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Special Report

e-Xtra*

Using Panel Community Surveys to Track the Impact of Crop Pests Over Time and Space – The Case of Maize Lethal Necrosis (MLN) Disease in Kenya from 2013 to 2018

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Abstract

Maize lethal necrosis (MLN) disease appeared in Kenya in 2011, causing major damage. In a first survey of 121 communities in 2013, participants estimated the proportion of households affected and the yield loss in affected areas; from this survey, the overall loss was estimated at 22%, concentrated in western Kenya (94%). Efforts to combat the disease included planting resistant varieties, creating awareness of MLN management, and producing pathogen-free seed. In 2018, the same communities were revisited and asked the same questions, establishing a panel community survey. The results showed that incidents of MLN had greatly decreased, and the number of communities that had observed it had reduced from 76% in 2013 to 26% by the long rains of 2018; while still common in western Kenya (60%), MLN had greatly reduced elsewhere (to 10%). In 2013, 40% of farmers were affected, yield loss among affected farmers was estimated at 44%, and total yield loss was estimated at 22% (a production loss of 0.5 million metric tons/year), valued at US$187 million. By the long rains of 2018, 23% of farmers were affected, with a loss among affected farmers of 36%; overall annual loss was estimated at 8.5% or 0.37 million metric tons, valued at US$109 million, concentrated in western Kenya (79%). Of the recommended control measures, only the removal of diseased plants was commonly used (by 62% of affected communities), but not the use of agronomic practices (11%) or resistant varieties (9.5%). The reasons for the reduction in MLN are not well understood; external factors such as spraying insecticide against fall armyworm and unfavorable weather likely played a role, as did using disease-free seed, but not the use of resistant varieties or appropriate management practices. Still, as the pathogen remains in the fields, it is important to keep disseminating these control methods, particularly resistant varieties.

Keywords: maize lethal necrosis, crop loss, farmer estimates, disease, community survey, focus group discussions

Maize lethal necrosis (MLN) is a viral disease of maize (*Zea mays* L.) that suddenly appeared in Kenya around 2011 in the Rift Valley and has subsequently spread to different maize agroecologies countrywide, where it has caused considerable losses (Mahuku et al. 2015; Wangai et al. 2012). A first study to collect systematic information on the geographic distribution of MLN in Kenya, and the damage that MLN causes, was conducted in 2013, based on 121 community surveys; from this study, losses in maize production were estimated at 22%, or 0.5 million metric tons, valued at US$180 million (De Groote et al. 2016b). As almost all commercial maize varieties available in Kenya were susceptible, a range of measures were taken to combat the spread of the disease (Boddupalli et al. 2020), including the production of virus-free seed and the establishment of a facility to screen varieties for MLN resistance. To analyze the current situation and the effect of the measures put in place, the same 121 communities of the 2013 study were revisited in 2018, and the results of that survey are presented here. Furthermore, we compare the two surveys using descriptive statistics and regression analysis and show a substantial reduction of the pest problem since 2013. This is the first time, to our knowledge, that panel community surveys have been used to track the changes over time and space in a crop pest problem and the losses that it causes. MLN is caused by a combination of maize chlorotic mottle virus (MCMV) and sugarcane mosaic virus (SCMV) or any other cereal virus of the *Potyviridae* family (Das et al. 2019; Redinbaugh and Stewart 2018). MLN was first reported in Kansas, U.S.A., in 1978 (Niblett and Claflin 1978) and has subsequently been documented in Hawaii (Jensen et al. 1991), and in China (Xie et al. 2011), where it is primarily a problem in warmer regions with multiple cropping cycles. Cereal potyviruses have been reported in Kenya before (Louie 1980), but the first report of MCMV and MLN disease in Africa was in 2011 in Kenya, following a severe outbreak in the Rift Valley (Wangai et al. 2012). It spread quickly through the region, in particular to Ethiopia (USDA 2014), Uganda (Mudde et al. 2018), South Sudan (FAO 2012), Tanzania (CIMMYT 2013), DRC (Lukanda et al. 2014), and Rwanda (Adams et al. 2014).

Characteristic symptoms of MLN include chlorotic mottling on leaves, stunted growth and shortened internodal distance, dead heart, leaf necrosis, tassel sterility, and poor seed set (Scheets 1998; Uyemoto et al. 1980). If a maize field is infected early in the cropping cycle, total yield loss may occur (Uyemoto et al. 1980; Wangai et al. 2012). MLN-causing viruses can be transmitted by a range of insect vectors endemic to East Africa, including thrips (Cabanas et al. 2013) and chrysomelid beetles (Nault et al. 1978) for MCMV, and predominantly aphid species for potyviruses (Brault et al. 2010). Crucially, both viruses can also be transmitted through infected seed, which can contribute to rapid and wide dissemination of MLN (Jensen et al. 1991; Zhang et al. 2011). Seed transmission of MCMV was first established in the Americas (Jensen et al. 1991) and confirmed by research in China (Zhang et al. 2011) and more recently in Africa (Mahuku et al. 2015). The transmission of SCMV has also been reported (Li et al. 2011), but it is not currently considered to be a major issue (Redinbaugh and Stewart 2018).

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Almost all commercially available maize varieties in Kenya and East Africa were found to be extremely susceptible to MLN disease (Boddupalli et al. 2020), as were most prerelease hybrids and elite inbred lines in eastern and southern Africa (ESA) (Marenya et al. 2018). In 2012, the Kenya Ministry of Agriculture estimated a 2% loss in national maize production due to MLN disease. By that time, MLN had been reported in most maize-growing districts in Kenya as well as in several countries in East Africa where maize is an important staple food. The USDA Foreign Agricultural Service estimated yield losses as high as 10% of production for the 2014–15 marketing season, amounting to a loss of production of 15,206 metric tons, with an economic value of over US$50 million (USDA 2014). A study conducted in 2013, based on community surveys, estimated total maize losses in Kenya at 0.5 million metric tons per year, or 22% of the average annual production, with a value estimated at US$180 million (De Groote et al. 2016b). Losses were concentrated in western Kenya, in particular in the moist transitional zone (situated between the midaltitude and highland areas, as defined by Hassan et al. 1998a), where 58% of all maize was lost, but also in the moist mid-altitudes (19%) and the highlands (17%). Losses were small at the coast (15%) and in the drylands (3%).

Management of MLN disease in East Africa has been hampered by the continuous cultivation of maize throughout the year, lack of resistant maize germplasm, and the complicated nature of the spread and development of the disease. Most smallholder farmers in East Africa cannot afford to apply pesticides to control vector populations, while the recycling of seed that may be infected with MLN disease is common in many regions. In Kenya, the use of formally purchased maize seed is estimated at 87%, with the remainder coming from recycled (10%) or informally purchased (3%) seed (Ayieko and Tschirley 2006). The International Maize and Wheat Improvement Centre (CIMMYT) and its partners therefore developed and implemented an MLN control strategy for Africa that included the fast-tracked development and deployment of MLN-tolerant/resistant maize hybrids at a specially established, high throughput, artificial inoculation facility; MLN monitoring and surveillance; and production of MLN pathogen-free commercial maize seed (Boddupalli et al. 2020). For breeding purposes, a 9-point MLN severity score was developed (https://mln.cimmyt.org/mln-scoring/mln-hybrid-scoring-scale/) from 1 = "no symptoms" to 9 = "complete necrosis" (Supplementary Material SM1). MLN-resistant varieties are defined as those with a score of 1–3 (mild or no symptoms) while tolerant varieties are defined as those with a scale of 4–5 (moderate symptoms) (Boddupalli et al. 2020). Tolerant varieties are useful for areas where the incidence of MLN is low and can help bridge the gap until resistant varieties that are recommended for areas with high pressure from the disease can be developed and deployed.

To analyze the effectiveness of pest-control strategies, it is important to follow the evolution of the pest, and to estimate the losses that it causes over time and space. This study therefore revisited the same communities of the 2013 study, 5 years later, to analyze changes in the occurrence and severity of the pest over time and space, and to explore farmers' coping strategies and control methods. The same basic method was used: a community survey where participating farmers were first asked if a pest had been observed, and subsequently to estimate the proportion of farmers affected and the losses caused by the pest. However, this study expanded on the methods used in the earlier survey by now asking participants the same questions with respect to the last three seasons, thus providing more detail on the evolution of the pest. Moreover, statistical analysis was added to study the evolution of the disease over time, and the effect of climate variables. The specific objectives of this study were: i) to estimate the extent of MLN in Kenya in 2018 and the progress of the disease since 2013, as measured by the proportion of communities affected and the geographic distribution of the disease; ii) to estimate the losses from MLN, in percentages as well as in quantity, and the changes in these over time and space; and iii) to analyze farmers' coping strategies and control methods.

Materials and Methods

Conceptual framework. To assess the impact of a pest problem, information is needed on the geographic distribution of the disease and an estimation of the losses incurred. While accurate scientific observations are expensive and time-consuming, collecting estimates from farmers is relatively inexpensive and straightforward. Farmers, with their years of hands-on experience of pest problems, including long-term observations and regular experiments with different control methods, are able to provide good estimates of their spread, severity, and the losses caused, and can share their experiences of different control methods (De Groote 2002; De Groote et al. 2008). Clearly, the pests have to be visible, which can sometimes be a problem in the case of diseases (Trutmann et al. 1996), but not usually for insects or, in this case, for MLN with its distinctive symptoms. In the earlier community survey conducted in 2013, questions on the history, spread, and severity of MLN disease were added to a community survey conducted in the major maize-growing zones in Kenya (De Groote et al. 2016b). These communities were randomly selected from a list of sublocations obtained from the 2010 census report, stratified by the different maize-growing agroecological zones, using probability proportionate to size (De Groote et al. 2016a). This stratification allowed for interpolation of the results to obtain estimates of national and regional losses. The same communities were revisited in 2018 for another survey on stresses in maize production for the Stress Tolerant Maize for Africa (STMA) (De Groote et al. 2020), and the same questions on MLN that had been used in the 2013 study were asked again, with some extra questions on control methods and coping strategies. In this paper, we compare the results of the two consecutive surveys in the same communities, in 2013 and 2018, to track the evolution of MLN and the losses caused over time and space. No visits were conducted during the years in between.

The study of systematic crop loss assessment started with influential workshops organized by the Food and Agriculture Organization (FAO), leading to a first manual (Chiarappa 1971), later updated (Teng 1991), and followed by several reviews (Esker et al. 2012; Nutter et al. 1993; Teng and James 2002). The standard definition of crop loss, following the FAO, is the difference between attainable yield Y_a and actual or realized yield Y_r (Nutter et al. 1993). When expressed as a proportion, this definition is the same as the difference between attainable production X_a and actual or realized production X_r expressed mathematically as:

$$r = \frac{(Y_a - Y_r)}{Y_a} = \frac{(X_a - X_r)}{X_a} \quad (1)$$

Instead of trying to measure Y_a and Y_r directly, for this study we asked farmers, during group discussions, to estimate the proportion of farmers affected (F_a) in their community, and the loss (in %) experienced by the affected farmers (L_a). Total relative loss in the community was then calculated as:

$$r = F_a L_a. \quad (2)$$

Actual quantities of losses can then be calculated from the attainable production X_a before the arrival of the pest:

$$L = rX_a \quad (3)$$

Because the communities were randomly selected from their agroecological zones (AEZs), the relative loss r is representative for each AEZ and can be multiplied by attainable production in each zone to obtain the absolute loss. This method depends on production statistics from before the pest problem and was previously used to estimate crop loss and its distribution caused by MLN disease (De Groote et al. 2016b) and fall armyworm (FAW) (De Groote et al. 2020) shortly after their arrival. However, when pests have been established for some time, loss can be derived from actual production X_r by rephrasing Equation (1) as follows:

$$X_r = (1 - r)\, X_a \text{ or } X_a = X_r \frac{1}{1 - r}$$

This results in the alternative formulation used for this paper:

$$\text{Loss } = X_a - X_r = X_r \frac{1}{1 - r} - X_r \frac{1 - r}{1 - r} = X_r \frac{r}{1 - r} \quad (4)$$

Group discussions and farmer participatory methods used to estimate crop loss. The different reviews of crop loss assessment methodology, ranging from the first FAO manual (Chiarappa

1971; Zadoks 1990) to a recent CABI review (Esker et al. 2012), focus on scientific observations. They do include expert opinion (Teng 1990; Teng and James 2002) but pay scant attention to farmers' estimations of loss. It is often assumed that farmers overestimate crop losses (Esker et al. 2012), although this is based on little evidence (an example is Waibel 1990). Farmers' estimates of storage losses were actually found to be lower than FAO estimates (Kaminski and Christiaensen 2014). With the increased interest of agricultural research in participatory approaches, however, group discussions, including participatory rural appraisals (PRAs) (Chambers 1994) and focus group discussions (FGDs) (Krueger and Casey 2000), have become an integral part of the methods used. PRAs in particular have been widely used to assess crop pest problems in Africa, including *Striga* spp. (Debrah et al. 1998), locusts (De Groote et al. 2001), and stemborers (De Groote et al. 2004), but rarely used for quantitative assessment. Group discussions are often recommended for collecting qualitative information, and individual surveys are recommended for gathering quantitative information (Escalada and Heong 1997). Farmer estimates of crop losses during these surveys can be general (Hassan et al. 1998b) or specific, including losses caused by stemborers (De Groote 2002), *Striga* spp. (De Groote et al. 2008), and storage losses (Kaminski and Christiaensen 2014).

The use of group discussions to quantify crop loss, on the other hand, is relatively new. The first such assessment, as far as we know, took advantage of a community survey organized in 2013 when MLN had just started to appear (De Groote et al. 2016b). When FAW suddenly appeared, the same communities were revisited to assess loss from FAW (De Groote et al. 2020), and at the same time the loss from MLN was revisited, albeit with slightly modified questions.

Study areas and selection of communities and participants. The maize agroecological zones include, from east to west, the lowland tropics (LT) on the coast, followed by the dry mid-altitudes and dry transitional zones around Machakos (Fig. 1) (Hassan et al. 1998a); these three zones are characterized by low yields (0.5 to 1 t/ha), and although they cover 27% of the total maize area, they only produce 8% of all the maize produced in the country (see details in De Groote et al. 2020). Further inland are the highland tropics (HT) in central and western Kenya, bordered on the west and east by the moist transitional (MT) zone; both zones have high yields (1.5 and 2.5 t/ha respectively) and produce 67% of the maize in Kenya on 47% of the area. Finally, surrounding Lake Victoria is the moist mid-altitude (MM) zone, with moderate yields (1.27 t/ha), producing 12% of the country's maize on 12% of the area.

The first community survey was conducted in June 2013 by CIMMYT and the Kenya Agriculture and Livestock Research Organization (KALRO). It was linked to a household survey that used a stratified two-stage sampling design, with the agroecological zones as the strata, the sublocations (Kenya's smallest administrative units) as determined in the 2009 census (KNBS 2010) as the primary sampling units (PSU), and the households as secondary sampling units (SSU). The number of PSU and SSU in each of the strata was determined by optimizing the sample size needed to obtain a precision of at least 15% in each stratum and 8% overall for the major maize-related variables (yield and maize area and production per household), leading to a total of 121 sublocations (De Groote et al. 2016a) (Fig. 1). In order to obtain good estimates within the minimum precision for each stratum, the smaller agroecological zones were oversampled, so to calculate national averages, appropriate weights need to be used.

The second community survey was conducted in June and July 2018, in the same 121 communities, by CIMMYT and Agri-Foods Economics Africa (now Kula Vyema Centre of Food Economics), a research institute based in Kenya, for the Stress Tolerant Maize for Africa project. The purpose of the survey was to gain a better understanding of the constraints and stresses faced by smallholder maize farmers, and the control methods and coping strategies that the farmers used. These stresses included FAW, reported elsewhere (De Groote et al. 2020), stemborers, storage pests, and MLN, the results of which are presented here. A special questionnaire was developed and tested for this survey (Supplementary Material SM2). The contact people in the communities (from the 2013 survey) were asked to invite between 6 and 10 people to FDGs, and to make sure that both men and women participated, as well as older and younger farmers. The FGDs were attended by between 8 and 20 people (an average of 12), making a total of 1,439 people (Table 1). Slightly more than half of the participants (52%) were women, and in each group, participants included at least two men and two women.

Data collection. When discussing MLN, participants were first asked as a group if they had heard about it. For those who had not, the enumerators provided a description, based on a CIMMYT document (CIMMYT 2013) that explained the cause and symptoms of the disease and distinguished it from other diseases with pictures (Fig. 2). Those who had heard about MLN were asked to describe it and were then taken through the same presentation to ensure that all participants had the same information. The symptoms discussed included severe mottling of leaves, dead heart, leaf necrosis, stunted growth, shortened internodes, and barren ears.

Once the definition was clear, participants were asked if they had ever observed the disease in their community. In the 2013 survey, participants were then asked to estimate the proportion of households in the community that had been affected, and the relative yield loss (in %) that MLN had caused among the affected farmers. In 2018, a more elaborate procedure was used to collect data from the last three seasons. After being asked if they had ever observed MLN in their community, participants were now asked if they had observed it in the ongoing season (the long rains of 2018, with maize planting in March and harvesting in July and August) as well as in the two previous seasons (the long rains of 2017, and the short rains of 2017, with planting in October 2017 and harvesting in January and February of 2018). Then, for the same three seasons, they were asked to estimate the proportion of households in the community that had

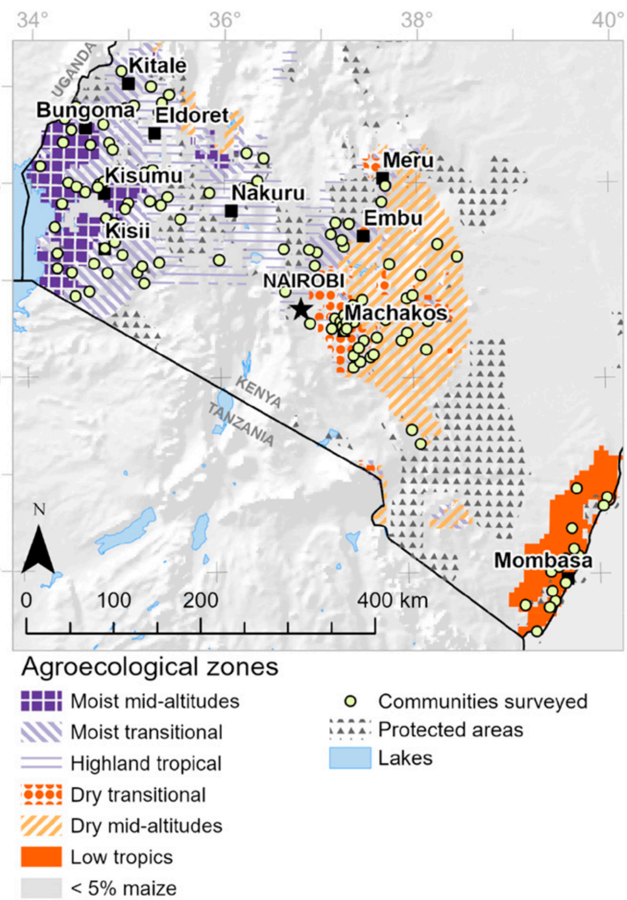

Fig. 1. Maize production zones in Kenya and community survey sites.

been affected, and the relative yield loss (in %) that MLN had caused among the affected farmers. Participants were not asked to identify MLN and estimate its losses in their own individual fields, but rather in the maize fields of the community as a whole.

Analysis. The group discussions provided geo-referenced point estimates for four points in time (one annual estimate for 2013 and three seasonal estimates for 2018) for three variables: observation of MLN (binary variable), the proportion of households affected by MLN, and the proportion of yield loss in affected areas. The product of the last two variables provided point estimates of the proportion of maize lost due to MLN in the community, using Equation 2, equivalent to the relative loss r. Because the communities were representative for their AEZ, the average estimated relative loss r for each AEZ was also representative and could be multiplied with the production in the zone before the occurrence of the pest using Equation 3. Maize production was estimated by aggregating the layer of the 2005 Spatial Production Allocation Map (SPAM) data (You et al. 2000) over the different zones, using the layer of the zones (Hassan et al. 1998a).

For statistical analysis of the change over time, we use two methods: pair-wise comparison and regression over time, for two variables—the binary O (if MLN was observed or not) and the continuous r (relative loss). Because the questions asked in the 2013 survey were not season-specific, for the pair-wise comparison we compared 2013 to 2018 by combining the short and long rains of 2018. For the binary variable we compared the 2013 observation (= 1 if MLN had been observed in 2013, = 0 otherwise) to the 2018 observation (= 1 if MLN was observed in either of the seasons, = 0 otherwise), using the McNemar test (Adedokun and Burgess 2012). For the pair-wise comparison of r we compared the calculated r of 2013 to that of 2018, calculated as the weighted average of r in the short and long rains of 2018, weighted by the relative production in those seasons, specifically for each zone, and used the pairwise t test.

To map the distribution of the losses, the point estimates of the 2013 data were interpolated over the maize-growing areas of Kenya, using inverse distance weighting (IDW) at a spatial resolution of 1 km, to generate a continuous surface of relative yield loss in maize.

Table 1. Distribution of focus group discussions and number of participants, by agroecological zone

Item	Coastal lowland	Dry mid-altitude	Dry transitional	Moist transitional	High tropics	Moist mid-altitudes	Total
Number of communities participating	15	17	18	32	20	19	121
Average number of participants per community	11	11	11	13	12	12	12
Total number of female participants	83	104	112	208	118	117	742
Total number of male participants	85	91	87	194	128	112	697
Total number of participants	168	195	199	402	246	229	1,439
Percentage of female participants	49	53	56	52	48	51	52

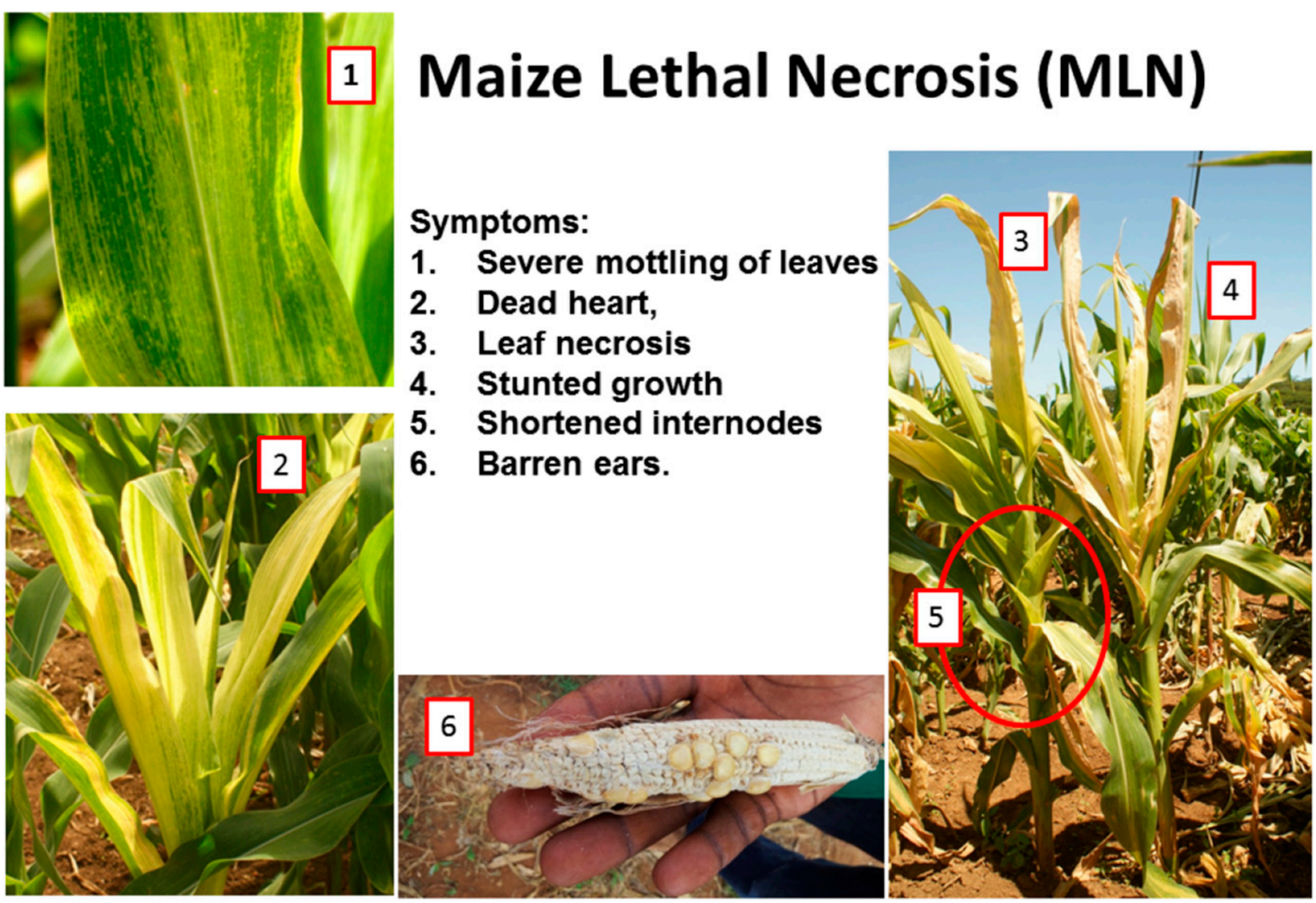

Fig. 2. Symptoms of MLN, as presented to farmers during the focus group discussions.

Spatial data on maize production, in 10 km grid cells, were obtained from HarvestChoice's SPAM data and converted to a finer resolution of 1 km cells by interpolating the information at the centroids of the original cells with IDW, resulting in a maize production surface in metric tons per km^2. Multiplying the yield loss surface with the maize production surface results in the absolute loss, or quantities of maize lost in metric tons per km^2.

For the analysis of the 2018 data, we first used the same production data and formulae to allow for a direct comparison. However, as maize production has increased substantially since 2013, we then repeated the analysis with the actual maize production in 2017 and 2018, as estimated by the FAO. We distributed the FAO estimates over the AEZs using the 2010 SPAM (You et al. 2014; Yu et al. 2017). As these were now actual production data, we used Equation 3 to calculate the losses. Finally, we mapped the geographic distribution of the losses by extrapolating the point estimates to a surface and multiplying this surface with the SPAM production data, adjusted for the 2018 FAO production estimates.

As an alternative analysis, now making use of all four observations over time, we used multivariate regression over time, for both the binary variable O and the continuous r using the data from 2013. To include the seasonal data from the 2018 survey, we assumed that the 2013 data were also good point indicators for the situation in the long rains of 2013 (as this is the major season). For the binary variable we used the linear logistic model with random errors, in which the dependent variable is the logarithm of the odds of an event, in this case O (observing MLN) in community i at time t (Equation 5). For the continuous variable r, we used ordinary least squares (OLS) regression. For both variables, the right-hand side is a linear function of time, seasonality, and weather variables. As data from the last three time points are closer in time to each other than to the data from the first point, we assigned the time variable a starting value of 0 for 2013, a value of 8 for the long rains of 2017 (8 seasons later), 9 for the short rains of 2017, and 10 for the long rains of 2018. We also included a binary variable for the short season (SR = 1 for the short rains of 2017, and = 0 elsewhere). For weather variables, we included the accumulated rainfall (*Rain*, in mm) and the average temperature (*Temp*, in °C) for the four months of the growing season (March to June for the long rains, October to January for the short rains), obtained from CRU-TS 4.03 (Harris et al. 2014) downscaled with WorldClim 2.1 (Fick and Hijmans 2017). Finally, as the observations for the different communities could be correlated over time, we included a random error u_i for each community i. The model becomes:

$$Y = \alpha + \beta_1 t + \beta_2 SR + \beta_3 Rain_{it} + \beta_4 Temp_{it} + u_i + e_{it} \tag{5}$$

where Y is either the log odds of MLN observed $\left(Ln \frac{P(\text{MLN observed})_{it}}{1 - P(\text{MLN observed})_{it}} \right)$ or is the relative loss (r); α and β are the coefficients to be estimated, and e_{it} is the remaining error term.

Results

Observations and spread of MLN over time. In 2013, we asked farmers in the communities if they had observed MLN, after

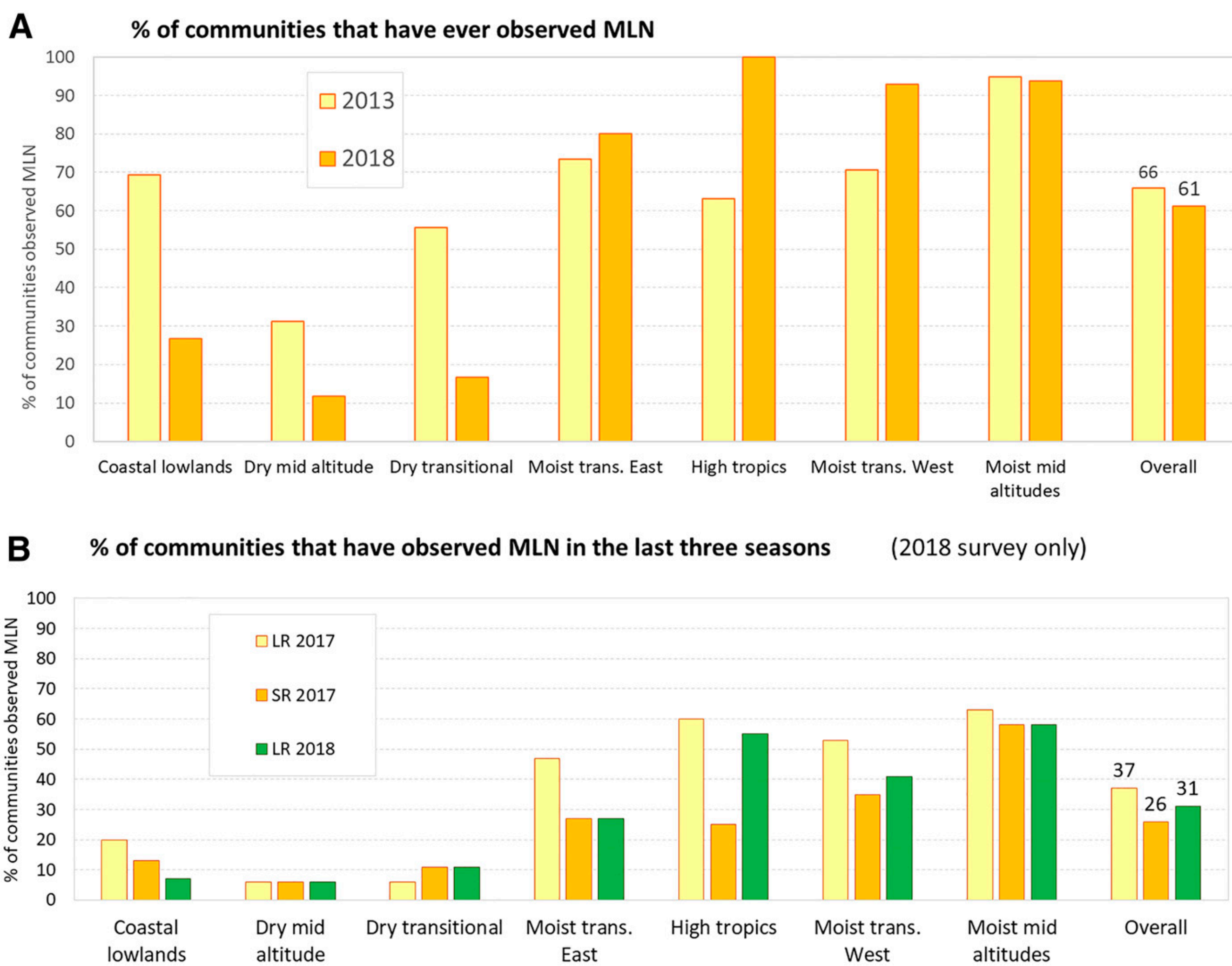

Fig. 3. Observations of maize lethal necrosis (MLN) by communities in the different agroecological zones at different times. **A,** percentage of communities that have ever observed MLN in 2013 and 2018; **B,** percentage of communities that observed MLN in specific seasons (2018 survey only).

discussing the symptoms with pictures, and in 66% of the communities (77 out of 121) the response was positive. In 2018, the same communities were revisited for the first time since 2013 and were again asked if they had ever observed MLN and if MLN had been observed in the current season and the last two seasons. In 2018, only 61% of communities reported having (ever) observed MLN (74 out of 121) (Fig. 3). This reduction in reported observations was, however, only observed in the east (in the low tropics and both dryland zones) where in 2018 less than 30% of communities indicated that they had ever observed MLN, as compared with 40 to 60% in 2013. In contrast, the proportion of communities where MLN had been observed had increased slightly in all the western zones (the moist mid-altitudes, moist transitional, and highlands). Note that in principle, the number of communities having ever observed a pest problem should not decrease. However, human observations, or rather the recall of those observations, do not always follow that principle. Also, the disease and its symptoms were explained to participants at the meetings in 2013 with pictures and discussions, after which participants were asked if they had observed the disease. Five years later, they might not have recalled that discussion or, if the disease was not important, recalled ever having observed it.

In 2018, 61% of the communities had observed MLN at some time. However, only half of those had also observed MLN in any of the last three seasons, indicating a strong reduction in observations over time. Specifically, only 37% of communities had observed MLN in the long rains of 2017, and only 31% in the long rains of 2018. There was a clear geographic pattern: MLN remained common in the western maize areas but had reduced substantially in the eastern and coastal areas. MLN was still prevalent in most communities in the high rainfall areas of the west, where most maize is grown, with about 60% of communities having observed the disease in both long rainy seasons (although down from 80 to 100% in 2013). In the low tropics and dryland zones of the southeast of the country, on the other hand, the prevalence of MLN had greatly reduced, to about 10% of the communities.

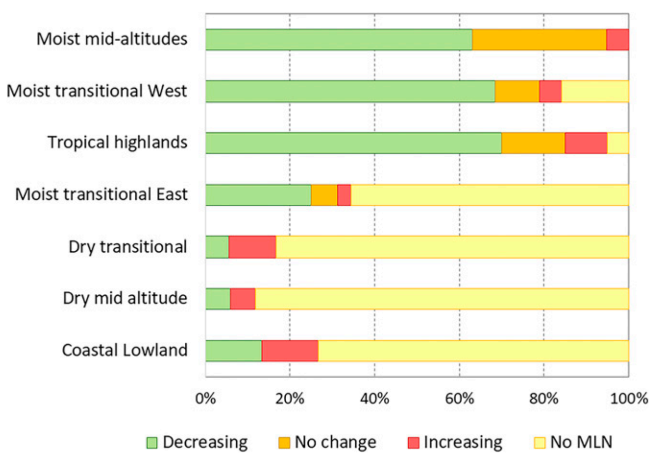

Fig. 4. Trends in maize lethal necrosis (MLN) observations, in percentage of communities that observed a decrease, no change, or an increase.

There was also a seasonal difference in MLN observations: these were generally fewer for the short rainy season of 2017 (26% of communities) than for both long rainy seasons (37% in 2017, 31% in 2018). However, this seasonal difference derived mostly from the highland and moist transitional zones, where maize production is not important in the short rainy season. In the other regions, where both seasons are equally important, the number of MLN observations was similar for both seasons.

In 2018, participants in the communities that observed MLN were also asked about the trends that they had noticed. In those communities, 13% reported no change in MLN occurrence, while 42% observed a decrease and 8% an increase (Fig. 4). There were some major regional differences, with most communities at the coast and in the drylands (82%) having not observed MLN, while most of the communities in the other zones (66%) had seen a decrease, especially in the moist transitional zone and in the highlands. Most of the communities that had seen a decreasing trend indicated that the peak had been observed in 2015 or 2016 (65%).

Farmers' observations were confirmed by the significant reduction in the percentage of communities that had observed MLN (McNemar's test, $P < 0.001$, Table 2). The test was also significant for the dry transitional zone ($P = 0.008$) and marginally significant for both the east and west sides of the moist transitional zone ($P = 0.063$).

The alternative analysis using logistic regression of observations of MLN during 2013 and the last three seasons (Equation 5) found a significant reduction of MLN observations over time, confirming farmers' responses concerning trends (Table 3). Moreover, the odds of observing MLN were significantly less in the short rainy season, and also increased with rainfall, but were not affected by temperature. Further, as the rainfall in 2018 was higher than in 2017, the difference in rainfall could not explain the reduction in MLN.

Number of farmers affected, loss in affected areas, and relative total loss. In 2013, participants estimated that 40% of farmers in their communities were affected (from 15% in the dry transitional zone to 60% in the moist mid-altitude zones), and that yield loss among affected farmers was 44% (from 15 to 75% in the same zones, respectively). Five years later, the proportion of affected farmers had substantially decreased, down to 15% in the long rains of 2018 (Fig. 5A), with a yield loss among affected farmers of 36%

Table 2. Differences in loss from maize lethal necrosis (MLN) between 2013 and 2018 – statistical analysis (numbers are means, standard errors in brackets)

	MLN observed (% of communities)				Loss (r)				
Agroecological zone	2013	2018	Difference	P	2013	2018	Difference	P	N
Coastal lowlands	60 (51)	20 (41)	–40	0.109	25.6 (8.1)	3.2 (1.8)	–22.4 (8.1)	0.015	15
Dry mid-altitudes	29 (47)	6 (24)	–24	0.125	4.4 (2.7)	0.7 (0.7)	–3.7 (2.1)	0.1	17
Dry transitional	56 (51)	11 (32)	–44	0.008	13.4 (5.6)	4.5 (3.4)	–8.9 (6.9)	0.231	18
Moist transitional east	73 (46)	40 (51)	–33	0.063	37.9 (11.0)	7.8 (3.8)	–29.5 (9.3)	0.008	15
Tropical highlands	60 (50)	70 (47)	10	0.727	14.4 (6.0)	11.5 (3.9)	–2.9 (6.5)	0.662	20
Moist transitional west	71 (47)	59 (51)	–12	0.678	27.6 (8.7)	8.6 (4.0)	–19.0 (8.3)	0.037	17
Moist mid-altitudes	95 (23)	68 (48)	–26	0.063	38.6 (8.1)	10.0 (3.2)	–28.6 (9.5)	0.008	19
Total	64 (48)	40 (49)	–23	0.000	22.7 (2.9)	6.8 (1.2)	–15.8 (3.0)	0	121

(Fig. 5B). The detailed results are presented in Supplementary Material SM3.

The 2018 survey also showed a decrease in the proportion of affected farmers over the last three seasons, from an average of 23% of farmers affected in the long rains of 2017, down to 19% in the short rains of 2017, and 15% in the long rains of 2018. Moreover, this decrease was observed in all zones except the drylands, where the proportion of affected farmers was already very low (less than 7%). We also observed a dip in the proportion of affected farmers in the short rains in the high potential areas (moist transitional and highlands), where the short season is less important for maize production than the long season. The crop loss at affected farms, on the other hand, did not differ much between the two surveys, and did not show a clear trend. Overall, it reduced somewhat over the last three seasons, from the long rains of 2017 (50%), over the short rains of 2017 (with a slight increase to 53%) to the long rains of 2018 (36%) (Fig. 5B).

Finally, the total relative loss among all farmers in the community (in %) was calculated by multiplying the number of affected farmers with the loss suffered by those farmers. In 2013, this total loss was thus calculated at 22%, but five years later this had substantially reduced, to 18% in the long rains of 2017, 10% in the short rains of 2017, and 9% in the long rains of 2018 (Fig. 5C). The reduction of overall loss in the last three seasons was also observed in all zones except the drylands, but there the loss was already very small (only 1% in the mid-altitudes and 5% in the dry transitional zone). The pattern of total relative loss mainly followed the same trend as the proportion of affected farmers, because the % loss among affected farmers did not change much: it decreased in all zones except the drylands, with a dip for the short rains in the high potential zones.

Pairwise comparison of relative loss between 2013 and 2018, calculated as the weighted mean of the loss in long and short rains, indicates a significant reduction of loss due to MLN over time, on average 15.8 percentage points (pairwise *t* test, $P < 0.001$) (Table 2). This reduction is also high and significant in the moist transitional zone, in the east (28 percentage points, $P < 0.01$) as well as in the west (19 percentage points, $P < 0.05$) and in the coastal lowlands (18 percentage points, $P < 0.05$).

Statistical analysis of the relative loss over time, using a linear random effects model, confirms that the reduction over time is significant, with a reduction of loss of 1.5 percentage points per season over the 10-season (5-year) period (Table 3). Also significant is the reduction of loss in the short season: 2.2 percentage points less than in the long rainy season. Rainfall is also significant: an increase of rainfall over the season by 100 mm is associated with an increase in losses due to MLN of 0.7 percentage points.

Estimation of the quantity of maize lost through MLN. In 2013, the losses from MLN were estimated at 22% of the pre-MLN annual production of 2.3 million metric tons, or a quantity of about half a million metric tons (Table 4). At the 2013 price of maize (US$364/metric ton), these losses were valued at US$187 million. At that time, most of the losses from MLN occurred in the west (83%), with more than half in the moist transitional zone (58%).

To calculate the quantity of maize lost from the 2018 survey data, we first combined the relative losses in the last two seasons for each zone (from Fig. 5) into a weighted annual mean for 2018 (with production in the different seasons as weights) and multiplied the resulting annual loss to the same production data from before the MLN outbreak. The total quantity of maize lost in 2018 was thus estimated at about 0.171 million metric tons or 7.4%, less than half the losses in 2013 (Table 4). Similarly, the value of this quantity of maize lost at the 2013 price would amount to US$62 million, but should be valued at the lower 2018 price of US$297/metric ton (Food Security Portal 2020), and the value of the loss estimated at US$51 million. The regional distribution of the losses did not change much: the three most western zones still accounted for most losses (86%), and the moist transitional west was still the most affected area, although slightly less so (42% of all losses).

However, maize production has increased substantially in the last few years, to 3.7 million metric tons in 2017 and 4.0 million metric tons in 2018 (FAOSTAT 2020), hence loss calculations should take that into account. Because these data are now actual production data after losses have occurred, unlike the calculations of the 2013 survey, the appropriate calculation is now Equation 2, and this was used to update the calculations for the three different seasons.

For the long rains of 2017, based on a total maize production of 3.7 million metric tons and the proportion produced in the long rains (De Groote et al. 2020), losses due to MLN were thus calculated at 0.604 million metric tons. Again, most losses occurred in the three most western zones (79%), especially the moist transitional (33%). As the maize price in Kenya in 2017 was US$424/metric ton, the value of these losses was estimated at US$256 million. The harvest from the short rains of 2017 took place in January and February 2018, so we used that year's production data (4.0 million metric tons), proportionate to the production in the short rainy season, to calculate the losses of that season, resulting in a loss of 78,000 metric tons. In 2018, maize prices were US$297/metric ton, so the value of the loss was estimated at US$23 million. Using the same approach, losses of the long rains of 2018 were estimated at 0.288 million metric tons.

Therefore, after adjusting for increased maize production, the total quantity of maize lost in 2018 was estimated at 0.37 million metric tons, substantially less than in 2013 (a reduction of 29%). The value of this loss was estimated at US$109 million, 58% of the value of the maize lost in 2013, after taking into account the decrease in price.

Geographic information system (GIS) analysis. The point data for maize losses due to MLN were interpolated between the points to create a grid surface and a map with the geographic distribution of relative losses (loss expressed as a % of potential maize yield as per Equation 1) due to MLN in 2013 and in 2018 (Fig. 6). The results of the 2013 survey showed high maize losses in most agroecological zones, especially in western Kenya, and in particular in the Bungoma-Kitale-Eldoret triangle and between Kisii and Kericho,

Table 3. Regression analysis of observation of maize lethal necrosis (MLN) over time (logistic regression, random effects model)

	Model 1: Y is log odds ratio			Model 2: Y is relative loss *r*		
Variables	Coefficient	Standard error	P>z	Coefficient	Standard error	P>z
Time[a]	–0.201	0.032	0.000	–1.543	0.242	0.000
Short rainy season	–0.672	0.328	0.041	–2.226	2.237	0.320
Rainfall (mm, over the season)	0.002	0.001	0.011	0.007	0.004	0.069
Temperature (°C)	–0.096	0.075	0.205	–0.181	0.426	0.671
Constant	2.288	1.702	0.179	22.55	9.722	0.020
σ_u	2.095	0.319	1.554	10.30		
ρ	0.572	0.075	0.423	0.215		
Log likelihood	–255.296					
Wald χ^2	55.680			54.03		
Prob > χ^2	0.000			0.000		
N observations	484			484		
N groups	121			121		

[a] 2013 = 0, long rains 2017 = 8, short rains 2017 = 9, long rains 2018 = 10.

with lower levels observed in central and eastern Kenya. In 2018, on the other hand, a general reduction in relative losses was observed over all zones (Fig. 6B). The reduction was especially noticeable in northwest Kenya. However, some pockets of high losses remained, in particular in the moist transitional zone around Kisii and also in the area to the north of Embu.

By combining the relative loss map (Fig. 6) with the SPAM maize production data, adjusted for the 2018 estimated production data, a map was created with the absolute losses for each pixel (in metric tons/km^2) (Fig. 7). Again, a large reduction of losses due to MLN was observed, as well as a general reduction of the area affected by MLN. In 2013, most of the losses occurred in two regions: the major one in the west, along the Kisi-Kisumu-Kitale axis, and a second one in the east, along the Machakos-Embu-Meru axis (Fig. 7A). In 2018, however, most losses in the northern part of the first region had disappeared, while losses in the southern part were strongly reduced, with some pockets remaining around Kisii. Similarly, losses in the eastern part had also reduced and the affected area shrunk, with only

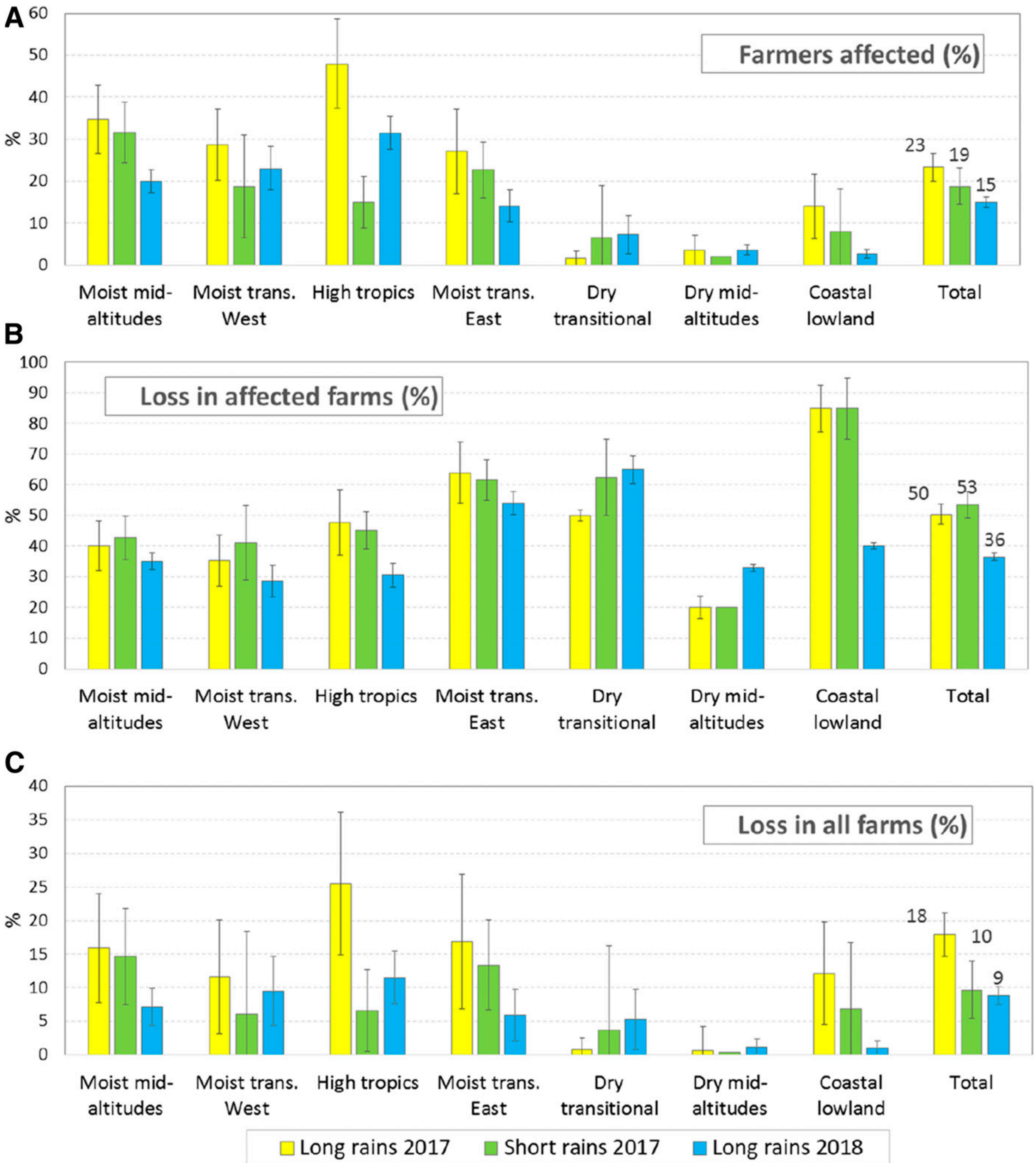

Fig. 5. Proportion of farmers affected by maize lethal necrosis (MLN) (**A**), the percentage loss in their maize fields (**B**), and the total relative loss in all farmers' fields (**C**), by agroecological zone and season (last three seasons before the survey). The overall means are calculated by taking weighted means of the zonal means.

Table 4. Losses in maize production due to maize lethal necrosis (MLN) by year, season, and agroecological zone

	Calculations based on maize production before MLN						Calculations based on actual maize production[b]								
	Maize annual production before MLN's arrival[a]		Loss from MLN in 2013[a]		Loss from MLN in 2018 (based on same production)		Production 2018	Loss from MLN in LR 2017		Loss from MLN in SR 2017		Loss from MLN in LR 2018		Losses from MLN in 2018	
Agroecological zone	Metric tons	LR[c] (%)	%[d]	Metric tons	%[d]	Metric tons	Metric tons	%	Metric tons	%	Metric tons	%	Metric tons	%[d]	Metric tons
Moist mid-altitude (MM)	304,994	61	31.7	96,707	11.7	35,663	517,051	16.0	54,923	14.7	29,710.43	7.1	22,275	9.1	51,985
Moist transitional (MT) West	1,040,794	74	28.7	298,277	7.0	72,392	1,388,314	11.6	140,291	6.1	21,998.39	9.5	97,370	7.9	119,368
Highland tropical (HT)	583,681	99	15.0	87,750	6.7	38,822	1,023,586	25.5	318,873	6.6	701.35	11.5	116,896	10.3	117,597
Moist transitional (MT) East	49,003	74	5.4	2,649	11.4	5,603	263,377	16.9	10,482	13.4	9,238.89	5.9	11,445	7.3	20,684
Dry mid-altitude (DM)	157,159	51	3.2	5,021	4.5	7,071	244,762	0.8	963	3.8	4,500.37	5.3	6,584	4.3	11,085
Dry transitional (DT)	27,409	41	2.8	762	0.8	231	46,809	0.7	125	0.4	106.37	1.2	226	0.7	332
Lowland tropical (LT)	8,228	62	14.9	1,227	4.6	380	47,097	12.1	3,718	6.8	1,215.38	1.1	312	3.1	1,527
Other	141,579	77	15.3	21,634	7.4	10,444	482,780	17.9	74,197	9.7	10,885.57	8.8	32,662	8.3	43,548
Total maize zones	2,171,268	77	22.7	492,393	7.4	160,163	3,530,997	17.9	529,375	9.7	67,471	8.8	255,108	8.4	322,579
Total	2,312,847	77	22.2	514,027	7.4	170,606	4,013,777	17.9	603,572	9.7	78,357	8.8	287,770	9.1	366,127
Value (US$ million, at 2013 price of US$364/ metric ton)	842			187	7	62	1,461								133
Value in US$ million, at 2017 (US$424) and 2018 (US$297/metric ton) price						51	1,192		256		23		85		109

[a] De Groote et al. 2016b.
[b] Based on FAOSTAT production of 3.688 million (FAOSTAT 2020).
[c] Based on CIMMYT household survey (De Groote et al. 2016a).
[d] Weighted mean over both seasons.

a few pockets remaining. Finally, while there were some losses at the coast in 2013, these had almost disappeared in 2018.

MLN control strategies. During the 2018 survey, the communities who had observed MLN were further asked what methods had been used to control the disease, what proportion of farmers had used them, and how effective they had been (on a scale of 1 to 5). Of the 74 communities who had observed MLN, 55 (74%) reported using at least one control method, while nine communities had used two methods and one had used five methods (Table 5). The most popular strategy was to remove the affected plants, practiced by 46 (62%) of the communities. Different practices were mentioned, including cutting, uprooting, or roguing. In total, 33 communities removed affected plants without mentioning further treatment or use (45% of communities), while others combined removing the plants with burning them (12%) or feeding them to the animals (12%). Removal was practiced by 68% of the farmers in those communities. The effectiveness of removing affected plants in controlling MLN was rated between medium for removing and using for feed (2.8 out of a maximum of five) and high for removing and burning (3.8).

The next most popular control method consisted of planting resistant maize varieties, practiced by seven communities (9.5%), in one of which planting other maize varieties was also mentioned. In these communities, resistant varieties were planted by most farmers (78%), and this method received the highest efficiency score of all the control methods (4.7 out of a maximum of 5). When specifically asked if they grew resistant varieties, however, 27 communities answered that they did, with three indicating that they grew two resistant varieties, and one that they grew three. The most common resistant varieties, as by their own classification, were local varieties (21 communities), DK777 (five communities), and DK8031 and SSC Duma (two communities each). Further, seven more varieties were grown by one community each: DH04, H513, H613D, H6213, KDV1, KSH624, and PHB353. Evaluation of these varieties after inoculation at the Naivasha MLN facility, however, found that only DK777 was tolerant while the others were found to be susceptible. Varieties at the facility are screened using a 9-point scale from 1 = "no visible symptoms" to 9 = "complete plant necrosis, and dead plant" (MLN Web Portal) (Supplementary Material SM1). During these tests, DK777 consistently received a score of 5 (chlorotic streaks and mottling throughout the plant), while other varieties received scores of 6 (intense chlorotic mottling throughout plant, necrosis of leaf margin) or 7 (excessive chlorotic mottling, mosaic, and leaf necrosis, at times dead heart symptoms) (see evaluation of these varieties in Supplementary Material SM4).

Different agronomic control methods were also popular; these were practiced by eight communities (11%) and included crop rotation (7%), early planting, and moving to a new plot (3% each). Agronomic control methods received medium to high effectiveness scores, between 3.0 and 4.5. Finally, only two communities used pesticides, but they did not give them high scores for effectiveness, with an average score of 2 (one community scored them 1, the other 3).

Discussion

The main result of this community panel survey is that it shows a strong reduction in MLN observations in the communities from 2013 to 2018, as well as a reduction in affected farmers and losses during the same period. The number of communities that had observed MLN reduced from 76% in 2013 to 31% in 2018 (the long rains), a reduction of more than 50%, while the number of affected farmers reduced from 40 to 23% in the same period. As a result, the losses caused by the disease also greatly decreased, from 22% in 2013 to 8.5% in 2018 (a two-thirds reduction). This loss was partly offset by an increase in maize production, so the reduction in absolute losses was not as strong, from 0.5 to 0.37 million (a reduction of 29%). On the other hand, the price of maize also reduced over the study period, so the value of the losses was reduced from US$187 to US$109 million (–42%).

Geographically, the reduction in observations over time has occurred mostly in the eastern lowland and mid-altitude zones, not in the west. However, losses in the maize production areas in the west have also reduced, leading to a general reduction in losses over all zones. Still, the west, and in particular the moist-transitional and highland zones, remains the major problem area where 79% of MLN losses occur. In Ethiopia, the geographic areas affected by MLN were reported as mid- to low altitude, although, unlike in Kenya, no specific areas have been identified. A modeling study from Bomet, Kenya, also indicates that high temperatures (average 27.5°C) and altitude (1,888 m) are favorable to MLN (Osunga et al. 2017). Other studies have detected the two viruses that cause MLN (MCMV and SCMV) in all the maize-growing regions, albeit at varying levels (Mwatuni et al. 2020), but our study shows that MLN itself is not as widespread, or at least not in noticeable levels. This also confirms the observations from another study that, while some plants have the disease, they have atypical symptoms (Wamaitha et al. 2018).

The results also show a concerning trend of farmers using few measures to control MLN. The most common strategy, removing affected plants, was only practiced by 62% of the affected communities. The next method, planting resistant varieties, was only practiced by 9.5% of the affected communities, although in these communities the method was used by most farmers (78%) and it also received the highest efficiency score (4.7/5). However, with the exception of DK777, the MLN tolerant varieties farmers mentioned did not show MLN tolerance in trials. Farmers did not mention the use of clean seed, and it is possible that they confused the effect of tolerance in the variety and the effect of purchasing fresh, clean seed. Further, while by 2018 a range of MLN resistant varieties had been released (Boddupalli et al. 2020), none of these were available at the time of the survey, as they were in the process of being bulked.

Agronomic control methods were only used by 11% of the communities. A study in Kenya indicated that large-scale farmers could achieve good control by combining clean seed and insect control with crop rotation, but that small-scale farmers had to rely on rotation and roguing, and could only achieve more limited control (Hilker et al. 2017). In our study, respondents were mostly small-scale farmers, and they confirmed that the practice of roguing was common, but few used crop rotation and none mentioned the use of clean seed (although they mentioned resistant varieties). Clearly, more effort is needed to bring resistant or tolerant varieties to the communities, and to educate farmers better on the use of clean seed and on complementary agronomic measures.

While much progress has been made in developing resistant varieties (Das et al. 2019; Gowda et al. 2018), these have not yet reached the farmers, or at least had not reached them in 2018. In particular, communities are not aware of the need for leaving a maize-free period of two months between seasons to avoid contamination over the seasons, nor are they aware of the use of certified seed, or the need for the timely removal and destruction of contaminated plants.

The results of this study raise a major question: why has MLN so clearly and strongly reduced over the study period? Unfortunately, our data do not provide clear answers, and neither do other data or studies. Still, the available information to date allows us to discuss several likely as well as unlikely factors, which can be divided between interventions and external factors. The sudden and dramatic arrival of the disease led to immediate and widespread attention by the scientific, development, and donor communities, resulting in a slate of activities and projects. Interventions included (i) the development and deployment of MLN-tolerant/resistant maize hybrids, (ii) awareness creation about MLN management, (iii) the development of diagnostics for MLN-causing viruses and MLN monitoring

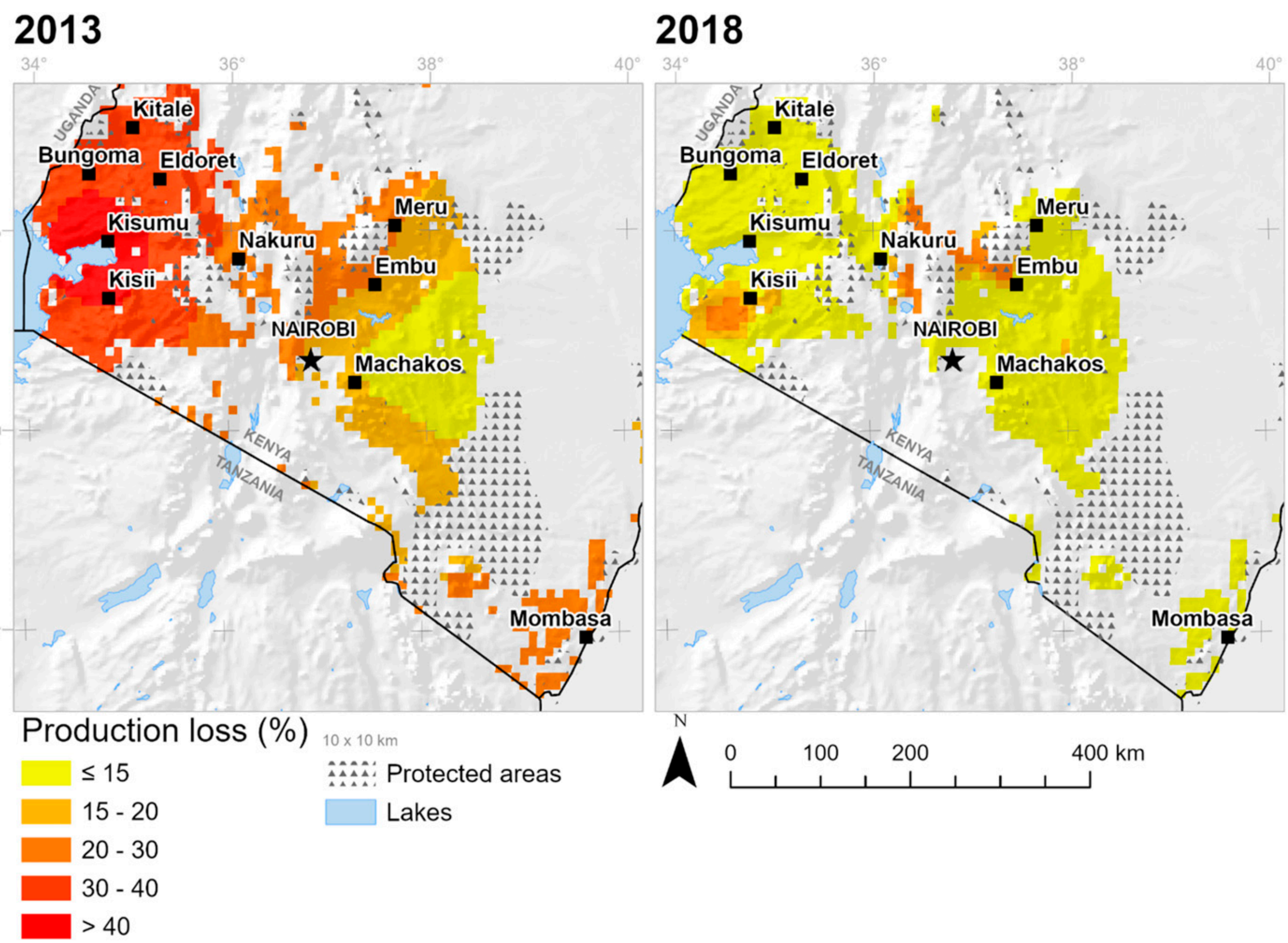

Fig. 6. Geographic distribution of relative loss of maize, in % of annual production.

and surveillance, and (iv) production and dissemination of MLN pathogen-free commercial maize seed (Boddupalli et al. 2020). Our results throw some light on the effect of these actions. Resistant varieties, the first intervention, have not yet taken off, although they are well appreciated by those farmers who use them. Similarly, the adoption of good management practices (the desired result of intervention), and in particular crop rotation to control MLN is limited. MCMV incidence has been shown to be exacerbated in fields with continuous maize production (Nelson et al. 2011). Nor does the third intervention, the development of diagnostics and the monitoring and surveillance of MLN, seem to have advanced the understanding of the spread of the disease and the factors affecting it, as the

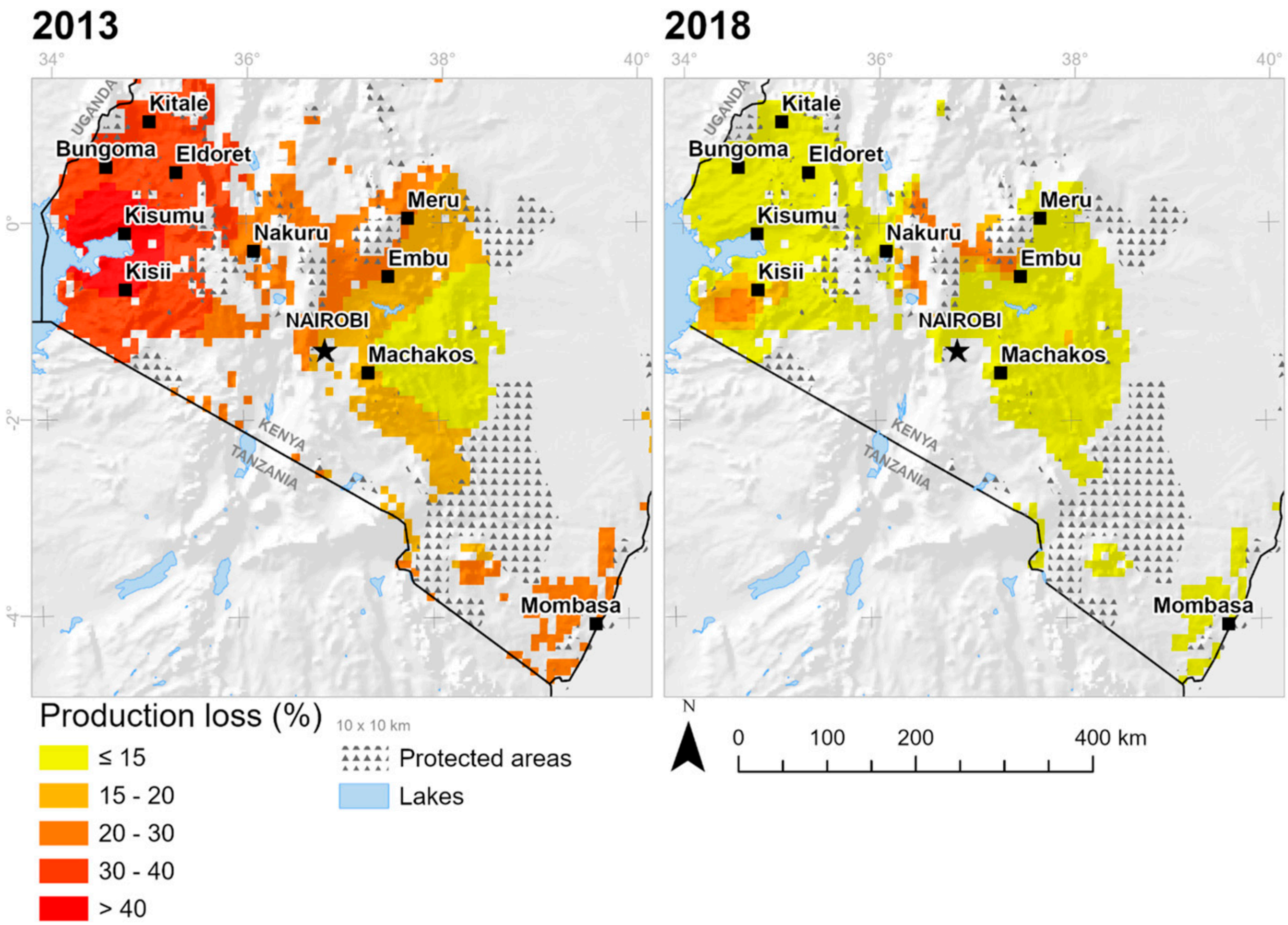

Fig. 7. Geographic distribution of absolute loss in maize, in metric tons per km^2.

Table 5. Methods used to control maize lethal necrosis (MLN), with the proportion of communities and farmers practicing each method, and their effectiveness as judged by the participants

Control strategy	Communities practicing		Proportion of farmers in the community using this method			Effectiveness of the method in controlling the disease (1, least effective to 5, most effective)		
	N	%[a]	Mean	N	St. dev.	Mean	N	St. dev.
Removing the affected crops[b]	33	44.6	67	22	24.7	3.0	33	1.4
Removing and burning the affected crops	9	12.2	76	9	33.1	3.8	9	1.1
Removing and feeding to the animals	5	6.8	54	5	40.4	2.8	5	0.8
Any removing	46	62.2						
Planting resistant maize varieties	7	9.5	78	5	39.0	4.7	7	0.5
Changing maize varieties	1	1.4	100	1		4.0	1	
Resistant or other maize varieties	7	9.5						
Crop rotation	5	6.8	52	5	27.7	4.2	5	0.8
Early planting	2	2.7	70	2	14.1	4.5	2	0.7
Fallowing-shifting to a different plot	2	2.7	35	2	7.1	3.5	2	0.7
Wider spacing	1	1.4	90	1		4.0	1	
Changing cropping seasons	1	1.4	100	1		3.0	1	
Agronomic practices	8	10.8					8	
Pesticides	2	2.7	20	1		2.0	2	1.4
Total	55	74.3		54	32.2	3.4	68	1.4

[a] Out of 74 communities that observed MLN.
[b] Respondents also used other terms, including cutting, uprooting, and roguing.

data for Kenya and other countries have apparently not yet been analyzed, with the exception of Ethiopia (Regassa et al. 2020). This leaves the production and distribution of MLN-free seed. The Kenyan Plant Health Inspectorate Services (KEPHIS), the regulatory agency, has implemented a system for the inspection of seed production fields to ensure that only MCMV disease-free seeds are produced and certified. From 2016 onward, farmers have mostly been using disease-free certified seed, and this is probably one of the major factors that has reduced the disease load in the field. Unfortunately, data to formally test this hypothesis are not available. Still, given that all certified seed is inspected by KEPHIS both during the vegetative stage and during seed storage, and that only MLN-free seeds are approved for distribution and sale, this inspection seems likely to have been a major factor in reducing MLN.

The observed reduction of MLN could also be driven by external factors, in particular the arrival of FAW and weather. We speculate that the sudden arrival of FAW in Kenya in 2016 and its rapid spread over the different maize production areas (De Groote et al. 2020), with the resulting increase in the spraying of insecticide in maize fields, has led to a reduction of the vectors of MLN viruses. Spraying of maize with insecticides has been shown to have a negative effect on MLN (Namikoye et al. 2020). A second external factor could be weather conditions in 2018 that were unfavorable to the spread of MLN or its vectors, in particular the very high rainfall that fell in almost all maize production zones during the March-May season of 2018 (which incidentally caused the execution of the community surveys to be delayed until June 2018). This is also supported by a study in Bomet County, located in Kenya's southern Rift Valley, which found a relatively higher rate of MLN infection in lower rainfall areas (Jafari Jozani et al. 2020). Statistical analysis of our data, on the other hand, found a positive correlation between MLN and rainfall.

The reduction in MLN was also observed in some neighboring countries: in Ethiopia (Regassa et al. 2020) and Uganda (unpublished monitoring data), but not in Rwanda or Tanzania. In Ethiopia, the reduction was attributed to an increase in maize growers' awareness and understanding of MLN and its management, due to campaigns implemented by different governmental and other institutions (Regassa et al. 2020), in contrast to our results in Kenya; the continuous spraying of insecticides there to control FAW, which has become an important maize pest since 2017 (Keno et al. 2018), might also have contributed to the control of insect vectors (Regassa et al. 2020).

Methodologically, the 2013 survey already showed how group discussions with a representative sample of communities could provide relevant estimates of losses due to pests and could be easily extrapolated to regional and national levels. In this paper, we show how this type of study can easily be converted into panel data to analyze trends in pest problems over space and time. By using farmer recall instead of scientists' observations, several seasons can be covered in one sitting; further, by using group discussions instead of individual farmers, a wider area can be covered, typically a village or community, instead of an individual farm or field. Farmer recall does have some limitations, as noticed in the results of the 2018 survey where fewer communities recalled having ever observed MLN than in 2013. These results indicate that after a few years, recall data can become problematic; this could be a problem of memory recall but could also be due to having different people in the FGD. However, this discrepancy was only seen in those agroecological zones in the east where MLN was not a major problem, so accurate recall is also likely to be related to the severity of a pest problem. A second limitation of the study is the limited precision at the zonal level, as indicated by the P values of the differences between the 2013 and the 2018 losses: the differences tend to be significant when they are above 20 percentage points, but not below, because of the low sample size. However, the results of this study, in particular the variability indicators, can be used to calculate the power of the test and to calculate the required number of communities for future studies. The last limitation of the method is that statistical analysis is limited to exogenous variables such as time and weather, as management variables such as the use of resistant varieties or appropriate agronomic practices are highly correlated to the occurrence of the pests.

This method contributes to the expansion of participatory approaches from PRAs to participatory learning and action (PLA) (Chambers 2008). While our study does contribute to participatory mapping, we also hope to contribute to PLA, especially to the intersection of PLA and GIS, which has been explored before (Chambers 2006; De Groote et al. 2004), in particular by quantifying incidence and losses over time and space.

In conclusion, our results show a clear decreasing trend in the importance and geographic spread of MLN, the reasons for which are not well understood. Several factors such as disease-free seed, increased insecticide use against FAW, and heavy rains have probably played a role in this trend, while other factors, such as farmers' understanding of the biology of the disease and responding with proper agronomic practices and resistant varieties, have probably not. Still, as the disease continues to be present and could flare up under favorable circumstances, it is important to continue agricultural extension efforts to improve farmers' knowledge and understanding of the disease and to increase the adoption of control measures such as a maize-free period of 2 months between seasons, the timely removal and burning of affected plants, and the use of resistant varieties and certified, clean seed (CIMMYT 2013). Clearly, seed inspection to ensure disease-free seed, and the further development and dissemination of resistant varieties, which offer the best long-term and the most economical solution, should be continued.

Acknowledgments

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