (2,205 kcal). Despite a declining trend in per capita maize consumption, the maize yield of Kenya failed to increase because the increase in aggregate demand stemmed from the increase in population. Consequently, the net maize import of Kenya has increased over the years. In 1961, the net maize import of Kenya was 103 thousand tons, which has increased to 260 thousand tons in 2019. In 2010, the year before the MLN infestation, the maize yield was 1.73 tons/ha, whereas in 2011, when the MLN emerged, maize yield was 1.58 tons/ha. In a report, the Government of Kenya recognized that the MLN outbreak is a major threat to achieving self-sufficiency in the country's maize production (Government of Kenya 2019).

In DR Congo, maize is the second major staple food after cassava. As shown in Table 13.2, maize area (million ha) and production in the country have increased during 1961–2020. Over the years, the maize area and maize production have consistently increased in DR Congo. However, like Kenya, maize yield in DR Congo also stagnated at less than 0.80 tons/ha for a long time. As a result, the growth in maize production has mainly come from area expansion than a productivity gain. Also, the per capita maize consumption in DR Congo has shown a declining trend. In 2011, the yearly per capita maize consumption in DR Congo was 24.1 kg, equivalent to 221 kcal dietary energy per person and more than 11% of the daily total calorie intake (1,920 kcal) of a person in DR Congo. In 2019, yearly per capita maize consumption was reduced to less than 21 kg, equivalent to 190 kcal dietary energy or nearly 10% of a person's total dietary energy intake (1,913 kcal) in DR Congo. Despite a declining trend in per capita maize consumption, the domestic maize production of DR Congo failed to increase since the increase in demand stems from the increase in population. Consequently, the net maize import of DR Congo has increased over the years. In 2011, the net maize import of DR Congo was 64 thousand tons, which has increased to 121 thousand tons in 2019. The MLN emerged in DR Congo in 2013.

Table 13.2 Temporal changes in maize area (million ha), production (million tons), and yield (tons/ha) in the sampled countries, 1961–2019 (FAOSTAT 2022a)

Country	Year	Area (million ha)	Production (million tons)	Yield (ton/ha)	Export–Import ('000 tons)	Consumption (yearly per capita per kg)	Daily kcal
Kenya	1961	0.75	0.94	1.25	−103	112	972 (43)
	1971	1.15	1.40	1.22	−29	109	953 (41)
	1981	1.12	1.77	1.58	−76	115	997 (44)
	1991	1.31	2.40	1.83	21	88	763 (38)
	2001	1.64	2.79	1.70	−318	85	740 (36)
	2011	2.13	3.38	1.58	−299	87	757 (35)
	2019	2.29	3.58	1.56	−260	73.7	642 (29)
	2020	2.19	3.79	1.73	–	–	–
DR Congo	1961	0.54	0.37	0.69	–	–	–
	1971	0.61	0.44	0.72	–	–	–
	1981	0.76	0.64	0.83	–	–	–
	1991	1.26	1.02	0.81	–	–	–
	2001	1.46	1.17	0.80			
	2011	2.43	1.89	0.78	−64	24.1	221 (11.5)
	2013	2.55	1.98	0.78	−44	24.6	226 (12.0)
	2019	2.77	2.14	0.78	−121	20.7	190 (9.9)
	2020	2.74	2.11	0.77	–	–	–
Tanzania	1961	0.79	0.59	0.75	−47	50.4	451 (25.8)
	1971	0.98	0.72	0.73	4	46.8	419 (24.9)
	1981	1.35	1.84	1.36	−155	84.0	751 (34.2)
	1991	1.84	2.33	1.26	5	76.9	687 (30.8)
	2001	0.85	2.65	3.14	−65	68.6	613 (30.2)

(continued)

Table 13.2 (continued)

Country	Year	Area (million ha)	Production (million tons)	Yield (ton/ha)	Export–Import ('000 tons)	Consumption (yearly per capita per kg)	Daily kcal
	2011	3.29	4.43	1.32	−12	57.7	516 (22.8)
	2012	4.12	5.10	1.24	160	61.1	516 (23.8)
	2019	3.43	5.65	1.65	184	55.9	500 (21.1)
	2020	4.2	6.71	1.60	–	–	–

In terms of yearly per capita consumption, maize (56 kg per capita per year) is the second major staple food after cassava (92 kg per capita per year) in Tanzania, but in terms of the daily dietary energy intake per capita, maize is the major staple food (500 kcal daily per capita). As Table 13.2 illustrates, maize area and maize production have consistently increased over the years. Maize yield, however, initially increased and then declined drastically. In 1961, the maize yield in Tanzania was 0.75 tons/ha, increasing to 3.14 tons/ha in 2001. However, after that, the maize yield in Tanzania decreased significantly. In 2020, maize yield was 1.60 tons/ha. In terms of net trade (export–import), Tanzania emerged as a net exporter of maize. In 2019, the country exported 184 thousand tons of maize. MLN-affected the maize fields in Tanzania in 2012. In 2011, the year before the MLN invasion, maize yield was 1.32 tons/ha, whereas in 2012, when MLN emerged, maize yield was 1.24 tons/ha. This reduction in maize yield in 2012 is mainly due to MLN.

13.4   Major Findings: Quantifying the Economic Loss of MLN Outbreaks

Estimated functions explaining maize yield prediction in Kenya, DR Congo, and Tanzania applying the ARIMA estimation process are presented in Table 13.3. The model's fitness was checked by examining the white-noise property of the error term and the Eigenvalue stability conditions for both AR (autoregressive) and MA (moving average). Table 13.3 also shows that the estimated functions explaining maize yield in the sampled countries are statistically stable and are good fits.

The actual maize yield in the three countries during 1961–2020 and the predicted yield applying the Box-Jenkins method after the ARIMA estimation process for 1961–2030 are shown in Figs. 13.2, 13.3, and 13.4. The parallel movement of the actual maize yield trend and the predicted maize yield in the sampled countries indicates the strength of the prediction process used in this study.

The model estimated that the expected maize yield in Kenya in 2011, when MLN first emerged in the country, was 1.79 tons/ha, and the actual maize yield was 1.58

Table 13.3 Estimated functions applying the ARIMA estimation process explaining maize yield in the sampled countries (Author's estimation)

	Kenya	DR Congo	Tanzania
	ln (maize yield)	d.ln (maize yield)	ln (maize yield)
Constant	0.40*** (0.11)	0.0020 (0.00)	9.37*** (0.23)
ARMA			
AR			
ln (maize yield)$_{t-1}$	0.94*** (0.07)		0.94*** (0.10)
d.ln (maize yield)$_{t-1}$		−1.15*** (0.17)	
d.ln (maize yield)$_{t-2}$		−0.29 (0.18)	
MA			
u_{t-1}	−0.19 (0.14)	1.00 (56.27)	−0.53* (0.31)
u_{t-2}	−0.75*** (0.12)		0.16 (0.23)
u_{t-3}	0.23* (0.13)		−0.18 (0.19)
u_{t-4}	0.22* (0.13)		
Sigma			
Constant	0.10*** (0.01)	0.024 (0.67)	0.25*** (0.02)
Observations	60	59	60
Log-likelihood	51.47	136.0	−1.95
Wald chi^2 (5)	221.7	158.1	386.21
Prob < chi^2	0.00	0.00	0.00
Portmanteau test for white noise			
Portmanteau (Q) statistic	18.7	16.3	19.27
Prob < chi^2 (28)	0.91	0.95	0.89
Eigenvalue stability condition			
AR parameters satisfy stability condition	Yes	Yes	Yes
MA parameters satisfy the invertibility condition	Yes	Yes	Yes

tons/ha (Table 13.4). Thus, the per ha loss in maize yield was 211 kg. As the total maize area in 2011 was 2.13 million ha, the total maize production loss is estimated at more than 442 thousand tons. In 2011, the producer's price of maize in Kenya was USD 281/ton. Thus, the loss in maize production in Kenya in 2011 is estimated at USD 124.2 million. This finding is lower than the findings of De Groote et al. (2016), who estimated a loss of 0.5 million tons of maize worth USD 187 million in Kenya due to MLN.

The model estimated for DR Congo (Table 13.4) shows that the expected maize yield in 2013, when MLN emerged in the country for the first time, was 0.784 ton/ha, while the actual maize yield in the same year was 0.779 ton/ha. Thus, the per hectare loss in maize yield in DR Congo was calculated at 4.62 kg. As the total maize area
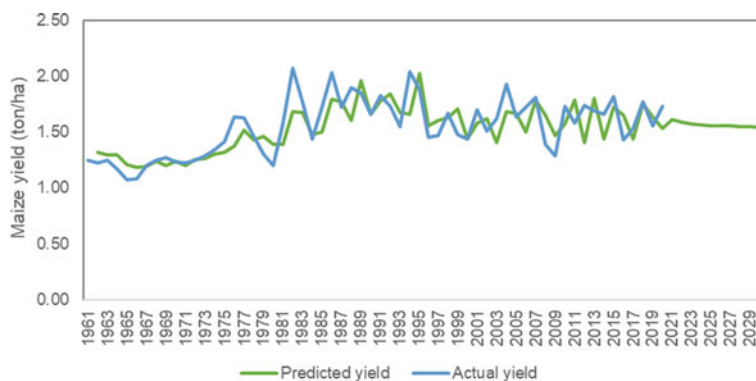
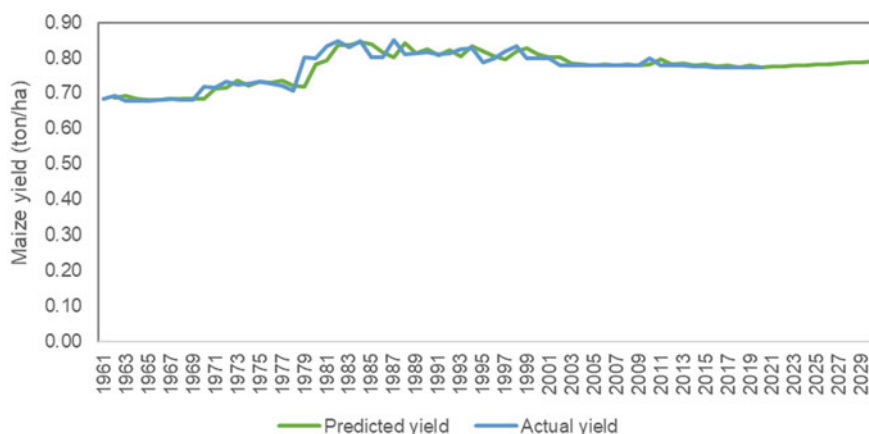**Fig. 13.2** Predicted (1962–2030) and actual (1961–2020) maize yield in Kenya

Fig. 13.3 Predicted (1962–2030) and actual (1961–2020) maize yield in DR Congo

was 2.50 million ha, the total maize production loss in 2013 is calculated at more than 11.6 thousand tons. In 2013, the maize export price of DR Congo was USD 84.8/ton,[1] with the loss in maize production estimated at USD 0.98 million.

The model estimated for Tanzania (Table 13.4) shows that the expected maize yield in 2012, when MLN first emerged in the country, was 1.40 tons/ha, and the actual maize yield in the same year was 1.24 tons/ha. Thus, the per hectare loss in maize yield for Tanzania was calculated at 162 kg. As the total maize area in Tanzania in 2012 was 4.10 million ha, the total maize production loss in 2012 is calculated at more than 663 thousand tons. In 2012, the producer's price of maize in Tanzania was USD 163/ton, with the loss in maize production estimated at USD 108.1 million.

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[1] Producer's price of maize for DR Congo in 2013 was not available in FAOSTAT. In 2013 DR Congo reportedly exported 224 tons of maize worth USD 84.8/ton. In quantifying the production loss for DR Congo, this study used the maize price of USD 84.8/ton.
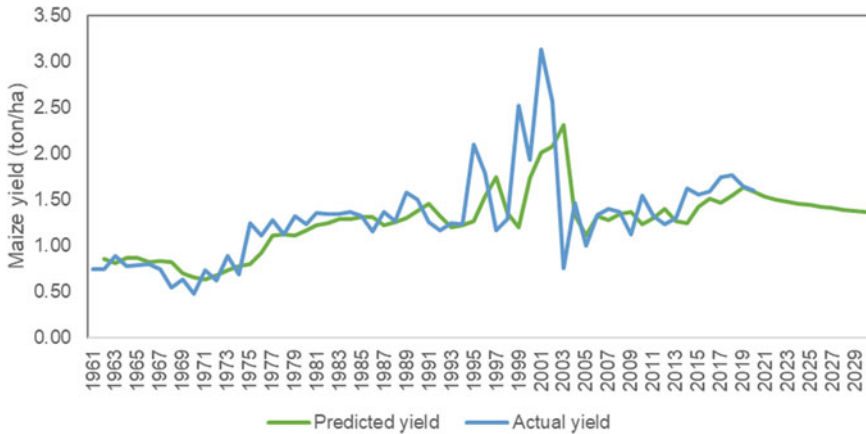
Fig. 13.4 Predicted (1962–2030) and actual (1961–2020) maize yield in Tanzania

It must be mentioned here that this study only considered the direct loss in maize production due to the MLN outbreak in the sampled countries. In reality, because of MLN, many smallholder farmers were forced to stop maize cultivation partially or completely or were forced to switch to other crops. Such involuntarily transition in cropping pattern is a deviation from the Marshallian net utility maximization or Pareto optimality condition. However, this study did not consider market loss due to involuntary transition in cropping patterns in the sampled countries.

13.5 Conclusion and Policy Implications

While it is imperative to supply more food, the emergence, re-emergence, and the global spread of lethal pests and diseases of crops have generated credible threats to sustainable crop production systems. A successful minimization of crop losses due to pests and disease infestations can significantly contribute to global food security. Developing and scaling out improved agronomic practices and resistant and resilient crop varieties are imperative to minimize crop losses due to pests and diseases. For this, strong financial support for research and development (R&D) from the donor communities is necessary. However, to convince donor communities, evidence-based cases must be presented. Using the MLN outbreak in Africa, this study quantified the economic loss in maize production due to the MLN outbreak in Kenya, DR Congo, and Tanzania.

Historically, MLN was long confined to the Americas. For the first time in history, in 2011, MLN was first reported in southwestern Kenya (Wangai et al. 2012), and by 2013, this lethal maize disease had spread to all maize-cultivating areas of Kenya (CIMMYT 2022b). In DR Congo, MLN emerged in 2013, and in 2012 MLN emerged in Tanzania.

Table 13.4 Quantifying loss in maize production due to MLN outbreak in the sampled countries. (Sources: FAOSTAT 2022b[a], c[b])

Country	Predicted maize yield	Actual yield in the MLN-affected year	Maize area in the MLN-affected year (A_0) (million ha)	Yield loss (kg/ha)	Total production loss ('000 tons) Q_1 = $\Delta Y \times A_0$	Producers' price of maize in the MLN-affected year (USD/ton)[a]	Monetary value (million USD) of the total lost production ($Q_1 \times P_r$)
Kenya	1.79	1.58	2.13	211	442.1	281	124.2
DR Congo	0.784	0.779	2.50	4.62	11.56	84.82[b]	0.98
Tanzania	1.40	1.24	4.10	162	663.1	163	108.1

This study estimated that the losses in maize production in Kenya and Tanzania are significantly large. In Kenya in 2014, 26.2% of the children under five years old were stunted; in 2019, 13.4% of adult males and 8.9% of adult females were underweight (Development Initiatives 2021d). In DR Congo in 2017, 41.8% of the children under five were stunted; and in 2019, 17.8% of adult males and 12.3% of adult females were underweight (Development Initiatives 2021b). In Tanzania in 2018, 31.8% of the children under five were stunted; and in 2019, 11.5% of adult males and 9.0% of adult females were underweight (Development Initiatives 2021c). The emergence of MLN and the loss in maize production due to MLN have created further havoc on these three countries' already precarious food security situation.

This study is a call for action to fight MLN in Africa. This study strongly suggests short- and long-term effective strategies to eliminate the MLN threat in Africa. In the short-run, assured investment is needed in R&D to fully understand the disease dynamics in the African setting, actively observe its emergence and re-emergence in the regions, and develop and scale-out effective practices to control the spread and crop damage. Since the disease is new in Africa, it is important to develop awareness among the farmers about this lethal disease. For example, as MLN is mainly a seed-borne disease, the movement of seeds from infected areas must be strictly controlled (Boddupalli et al. 2020). In addition, crop rotation and diversification, seed treatment with fungicides, and foliar sprays can be useful in the short-run to control MLN (Boddupalli et al. 2020). It is imperative to develop and deploy resistant maize varieties to fight MLN successfully in the long-run. Importantly, the International Maize and Wheat Improvement Center (CIMMYT) in Mexico has already developed 18 MLN-tolerant maize varieties and deployed them in Kenya, Uganda, and Tanzania (Boddupalli et al. 2020). Among the 18 MLN-tolerant varieties, 14 varieties are second-generation seeds with higher yield potentials and more tolerant to MLN. A study demonstrated that scaling out of MLN-tolerant maize varieties can generate economic benefits of USD 195–678 million in Kenya and USD 245–756 million in Ethiopia (Marenya et al. 2018). This study thus strongly urges external support to scale-out MNL-tolerant maize varieties in the affected countries on an emergency basis since the usual process of seed dissemination takes a relatively long time (Mottaleb et al. 2019).

Recollections of Professor Keijiro Otsuka

Otsuka sensei was my class teacher, mentor, philosopher, and guide. I learned many things from him, including how to write the introductory paragraph of a research article. I still remember the example he presented in the class explaining the tragedy of the commons. He taught us that it is important to go to the field, see things, and talk to stakeholders to understand an issue's complexity and relate it with the existing theories. As a student of Otsuka sensei, I know that he has never taken a day off on Saturday in his career, and every morning he starts his day by reading a new article. He demonstrates that there is no substitute for hard work and dedication to become successful in anyone's field. Being a student of Otsuka sensei, it is my immense pleasure and honor to be part of the Festschrift celebrating his glorious lifetime achievements.

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