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Abstract
Farmer-managed natural regeneration (FMNR) practice aims to improve maize health and increase maize yield in semi-arid areas in Kenya. Under the practice, farmers select and manage trees regeneration in their farmlands while growing maize. Whereas FMNR practice is known to contribute to food security, income diversification, and increased employment opportunities, its beneficial contribution to maize farmers in Nyatike, Kenya, has not been researched. This study applied a quantitative field survey design using the Land Degradation Surveillance Framework technique for its hierarchical sampling design. The area of study is divided into seven (7) blocks (sites) represented by wards of Nyatike Sub-County. Forty-five (45) farmers were randomly selected to participate in the study. In each selected farm, maize under different tree canopies was considered to be treatment sites (TT) while those in the open (not under the tree canopies) were considered as controls (NT) using a block sampling design. Maize plant growth was monitored with measurements of height, number of leaves, diameter of maize stalk taken at intervals, and finally, maize yield after harvesting. The results show no significant difference in height, number of leaves, or diameter of maize stalk between the treatment and controls. Farms under FMNR practice had relatively higher yield compared to non-treatment, with an equivalent increase in maize yield of 1,432.18 kg/ha. There is a need for research on high-performing tree species to be carried out to improve both biodiversity and maize yield, thus presenting a sustainable model for restoring land and increasing food security in dryland areas.

Introduction

Maize (*Zea mays* L.), also known as corn, is the leading global staple cereal, cultivated on approximately 200 million hectares with annual production exceeding 1 billion metric tonnes (García-Lara et al., 2019). Despite its domestication dating back over 9,000 years in southern Mexico (Awika, 2011; Kennett et al., 2020), it has become widely accepted across the globe, forming a major component of the human diet and is a source of income for millions of farmers (Boddupalli et al., 2020). It has become a vital and preferred human food crop in sub-Saharan Africa (SSA), Asia, and Latin America, contributing over 20% of food calories (Shiferaw et al., 2011; Stat, 2021). The usefulness of maize transcends human food needs to serve several purposes. In developed countries, maize is used as a livestock feed crop and as an industrial and energy crop, increasing its demand (Erenstein, 2010). This has made the maize crop a significant driver in global agri-food systems and food security over the last decade (Brouwer et al., 2020; Fanzo et al., 2017; Fanzo et al., 2021; Grote et al., 2021; Poole et al., 2021). For instance, climate change has continued to ravage the world, resulting in more than 33% of the degraded land (Abhilash, 2021). As a result, over three billion people now suffer from famine, hunger, water shortage, and severe weather events, where they continue losing productive landscapes, valued culture, their livelihoods, and eventually loss of life. Through Sustainable Development Goals (SDGs) of leaving no one behind, initiatives such as Farmer-Managed Natural Regeneration (FMNR) have sustained livelihoods and landscapes, providing a pathway of escape from climate change impacts (Walker et al., 2024).

SDG 2, which aims at eradicating hunger and promoting food security, can be realised through sustainable agricultural practices like FMNR. By extension, restoration of terrestrial ecosystems, degraded lands, and biodiversity will be achieved, realising SDG 15. Restoration of degraded land and increasing agriculturally productive land area will support the ever-growing population (Abhilash, 2021). The projection of the world population hitting 10.3 billion by the year 2084, an increase of 2.1 billion people from 2024 statistics (Lam, 2025), has made land degradation gain immense attention globally. The question that needs to be answered is how the world will provide enough food for this increased population without destroying forests to increase cultivated land. Statistics have shown that over the last quarter century, maize yield production more than doubled, but supported by a land area increase of about 50 % (Erenstein et al., 2022; Stat, 2021). Reversal of land degradation is inevitable (Fitawek & Hendriks, 2024). Projections show that 512 million people will still face hunger in 2030, of whom about 60 per cent will be in Africa, if nothing is done to change the current situation. Also, food prices rose throughout 2023 and 2024, an indication of a food crisis (Unicef, 2025).

Farmer-Managed Natural Regeneration (FMNR) practice is a sustainable land management technology that facilitates the regrowth of trees and shrubs from felled tree stumps, sprouting root systems or seed banks while cultivating crops. FMNR has been widely promoted as a low-cost and scalable approach in communities embracing the activities aimed at reversing environmental shifts that have resulted in soil deterioration affecting livelihoods (Lohbeck et al., 2020; Rinaudo, 2007; Rinaudo et al., 2019). It is widely believed that FMNR is crucial in achieving the Sustainable Development Goals (SDGs), contributing significantly to addressing climate action, food security, and improving the livelihoods of the rural population living in semi-arid areas (Ojuok & Ndayizigiye, 2021).

The African continent is likely to experience food insecurity due to a rapidly growing population (Amede et al., 2023). This has prompted many farmers in the Sahel to adopt FMNR practice (World Vision Kenya, 2021), resulting in restored lands increasing agricultural productivity and improved food security (Haglund et al., 2011). In Niger, food security for over 2.5 million people has been secured (Reij et al., 2009). In Senegal, Ghana, and Niger, FMNR has resulted in improved access to nuts, berries, roots, wild animals, birds, and insects (Francis et al., 2015; Gates, 2012; Weston et al., 2013). Yield increase of between 50 per cent and 100 per cent in Zambia, 115 per cent in Burkina Faso, 200 per cent in Niger, and up to 300 per cent in Malawi (Indexmundi, 2018) has been realised. Millet grown by FMNR adopters increased by 23 per cent in Senegal (Kabore et al., 2012). Various technologies used in semi-arid areas in Mali, including assisted natural regeneration, increased maize yield by 673 kg/ha (Sissoko et al., 2023).

Over 90% of Kenyans depend on maize for food (consuming up to 4.3 million tonnes annually, as per 2018 statistics), income, and employment (Indexmundi, 2018; Kusia, 2018). This makes maize farming a very significant activity. However, maize farming is hampered by land degradation affecting over 30 per cent of the land, with 80 per cent of Kenyan land classified as arid or semi-arid (World Vision Kenya, 2021). This, in turn, reduces the food crop productivity potential of the productive land, producing only between 1.43 and 1.82 t/ha annually (Gennari et al., 2019; Njeru et al., 2022), resulting in hunger and a lack of dietary and malnutrition of about 26 per cent of children under the age of five (Wanjira et al., 2020). As one of the strategies to achieve food security, Kenya adopted the FMNR practice (Government of Kenya, 2019). FMNR practice is carried out in partnership with World Vision Kenya, in collaboration with CIFOR-ICRAF (Odhiambo, 2024). Despite the effort put in place so far, the success of FMNR technology in Kenya is still unknown. Reports on the challenges and successes in terms of the impact of FMNR on maize health and maize yield remain scanty. The significance of maize cannot be underrated, even as its demand is expected to rise by 2.3 per cent by 2050 (Robinson et al., 2015). In Nyatike, as in other semi-arid areas, maize is the major staple food crop that is depended on (De Jager et al., 2001).

In this paper, we focus on the benefits that the FMNR practice provides for maize health and maize yield production in Nyatike Sub-County, Kenya. This was done by monitoring maize plant growth in terms of height, diameter, and number of leaves, and maize yield measurement during harvesting. The parameters of maize under FMNR were compared to those of maize health and yield not under FMNR.

Research Methodology

The study was carried out in Nyatike Sub-County, Kenya, as shown in Figure 1.1. The Sub-County covers an area of approximately 676.9 km^2, and had a population of 176,162 according to the 2019 census (Starnes et al., 2021). Projections indicate that by 2025, the population will reach 203,865 individuals. It is divided into seven wards: Kachieng’, Kanyasa, North Kadem, Macalder /Kanyarwanda, Kaler, Got Kachola, and Muhuru. The region is characterised by unreliable and poorly distributed rainfall, with annual totals ranging between 700mm and 1,800 mm (Migori County Government, 2023).

This study adopted a quantitative field survey research design. Farmers who were practising farmer-managed natural regeneration technology and planted maize were included in the study. In each selected farm, maize under different tree canopies was considered to be treatment sites (Tree Treatment) while those not under the tree canopies were considered as controls (Non-Treatment) using a block sampling design. Maize plant health was monitored with measurements of height, number of leaves, and diameter of maize stalks taken at intervals, and maize yield was measured after harvesting.

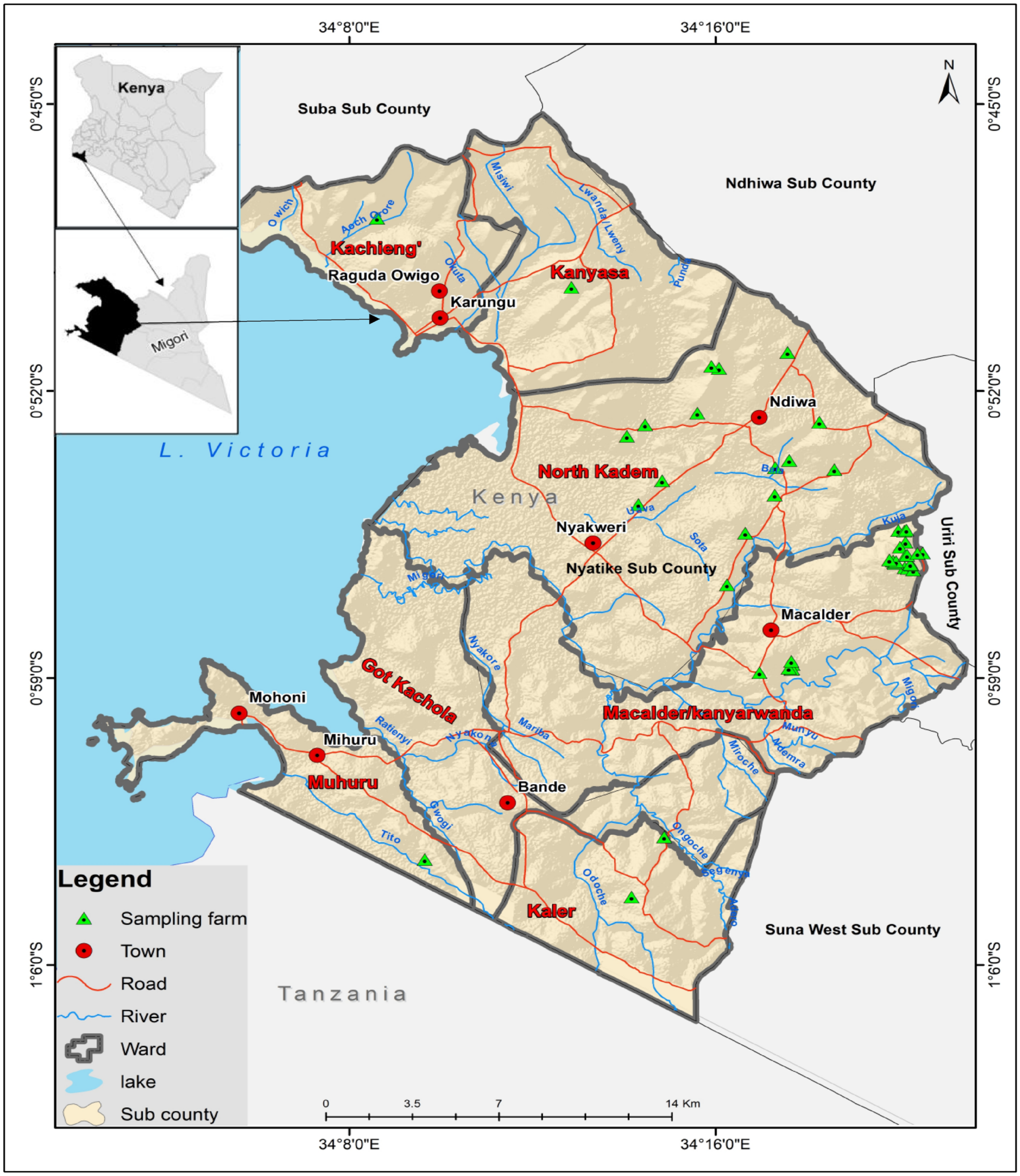

Figure 1: Map of Nyatike Sub-County showing study site and sampling plots

Sampling Technique and Procedure

The target population for the study was the 2,727 farmers practising FMNR in Migori County, as per the database from World Vision, spearheading the project of Regreening Africa, in the Migori County offices. The sampling technique used was the Land Degradation Surveillance Framework. This technique is effective in assessing the processes of land degradation and restoration over time (Vâgen et al., 2013), hence, its choice for the study.

A hierarchical sampling design comprising three levels of randomisation was used. Since the area covers 676.9 km^2, the area was divided into seven (7) blocks (sites) of approximately 10 km by 10 km in size. For purposes of this study, the seven blocks were the wards within the Sub-County: Kachieng', Kanyasa, North Kadem, Macalder /Kanyarwanda, Kaler, Got Kachola, and Muhuru. With a target population of less than 10,000, a sample size of between 10% and 30% was a good representation of the target population (Mugenda & Mugenda, 2003). This study adopted 12% of the target population as the sample size. This gave a sample size of 332 farmers. Further, systematic sampling was carried out where every 8th farmer was selected for the study. This resulted to forty-five (45) farmers, as shown in Table 1.1 below. This is because the farmers were assumed to have homogeneous characteristics and shared the same climatic conditions. In each plot, 8 sampling plots (subplots or treatment sites) were selected, four treatment sites were selected, and also four non-treatment sites, where there were no trees, but of the same area as the one next to or immediately under the tree canopy, were selected. This resulted in 360 treatment sites under a complete randomised block sampling design.

In each sampling plot, eight soil samples were collected at intervals using the traverse method and mixed to form a composite sample for analysis. Also, in each sampling plot, 10 maize plants were randomly and systematically selected, giving a total of 3600 samples. Data on plant height, number of leaves, stem circumference and yield were measured and recorded. The measurements of height, number of leaves and stem circumference were done monthly, while the yield was measured after harvesting. The soil sampling technique adopted was as described by (Okalebo et al., 2002; Vâgen et al., 2013).

Table 1: Blocks, Sample Size and Treatment Plots

Blocks	**Number of farmers**	**12% of the target population (Sample size)**	**Systematic sampling of samples (8th farmer)**	**Treatment plots (4 for each farmer)**	**Non-Treatment plots (4 for each farmer)**
North Kadem	1068	129	16	64	64
Macalder/ Kanyarwanda	1577	190	24	96	96
Kaler	18	3	1	4	4
Muhuru	21	3	1	4	4
Got Kachola	09	2	1	4	4
Kanyasa	15	2	1	4	4
Kachieng'	19	3	1	4	4
TOTAL	**2727**	**332**	**45**	**180**	**180**

Data Collection Procedures

Maize farmers who were selected to participate in the study, together with the researcher and research assistant, identified four treatment sites and four non-treatment sites within the farms. For the treatment site (maize under the tree), ten maize crops within the tree canopy and ten under non-treatment sites (not under the tree or nearer the influence of the tree canopy) were randomly selected and tagged using plastic labels for identification and monitoring. Maize crops were monitored from planting through to harvesting. Key growth parameters, including the number of leaves, plant height, and stem circumference, were measured and recorded monthly, beginning with the first month after planting up to the third month. The number of leaves was counted and recorded while the plant height and stem circumference were measured using a tape measure. The maize yield was measured after harvesting, sun drying for five days, and cob shelling, using a weighing machine. This was done while ensuring the storage of maize yield was done in well-labelled bags as per each sampling site. Before harvesting, farmers were not allowed to interfere with maize crops within the sampling site.

Data Processing and Analysis

The quantitative data collected were analysed using the Statistical Package for Social Sciences (SPSS) version 25. The results of the analysis are presented in tables, graphs, frequency distribution tables and charts, among other visual aids. Both descriptive and inferential statistical analyses were performed to address the specific objectives, respond to the research questions and test the stated hypotheses. While descriptive statistics have been provided to summarise, organise, observe trends and provide insights into the data, inferential statistical analysis has been used to determine whether or not there exists any significant relationships between or among the variables of interest as governed by either the objectives, research questions or hypotheses. Descriptive analysis involving mean, standard deviation and standard error of mean for each case of the attributes for NT and TT was also done. The impact of FMNR practices was checked by determining whether or not the differences in the means were significant. To this end, an independent t-test was conducted where normality assumptions were tenable or where the violation of normality was not too serious, given the robustness of the t-test in such situations. The assumptions of normality were tested using the Shapiro-Wilk test and the Kolmogorov-Smirnov test (with Lilliefors significance correction). In cases where multiple variables significantly violated the normality assumption, non-parametric alternative tests such as the Mann-Whitney U test were considered.

To evaluate land productivity under FMNR in terms of crop yields in Nyatike Sub-County, a comparative analysis was undertaken to determine whether significant differences existed between TT areas and NT areas. The statistical tests in this regard were based on the average maize yield generally and then blockwise. The blockwise analysis was designed to determine the variability of the average maize yield across the blocks (wards) between TT and NT areas. In addition to descriptive statistics such as means, frequencies, and standard deviation, inferential statistical analyses were carried out to determine whether the differences in the average maize yield between TT and NT were statistically significant. To achieve this, an independent samples t-test was conducted as the normality assumption was satisfied, or any minor violations were not severe enough to compromise the robustness of the test. In situations where violation of normality was significant, the Mann-Whitney U test, as a nonparametric alternative, was conducted. In addition, the productivity levels were checked across the different tree species. A two-way ANOVA was conducted to test the effects of blocks (wards), intervention category and their interaction on productivity levels. Productivity was measured in terms of maize yield expressed as the average maize yield. To provide further insight into tree species that could sustain higher productivity levels, a comparison of average maize yield across tree species was conducted.

Results and Discussion

Productivity Levels of Land under FMNR in Terms of Maize Yields

Comparisons Based on Plant Health: Plant Circumference

Generally, across Nyatike Sub-County, the mean maize circumference for the treatment areas (mean = 8.02, Standard Deviation = 0.75) was slightly lower than the non-treatment areas (mean = 8.69, Standard Deviation = 5.20), with a mean difference of -0.67 units.

An independent samples t-test was conducted to compare the mean stem circumference of maize between the TT (N = 166) and NT (N = 166) groups. Levene's test for equality of variances indicated that the assumption of equal variances was violated, F (1, 330) = 6.174, p = .013.

Table 2: T-Test of Plant Circumference

		Levene's test for equality of variances		**t-test for equality of means**						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean difference**	**Std. error difference**	**95% Confidence Interval of the difference**	
									Lower	**Upper**
Average of maize circumference	Equal variances assumed	6.17	.013	-1.63	330	.103	-.67	.41	-1.47	.14
	Equal variances not assumed			-1.63	171.82	.104	-.67	.41	-1.47	.14

The results of the t-test, as shown in Table 1.2, indicate that there is no statistically significant difference in maize circumference between the two groups, t(171.82) = -1.63, p = .104.

This implies that there is no sufficient evidence to suggest a significant difference in maize stem circumference between the treatment (TT) and non-treatment (NT) areas, and that observed differences in stem circumference were likely due to random variation rather than the intervention of FMNR practice.

These results suggest that the FMNR practice does not compromise maize growth in any way and should be encouraged, allowing farmers to benefit from trees on their farms in addition to their maize yield production.

Comparisons Based on Plant Health: Maize Height

An independent samples t-test was carried out, as shown in Table 1.3, to assess the difference in the average height of maize between the TT (N = 166) and NT (N = 166) groups. Levene's test for the equality of variances showed that the assumption of equal variances was satisfied, F(1, 330) = 1.112, p = .292.

The analysis showed that there was no meaningful difference in maize height between the treatment and non-treatment groups, t (330) = -0.213, p = .832, showing that FMNR did not influence crop height. The average height of maize for the treatment group (M = 223.72, SD = 35.03) was marginally lower than the non-treatment group (mean = 224.57, SD = 37.67) with a mean difference of -0.85 units. However, this difference was not statistically significant, 95% Confidence Interval [-8.70, 7.00]. These findings suggest that the treatment did not result in a substantial change in maize height when compared to the non-intervention group.

Table 3: T-Test for Equality of Means of Maize Height

		Levene's test for equality of variances		**t-test for equality of means**						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean difference**	**Std. error difference**	**95% Confidence Interval of the difference**	
									Lower	**Upper**
Average of height of maize	Equal variances assumed	1.11	.29	-.21	330	.83	-.85	3.99	-8.70	7.00
	Equal variances not assumed			-.21	328.28	.83	-.85	3.99	-8.70	7.00

Comparisons Based on Plant Health: Plant Leaf Count

An independent samples t-test was conducted as shown in Table 1.4 to examine the difference in maize leaf count between the TT (N = 166) and NT (N = 166) groups. Levene's test for equality of variances revealed that the assumption of equal variances was not violated, F(1, 330) = 0.010, p = .921.

Table 4: T-Test for Maize Leaf Count Means

		Levene's test for equality of variances		**t-test for equality of means**						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean difference**	**Std. error difference**	**95% Confidence Interval of the difference**	
									Lower	**Upper**
Average of maize leaf count	Equal variances assumed	.010	.92	1.52	330	.131	.20	.13	-.06	.46
	Equal variances not assumed			1.52	329.74	.131	.20	.13	-.06	.46

The t-test results indicated no significant difference in the average number of maize leaves between the two groups, t (330) = 1.515, p = .131. The intervention group had a slightly higher mean maize leaf count (mean = 10.70, SD = 1.22) compared to the non-intervention group (M = 10.50, SD = 1.18) with a mean difference of 0.20 units. However, the evidence from the analysis suggests that this difference was not statistically significant, 95% Confidence Interval [-0.06, 0.46]. Therefore, the treatment (TT) did not provide sufficient evidence to show a significant effect on maize leaf count compared to the non-treatment (NT) group.

Comparisons Based on Maize Yield

The results of maize yield compared for treatments and controls across all the wards are shown in Figure 1.2 below. The average maize yield for treatments was better than that for non-treatments in all the wards except Muhuru. Got Kachola TT (171.15), NT (147.31); Kachieng' TT (152.09), NT (102.15); Kaler TT (136.61), NT (121.57); Kanyasa TT (114.73), NT (91.54); Macalder/Kanyarwanda TT (133.51), NT (127.56); Muhuru TT (119.67), NT (125.91) and North Kadem TT (119.77), NT (116.40). Maize crops growing under indigenous trees yielded better. The tree canopies seem not to have had any effect on maize growth and development, and many of them are not known to have the Biological Nitrogen Fixation (BNF) property, which needs further investigation on their influence.

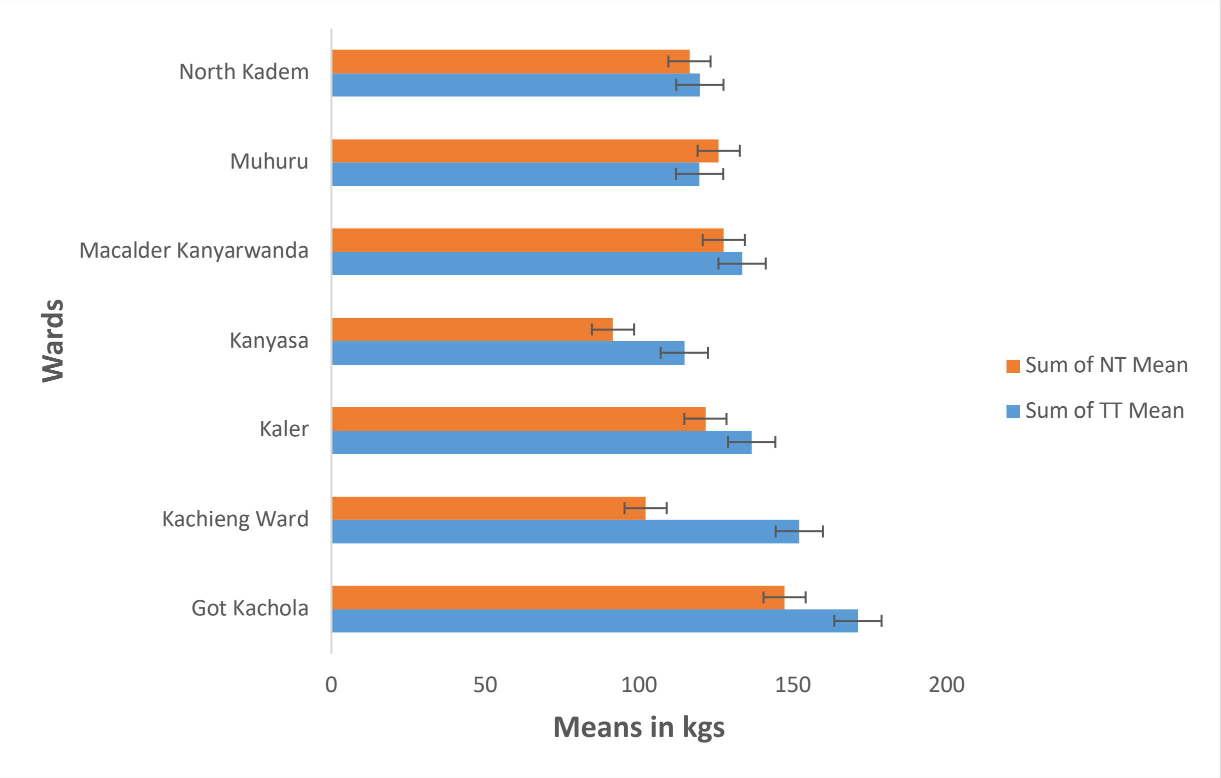

Figure 2: Average maize yield per ward

To test the significance of the differences in the means, an independent t-test analysis was carried out. The normality of the average maize yield was assessed for both the treatment (TT) and non-treatment (NT) groups using the Kolmogorov-Smirnov and Shapiro-Wilk tests. In the treatment group, the Kolmogorov-Smirnov test indicated no significant deviation from normality D (166) = .058, p = .200), suggesting that the data were normally distributed. However, the Shapiro-Wilk test revealed a significant departure from normality W (166) = .971, p = .002), indicating that the distribution of maize yield in this group was not perfectly normal.

For the non-treatment group, both tests indicated a significant deviation from normality (Kolmogorov-Smirnov: D (166) = .173, p < .001; Shapiro-Wilk: W (166) = .578, p < .001), which suggests that the average maize yield in this group did not follow a normal distribution.

An independent samples t-test was conducted as shown in Table 4.14 to compare the average maize yield between the TT (N = 166) and NT (N = 166) groups. Levene's test for equality of variances confirmed that the assumption of equal variances was satisfied, F (1, 330) = 0.000, p = .998.

The results of the independent samples t-test indicated no significant difference in maize yield between the two groups, t (330) = 1.094, p = .275. The mean maize yield for the treatment group (mean = 128.30, SD = 34.92) was slightly higher than that for the non-treatment group (mean = 122.95, SD = 52.32), with a mean difference of 5.34 units. However, this difference was not statistically significant, 95% CI [-4.26, 14.95]. Hence, there is sufficient evidence to suggest a meaningful effect of the intervention on maize yield compared to the non-intervention group.

Table 5: T-Test of Maize Yield Means

		Levene's test for equality of variances		**t-test for equality of means**						
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean difference**	**Std. error difference**	**95% Confidence Interval of the difference**	
									Lower	**Upper**
Average of maize yield	Equal variances assumed	.000	.998	1.09	330	.275	5.34	4.88	-4.26	14.95
	Equal variances not assumed			1.09	287.671	.275	5.34	4.88	-4.26	14.95

The study findings show that FMNR practice had a significant effect on maize yield, despite not showing any statistically significant difference in terms of maize stalk circumference, maize plant height and the number of leaves that the maize plant had. The findings showed that in most wards, maize yield was higher where there were trees compared to where there were no trees, except for Muhuru ward, where the maize yield was slightly higher where there were no trees compared to where there were trees. Overall, mean maize yield was 128.30 kg for treatment areas compared to 122.95 kg for non-treatment areas, a difference that was not statistically significant (p = .275). This suggests a positive but modest impact of FMNR on maize productivity. However, these results contrast with findings from a study by Siedenburg (2022), which reported that scattered trees in fields significantly reduced maize yields. This could be because the trees had only been in the farms for three years, whereas in this study, the FMNR in Nyatike Sub-County had been in place for more than ten years since its introduction.

In Malawi, maize yields increased by 12–14 per cent in the fields with *Faidherbia* tree species compared to fields without them, averaging 1,350 kg/ha (Glenn, 2012). This study suggests that trees may have had species-specific influences, as evidenced by the observation of higher maize yield under *Capparis decidua* and *Cedrela odorata*. Various technologies used in semi-arid areas in Mali, including assisted natural regeneration, increased maize yield by 673 kg/ha (Sissoko et al., 2023). This study had similar findings, where there was an increase of 5.35 kg per treatment site. This is equivalent to an increase in maize yield by 1,432.18 kg/ha, which is almost three times the increase that was realised in Mali. This yield increase is mainly because of the use of FMNR technology only as opposed to the use of multiple technologies such as microdosing of mineral fertiliser, seed priming and new cereal varieties, horticulture, assisted natural regeneration and ridging. This is a demonstration that FMNR practice, if embraced wholly, has a great impact on maize production and provides the solution to food insecurity for arid and semi-arid areas. This was also demonstrated where improved fallow species improved maize yield (Place et al., 2004). Also, *Terminalia brownii* enhanced maize yield by influencing microclimate and improving soil nutrients (Handiso et al., 2024). These differences suggest that tree species can significantly influence maize yield. Species associated with higher maize yield may provide favourable conditions, such as improved soil fertility or shade regulation, while those with lower values might compete with maize for resources. Plate 1.1 shows maize growing under the *Balanites aegyptiaca* tree species.

Plate 1: Maize growing under Balanite aegyptiaca trees' canopy

Conclusion

Maize is a key cereal crop in semi-arid areas in Kenya, and it is associated with food security not only in Migori County in Kenya, but also in Kenya as a whole and in sub-Saharan Africa. Maize productivity under FMNR showed positive trends, particularly in maize yield, although differences in plant health parameters were not statistically significant. The maize yield increase is equivalent to an increase in yield by 1,432.18 kg/ha. These yield improvements were strongly influenced by tree species that were utilised by farmers practising FMNR. Although the average maize yield in Kenya is far below the global average, FMNR practice shows that its adoption has great potential to improve the average to that of the global level. This shows that numerous opportunities are available to further improve maize's contribution to the food and nutrition, environmental sustainability, resilience, and livelihoods outcomes of agri-food systems in Kenya and the region at large.

References

Abhilash, P. C. (2021). Restoring the unrestored: strategies for restoring global land during the UN decade on ecosystem restoration (UN-DER). *Land, 10*(2), 201.

Amede, T., Konde, A. A., Muhinda, J. J., & Bigirwa, G. (2023). Sustainable farming in practice: Building resilient and profitable smallholder agricultural systems in sub-Saharan Africa. *Sustainability, 15*(7), 5731.

Boddupalli, P., Suresh, L., Mwatuni, F., Beyene, Y., Makumbi, D., Gowda, M., Olsen, M., Hodson, D., Worku, M., & Mezzalama, M. (2020). Maize lethal necrosis (MLN): Efforts toward containing the spread and impact of a devastating transboundary disease in sub-Saharan Africa. *Virus Research, 282*, 197943.

Brouwer, I. D., McDermott, J., & Ruben, R. (2020). Food systems everywhere: Improving relevance in practice. *Global food security, 26*, 100398.

De Jager, A., Onduru, D., Van Wijk, M., Vlaming, J., & Gachini, G. (2001). Assessing sustainability of low-external-input farm management systems with the nutrient monitoring approach: a case study in Kenya. *Agricultural systems, 69*(1-2), 99-118.

Erenstein, O. (2010). The evolving maize sector in Asia: Challenges and opportunities. *Journal of New Seeds, 11*(1), 1-15.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food security, 14*(5), 1295-1319.

Fanzo, J., Arabi, M., Burlingame, B., Haddad, L., Kimenju, S., Miller, G., Nie, F., Recine, E., Serra-Majem, L., & Sinha, D. (2017). Nutrition and food systems. *A report by the high level panel of experts on food security and nutrition of the committee on world food security*.

Fanzo, J., Haddad, L., Schneider, K. R., Béné, C., Covic, N. M., Guarin, A., Herforth, A. W., Herrero, M., Sumaila, U. R., & Aburto, N. J. (2021). Rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals. *Food Policy, 104*, 102163.

Fitawek, W., & Hendriks, S. L. (2024). Sustainable Development Goal 15: Life on land *Handbook on Public Policy and Food Security* (pp. 354-364): Edward Elgar Publishing.

Francis, R., Weston, P., & Birch, J. (2015). The social, environmental and economic benefits of Farmer Managed Natural Regeneration. *World Vision Australia*, 6-23.

García-Lara, S., Chuck-Hernandez, C., & Serna-Saldivar, S. O. (2019). Development and structure of the corn kernel. *Corn*, 147-163.

Gates, M. B. (2012). *An Examination of a Farmer-managed Natural Regeration Program in Senegal After Three Years.* Cornell University.

Gennari, P., Rosero-Moncayo, J., & Tubiello, F. N. (2019). The FAO contribution to monitoring SDGs for food and agriculture. *Nature plants, 5*(12), 1196-1197.

Glenn, J. V. (2012). Economic Assessment of Landowner Incentives: Analyses in North Carolina and Malawi.

Government of Kenya. (2019). *National Climate Change Action Plan (2018–2022). Nairobi.*

Grote, U., Fasse, A., Nguyen, T. T., & Erenstein, O. (2021). Food security and the dynamics of wheat and maize value chains in Africa and Asia. *Frontiers in Sustainable Food Systems, 4*, 617009.

Haglund, E., Ndjeunga, J., Snook, L., & Pasternak, D. (2011). Dry land tree management for improved household livelihoods: farmer managed natural regeneration in Niger. *Journal of environmental management, 92*(7), 1696-1705.

Handiso, M. A., Asfaw, Z., Glaser, B., Bromm, T., Gross, A., & Lemma, B. (2024). Effects of canopy management of umbrella tree (Terminalia brownii Fres.) on microclimate and maize (Zea mays L.) yield in agroforestry parkland of South Ari District, southern Ethiopia. *Frontiers in Sustainable Food Systems, 8*, 1464609.

Indexmundi. (2018). Kenya corn domestic consumption by year. Available at https://www.indexmundi.com/agriculture/?country=ke&commodity=corn&graph=domestic-consumption.

Kabore, C., Bakhoum, C., Rinaudo, T., Nzale, M., Sow, C., Kokou, A., & Nuwame, F. (2012). End of project evaluation. Senegal Food and Livelihood Enhancement Initiatives (SFLEI). *World Vision Australian Aid (95 p)*.

Kusia, E. S. (2018). *Characterization of maize chlorotic mottle virus and sugarcane mosaic virus causing maize lethal necrosis disease and spatial distribution of their alternative hosts in Kenya.* JKUAT-PAUSTI.

Lam, D. (2025). The Next 2 Billion: Can the World Support 10 Billion People? *Population and Development Review, 51*(1), 63-102.

Lohbeck, M., Albers, P., Boels, L. E., Bongers, F., Morel, S., Sinclair, F., Takoutsing, B., Vågen, T.-G., Winowiecki, L. A., & Smith-Dumont, E. (2020). Drivers of farmer-managed natural regeneration in the Sahel. Lessons for restoration. *Scientific reports, 10*(1), 15038.

Migori County Government. (2023). *County Integrated Development Plan 2023-2027.*

Mugenda, O. M., & Mugenda, A. G. (2003). *Research methods: Quantitative & qualitative apporaches* (Vol. 2): Acts Press.

Njeru, F., Mwaura, S., Kusolwa, P. M., & Misinzo, G. (2022). Maize production systems, farmers' perception and current status of maize lethal necrosis in selected counties in Kenya. *All Life, 15*(1), 692-705.

Odhiambo, C. O. (2024). Perspective Chapter: The Role of Development Partners in Kenya's Landscape Restoration towards Vision 2030 *Rural Areas-Development and Transformations*: IntechOpen.

Ojuok, I., & Ndayizigiye, T. (2021). Women Participation in Farmer Managed Natural Regeneration for Climate Resilience: Laisamis, Marsabit County, Kenya *African Handbook of Climate Change Adaptation* (pp. 2755-2773): Springer.

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). Laboratory methods of soil and plant analysis: a working manual second edition. *Sacred Africa, Nairobi, 21*, 25-26.

Place, F., Franzel, S., Noordin, Q., & Jama, B. (2004). *Improved fallows in Kenya: history, farmer practice, and impacts*: Intl Food Policy Res Inst.

Poole, N., Donovan, J., & Erenstein, O. (2021). Agri-nutrition research: revisiting the contribution of maize and wheat to human nutrition and health. *Food Policy, 100*, 101976.

Reij, C., Tappan, G., & Smale, M. (2009). *Agroenvironmental transformation in the Sahel: Another kind of" Green Revolution"*: Intl Food Policy Res Inst.

Rinaudo, T. (2007). The development of farmer managed natural regeneration. *LEISA-LEUSDEN, 23*(2), 32.

Rinaudo, T., Muller, A., & Morris, M. (2019). Farmer managed natural regeneration (FMNR) manual. *World Vision Australia: Melbourne, Australia*.

Robinson, S., Mason-D'Croz, D., Sulser, T., Islam, S., Robertson, R., Zhu, T., Gueneau, A., Pitois, G., & Rosegrant, M. W. (2015). The international model for policy analysis of agricultural commodities and trade (IMPACT): model description for version 3.

Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food security, 3*(3), 307-327.

Sissoko, P., Guindo, S. S., Togola, S., Dembélé, B. D., Grimsby, L. K., & Aune, J. B. (2023). Effect of adoption of climate-smart-agriculture technologies on cereal production, food security and food diversity in Central Mali. *Agriculture, 13*(6), 1196.

Starnes, J. R., Wamae, J., Okoth, V., Ressler, D. J., Were, V., Were, L. P., Moon, T. D., & Wamai, R. (2021). Population-based socio-demographic household assessment of livelihoods and health among communities in Migori County, Kenya over multiple timepoints (2021, 2024, 2027): A study protocol. *PLoS One, 16*(8), e0256555.

Stat, F. (2021). FAO Stat. FAO, Rome.

Unicef. (2025). *The State of Food Security and Nutrition in the World 2025: Addressing high food price inflation for food security and nutrition*: Food & Agriculture Org.

Vâgen, T., Winowiecki, L. A., Walsh, M. G., Tamene, L. D., & Tondoh, J. E. (2013). Te Land Degradation Surveillance Framework (LDSF) Field Guide v3 (World Agroforestry Centre, Nairobi, 2013).

Walker, B., Rinaudo, T., Radkovic, A., & Mulherin, A. (2024). Global movements for accelerating climate change action: the case of Farmer-Managed Natural Regeneration. *Journal of Global Ethics, 20*(2), 251-274.

Wanjira, E., Muriuki, J., & Ojuok, I. (2020). Farmer Managed Natural Regeneration in Kenya: A primer for development practitioners.

Weston, P., Hong, R., & Morrison, V. (2013). Talensi FMNR Project: Endof-Phase Evaluation Report, unpublished. *World Vision Australia/World Vision Ghana*.

World Vision Kenya. (2021). *FMNR Impact Report – Kenya Country Office.*