

**CLIMATE VARIABILITY ON DODDER (*Cuscuta spp.*) INFESTATION IN
TEA FARMS IN NANDI COUNTY, KENYA**

By

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DECLARATION

Declaration by Candidate:

I declare that this is my original work and has not been presented for a degree or award in any other University.

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DEDICATION

This thesis is dedicated to my parents, James Mongo and Rebecca Mongo. My siblings (Antonet, Brenda, Isaac and Victor) for their endless support throughout this journey.

ACKNOWLEDGEMENT

First and foremost, I am grateful to God for His Grace and Favour through this journey. I extend my deepest appreciation to my supervisors, Dr. James Koske and Prof. John Muriuki, for their invaluable guidance, encouragement, and constructive feedback through every stage of this research. Their expertise and mentorship have been instrumental in shaping the direction and quality of this work.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ASALS	Arid and Semi-Arid Lands
CADP	County Annual Development Plan
DJF	December January February
EEA	European Environmental Agency
ENSO	El Niño/Southern Oscillation
EPK	Eastern Produce Kenya
GDP	Gross Domestic Produce
GHG	Greenhouse Gases
GPS	Geo-Spatial Positioning
IPCC	International Panel on Climate Change
IPM	Integrated Pest Management
JJA	June July August
KALRO	Kenya Agricultural and Livestock Research Organization
KMD	Kenya Meteorological Department
KNBS	Kenya National Bureau of Statistics
KTDA	Kenya Tea Development Agency
KTGA	Kenya Tea Growers Agency
LH	Lower Highlands
LSD	Least Significant Difference
MAM	March April May
NACOSTI	National Commission For Science, Technology and Innovation
NCIDP	Nandi County Integrated Development Plan
SON	September October November
SPSS	Statistical Packages for Social Sciences
TBC	Tea Buy Centre
UM	Upper Midlands
WMO	World Meteorological Organization

DEFINITION OF TERMS

Tea plant: An evergreen shrub of the family *Theaceae*, specifically called *Camellia sinensis*, whose leaves are used to make beverages.

Haustoria: A slender dodder projection found in parasitic plants that penetrates the host and obtains nutrients from the host.

Holoparasite: A Parasitic organism that cannot complete its life cycle without exploiting a suitable host.

Dodder: A leafless, twining parasitic plant of the family Convolvulaceae and genus *Cuscuta* of about 200 species globally.

Host plant: In this thesis, host plants are species upon which dodder subsists.

Allelopathy: This refers to the ability of tea plants to produce biochemical responses that inhibit the growth of dodder species.

Phytochromes: A Class of photoreceptor proteins that dodder uses to detect light.

Tertiary education level: For this study, tertiary education level refers to post-secondary education and training in colleges, institutes, or Universities that the respondents attained.

Volatile cues: Signals emitted by dodder to convey the physiological status of suitable host plants .

ABSTRACT

Climate change and variability continue to significantly impact agricultural production and management worldwide. From the literature, it is reported that there has been an unprecedented emergence of pests and diseases associated with climate change and variability among other factors. In Kenya, crop cultivation and yield are affected primarily by changing climatic conditions, pests, and diseases. Of major concern in counties of Kenya, are the impacts of climate variability and parasitic dodder (*Cuscuta* spp.) on tea cultivation and production. From the literature, little is reported on the continuing invasion and effects of parasitic dodder on smallholder and large-scale tea farming. The purpose of this study was to assess the extent of dodder infestation on tea cultivation and yield in Nandi County. Specifically, the study sought to examine the trends of climate variability (temperature and rainfall) from 1992 to 2022. To assess tea farmers' perceptions on the influence of climate variability on the spread of dodder. To assess tea-growing farmers' perceptions of the effects and control of dodder on tea farms. An exploratory survey design was chosen for this study. A designed questionnaire was administered to 354 statistically determined heads of tea farming households that are members of the Kenya Tea Development Agency. Six tea estate managers and two field managers who were purposefully chosen were interviewed. For the set variables, primary data from the administered questionnaire were extracted and analyzed ($p \leq 0.05$). Secondary data was sourced from libraries and relevant repositories. Rainfall and temperature data for the period were obtained from the Kenya Meteorological Department, Nandi Station. To assess the extent of dodder infestation on tea farms, GPS coordinates were captured and presented on a map. 205 respondents didn't have dodder on their tea farms, while 149 reported a case of dodder infestation. In the Multinational tea estates, Siret, Chemomi, and Taito reported cases of dodder infestation in their catchment. Mann-Kendall Trend Analysis showed a significant increase in temperature, denoted by a Sen's slope= 0.031 and a strong positive correlation of Kendall's Tau 0.554 indicating an increase at $p < 0.000$. Rainfall showed an increasing trend Sen's slope= 5.618 was not statistically significant at $p = 0.341$ with a weak correlation of Kendall's Tau= 0.123. On the influence of rainfall and temperature on dodder occurrence, 95.6% and 68.9% of the respondents perceived that long rainy (March to May) and cold (June to August) seasons increased its intensity. While 69.8% perceived a moderate intensity of dodder during the hot season (December to February). 97.7% of the respondents acknowledged that dodder is a threat to tea farming. Of its effects on tea, dodder interfering with hand plucking was ranked first (mean= 4.90, standard deviation= 0.33). In conclusion, dodder has been extensively distributed on tea farms and is a threat to tea farming in the study area. This study recommends a need for community sensitisation on the spread and effects of dodder by relevant stakeholders. Further research is needed to identify effective and sustainable methods to control dodder.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

The dodder plant is an invasive alien parasitic species belonging to the Kingdom- Plantae; phylum- Tracheophyta; class- *Spermatopsida*; order- *Solanales*; family- *Convolvulaceae* (Morning glory) and genus- *Cuscuta* (Kaiser *et al.*, 2015; Olszewski, 2019; Yego *et al.*, 2022; Głofcheskie *et al.*, 2023). There are about 200 species globally, with field dodder (*Cuscuta campestris*) (Yuncker) as the most widespread (Ngare *et al.*, 2020). Dodder species are reported to be native to the Northern parts of America (Stefanović *et al.*, 2009; Missouri, 2018). They are characterized by leafless, smooth, threadlike stems that are either pale yellow or bright orange (Ding *et al.*, 2019), twinning on suitable plant hosts. After a successful invasion, it spreads vegetatively, building a dense web that covers the host plant, as in Figure 1.1. *Cuscuta* species lack chlorophyll to photosynthesize, thus acquiring nutrients through root-like structures (haustorium), eventually killing the host plant (Dawson, 1994; Shen *et al.*, 2020).



Figure 1.1: *Cuscuta* spp on a Yellow Oleander. Photo taken 27th May 2023, GPS (0.203823, 35.041870)

Globally, dodder species have destroyed crops of economic importance such as alfalfa, sugar beets, tomatoes, and onions (Üstüner, 2018; Teofanova *et al.*, 2022). Ding *et al.*, (2019) reported that *Cuscuta australis* (R. Br.) has a wide range of host plants, threatening biodiversity in China.

In Africa, dodder attacks have become increasingly prevalent, despite insufficient research, posing a threat to crops of economic importance (Masanga *et al.*, 2021). Dodder species have a wide range of suitable host plants, including potatoes, tomatoes, ornamental plants, and tea (Magazines 2014; Ngare *et al.*, 2020). They are predicted to have a high suitability for both tea and coffee plants in some parts of East Africa (Masanga *et al.*, 2021). For instance, in Uganda, dodder is reported to have invaded coffee plantations, a crop of greater economic value in the region (Kagezi *et al.*, 2021). Additionally, the results showed that of the crops studied, 93.9% were found to be of the class dicotyledonous.

In Kenya, dodder species have infested larger landscapes, destroying crops of economic importance (Masanga *et al.*, 2021; Eston *et al.*, 2020). Research by Chepkirui (2020) and Masanga *et al.*, (2022) further indicated that these species are extensively distributed across the western and eastern parts of Kenya. Additionally, *Cuscuta japonica* (Hook and Arn.) has been reported to infest Michuki Memorial Park in Nairobi, Kenya, showing the parasite's capacity to thrive in urban areas (Rotich *et al.*, 2021). Similarly, a study by Ngare *et al.*, (2020) showed that dodder species affected ornamental plants in urban areas, indicating their adaptability and expanding ecological range.

The major dodder species found in Kenya include *C. campestris*, *Cuscuta kilimanjari* (Oliv.), and *Cuscuta reflexa* (Roxb.), which have been proven to cause harm to the tea and coffee industry (Masanga *et al.*, 2021; Dechassa and Regassa, 2021). Studies by Masanga *et al.*, (2021), and Glofcheskie *et al.* (2023) revealed that *C. campestris* and *C. kilimanjari* belong to the subgenus *Grammica*, native to the northern parts of America and East Africa, respectively. In comparison, *C. reflexa* is native to Southeast Asia, belonging to the subgenus *monogynella*. *C. Campestris* exhibits thin, orange to yellow stems of diameter 1mm, having small white flowers with greenish-yellow capsules. They have separate styles, with globose stigmas and short stamens. In contrast, *C. kilimanjari* is distinguished by its purple, coarse vines with pale white and

waxy flowers. Have a separated style, spherical stigmas, and shorter stamens than the lobes. *C. reflexa* is characterized by greenish-yellow stems with large flowers. They have a fused style with two elongated stigmas.

Globally, agriculture and forestry are among the key sectors severely affected by climate change and variability (Chervenkov and Slavov 2022; Gwambene *et al.*, 2023). Changing climatic trends in temperature and rainfall favor the thriving of invasive species. (CABI, 2010; Zhou *et al.*, 2016; Ebrahimi *et al.*, 2021). These variations affect the distribution and growth of dodder (Liu *et al.*, 2020). A study by Bai *et al.*, (2018) reported that a rise in temperatures enhances the germination of dodder seeds and their growth in China. However, not all studies have found a positive correlation between dodder occurrence and climate variability, suggesting other complex relationships exist for dodder growth and spread. Ren *et al.*, (2020) reported that global warming threatens the habitat suitability of *C. chinensis*.

Tea, scientifically known as *Camellia sinensis* (L.) Kuntze is a perennial monocultural crop of the Kingdom- *Plantae*; phylum- *Magnoliophyta*; class- *Magnoliopsida*; order- *Ericales*; family- *Theaceae*; genus- *Camelia* that is used to make hot beverages (Gesimba *et al.*, 2005; Pandey *et al.*, 2021; Chen *et al.*, 2022). There are two varieties of tea species: *C. sinensis* var. *sinensis*, which is native to China (Mitra and Khandelwal, 2017). It has a small leaf cultivar and does well in cool temperatures and high elevations. The second variety is *C. sinensis* var. *assamica*, native to the Assam region of India, characterized by large and broad leaves (Karlsson, 2022). It does well in tropical regions with low elevation.

In Kenya, tea-growing regions have an ideal climate favoring tea farming (Kamunya *et al.*, 2019; Koros *et al.*, 2023). These regions lie 1500 to 2700 meters above sea level, with red volcanic soils, temperature ranges from 18 to 30°C, and well-distributed rainfall of about 1200 to 1500mm annually (TBK, 2023). In Nandi, tea is the most predominant cash crop (Ngure, 2020). It is produced in both large-scale farming owned by multinational tea companies and smallholder farms (Tuitoek *et al.*, 2020). Tanui *et al.*, (2012) reported that the most tea clones grown are TN14/3 (59%) and C12 (25.2%).

Despite tea being a monocultural crop, dodder species have infested the agro-ecosystem, leading to significant loss in production. Chepkirui (2020), revealed that in

Kericho County, Kenya, tea was a highly suitable host for dodder, with 2,391 out of 7,300 affected individual species being tea plants. These could lead to poor quality and low quantity of the infested tea bushes, resulting in financial losses to the farmer. Findings by Yego *et al.*, (2022) revealed that in Nandi County, Kenya, tea plants have been susceptible to dodder attacks since 2013. The study focused on the period 1992-2022 to extend earlier climate analyses in Nandi County, such as Kirui (2020) (1971-2000) and Omasaki and Mokoro (2022) (1980-2012). This thirty-year span provides updated evidence to assess both climate variability and emerging climate change impacts, addressing the gap in recent localised climate data for the County.

Although climate variability is known to be a key factor influencing the thrive of parasitic weeds, its specific relationship with dodder infestation remains unknown. Temperature changes and rainfall patterns may alter the growth dynamics of both the host and the parasite, thereby influencing the extent and distribution of dodder on tea farms. These infestations may affect tea bush physiology and productivity. Therefore, this study seeks to fill this knowledge gap by assessing the influence of climate variability on the spread of dodder and how this affects tea farming in Nandi County.

1.2 Statement of the Problem

Tea production is among Kenya's highest agricultural income earners and the backbone of the economy in Nandi County. Research institutions and managing bodies have put measures in place to ensure that the quality and quantity of tea is at par (TBK, 2019; TBK, 2025). However, dodder infestation continuously threatens tea production in quality and quantity, which may further result in economic instability. This invasive species has a haustorium that enables it to attach to and deprive nutrients from host plants. Therefore, it results in stunted growth, reduced yield, and in some cases, total crop failure.

Over time, climate variability has been reported as a major factor in the increase of invasive species (Zhang *et al.*, 2022). However, there is limited knowledge on the influence of climate variability on the spread of dodder. Despite the evident impact of dodder infestation Yego *et al.*, (2022), there is limited research on the extent of its infestation in the area of study and current control measures, as most existing studies are not specific to the region's unique ecological conditions.

This lack of integrated understanding of how climate variability influences dodder infestation, its effect on tea and the methods of control represents a critical knowledge gap. By filling existing knowledge gaps, this research aims to provide recommendations that can inform local farmers and policymakers to mitigate the adverse effects of dodder infestation on tea. Therefore, this study seek to assess the influence of climate variability on dodder infestation in tea farms in Nandi County.

1.3 Research Questions

The following questions were used to guide the study in Nandi County:

1. How has climate variability (temperature and rainfall) varied from 1992 to 2022?
2. What is the extent of dodder invasion in both large- and small-scale tea farms in the County?
3. How do tea farmers perceive the influence of climate variability (temperature and rainfall) on the spread of dodder in tea farms?
4. How do tea-growing farmers perceive the effects and control of dodder infestation on tea?

1.4 Research Objectives

The research aimed to achieve the following objectives for the study in Nandi County:

1. To examine the trends in climate variability from 1992 to 2022 in the study area.
2. To assess the extent of dodder invasion in both large- and small-scale tea farms within the County.
3. To assess tea-growing farmers' perceptions on the influence of climate variability (temperature and rainfall) on the spread of dodder on tea farms.
4. To assess tea-growing farmers' perceptions of the effects and control of dodder on tea.

1.5 Research Hypotheses

The following null hypotheses were tested ($p \leq 0.05$):

1. There is no significant variation in temperature and rainfall patterns from 1992 to 2022 in Nandi County.
2. Dodder has not significantly infested both large and small-scale farms in Nandi County.

3. Tea farmers perceive that climate variability (Temperature and Rainfall) does not significantly influence the spread of dodder in tea farms.
4. Tea farmers do not significantly vary in perception of the effects and methods of control of dodder on tea in Nandi County.

1.6 Justification of the Study

Dodder is a serious problem in tea plantations in Kenya as it can lead to reduction in its quality and quantity through its effects on the yield or failure. Despite report of its invasion on tea farms in Nandi (Yego *et al.*, 2022), little is known on the influence of climate variability on dodder distribution, the extent of invasion, effects and methods of control. The results from mapping the extent of infestation can be utilized by KTDA and the County agricultural department to monitor current and future dodder spread. This study will help in understanding the possible effects of dodder on tea. To farmers, the results and recommendations on better practices to control dodder will also be provided. Therefore, conducting a study on dodder infestation on tea plantations in Nandi County is important to enhance the productivity and economic sustainability of the tea industry.

1.7 Conceptual Framework

The conceptual framework (Figure 1.2) shows the relationship between the independent variables (Climate variability, *Cuscuta*) and the dependent variables (distribution, effects and methods of dodder control) and the intervening variables (agronomic management of tea- use of herbicides, policies on invasive species, and allelopathy of tea bushes to dodder infestation). It conceptualizes the effects of climate variability on *Cuscuta* infestation on tea yield and control techniques.

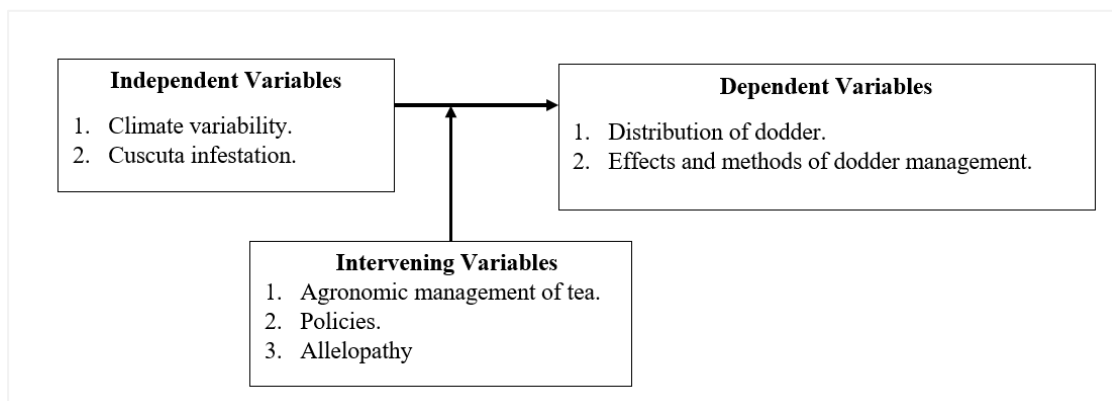


Figure 1.2 Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Climate Variability

The global climate has warmed significantly, with increased variability in rainfall patterns in the last century. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), global surface temperatures rose by 1.09°C between 1850-1900 and 2011-2020. Alexander *et al.*, (2022) observed intensified precipitation across Northern Hemisphere mid-latitudes, attributed to altered hydrological cycling under higher temperatures. Donat *et al.*, (2011) found that extreme rainfall poses risks to ecosystems and agricultural stability. This shifts favor the thrive of invasive species, causing ecosystem disturbance (Zhang *et al.*, 2022). Studies on *Cuscuta chinensis* revealed that its potential global distribution is sensitive to mean annual temperature, temperature seasonality, and rainfall variability (Ren *et al.*, 2020), while Cai *et al.*, (2022) reported that climate change could increase environmental niche overlap between multiple *Cuscuta* species and leguminous host crops, increasing agricultural vulnerability.

The African continent is vulnerable to the impacts of climate change due to its overreliance on rainfed agriculture to bolster its economy (Zougmore *et al.*, 2018). According to the WMO (2023), it is estimated that by 2030, up to 118 million people living on less than US\$1.90 per day in Africa will be exposed to drought, floods and extreme heat. Climate change is manifesting itself in Eastern Africa at a faster rate (Gwambene *et al.*, 2023). It is informed by the rising temperatures and unpredictable rainfall patterns, whereby some parts of Kenya, Ethiopia, and Tanzania experience rainfall with no significant trend (Gebrechorkos *et al.*, 2018). This variability is largely driven by global climate patterns, including the Indian Ocean Dipole (IOD) and El Niño–Southern Oscillation (ENSO), which can increase or reduce rainfall. The interaction of these climate modes alters regional atmospheric circulation, making precipitation patterns across the region unpredictable (Lyon, 2014; Nicholson, 2017). The Greater Horn of Africa was reported to have increasing temperature extremes and changing precipitation from 1961-2010 (Omondi *et al.*, 2014). These conditions favour the spread of invasive species threatening the crops of economic importance in the region.

In Kenya, empirical research shows that climate variability is already affecting staple crop productivity, food security, and livelihood strategies. Kabara *et al.*, (2022) found that unpredictable rainfall patterns in timing, frequency, and duration, with rising temperatures and pest infestations, occurred in Kitui and Laikipia counties. Studies in semi-arid regions; Machakos, Makueni, and Kitui Counties found that farmers perceive significant shifts in rainfall onset, duration, and intensity (Omoyo *et al.*, 2015). In Kajiado County, climate variability has led to recurrent food insecurity, forcing households to adopt drought-resistant crop varieties and water conservation practices despite financial and institutional barriers (Mwangi, 2020). In Kenya's highlands, the tea sector has been affected by climate change, where increased minimum temperatures and unpredictable rainfall have been linked to yield declines and frost-related losses (Ochieng *et al.*, 2016)

Nandi County experiences a bimodal rainfall regime. The long rainy season begins from March to May, when the planting season begins, while the short rainy season commences from September to November (Sitienei *et al.*, 2017; NCIDP, 2018). June to August is characterized by cold temperatures with minor peak rainfall amounts, while December to February are the drier months with little rainfall (Wakachala *et al.*, 2015). However, it is faced with unpredictable rainfall patterns, floods, frost, hailstorms, landslides, and prolonged dry spells (Nandi County Government, 2023). This impacts agricultural production due to crop failure and post-harvest losses and increased pests. Similarly, the County Climate Risk Profile (2023) by CGIAR synthesized historical and projected data (2020-2060), showing increased frequency of heavy rainfall events, frost in highlands, and elevated landslide risks. These climatic shifts are likely to exacerbate soil erosion and reduce yields of tea, the county's main cash crop. A study by Kirui *et al.*, (2020) using trend and spatial analyses examined spatiotemporal variability of rainfall and temperature from historical records and future projections. The findings showed an increasing rainfall pattern in the short rainy season with increasing warming trend.

2.2 Parasitic Dodder

Parasitic plants are species that depend on host plants to acquire nutrients and water essential for growth, causing harm to the host plants in the process (Smith *et al.*, 2001; Erdogan, 2021). Due to evolution, they have developed a specialised structure called a haustorium, which extract nutrients from host plants for survival (Yoshida *et al.*, 2016;

Dechassa and Regassa, 2021). Globally, there are about 4750 parasitic plant species belonging to 28 families representing 1% of the angiosperms (Gogoi *et al.*, 2021; Lu *et al.*, 2022). Parasitic plants of economic importance are grouped into the following families, namely: *Convolvulaceae* (*Cuscuta* spp), *Orobanchaceae* (*Orobanche* spp), and *Scrophulariaceae* (*Striga* spp) (Nickrent, 2020; Dechassa and Regassa, 2021; Zimdahl and Basinger, 2024).

These parasitic plants have been classified based on the presence or absence of chlorophyll and their dependence on host plants throughout their life cycle (Teixeira-Costa and Davis, 2021). Those that depend on the host plant entirely to complete their life cycle are called obligate/ holoparasites such as *Cuscuta* as they lack enough chlorophyll (Fernández-Aparicio *et al.*, 2020) whereas hemiparasites/ facultative have chlorophyll thus make their food and do not entirely depend on the host plant throughout their life cycle (Smith *et al.*, 2001; Furuhashi *et al.*, 2011) such as mistletoe. They can establish themselves on the upper parts of the host plant as dodders and mistletoes, or parasitize the roots, such as striga and orobanche (Aly and Dubey, 2014).

Dodder species are holoparasites belonging to the family *Convolvulaceae* of the morning glory family. There are up to 200 different species reported globally (Miguel *et al.*, 2014; Kaiser *et al.*, 2015; Yego *et al.*, 2022). They are yellow, leafless, and rootless holoparasitic plants with twinning stems that grow around the plant host. Dodders have specialized root structures (haustoria) (Dawson *et al.*, 1994; Shahid *et al.*, 2018; Saric-Krsmanovic *et al.*, 2020), which penetrate the host, sucking nutrients, water, and amino acids and reproducing mainly by flowering (Lusweti *et al.*, 2011). Most types of dodder species are native to North America and have now spread to most parts of the world (Missouri, 2018). They have destroyed higher plant species and crops; however, other dodder species such as *Cuscuta howelliana* (P. Rubtzov.), endemic to California, are keystone species in the plant communities, thus increasing plant species richness (Graffis and Kneitel, 2015; Olszewski *et al.*, 2020).

Dodders have specialized features helping them thrive in various habitats (Jhu and Sinha, 2022b). They grow fast, utilizing the food stored in their cotyledons while searching for viable host plants (Jiang *et al.*, 2022). These species have phytochromes and volatile cues to detect suitable host plants (Mescher *et al.*, 2006; Shen *et al.*, 2020). Vrbničanin and Sarić-Krsmanović (2020), reported that *C. campestris* has a diverse

range of host plants, enabling it to survive and thrive in any geographical area. The viability of dodder seeds is physically dormant, rendering them difficult to control as they can survive up to 10 years in the soil (Jhu and Sinha, 2022a). Field dodder produces about 15000 seeds per plant, which increases their chance of survival (Sarić-Krsmanović, 2020).

Dodder propagates through its stem twining and seed dispersal (Nice, 2006). After attaching itself to a suitable host, the twines continue to elongate rapidly, forming dense web networks (Liu *et al.*, 2020; Jiang *et al.*, 2022) that could spread to other nearby plants. Its stem fragments can continue growing even after they are cut and thus can be easily spread by vectors such as animals, especially birds (Costea *et al.*, 2016). Dodder seeds can survive even after ingestion by livestock, thus their fecal matter could spread dodder to new areas (Sandler, 2010). In large farms where machinery is used, dodder seeds and vines could be dispersed unintentionally, spreading to new areas. In rural areas, the bright-colored dodder vines attract school children, who pluck and distribute the vines to their homesteads. (Kagezi *et al.*, 2021). Research by Dawson (1994), reported that alfa alfa seeds were contaminated with dodder and therefore distributed to new regions. In aquatic ecosystems, dodder seeds are highly transported and dispersed by surface run-offs during rainy seasons, discharging contaminated effluents to wastelands and their environs. In addition, these seeds exhibit buoyancy, making it easier to transport by run-offs (Sandler, 2010).

2.2.1 Dodder Infestation: Life Cycle

Dodder species reproduce both asexually through vegetative growth and sexually through seed formation (Lanini *et al.*, 2010; Masanga *et al.*, 2021). During sexual reproduction, it undergoes four stages: seed germination, vegetative growth and attachment, flowering, and seeding (Mishra *et al.*, 2006; Furuhashi *et al.*, 2011; Dechassa and Regassa, 2021) as shown in Figure 2.1.

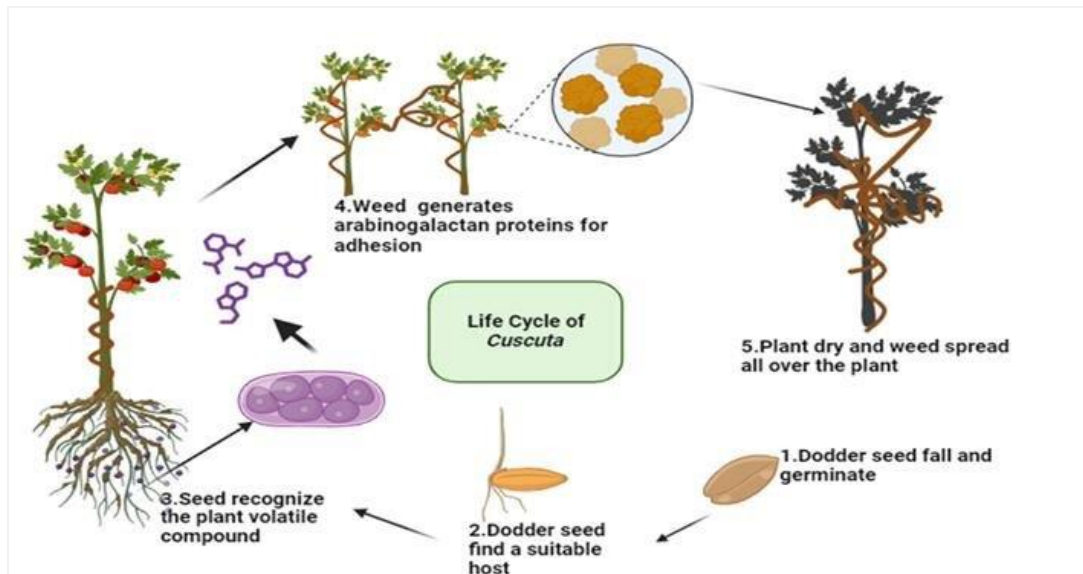


Figure 2.1: Life cycle of a dodder. Source: (Sharma *et al.*, 2024) Page 105.

Gemination of seeds occurs near or on the soil surface about 5cm deep from the soil surface (Mishra *et al.*, 2006). Didders depend on light and temperature for germination (Zagorchev *et al.*, 2022). A study by Dawson *et al.*, (1889) revealed that *Cuscuta* seeds germinate best in broad sunlight. However, it could still germinate in the absence of light at a temperature of about 16 °C (Dinelli *et al.*, 2005; Lanini *et al.*, 2019). Hutchison and Ashton (1980), observed that *C. campestris* can germinate at a maximum in the range of 30-33°C and the lowest temperature at which dodder seeds could germinate is 10°C.

Cuscuta spp depend on carbohydrates in their cotyledon for about 5 to 6 days before finding a suitable host lest they die (Kumar, 2019). Upon finding a host, it coils itself around the plant. It then produces a haustorium that penetrates the vascular tissues to suck nutrients from the host plant. After the attachment, the roots in the soil die, as it continues to spread to surrounding host plants (Tamer, 2018; Mahr, 2022).

The dodder plants use volatile clues and photoreceptors to detect suitable hosts (Zagorchev *et al.*, 2021). Findings by Sarić-Krsmanović (2020), reported that *C. campestris* seedlings grow in the direction of light sources, preferably the red and far-red light, which helps in identifying a suitable host. Additionally, the presence of blue and far-red light aids in the formation of haustoria. Similarly, a study by Shen *et al.*, (2020) found that *C. australis* uses the flowering locus to identify suitable hosts initiating parasitism during the reproductive phase.

After attaching to the plant host, dodder species produce numerous clustered flowers, typically 4 per cluster, about 2 to 3mm in diameter with 5 lobbed corollas (Loo, 1946; Masanga *et al.*, 2021) as shown in Figure 2.2. These flowers later develop into seed capsules containing 2 to 3 seeds, whereby they produce up to a thousand seeds on a single plant.

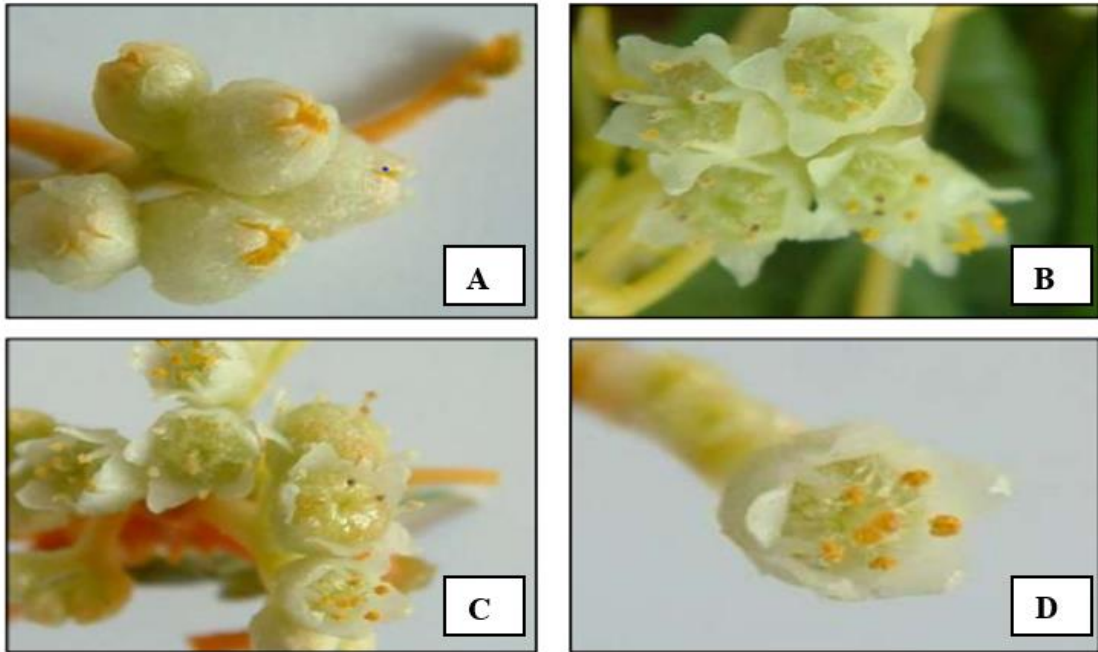


Figure 2.2: *Cuscuta campestris* Flowers Source: (Mishra *et al.*, 2006) Page 6

2.2.2 Interaction of Parasitic Dodder with the Host Plant

Parasitic plants have led to agricultural loss globally (Mäckelmann *et al.*, 2024). However, some host species develop defense mechanisms from parasitic plants by suppressing recognition during the pre-attachment and post-attachment phases (Jhu and Sinha, 2022b; González-Fuente, 2024). During the attachment phase, dodder coils itself to the host plant by forming a haustorium. It then undergoes cell differentiation in the meristem into tip and file cells, which grow to searching hyphae and axial cells (Nagar *et al.*, 1984; Nickrent, 2020). The axial cells penetrate the host epidermal tissues while the search hyphae elongate and intrude on the xylem and phloem vessels to establish vascular continuity for nutrient absorption (Hong *et al.*, 2011).

A study by Jhu and Sinha (2022), explains the developmental stages of dodder haustorium; the initiation phase is the first stage in which pre-haustorium structures are developed, the second stage is the adhesion phase where the epidermal cells differentiate into adhesive disks that will secure the haustoria attachments, the third stage is the penetration phase the tip of inner haustoria cell elongate and differentiate

to searching hyphae which searches for the vascular system of the host plants. Finally, the last stage is the vascular connection phase, where the searching hyphae divide into xylem and phloem bundles.

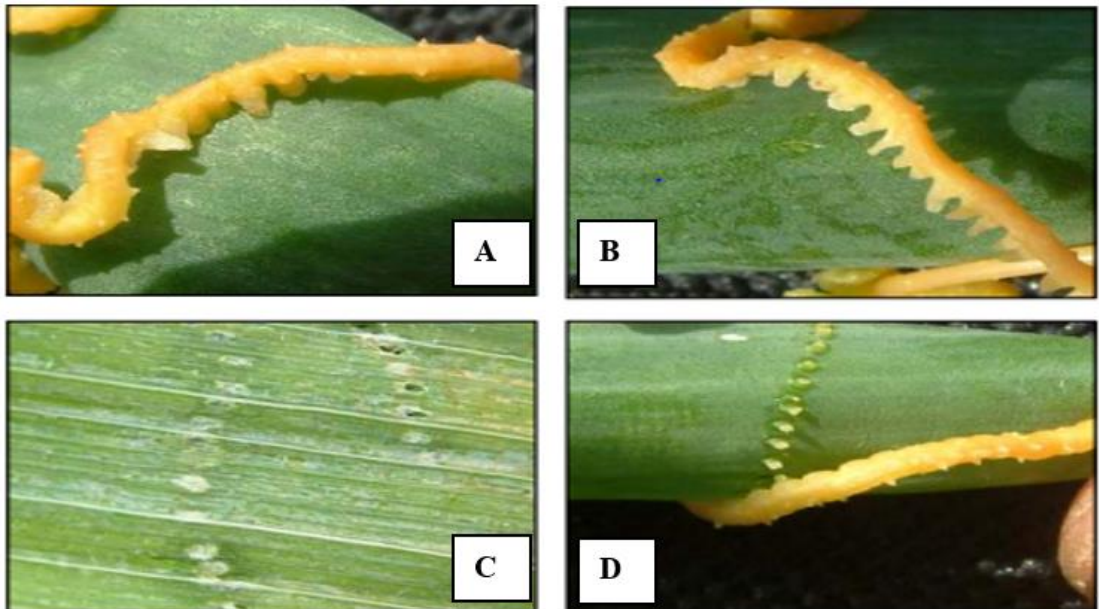


Figure 2.3: *Cuscuta* spp Haustorium Penetrating a Host Plant: Source: (Mishra *et al.*, 2006) Page 13

Host plants susceptible to this parasitic plant range from vegetable crops to ornamental and herbaceous garden plants, including some woody plants and shrubs (SarićKrsmanović, 2019; Ngare *et al.*, 2020). After a successful invasion of dodder, the host begins to have yellow leaves, poor fruiting and seed development. In a study to examine the effects of *C. campestris* on *Ambrosia trifida*, Bozic *et al.*, (2013) found that infestation significantly reduced plant height, biomass, and chlorophyll content, indicating severe physiological stress on the host. Similar studies conducted by Radivojević *et al.*, (2018) and Üstüner (2018), reported that field dodder reduced chlorophyll content in alfa alfa and sugar beet crops. In general, host plants infested by dodder are weakened gradually than immediately killed as it draws nutrients and water essential for growth.

In the eastern part of Africa, dodder has destroyed landscapes and plant species that are economic boosters. In a survey conducted by Nunda, (2021) found that 97% of farmers reported that dodder had infested their farms in the western part of Kenya and eastern Uganda, causing losses in tomatoes, sweet potatoes, tea and even coffee. In Tanzania, *C. reflexa* was found to be the most dominant species in croplands 94% spread linked

to irrigation and livestock movement, recommending integrated control measures (Nyoni and Bayo, 2021). In Busoga, Uganda, a survey study by Kagezi *et al.*, (2021) reported that dodder species had 40% infestation on coffee plantations, threatening their production. In Sudan, field dodder has been reported to cause a reduction in the yield of onions, tomatoes, and jew mallows (Zaroug *et al.*, 2014).

In Kenya, Masanga *et al.*, (2021), identified three *Cuscuta* species that have been dominant in Kenya: *C. Campestris*, *C. kilimanjari*, and *C. reflexa*, affecting the production of tea and coffee. In Uasin Gishu County, Kenya, a study by Kokwon *et al.*, (2022) revealed that 40% of farmers reported the presence of dodder on their farms and fences. In Kericho County, the most suitable dodder host is a tea bush (Chepkirui, 2020). A study by Yego *et al.*, (2022) to assess the impacts of field dodder on tea in Nandi county concluded a low correlation between its effects on tea clones, as the number of leaves did not reduce significantly; however reduced the dry mass of the harvested tea leaves. Once a dodder has infested a tea bush, it leads to the drying of leaves, henceforth reducing the chlorophyll content, which leads to low tea leaf yield as shown in Figure 2.4. This changes the plant physiology and eventually reduces their performance to produce viable yields (Masanga *et al.*, 2020).



Figure 2.4: Effect of Dodder on a Tea Bush. Picture A taken on 5th May 2023 GPS (0.200921, 35.041192), and B on 9th May 2023 GPS (0.294221, 35.033749).

However, there are plant species that are resistant to dodder attacks (Sarić-Krsmanović, 2020), which mostly belong to the class *Monocotyledonae*, except for their interaction with *C. australis* (Dawson *et al.*, 1994). Studies by, Runyon *et al.*, (2010), SarićKrsmanović and Vrbnicanin (2020) found that older tomato plants (*Solanum lycopersicum*) could resist the *Cuscuta* parasite compared to their saplings. Another

research conducted by Johnsen *et al.*, (2015) showed that desert tomato (*Solanum pennellii*) is susceptible to dodder attacks.

2.3 Relationship between Climate Variability and Parasitic Dodder

Rainfall and temperature are key climatic parameters that determine the distribution of plant species (JunCheng and HaiGen, 2010). Global warming and the variations in precipitation lead to an increase in the occurrence of invasive species (LaForgia *et al.*, 2020). According to Kogo *et al.*, (2021), agriculture is one of the most sensitive sectors to the adverse effects of climate change and variability. Korres *et al.*, (2016) reported that climate change could directly or indirectly affect crop production. One of the indirect effects is a result of crop competition for nutrients with the parasitic plants.

Limited studies have been conducted to show the relationship between climate change and the distribution of *Cuscuta*. Cai *et al.*, (2022) using the MaxEnt model, suggested that temperature and isothermally are the main climatic parameters that affect the distribution and suitability of *Cuscuta* occurrences. While dodder species require moderate temperature conditions for survival, *C. campestris* has a broad range of temperature tolerance (Zagorchev *et al.*, 2022). Research conducted by Zichun *et al.*, (2020), and Ren *et al.*, (2020), in China using a *Cuscuta* species *Cuscuta chinensis* (Lam.), implied that global warming is a major threat to its distribution and occurrence. However, other researchers concur that high temperatures promote the growth and spread of dodder species (Munywoki and Munywoki, 2022 and Sarić-Krsmanović *et al.*, 2022).

2.4 Methods of Dodder Management

Dodder reduces crop yield if uncontrolled (Ngare *et al.*, 2022). Its nature of attaching renders it difficult to manage (Orloff and Cudney, 1993). Its seeds can remain viable in the soil for up to 10 years (Costea *et al.*, 2016) and its rapidly growing twines spread fast to nearby host plants (Goldwasser *et al.*, 2012). Additionally, dodder species have a wide range of suitable hosts, making it difficult to manage. Despite researchers developing several strategies, effective management requires Integrated Pest Management (IPM), combining cultural, mechanical, biological, and chemical techniques (Nishikawa *et al.*, 2011; Eston *et al.*, 2020). A study in Uasin Gishu revealed that while farmers are aware of the dodder plant, their understanding of its origin, biology, and control methods remains limited, leading to ineffective or absent

management practices Kokwon *et al.*, (2022). To control dodder, residents in Mombasa adopted IPM to manage dodder, with the cultural method ranked first (Ngare *et al.*, 2022)

2.4.1 Cultural Method

Cultural methods of dodder control involve managing the environment to make it inconducive for growth, such as planting nonhost plants. According to Dawson (1994), and Dinneli (2005), cereals are resistant to dodder invasion and could be used as rotational crops. Almhemed and Ustuner (2024), found that cruciferous plants such as cabbage and broccoli reduce dodder seed banks in the soil. Therefore, planting these crops prior could help manage infestation. A study by Lanini *et al.* (2019) revealed that higher temperatures produced in compost could suffocate dodder seeds more effectively than soil solarization. Findings by Eston *et al.* (2020) recommend that farmers in Kenya prune infected branches to prevent further spread, burn infested plants to lower inoculum levels, and repeatedly till the land to kill germinating seedlings.

2.4.2 Mechanical Method

These are methods of dodder control entailing the use of physical barriers to prevent the dodder from attaching itself to host plants (Mishra, 2009). Hand-pulling involves detaching dodder stems from the host plants (Eston *et al.*, 2020). This method is effective before dodder seed production on small infestations. Pruning of infected branches, burying or burning of host plants to curb the spread (Saric-Krsmanovic and Vrbnicanin, 2015). Kwokon *et al.*, (2022) reported that farmers in Uasin Gishu handpick dodder vines as a way of control. In Kericho County, out of 93 households, 44 preferred the slashing of vines, especially on infested fences (Chepkirui, 2020).

2.4.3 Biological Control

Biological control entails the introduction of pathogens such as fungi or bacteria to control dodder (Lanini *et al.*, 2019). In an attempt to control dodder infestation on soybeans, Chinese researchers found *Colletotrichum gloeosporioides* suspension effective (Regassa and Dechassa, 2021). However, culturing these organisms for commercial use was quite challenging. A study by Shekari *et al.*, (2022) found that flower extracts of *Nepeta meyeri* (Benth) from the family *Lamiaceae* release allelochemicals that suppress *C. campestris* emergence in alfa alfa. Another report by Fallahpour *et al.* (2010) found *F. oxysporum* to be effective in controlling *C. campestris*

seeds. In Mombasa County, residents considered the use of predators such as feeder insects, ladybugs that feed on dodder, to control their population (Ngare *et al.*, 2022).

2.4.4 Chemical Control

Chemical methods involve the use of herbicides to kill or suppress the growth of dodder (Cook, 2006). Herbicides such as pronamide, trifluralin, and pendimethalin are sprayed before attachment, while post attachments are glyphosate and stomp to prevent dodder infestation (Zaroug *et al.*, 2014). Sarić-Krsmanović *et al.*, (2020) reported that glyphosate suppressed *C. campestris* in alfa alfa at 97.5%. Another research by Seif-El-Yazal and Ali, (2021) indicated that glyphosate effectively killed *C. campestris* in *Nerium oleander* L. However, it had dire effects on the host. A study by Eston *et al.*, (2020) revealed that Herbikill 20SL, Gramoxone 200 SL, Willosate 360 SL, and Agrimine 2-4D, were used in controlling dodder infestation in Kenya. Despite the use of herbicides to control dodder, they can have adverse effects on the host plant such as drying up. Therefore, further research should be conducted to find non-selective herbicides to kill dodder.

2.5 Origin of Tea Farming in Nandi

Tea belongs to the family *Theacea*, genus *Camelia*, its species name is *Camelia Sinensis* (Pandey *et al.*, 2021). Tea is grown for its leaves, prepared as white, green, oolong, or black consumed in almost all parts of the globe (Huda *et al.*, 2024). It has two varieties: *Camelia sinensis* var. *sinensis* and *Camelia sinensis* var. *assamica*, which have produced numerous cultivars and hybrid varieties (Mitra and Khandelwal, 2017). *C. sinensis* var. *sinensis* is distinguished by its small leaves, while *C. sinensis* var. *assamica* by its broad leaves (Karlsson, 2022).

Tea history dates back to around 2700BC, discovered by a Chinese Emperor, Shen Sung (Pandey *et al.*, 2021; Huda *et al.*, 2024). It was then grown for medicinal purposes and later evolved into its cultivation for making beverages (Xiousong, 1993; Kumar *et al.*, 2020). The components of tea have great health benefits, such as anticancer properties and stimulate antitoxic functions of the liver. However, Nyakundi *et al.*, (2024) revealed that drinking tea lowers the intake of iron absorption, which could lead to anemia.

The tea plant is native to China and grown in 60 countries globally (Bermúdez *et al.*, 2024). China is the leading tea producer globally, followed by India, Kenya, and Sri Lanka respectively (Beringer *et al.*, 2020; Nyakundi *et al.*, 2024). According to Voora *et al.*, (2019), the tea industry has supported the livelihoods of over 13 million people through employment. It has created a source of income for 9 million smallholder farmers. Africa and Asia contribute to about 70% of the global tea production.

African tea farming was introduced during the pre-colonial period and is currently practised in thirteen countries (Dufrêne, 2022). Tea production is one of the leading exports that support the GDP. Kenya is the leading tea producer, followed by Uganda, Malawi, Rwanda, Tanzania, Zimbabwe, Burundi, the Democratic Republic of Congo, Cameroon, Mauritius, Mozambique, South Africa, and Ethiopia (Vallis, 2020; Koros *et al.*, 2023). The most-produced tea in Africa is black tea, from *C. sinensis* var *assamica* originating from Assam, Sri Lanka, and the British Royal Botanical Gardens (Wambulwa, 2016; Dufrêne, 2022).

Kenya is the world's third-largest tea producer after China and India (Tuitoek *et al.*, 2020). Its tea contributes to about 18% of total global production (Sriram, 2022). In Kenya, tea farming was introduced by GWL Caine in 1903 (Mwaura and Muku, 2008; (Ngure, 2020). In 1924, tea farming was done on large- scales, and later small-scale cultivation was introduced in 1954 (Mutai *et al.*, 2020). In 1964, KTDA took the mandate to manage small-scale tea growers (Nyangito, 2002; Tanui *et al.*, 2012) while the KTGA manages the large-scale tea farms (Karuri, 2020). Currently, small-scale tea farming is practiced in almost 19 counties in Kenya situated in the highlands accounting for 60% of the total Kenyan tea production (Onduru *et al.*, 2012).

Tea farming earns Kenya 20% of the foreign exchange and 4% of the total GDP (Karuri, 2020). Additionally, it supports the livelihoods of 0.6 million Kenyans (Kamunya *et al.*, 2019). According to the Kenya National Bureau of Statistics (KNBS) (2024), tea is the second leading Kenyan export after horticulture earning the country Ksh. 187.4 billion in 2023.

Tea farming in Kenya is grown under specific climatic conditions for productivity (TBK, 2002; Mwaura and Muku, 2008). It requires 1200mm to 2200mm of rainfall annually, with temperatures ranging from 13°C to 30°C, and an altitude of 1500 to 2250

meters above sea level (Kamunya *et al.*, 2019; Koros *et al.*, 2023). Tea bush is soil-specific requiring deep well well-drained acidic red volcanic soils of pH 4-5.6 (Mwaura and Muku, 2008).

In Nandi County, tea is one of the most-grown cash crops (Jalang'o *et al.*, 2023). It covers about 19,920 hectares with an average production of 9 tonnes per hectare, (NCIDP, 2018). According to NCIDP (2023), tea production had increased by 0.7% tonnes in the last year. It supports the livelihoods of many residents as it offers employment (Jalang'o *et al.*, 2023). Tuitoek *et al.*, (2020) revealed that TN14/3 and C12 are the most adopted tea clones in the region.

Tea farming was introduced by the white settlers in Nandi Hills around 1947. (Kipchirchir *et al.*, 2022). At the time, tea farming was done in large-scale production managed only by the colonialists. This led to present-day multinational tea estates in Nandi County; Eastern Produce Kenya Limited (EPK), Nandi Tea Estates Limited, and The Williamson Tea Kenya Limited. According to Jalang'o *et al.*, (2023), small-scale tea farming was introduced in the 1960s, leading to the development of KTDA to manage the subsector. Currently, there are two KTDA factories in Nandi; Chebut and Kaptumo that process tea from smallholders (Koech, 2022).

Nandi is endowed with climatic conditions that favor the growth of tea (Jalang'o *et al.*, 2023). According to the Ministry of Agriculture report of (1987), it classified the agroecological zones suitable for tea as upper midland and lower highlands. These zones are ideal for tea farming as they receive an average of 1500mm of rainfall annually; the average maximum temperature is 23 °C and the minimum is 14 °C (NCIDP, 2018).

2.6 Research Gaps

The review of existing literature shows that climate variability has negatively impacted the tea sector. This is evident by the increased variation of temperatures and rainfall patterns throughout the decades. On the trends of climate variability, recent studies in Nandi County such as Kirui *et al.*, (2020), which analyzed the period 1971-2000, and Omasaki and Mokoro (2022), which examined 1980-2012, have provided valuable insights into historical rainfall and temperature patterns. However, there remains limited localized evidence on recent climatic changes. This study, therefore focused on

the period 1992-2022 to extend previous analyses and allow for a more comprehensive assessment of both climate variability and emerging climate change impacts within the County. As a result of rising temperatures, dodder plant species have spread across the globe. They have destroyed plants of importance in most countries. In Kenya, Ngare *et al.*, (2022) and Masanga *et al.*, (2021) have reported economic losses associated with dodder infestation on crops such as tea and coffee. Despite Chepkirui (2020), revealing that tea is the most suitable dodder host, there have been a few studies to ascertain its effects on tea.

From the literature, most studies on *Cuscuta* have only focused on its effects on many crops besides tea thus a notable gap in dodder infestation of tea. In Kenya and Nandi County, extensive research on various pests and diseases affecting tea production. However, dodder infestation has not been addressed. Therefore, this study seeks to research the extent of dodder infestation on both small and large-scale tea farms. Tea farmers' perceptions on the influence of climate variability (rainfall and temperature) on the propagation of dodder. The effects and dodder management strategies used by tea farmers in Nandi county to fill the existing knowledge gap.

CHAPTER THREE: METHODOLOGY

3.1 Study Area

Nandi County is located in the North Rift of Kenya. It lies across the equator between longitudes 34°45' 00 E and 35° 25' 00" E and latitudes 0° 35' 00" N and 0° 06 00" S covering 2855.8 square kilometers. Nandi borders Kakamega to the west, Uasin Gishu to the northeast, Kisumu to the south, Vihiga to the southwest, Bomet, and Kericho to the southeast.

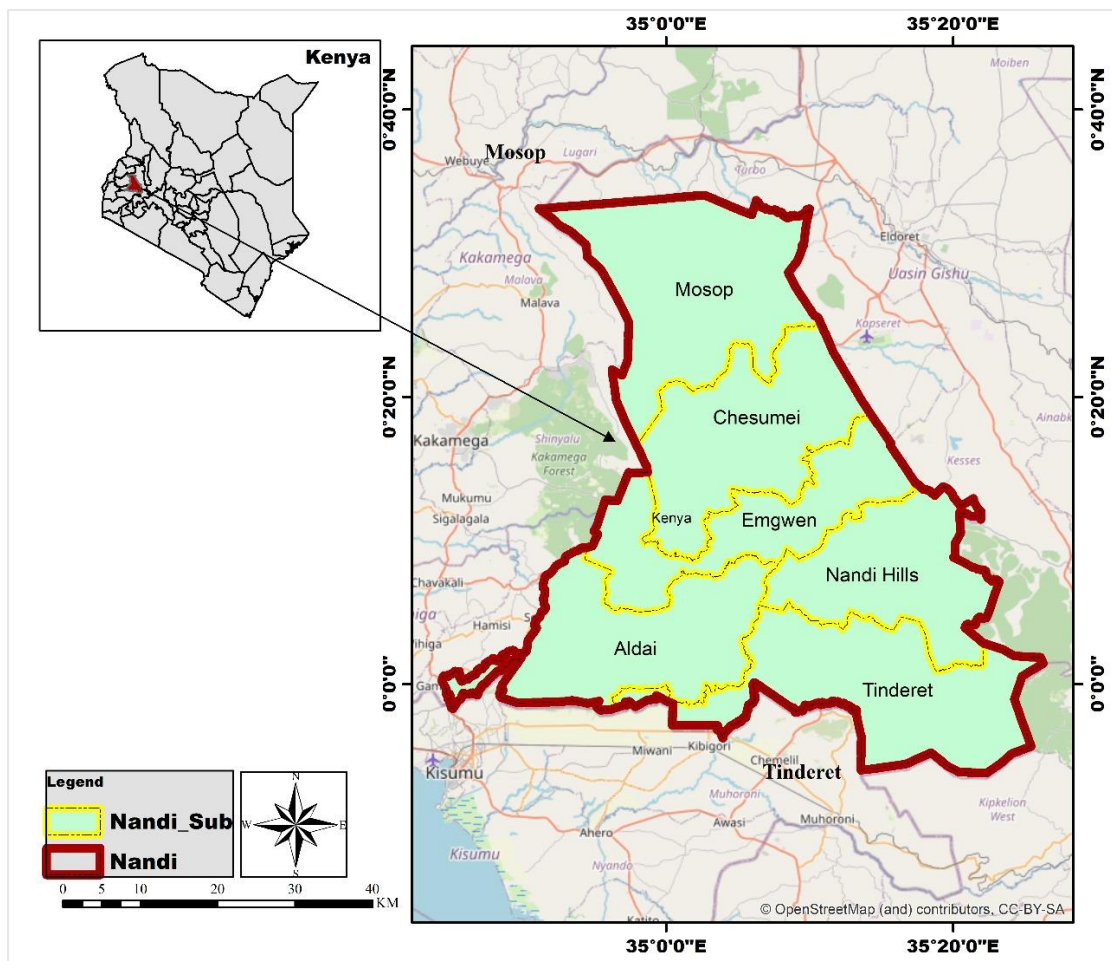


Figure 3.1: Map of Nandi County- Study Area Adapted from ArcMap version 10.8.2

3.1.1 Topography

The topographical features include the rolling hills to the west, and the Kapsabet plateau standing at 2020m above sea level. King'wal swamp lying at an altitude of 1960m. The Nyando escarpment on the southern border is extremely rugged with granite and volcanic rocks. The Tindiret hills are an extension of the Kenyan highlands which is 2500m high (NCIDP 2018).

3.1.2 Ecological Conditions

The County's diverse topography and climatic conditions influence ecological conditions. Nandi has a forest cover of about 12% of the total land mass, including the Nandi North and South forests, which affects the rainfall distribution (NCIDP, 2013). The County is characterised by relief rainfall with diverse tree species. The forested areas are a mixture of exotic and indigenous trees (NCIDP, 2018). The County has different Agroecological zones that promote different agricultural practices: the Upper Midland (UM1) altitude 1600-1850 m where coffee and tea are grown, Lower Highland (LH1) of altitude 1900-2400 m covered by a tea belt, and dairy farming, Lower Highlands (LH2 and 3) altitude 1200-1400m covered by wheat, barley, pyrethrum, and maize, and Upper Highland (UH1) zone 2400 - 2600 m covered by forests (NCIDP, 2013; NCIPD, 2023).

3.1.3 Climatic Conditions

The northern parts of the County receive rainfall ranging from 1300mm to 1600mm, while the southern half experiences 2000mm annually (NCIDP, 2023). Long rainy seasons are experienced from March to May, and short rainy seasons from September to November. A dry spell is experienced from December to late February while cold seasons are experienced in June and August. Those regions receiving above 1500 to 2000mm annually are under tea farming (NCIDP, 2023). The mean temperatures range from 18 to 22 °C. Generally, the county experiences moderate to warmer temperatures throughout the year (CADP 2019). Nandi County has an altitude of 1300m above sea level (NCIDP, 2018).

3.1.4 Economic Activities

In Nandi County, the mainstay is agricultural activities (Adelekan *et al.*, 2024). The County is characterized by small-scale farmers with 75% of the population depending on rainfed agriculture for sustainability (Jalang'o *et al.*, 2023). Tea is the main cash crop grown. Besides tea, dairy farming is practiced, growing maize, sugarcane, legumes, and vegetables among other subsistence crops. (NCIDP, 2013; NCIDP, 2018; NCIDP, 2023).

3.2 Study Design

An exploratory survey design was utilised in this research. This research design was suitable as it investigated a new phenomenon in the study area (Olawale *et al.*, 2023).

This design provided insights into dodder infestation on tea, as it is a new area of study within the specific context of Nandi County. Through interviews, survey questionnaires, and observations, primary data were collected in a period of three months. This study gathered information on the extent of dodder infestation on both large and small scales to map the spatial distribution of dodder. Examined the variations of climate trends of rainfall and temperature from 1992 to 2022. It established tea farmers' perceptions on the influence of climate variability, temperature and rainfall on the spread of dodder. Additionally, it sought tea farmers' perceptions of the effects of dodder on tea and their methods of management.

3.3 Population

The County has a total population of 885,711, comprising 441,259 males, 444,330 females, and 22 intersex (KNBS 2019). In the County, about 19,574 households practising tea farming were registered under KTDA, who were chosen as the target population for this study. In Nandi, there are only two KTDA factories where small-scale tea farmers take their tea for processing, namely Chebut and Kaptumo. The key informants were field managers from the KTDA factories, estate field managers in multinationals companies to represent large-scale tea farms, and County agricultural officers purposefully chosen.

3.4 Sampling Procedures

The sample (n) for the study was drawn from registered practising farmers (N) who delivered their tea leaves for processing in the Kaptumo and Chebut factories. To obtain the sample (n), a statistical sampling formula (Yamane, 1976) was applied. The process of delivering tea to the factory is by way of KTDA Tea Buying Centres (TBCs) designated for each factory. Chebut tea factory had 66 TBCs and Kaptumo tea factory had 33 TBCs. Every tea buying centre (TBC) had a list of tea farmers who delivered tea leaves for quality control, weighing, and packing for delivery to their respective factories. The obtained sample (n) calculated in section 3.5 was distributed proportionately to the total registered farmers in a TBC. Once the representative sample of farmers was determined for a TBC, the listed names of the tea farmers were obtained. A systematic sampling technique was applied to pick respondents at an interval of 3 from the list of tea farmers in a TBC. Information about the respondents (such as the location of the farmer's residence) was sought from the Chairman of the Tea Buying

Centre for farm visits. The individual respondent was notified of the dates of farm visits and interviews.

For multinational tea-growing companies namely Williamson Tea Kenya Limited (Kapchorua, Kaimosi, Tindiret). Eastern Produce Kenya Limited (Kibabet, Kapsumbeiwa, Kipkoimet, Kepchomo, Chemomi, Savani, Sitei, Kaboswa, Kipkeibon, Siret, Kibwari and Kaprachoge. Nandi Tea Estate Limited covers (Mokon, Kapsiwon, and Taito) and Nyayo Tea zones Development Corporation Kipchabo tea factory (Nandi south and Nandi north forests). For this study, Kapchorua, Kaimosi, Chemomi, Siret, Kapsumbeiwa, Kipchabo, Chebut, and Kaptumo were purposefully selected and interviews were scheduled with their field managers.

3.5 Sample Size

The sample size was obtained by applying the Yamane formula (1967) to the total number of tea-growing households as described in section 3.3, as follows:

$$n = \frac{N}{(1 + N(e)^2)}$$

Where N was the total number of tea-growing households, n was the sample size, and e was the margin of error, taken as 0.05 at a 95% confidence level. Therefore,

$$n = \frac{19,574}{(1 + 19,574(0.05)^2)}$$

$$n = 392.3034$$

Rounded off, the sample size is 392 tea-growing households. The sample size (n) obtained was distributed proportionately to the number of tea-growing households in the two factories, as shown in Table 3.1.

Table 3.1: Sample frame for the study.

S/N	Factory	No. of TBCs	Population	Sample size
1	Chebut	64	12,084	242
2	Kaptumo	32	7,490	150
Total		96	19,574	392

3.6 Instruments

Semi-structured interviews are used in unclear data situations to gather needed information, offering diverse perspectives (Mashuri *et al.*, 2022). The study utilized a semi-structured questionnaire to collect primary data from small-scale tea farmers. The questionnaire entailed three parts: the socioeconomic characteristics of the respondent, the second part entailed perceptions of climate variability (rainfall and temperature patterns) and dodder infestation. The third part entailed the tea farmers' perceptions of the effects of dodder on tea and the methods used to control dodder on tea farms. A Likert scale is designed to assess attitudes towards a specific subject by combining responses from various statements (Joshi *et al.*, 2015). Therefore, a Likert scale was used alongside the questionnaire to obtain respondents' perceptions on the influence of climate variability on dodder's spread.

For this study, field observations on whether the presence or absence of dodder on the tea farm were recorded on an observation checklist. A camera was used to capture photographs of the affected tea bushes supporting the respondents' opinions (Busetto *et al.*, 2020). A Geospatial Positioning System (GPS) device was used to capture the coordinates of the farms infested with dodder. To validate the instruments, pilot testing was done two weeks before the actual study.

3.7 Data Collection Procedures

The data collection procedures comprised both secondary and primary data for the study. Secondary data was obtained from KMD in Nandi County. The data collection involved obtaining the historical climate data for rainfall and temperature from 1992 to 2022. It was analysed to identify trends and variations for the given period. The information provided was critical in understanding how changes in climate influence dodder infestation and spread. Additionally, it was used to compare respondents' perceptions of trends in rainfall and temperature. Other secondary repositories were journals, Nandi County Integrated Development Plans (NCIDP), and other online publications relevant to the study.

Primary data was obtained from the use of a semi-structured questionnaire. The extent of dodder infestation on tea farms was determined through direct observations. An observation checklist allowed the recording of the presence or absence of dodder on tea farms see Appendix I. Coordinates were collected using GPS software to ensure geo-

referencing of infested farms. The coordinates obtained were then analysed and presented on maps to show their distribution as in Figure 4.2.

To establish the influence of climate variability, rainfall and temperature on the spread of dodder, a Likert scale alongside a semi-structured questionnaire was used. First, the respondents' opinions on rainfall and temperature trends were gathered. Secondly, the respondents' perceptions of the changes in temperature and rainfall influenced the spread and intensity of dodder were gathered. This was important in understanding the local knowledge on the nexus of climate variability and dodder.

To assess the effects and methods of dodder control, a questionnaire and pictorial documentation were used. Respondents' perceptions were obtained through a questionnaire alongside a Likert scale. This was to gauge the most significant effects felt on tea and the most preferred methods farmers used to control dodder on their farms. Photographs captured the effects of dodder on tea bushes and the visible control techniques used by respondents at the time of this study.

Interviews were guided by an interview schedule for tea field managers in both KTDA factories, multinational tea estates and selected environmental and agricultural officers in the County. The information provided an in-depth understanding of whether they have any record of dodder infestation, the effects and control techniques employed in their catchment.

3.8 Ethical Considerations

The study ensured that all tea farmers participating in the research were treated with respect, dignity, and fairness, and could express their views freely. Informed consent was obtained, and confidentiality and anonymity of farm data were strictly maintained. No material incentives were offered, and participation was entirely voluntary, though farmers could benefit from discussing dodder management and climate-related issues. Measures such as careful translation, participant feedback, and transparent researcher-participant interactions were employed to enhance trustworthiness and credibility.

3.9 Data Analysis

After field visits, the data obtained were arranged in an organised manner and entered into an Excel spreadsheet. Qualitative data were assigned numbers and coded for easy analysis. Various statistical methods were employed to analyse the collected data. In

the study of temperature and rainfall variations from 1992 to 2022, the Statistical Package for Social Sciences (SPSS) was utilised, applying Analysis of Variance (ANOVA) to determine the statistical significance of variations in climatic variations over the study period. ANOVA was chosen because it is effective for comparing means across the decades and identifying any significant differences. For temperature analysis, the Least Significant Difference (LSD) test was employed for post-hoc comparisons. The analysis gave detailed insights on decadal differences. Linear regression analysis was also used to assess the relationship between time and the stated climatic variables, to determine the trends. Assumptions of linearity, normality, independence of errors, and homoscedasticity were checked in SPSS and met before interpreting the results. Additionally, the Mann-Kendall Trend analysis was applied to detect monotonic trends in the data without assuming any specific distribution and to test the null hypothesis that there were no significant variations in temperature and rainfall trends.

The extent of dodder infestation was obtained through spatial analysis. The coordinates recorded during field visits were uploaded into a Geospatial Information System GIS software (ArcGIS 10.8.2) as a CSV file and converted into point shapefiles. It was then projected to the WGS 84 coordinate reference system and overlaid on administrative boundaries and base map layers of the study area. This helped in visualising the spatial distribution of dodder infestation in the study area. The method of analysis was justified as it enabled the identification of dodder hotspots and their dynamics of spread.

To assess respondents' perceptions of the influence of climate variability, rainfall and temperature on dodder spread, data collected from the questionnaire were processed utilising SPSS. To summarise the frequencies, percentages and mean scores of the respondents' perceptions, descriptive statistics were used. A systematic scale was used to interpret the mean values and determine the respondents' perceived influence of each climatic variable on the spread of dodder.

To assess respondents' perceptions of the effects and methods of dodder control, SPSS was used again to analyse both qualitative and quantitative data. The Friedman test was used to compare respondents' perceptions of various control methods. This non-parametric test was suitable for ordinal data and multiple related samples. It was also used to rank the effects and most used techniques by the respondents to control dodder. The Chi-Square test was also applied to assess the association between categorical

variables, such as the most used method of control and the presence of dodder on the tea farm. This test was important as it determined the distribution of responses and significant associations between two categorical variables. To test the reliability of the results, the independence of observations and adequacy of expected cell frequencies were confirmed.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Demographic Characteristics of the Respondents

A sample frame for this study was drawn from KTDA tea farmers as described in Chapter Three above. The socioeconomic characteristics of the respondents were classified as follows: age, gender, household income, the factory in which they take their tea, educational level, length of stay in the area, and the size of the household farm. This was recorded in the questionnaire in Appendix I. The data was then coded in an Excel spreadsheet and exported to SPSS for statistical analysis.

The response rate for the study was 354 (90.3%) out of the total 392 tea farmers. There were 218 (61.6%) tea farmers who delivered their tea to Chebut and 136 (38.4%) delivered their tea to Kaptumo Factory, as shown in Table 4.1. Kaptumo catchment had a total of 31 (34.8%) tea-buying centres, whereas Chebut catchment had 58 (65.2%). This is because the Chebut factory was first established, then the Kaptumo factory. This meant that all tea farmers were registered with the Chebut tea factory before the establishment of Kaptumo.

Table 4.1: Demographic Characteristics of the Respondents

Gender	Chebut Factory		Kaptumo Factory		Both Factories	
	Frequency	%	Frequency	%	Frequency	%
Male	181	83.1	94	69.1	275	77.7
Female	37	16.9	42	30.9	79	22.3
Total	218	100	136	100	354	100

The majority of the population being male, 275 (77.7%) and women were 79 (22.3%), as shown in Table 4.1. A Chi-Square test indicated that there is a significant difference in the gender of households of tea farmers ($N= 354$, $\chi^2=108.520a$, $df= 1$, $p < 0.001$) as there are more males than females. From the results, it was observed that the majority of the respondents were the male gender, which agreed with studies conducted by Limo (2013), Makone *et al.*, (2017), and Onchwari *et al.*, (2022). The predominance of male farmers could have implications for the adoption of dodder control techniques and the

allocation of labour in the farm. Therefore, interventions should consider these gender dynamics to ensure inclusive and effective pest management strategies.

4.1.1 Gender and Age Distribution of the Respondents

The age of the household head was essential for the study, as the variability in the age of the respondents could contribute to knowledge of climate, land use, and tea growing time. A 7-year age interval was determined using the class interval, subtracting the lowest age from the highest age, then dividing by the number of classes $(89-24)/9=7.2$. This was truncated to a width of 7. Additionally, data on gender were significant in determining the perception of effects and methods used to control dodder. The results on gender and age are presented in Table 4.2.

Table 4.2: Age Distribution of the Respondents and Gender

Age in years	Frequency (n)	Gender	
		Male Frequency	Female Frequency
24 - 30	18	7	11
31 - 37	29	17	12
38 - 44	36	29	7
45 - 51	56	47	9
52 - 58	68	59	9
59 - 65	64	56	8
66 - 72	36	26	10
73 - 79	32	23	9
80 - 86	11	7	4
87 - 93	4	4	0
Total	354	275	79

The youngest tea farmer was 24 years old, while the oldest was 93 years. The results presented in the table above ($N = 354$, Mean = 55.03, SD = 14.40) indicate that the average age of tea farmers was approximately 55 years. The majority of the farmers were within the 52-58 years ($n = 68$) and 59-65 years ($n = 64$) age categories, showing that tea farming was predominantly undertaken by middle-aged to older individuals. These findings are comparable with Koech (2022), who reported that most tea farmers were of middle age with a mean age of 55 years. Male farmers were most represented in the 52-58 age group ($n = 59$), which reflects traditional land inheritance patterns in the region where men are the primary landowners. In contrast, most female tea farmers

were within the 31-37 years age bracket (n = 12), suggesting increasing participation of younger women in tea cultivation activities.

4.1.2 Education Level of the Respondent

For this study, the education level of the respondents was evaluated to gauge knowledge on climate variability and management of dodder. Referring to item no. 7 of the questionnaire in Appendix I, the education level of the respondents was recorded from farmers who had not gone to school to those who had reached the tertiary. For this study, tertiary education level was classified as any post-secondary training, including institutes, polytechnics, colleges, or universities. Analysis by gender showed a gender disparity in educational attainment among the respondents. The results are presented in Figure 4.1.

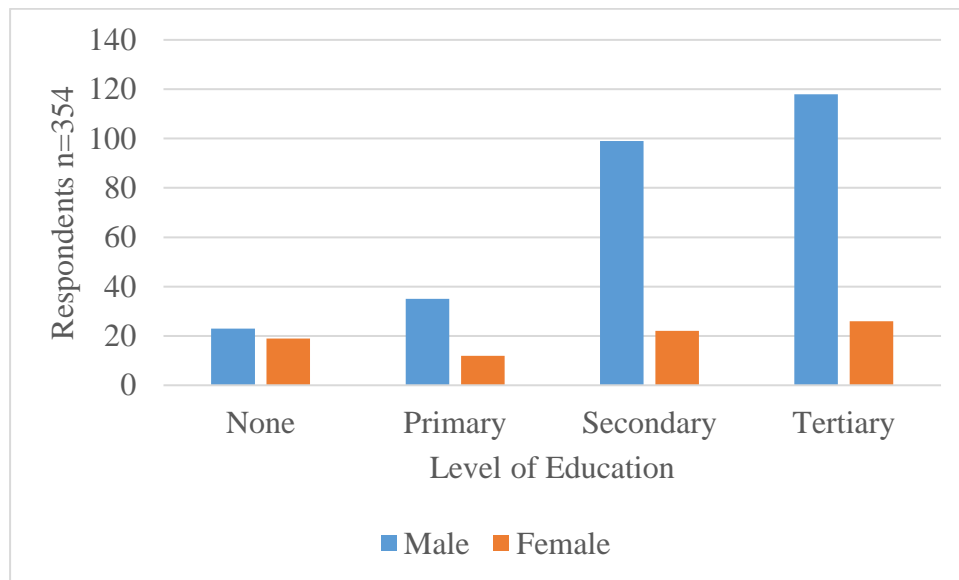


Figure 4.1: Educational Level by Gender.

81.9% of male and 18.1% of female respondents had pursued a tertiary education level. Respondents who had attained secondary education; males were 81.8%, and females 18.2%. 74.5% of the males and 25.5% of the females reached primary education. 54.8% of the males, while 45.2% of the females did not go to school.

The Chi-Square test was used to determine the association of gender and educational levels among the respondents and the results showed there was a significant relationship between gender and level of education among the respondents ($\chi^2 = 15.710$, $df = 3$, $N = 354$, $p = 0.001$). These findings agree with the KNBS (2019), that men are more educated than women.

4.1.3 Farm Size and Land Use of the Household

As an indicator of wealth status, item no. 9 required the respondent to indicate the size of the farm he/she owns in acres. The responses were analyzed and the results were as follows: (N= 354, Mean= 3.634, Std. dev. = 3.1249). The total land area coverage for the sample size was 1286.5 acres. Farmers with less than 1 acre with 1%, 1 to 2.9 acres being the highest at 44%, 3 to 4.9 acres at 36%, 5 to 6.9 at 11%, 7 to 8.9 acres 2%, 9 to 10 acres 2%, 11 to 12.9 acres at 1%, 13 to 14.9 acres is 0%, 15 to 16.9 at 2%, 17 to 18.9 acres at 1% and finally 19 to 20.9 acres at 1%. From these results, it is observed that the majority of the respondents owned land sizes of about 1 to 2.9 acres at 44% which confirms a report by NCIP (2018). This observation could be due to the increased population leading to subdivision of land, which agrees with findings by Auya *et al.*, (2022).

Item no. 11 of the questionnaire was used to capture the respondents' land use practices by crop type. Crops were categorized into annual and perennial crops. The respondent was then instructed to list all the crops on their farm with their respective acreage. From the data obtained, analysis was done and the results presented in Figure 4.2

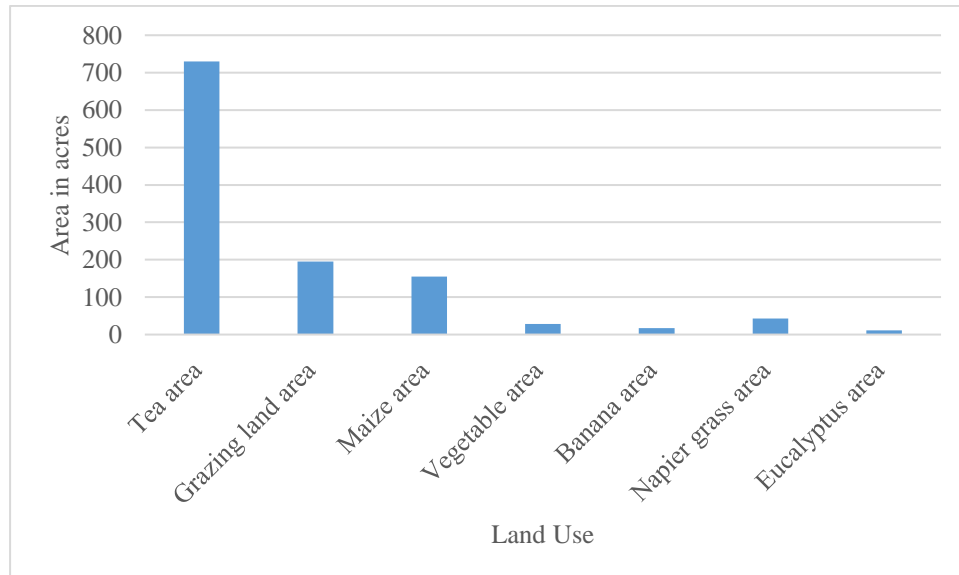


Figure 4.2: Major Land Use in the Study Area

The most common crops were: tea, 729.7 acres (61.9%), maize, 155 acres (13.2%), vegetables, 28.7 acres (2.4%), bananas, 15.8 acres (1.3%), Napier grass, 42.8 acres (3.6%), and eucalyptus, 10.9 acres (0.9%). Dodder is likely to thrive on perennial hosts providing a stable and continuous source of nutrients, making tea farms more

susceptible to infestation, unlike annual crops with short growth cycle. Therefore, the dominance of perennial crops likely contributes to the observed spread of dodder.

4.2 Climate Variability Trend in Nandi County

The third objective of the study was to assess tea farmers' perceptions of the influence of climate variability on the spread of dodder. To achieve this, a comprehensive analysis of temperature and rainfall trends in the study area was conducted using data obtained from the KMD Nandi station.

Item no. 13 was used to see Appendix I, where the respondent was asked for their opinion on whether there have been changes in temperature and rainfall. Followed by the opinion on whether temperature and rainfall have increased or decreased in the past 10 years as it was easier for the respondent to recall. A five-point Likert scale was used to record the responses.

4.2.1 Perceptions of Climatic Trend in Nandi County

IPCC (2021), reported that the agricultural sector has been negatively impacted by increasing temperature with a reduction in rainfall. Therefore, understanding the perception of tea farmers on climatic variables (rainfall and temperature) is essential for sustainable agricultural practices. For this study, the perceptions of tea farmers concerning rainfall and temperature were crucial in understanding the occurrence and spread of dodder. First, the respondents were asked about their perceptions of changes in climatic trends. The responses were recorded as yes or no. The responses were analyzed as follows: 98% of the respondents agreed there had been variations in climatic trends, whereas 2% did not perceive any changes in climate trends.

The responses earned points out of 10 to those who strongly agreed, 8 points to those who agreed, 4 points to those who disagreed, and 2 points to those who strongly disagreed that rainfall has been reducing with increasing temperature. The results for the scores recorded in Table 4.3.

Table 4.3 Scores of Responses on Rainfall and Temperature Trends

Score	Percentage of Respondents	Percentage of Respondents
10	48.2%	43.6%
8	51.2%	55.1%
4	0.2%	0.6%
2	0.4%	0.6%
Total	100%	100%

Results implied that the majority of the respondents in Nandi County perceived that rainfall had been reducing in the past decade. While temperatures have been rising in the last 10 years. The results on farmers' perceptions on temperature variations agree with the findings by Limo (2013), that tea farmers in Nandi are aware that there has been rising temperatures. The responses were then compared to historical data obtained from the KMD Nandi County, Kenya to ascertain the trends in climate change.

Using the Chi-Square test of independence, the relationship between education levels and climate variability showed that there's no significant relationship ($\chi^2 = 3.340$, $df = 3$, $N = 354$, $p = 0.342$). This implies that a tea farmer is knowledgeable on the changes of climatic trends regardless of their educational level.

4.2.2 Temperature Variability

This study analyzed temperature data from 1992 to 2022 in Nandi County, Kenya in order to examine trends in temperature. The results were compared with respondents' opinions on temperature changes. Historical temperature data was obtained from the KMD, Nandi Station. Regression analysis was performed to understand the impact of time in (years) on the dependent variable, temperature. This data was computed and presented on a graph showing the linear trend over the 30 years as shown in Figure 4.3. The highest temperature was recorded in 2017 at 19.5 °C and the lowest was in 1999 at 18.1 °C.

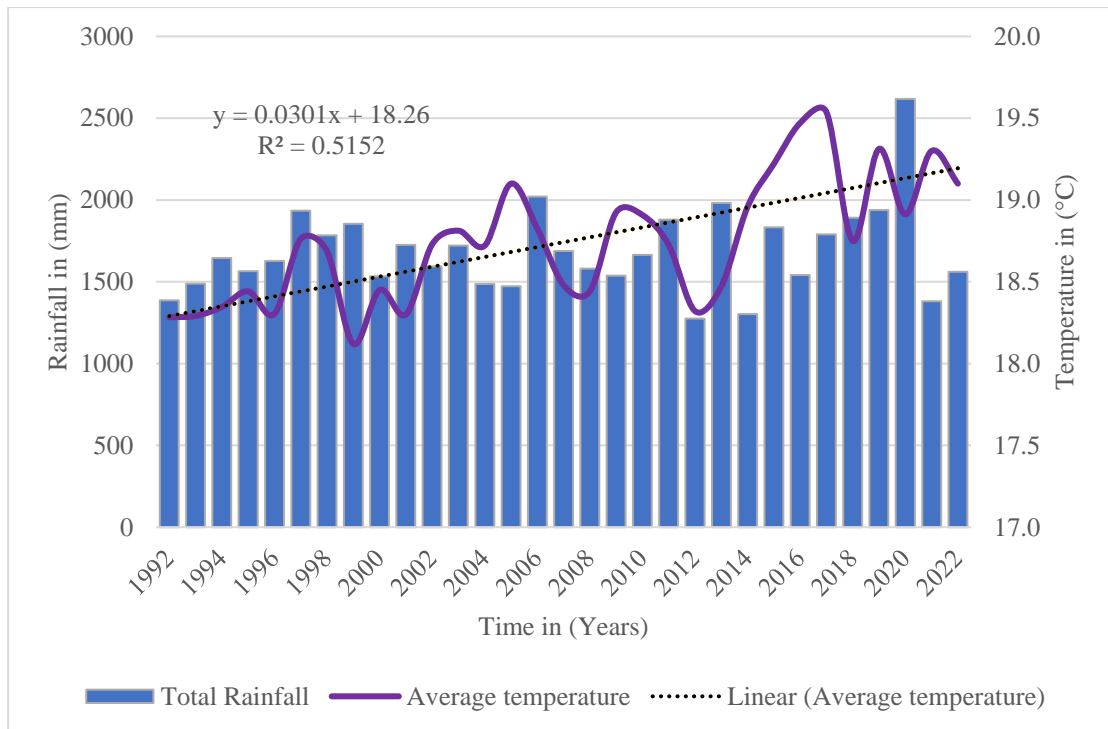


Figure 4.3: The mean annual temperature from 1992 to 2022. Data source: KMD Nandi Station, Kenya

Linear regression analysis was used to test the trend with the equation $y = 0.0301x + 18.26$. The slope indicated that the mean temperature had been rising by 0.0301°C yearly. The Coefficient of Determination R^2 represented by the value (0.5152) explained that approximately 51.52% of the variability in temperature could be due to the linear relationship with the year. The trendline in Figure 4.3 confirmed the respondents' opinions in section 4.2.1 that temperatures have been rising. These findings concur with the conclusions drawn from studies by Kirui *et al.*, (2020), and Omasaki and Mokoro (2023) that temperatures have been increasing in Nandi County.

Man Kendall Trend analysis was used to determine whether trends in temperature were significant. This type of analysis was suitable as it provided the relations on whether there are positive, negative, or no trends in temperature. The results were computed and presented in Table 4.4. Results for maximum temperature showed no significant association p value= 0.168.

It was observed that there was an increase in the minimum temperature denoted by the Sen's slope= 0.039. Kendall's Tau indicated a moderate positive correlation with a p -value of 0.000, implying that the minimum temperature has been rising significantly.

For average temperature, denoted by a Sen's slope= 0.031 and a strong positive correlation of Kendall's Tau 0.554 indicated an increase which was significant at $p<0.000$.

Table 4.4: Man Kendall's Trend Analysis of Temperature Variation, 1992-2022

	Kendall's Tau	S	<i>p</i> - value	Sen's slope	Lower bound (95%)	Upper bound (95%)
Maximum Temperature	0.177	82	0.168	0.013	-0.007	0.037
Minimum Temperature	0.491	228	0.000	0.039	0.023	0.065
Average Temperature	0.554	257	<0.0001	0.031	0.017	0.041

Analyzing the variation of temperature from the long-term mean was important in detecting and understanding trends. This analysis provided a baseline for comparison and aided in identifying deviations and long-term anomalies. Temperature anomalies were computed to show the variance of temperature from the long-term mean in the study area as shown in Figure 4.4. The results showed that the temperature anomalies ranged from +0.84 in 2017 to -0.58 in 1999. As shown in Figure 4.6, temperatures have been rising in the past decade, from 2014 to 2022.

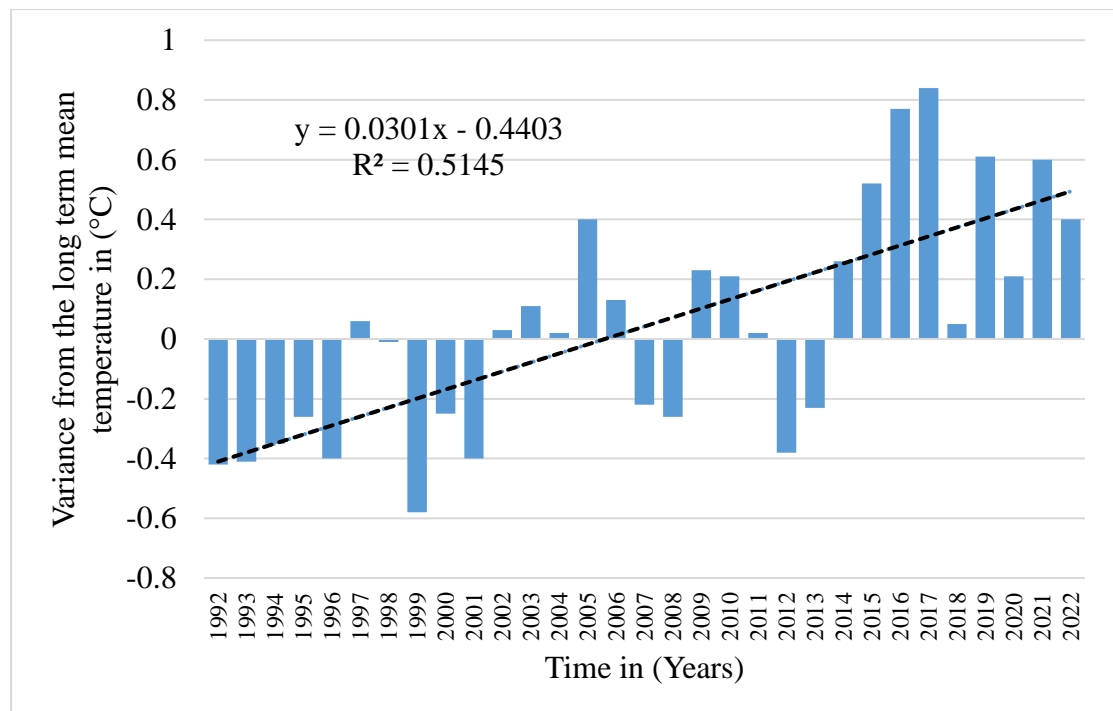


Figure 4.4: Variations from the long-term mean temperature for the period 1992 to 2022 in Nandi County

To compare mean temperatures across the decades: 1992 to 2002, 2003 to 2012, and 2013 to 2022 one-way ANOVA was performed. The results indicated that there has been a significant difference across the three decades (F test= 16.871, df= 2, Mean Square (Between Groups)= 1.194, $p= 0.000$). As shown in Figure 4.5, temperatures have been rising significantly and the hottest decade was that of 2013 to 2022 with an average of 19.1 °C.

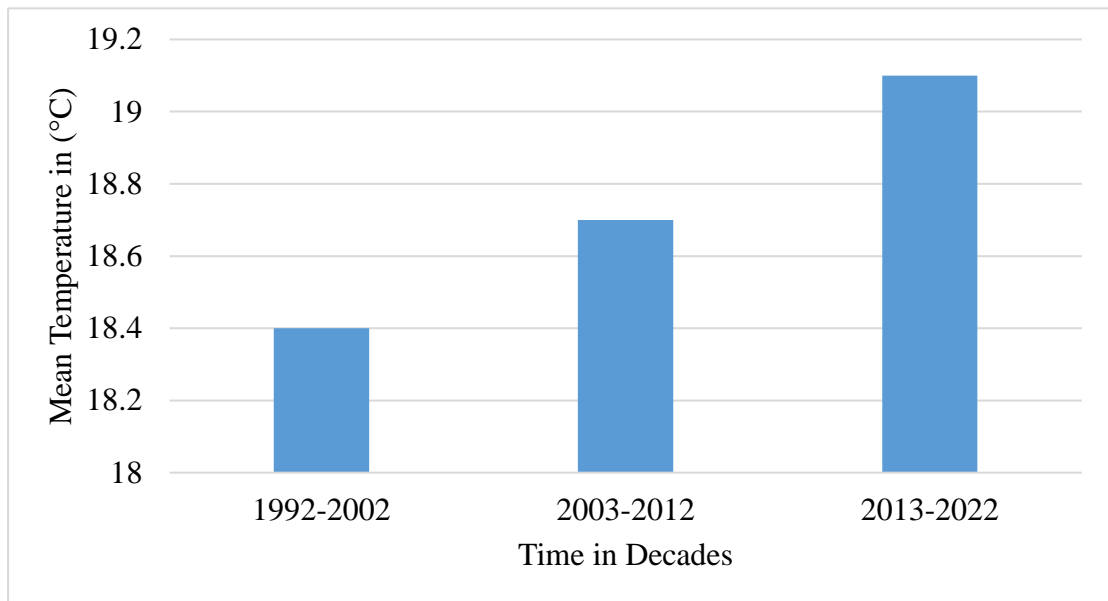


Figure 4.5: Mean Decadal Temperature since 1992 to 2022

Further, to identify which decades differ from each other, a post hoc test, Least Significant Difference (LSD), was conducted. Specific pairwise comparison was performed on the three decades and their mean difference was obtained. There were significant differences in mean annual temperature among all three decades, with Decade 1 differing from Decade 2 $p = 0.016$ and Decade 3 $p < 0.001$, and Decade 2 differing from Decade 3 $p = 0.004$. This indicates that mean annual temperatures have increased across the decades, with each subsequent decade being significantly warmer than the previous one.

Examining monthly temperatures was significant in identifying periods that favoured the growth and spread of dodder. The results obtained were used to compare respondents' opinions detailed in section 4.2.1. The mean monthly temperatures were calculated and represented graphically as shown in Figure 4.6. The hottest month recorded was February and March at 19.7 °C, while the coldest month recorded was July at 17.8 °C.

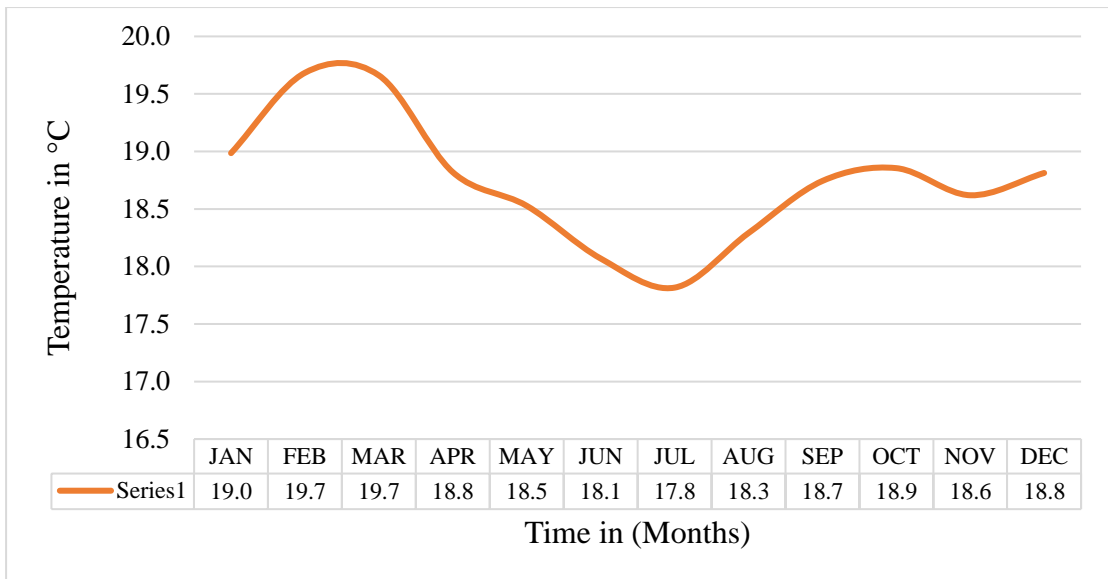


Figure 4.6: Monthly mean temperature from 1992 to 2022

4.2.3 Rainfall Variability

Nandi County experiences a bimodal rainfall regime. Just like any other plant, rainfall could be a major factor in the distribution and spread of dodder. Therefore, analyzing rainfall trends was essential in this study. Figure 4.7 shows rainfall analysis for the past 3 decades in Nandi County. From the results, it was noted that the year 2012 the County received low amounts of precipitation with a total of 1275.8 mm, whereas in 2020 recorded the highest rainfall amounts of 2618.6 mm.

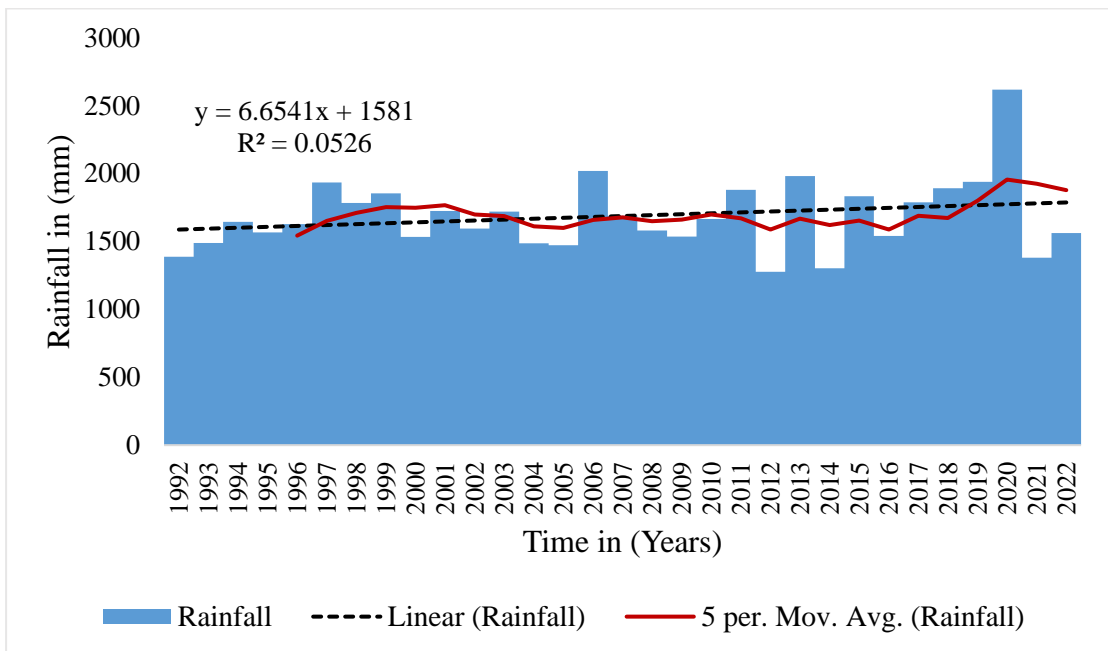


Figure 4.7: Total Annual precipitation from 1992 to 2022 in Nandi County. Source: (Data from KMD Nandi)

From the trend line $y = 6.6541x + 1581$, the positive coefficient of the year variable (6.6541) showed a positive linear relationship between the year and rainfall amounts. This meant that rainfall amounts are to increase by approximately 6.6541 units annually. These results agreed with a study done by Omasaki and Mokoro, (2023) that rainfall amounts in Nandi County showed an increasing trend. While the positive slope suggested an upward trend, the low R^2 value ($R^2 = 0.0526$, translating to 5.26%) indicated that the linear relationship with the year does not adequately account for the variability in rainfall amounts.

To test the significance of the increase in rainfall, the Mann-Kendall Trend analysis was employed. The results in Table 4.5 indicated an increase in rainfall amounts, denoted by Sen's slope = 5.618. However, Kendall's Tau = 0.123 showed a weak positive correlation, which was not statistically significant at $p = 0.341$.

Table 4.5 Man Kendall's Trend Analysis for Annual Rainfall from 1992 to 2022

Kendall's Tau	S	Mean	Std. deviation	<i>p</i> -value	Sen's slope	Lower bound (95%)	Upper bound (95%)
0.123	57	1687.510	263.901	0.341	5.618	-5.900	16.100

The results in Table 4.5 were compared to the respondents' opinions on rainfall refer to section 4.2.1. The results obtained from KMD showed a negative comparison from respondents opinions on rainfall trends. Majority of the respondents (99.4%) perceived that rainfall had been reducing significantly giving a discrepancy from the historical data obtained from KMD which showed a slight increase in rainfall amounts. The study aimed to detect shifts in rainfall patterns, and variations of rainfall from the long term were computed. The results were plotted and shown in Figure 4.8.

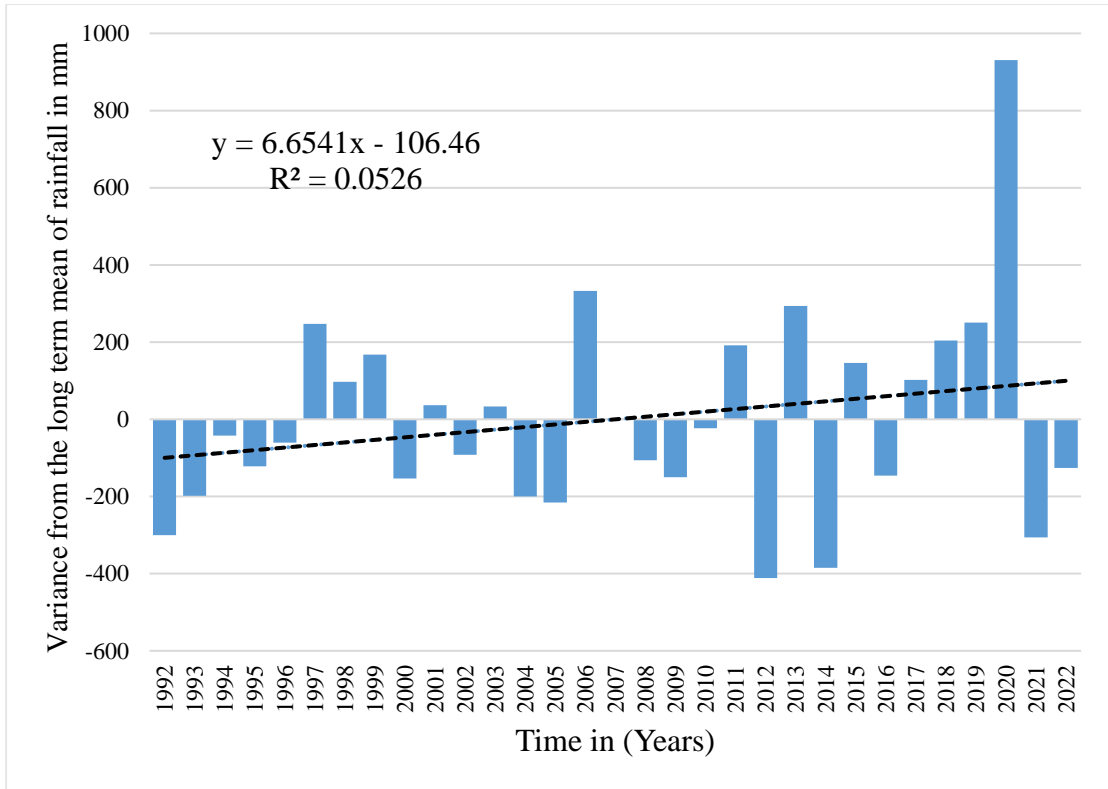


Figure 4.8: The Variance of Annual Rainfall from the Long-Term Mean

Analyzing monthly rainfall was crucial in understanding the seasonal variability and trends from 1992 to 2022 in the County. The results gave insights on dodder occurrence and identified the months that could likely promote rapid spread. Rainfall and temperature data were computed and the results plotted shown in Figure 4.9. It was noted that the month with the highest rainfall amounts was April and the lowest recorded was February with an average precipitation of 238.1 mm and 57.0 mm, respectively.

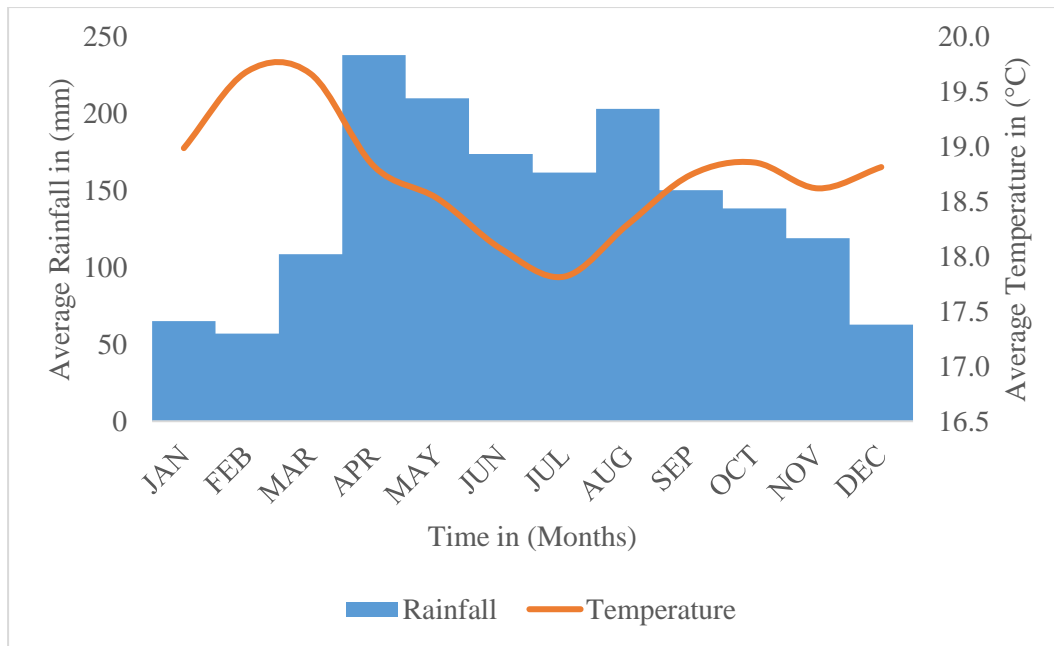


Figure 4.9: Monthly Mean Rainfall and Temperature Amounts for the Years 1992 to 2022

Additionally, the study aimed to analyze the seasonal rainfall patterns from 1992 to 2022 to identify trends. This information aids in determining which seasons were likely to increase the intensity of dodder occurrence. It was noted that there are two distinct rainfall seasons within a year. The March to May (MAM) season is the long rainy season, while the September to November (SON) season is characterized by short rains. December to February (DJF) are the drier months with little rainfall, and June to August (JJA) are the cold months with minimal rainfall (Kirui *et al.*, 2020). Historical data for rainfall were obtained from the KMD Nandi County. The mean for the total rainfall amounts in each season was computed, and then the Mann-Kendall Trend analysis was used to identify the trends. The results were recorded in Table 4.6

Table 4.6 Mann-Kendall Trend Analysis for Seasonal Rainfall from 1992- 2022

Seasons	Mean	Std. dev.	Kendall's Tau	S	p-value	Sen's slope	Lower bound (95%)	Upper bound (95%)
DJF	184.981	81.148	0.148	69	0.248	1.825	-1.500	5.357
MAM	556.477	141.282	0.037	17	0.786	1.100	-4.880	7.824
JJA	538.323	107.922	-0.062	-29	0.634	-0.787	-5.643	3.976
SON	407.729	129.338	0.123	57	0.341	3.033	-2.538	10.065

The results in Table 4.6 showed that MAM recorded the highest mean rainfall amounts, followed by JJA, SON, and DJF. However, these trends identified through the Kendall Trend analysis were not statistically significant at $p= 0.05$.

4.3 Dodder Distribution in Nandi County

Dodder distribution was assessed among 354 KTDA tea farmers and in the selected multinational tea estates as described in Chapter Three above. Examining parasitic dodder distribution was key to achieving the broader objectives within the study framework. Visual inspections were conducted in the fields, and the presence or absence of dodder was recorded in an observation checklist see Appendix I. For those who didn't know dodder, a sample of 1m was carried around to show the tea farmer. When the presence of a parasitic dodder was confirmed, GPS essential software was used to capture the GPS coordinates of the farm utilizing a smartphone. The coordinates were transcribed into Excel and later uploaded to the ArcGIS software. This facilitated the visualization of dodder distribution points on a map as shown in Figure 4.10. The tea-buying centres for the tea factories were taken and presented as well.

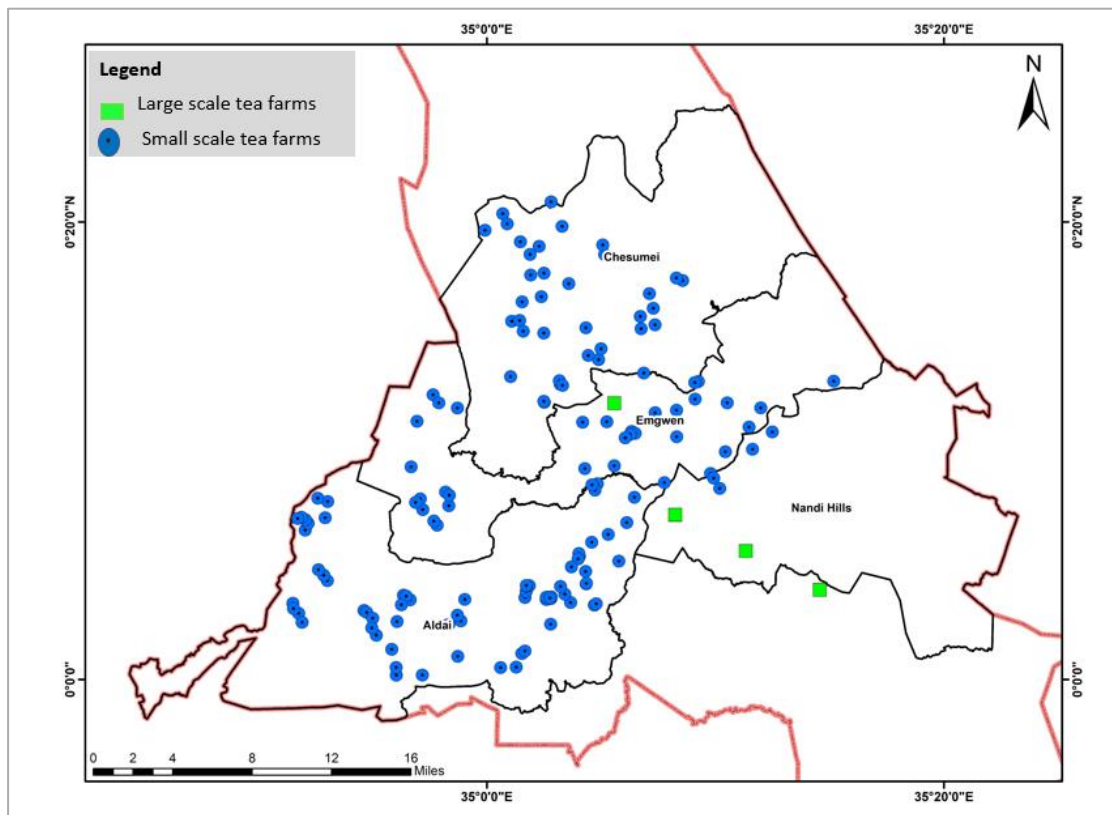


Figure 4.10: Dodder Distribution in the Study Area.

Out of the 354 tea farmer households chosen for the study, 149 farms had dodder, while 205 didn't have dodder on their tea farms. Kaptumo catchment recorded 71 while Chebut 78 tea farming households that dodder was present in their farms as presented in Table 4.7. Additionally, three out of 6 chosen multinational tea estates, had dodder on their farms that is Chemomi, Siret, and Taito tea estates.

Table 4.7: Dodder Distribution in Kaptumo and Chebut Catchment.

		Farms with dodder	Farms without dodder	Total
Factory	Kaptumo	71	65	136
	Chebut	78	140	218

From the study, it was noted that tea farms adjacent to the road were more susceptible to dodder attacks since school-going children could throw the dodder vines on the tea plantations, rendering their spread. The respondents reported that the dodder plant was introduced about 3 years ago and has greatly spread to many areas within the region. It first attacked other plants such as Mauritius thorns and K-apple and later onto their tea farms.

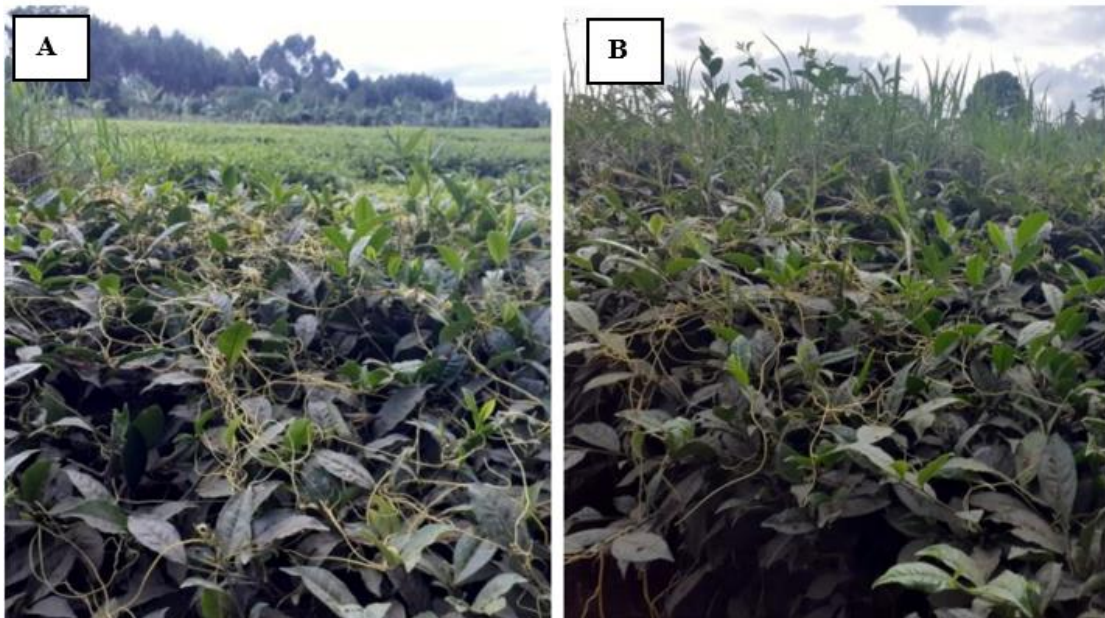


Figure 4.11: Dodder Vines on a Tea Plantation Adjacent to the Road. Picture taken on 20th June 2023. GPS A(0.048683, 35.080962); B(0.047817, 35.080793)

4.4 Climate Variability and Dodder Infestation

Climate variability accelerates the spread of invasive species (Wallingford *et al.*, 2020) by making host plants more vulnerable to attacks due to fluctuations in temperature and rainfall. Therefore, studying the role of climate variability in the occurrence and spread of dodder was crucial for a tea farmer, as it helps to employ effective management strategies.

A questionnaire alongside a Likert scale was used to gather respondents' opinions on the influence of rainfall and temperature on the spread of dodder. Initially, respondents were asked about their knowledge of dodder and its presence on their tea farms. They were then asked to rate the intensity of dodder occurrence as high, moderate, or low in response to changes in temperature and rainfall. For this study, a rating of 1 (least intensity) indicated isolated infestation on tea bushes, 2 (moderate intensity) reflected a noticeable but manageable spread in several areas of the farm, while 3 (high intensity) denoted extensive dodder growth affecting large portions of the tea canopy. To ensure consistency, farmers' perceptions were corroborated through on-site visual assessments conducted during data collection.

In this study, high rainfall was defined as the long rainy season from March to May, low temperatures as the cold months of June to August, high temperatures as the hottest months from December to January, and low rainfall as the short rainy season from September to November, as discussed in section 4.2.3. Responses were recorded in Table 4.8.

Table 4.8: Perceived Influence of Temperature and Rainfall on Spread of Dodder

Occurrence of Dodder	High Tempt		Low Tempt		High Rainfall		Low Rainfall	
	N	%	N	%	N	%	N	%
Least intensity	4	1.2%	2	0.6%	2	0.6%	6	1.7%
Moderate intensity	240	69.8%	105	30.5%	13	3.8%	326	94.8%
High intensity	100	29.1%	237	68.9%	329	95.6%	12	3.5%

A scaling approach was employed to systematically interpret the responses from the Likert scale in item no. 14 of the questionnaire. This approach included three levels of dodder intensity 1 (least intensive), 2 (moderate), and 3 (very intensive). To determine the interval width, the highest response value (3) was subtracted from the lowest (1), giving a range of 2. Subsequently, the interval, denoting the step size between adjacent

scale points, was calculated by dividing the range (2) by the total number of scale points (3), thus 0.67. This represents the degree of variation between perceived levels of intensity. Average scores of the responses in each Likert item were computed. This served as a quantitative representation of the perceived intensity for each item on the Likert scale. The means of the responses for high and low temperatures, as well as high and low temperatures, were recorded in Table 4.9.

Table 4.9: Mean Perception Scores of Dodder Spread by Temperature and Rainfall

	High temperatures	Low temperatures	High rainfall	Low rainfall
No. of respondents (N)	344	344	344	344
Mean	1.72	2.68	2.95	1.98

For categorization on how temperature and rainfall variations had influenced the intensity of dodder, their average scores corresponded based on the established scale and interval as follows: Least intensity average score falling under 1.00 to 1.67, moderate intensity at an interval of 1.68 to 2.34 and high-intensity average score falling at an interval of 2.35 to 3.00. A mean closer to 1.00 showed that the respondents perceived dodder infestation as the least intensive, while a mean close to 3.00 indicated respondents' perception of high intensity of dodder infestation. The results are presented in Table 4.10.

Table 4.10: The Implication of Temperature and Rainfall on Dodder

	No. of respondents (N)	Mean(μ)	Std. dev.	Implications for the Intensity of Dodder Occurrence
High temperatures	344	1.72	0.47	Moderate intensity
Low temperatures	344	2.68	0.48	High intensity
High rainfall	344	2.95	0.24	High intensity
Low rainfall	344	1.98	0.23	Moderate intensity

The results in Table 4.10 indicated that the intensity of dodder occurrence was moderate during dry months and short rainy seasons, which were characterized by high temperatures and low precipitation. However, 95.6% of respondents reported a high intensity of dodder occurrence during the long rainy seasons, and 68.9% noted a high intensity during cold seasons. Despite this, respondents were more confident in the

assertion that dodder spread is more intense during long rainy seasons than to cold seasons, as reflected by the standard deviations of 0.242 and 0.478, respectively.

Also, the study aimed to identify the seasons in which dodder infestations were likely to be high or moderate according to the responses given by the respondents. Data obtained from the KMD Nandi County, Kenya, was used to compute the monthly rainfall and temperature and was presented in Figure 4.12. Through the graph plotted, the various seasons were compared to the responses given by the tea farmers. It was observed that MAM to JJA seasons was more likely to have a high intensity of dodder infestation as the temperature curve falls from March (temperature 19.7 °C, and rainfall 108.5 mm) with increasing amounts of rainfall to August (temperature 18.3 °C, and rainfall 203.0 mm). SON to DJF was interpreted to be seasons of moderate intensity of dodder infestation due to reducing rainfall amounts with a rising temperature curve. From September to February temperature rose from 18.7 °C to 19.7 °C with reducing rainfall amounts from 150.3 mm to 57.0 mm respectively.

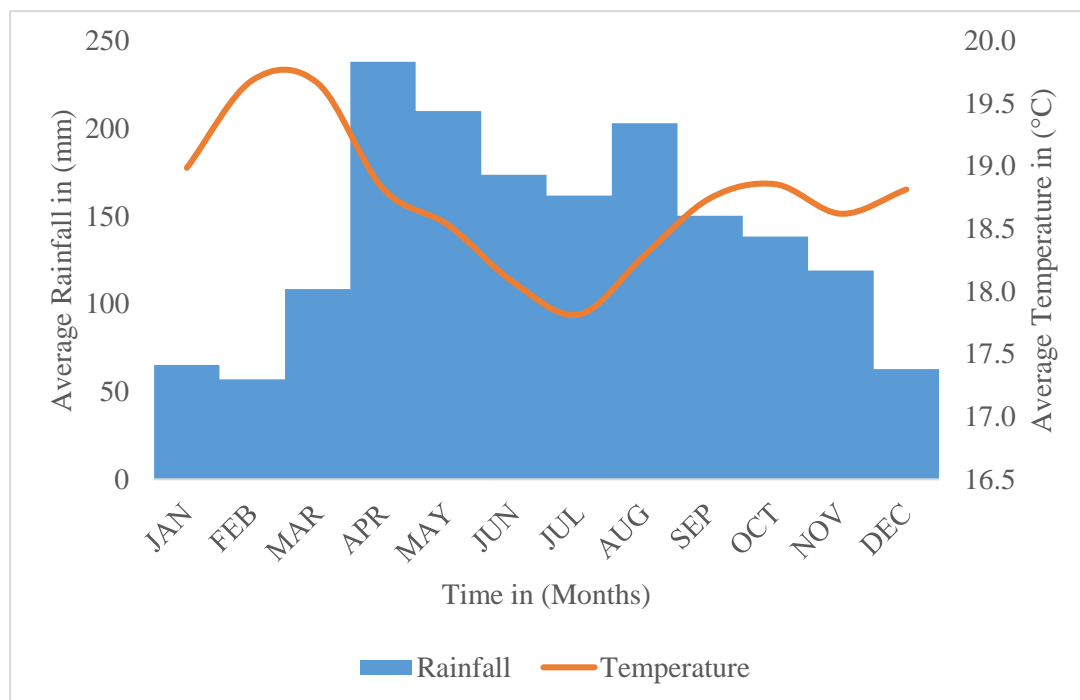


Figure 4.12: A Graph for Rainfall and Temperature in Nandi County

It was observed that in the dry and short rainy season there were moderate intensity in the occurrence of dodder. This was due to water scarcity leading to tea bush stress and hence slowing down the spread of dodder. In cold and long rainy seasons, water availability facilitated the fast growth of tea bushes and leaves that promoted the growth

and spread of dodder. However, Chepkirui (2020), and Orwah (2022) found that dodder species are likely to thrive in warmer environments.

4.5 Spread and Effects of Dodder

The spread of dodder poses a threat to tea yield and quality (Masanga *et al.*, 2021). To inform targeted interventions and effective strategies for dodder management, the various factors contributing to its propagation were assessed. Therefore, this study investigated the various pathways through which dodder enters the tea farms, which were not limited to; animals (birds), children, poor handling of infected farm tools, and poor handling of infected plants. A questionnaire was used to record respondents' opinions on the pathways of dodder see item no. 15. The data obtained was coded as a yes= 1 or no= 2 and results were recorded in Table 4.11.

Table 4.11: Perception of the Pathways of Dodder in Tea Farms

			Birds and animals	Children	Poor handling of infected farm tools	Poor handling of infected plants	Not aware
Yes	% Within the mode of spread		52	263	0	158	75
			14.8%	74.9%	0.0%	45.0%	21.4%
No	% Within the mode of spread		299	88	351	193	276
			85.2%	25.1%	100%	55%	78.6%

The majority of the respondents were aware of the pathways of dodder in their tea farms. Table 4.12 showed that 74.9% of respondents agreed that children are the major agents of dodder spread. School-going children are attracted by the bright yellow colored twining, hence pick them with little knowledge of the dire effects of the plant. This conforms with the findings by Kokwon *et al.*, (2022).

Coordinates were taken from GPS software and it was mapped to show the specific farms infested by dodder. Through spatial analysis, it was observed that the majority of the tea farms infested by dodder were near schools as shown in Figure 4.13. A respondent reported that as pupils pass by the tea fields with dodder, they pick the plant, play with and thus carelessly dispose of it or throw it on the tea farm adjacent to the road. This could lead to new infestation or further spread of dodder from one farm to the other.

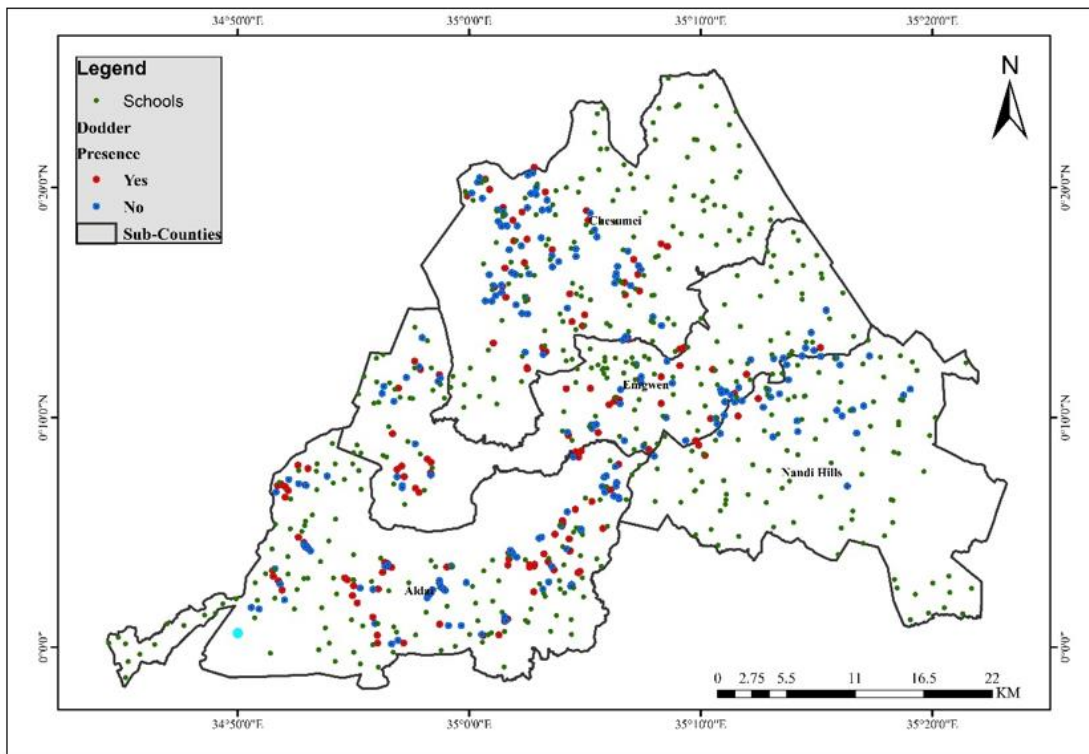


Figure 4.13: Distribution of Dodder overlaid with School Locations in the Study Area.

During field visits, 45% of the respondents recorded that poor handling of infected plants had led to the widespread spread of dodder. This was due to careless disposal of the infected plants, resulting in their reemergence on the tea plantation. It was also reported that workers on the tea farms tend to handpick dodder and throw it within the tea farm, leading to further spread to other tea bushes. From the field study, it was observed that after infected tea bushes were pruned, the farmer would leave the infected tea bushes on the tea farm, see Figure 4.14. This was related to their lack of knowledge that the dodder stems would continue to spread to other uninfected tea bushes within the farm as it only required a suitable host plant for survival.



Figure 4.14: Pruned-Infested Tea Farm. Date taken 2nd June 2023 GPS A(0.067716, 35.080760); B(0.067675, 35.080392)

It was noted that animals, especially birds, take the dodder twining to build their nests, hence spreading it from one point to another. This relates to a study by Costea *et al.*, (2016) that dodder can be transported through migratory flyways. Dodder was found to spread faster from poor handling of infected farm tools in large tea farms, specifically the multinational tea estates, where machines are used to pluck tea.

Findings by Eston *et al.*, (2020) showed that dodder is spread from one host plant to another by poor handling of infected plants, movement of infected tools from one point to the other, birds and animals, contaminated seeds, and water run-offs to aquatic environments. This also confirmed that dodder can be spread vegetatively, as it has the potential to reproduce both sexually and asexually. These results confirm studies done by Chepkirui (2020) and Orwah (2022), that children are the major pathways of dodder spread as they are attracted by the bright-colored dodder twining.

To assess the prevalence and awareness of dodder spread pathways among respondents, a cross-tabulated analysis was conducted. First, the presence of dodder on individual tea farms was categorized as "yes" or "no" and cross-tabulated with various identified pathways of dodder spread. The respondents who didn't know how dodder spread were asked to tick on the not aware bracket (see Table 4.11). This provided a preliminary

understanding of the association between farm-level dodder infestation and specific pathways.

The information was then compared to the actual presence of dodder on their farms, creating a 2x2 contingency table for each pathway as shown in Table 4.12. Subsequently, a Chi-square test of independence was applied to each table, evaluating the statistical significance of any observed association between awareness and actual infestation. This statistical analysis aimed to assess the farmers' understanding of dodder spread dynamics and identify potential gaps in knowledge that could inform future extension and education initiatives.

From the results shown in Table 4.12, poor handling of infected tools denoted by (.^a) showed that there was no variability in responses, as all the farmers gave a no response, meaning that dodder is not spread through poor handling of infected tools. This could mean that farmers are not ascertain that infected farm tools could lead to the spread of dodder.

Table 4.12: Perception of Dodder Pathways on Tea Farms

Pathways	Sig.	Modalities (n)	Presence of dodder	
			Yes (n)	No (n)
Animals (birds)	$\chi^2 = 3.080$ $p = 0.079$	Yes	28	122
		No	24	177
Children	$\chi^2 = 1.196$ $p = 0.274$	Yes	108	42
		No	155	46
Poor handling of infected farm tools	$\chi^2 = .^a$	Yes	0	0
		No	150	201
Poor handling of infected plants	$\chi^2 = 0.103$ $p = 0.748$	Yes	69	81
		No	89	112
Not aware	$\chi^2 = 1.697$ $p = 0.193$	Yes	37	113
		No	38	63

Sig. = Significance, χ^2 = Chi-Square, p = Probability Value, n = sample, ^a= No statistics are computed because Poor handling of infected tools is a constant.

Test of significance on animals (birds) ($\chi^2 = 3.080$, $p = 0.079$, $N = 351$), showed no statistically significant the association between the presences of dodder and the pathway of birds and animals. The test on children as the agents of dodder spread, poor handling of infected plants also showed no significant association with $\chi^2 = 1.196$, $p = 0.274$, $N =$

351 and $\chi^2 = 0.103$, $p = 0.748$, $N = 351$ respectively. this implied that those respondents with or without dodder present on their farms acknowledged that children are the lead pathways of dodder propagation. Some respondents disclosed that *Cuscuta* spp. was first, introduced as an ornamental plant as they were not knowledgeable of its dire effects to host plants.



Figure 4.15: Dodder Infestation from Adjacent Ornamental Plant Attaching Itself to a Tea Bush. Date taken 5th June 2023 GPS A(0.085162, 35.061476); B(0.083544, 35.061956); C(0.088157, 35.064550)

To test whether the perceptions of the respondents on the spread of dodder varied, a Friedman Test was used. This test was considered for the study as it was appropriate for testing the differences of multiple measures for the same subject. The various pathways of dodder spread are tested to ascertain their variations. The results showed that there was a significant variation in respondents' perception of the possible pathways through which dodder spread into the tea farms ($\chi^2_{\text{Friedman}} = 480.195$, $df = 4$, $p = 0.000$).

4.5.1 Effects of Parasitic Dodder on Tea

Dodder poses a significant threat to crop production worldwide (Dawson *et al.*, 1889) leading to biodiversity loss and food insecurity. A study by Chepkirui (2020), in Kericho County, Kenya, found that tea (*Camellia Sinensis*) was the most suitable host with 2391 out of the 7300 individual plants. Therefore, this study conducted in Nandi a county in Kenya aimed to assess the perceptions of tea farmers on the effects of dodder on tea as it is the main cash crop that supports livelihood in the region.

Item no. 16 of the questionnaire was used to collect respondents' perceptions on their observed effects of dodder on tea. Understanding the detrimental effects of dodder on

tea was crucial in developing effective control strategies and mitigating its economic impact. Their responses were recorded on a scale to ascertain their understanding of the effects of dodder. The responses were summarized by computing the average mean and standard (3.96, 0.65), respectively, with a total sample of n= 348. Friedman Test was used to obtain the ranks from the most effect to the least observed effect of dodder on tea. The computed average was used to compare with the results in Table 4.13. The mean value below 3.96 indicated that respondents perceived dodder to have a minimal impact, while the mean value above the average mean showed that respondents perceived dodder to affect tea. The value with a low standard deviation, compared to the 0.65 above, showed a little variation in their opinions on the effects of dodder on tea.

Table 4.13: Perceived Effects of Dodder on Tea

	Mean	Rank
Lowers tea productivity	4.39	VI
Lowers tea quality	4.39	V
Lowers tea taste quality	1.03	VIII
Interferes leaf hand plucking	4.90	I
Reduces tea bush vigor	4.51	IV
Interferes machine leaf plucking	3.10	VII
Lowers quantity of tea sales	4.66	III
Increased financial expenditure	4.70	II

The results in Table 4.13 showed that, on average, respondents perceived parasitic dodder to have a moderately high negative impact on lowering productivity, tea quality, tea bush vigour, quantity of tea sales, and interference with leaf hand plucking, as well as an increase in financial expenditure for management. The respondent's perceptions of dodder lowering tea productivity and tea quality by the low mean. The low mean and standard deviation in respondents' perception of the effect of dodder on lowering tea taste quality suggest a consensus that this aspect was minimally affected by dodder, as there have never been any experiments done to ascertain.



Figure 4.16: Dodder on Tea Bushes. Date taken: 16th May 2023. GPS A(0.172855, 34.997520); B (0.136626, 34.956151); C(0.136702, 34.951282)

It was observed that after attachment, dodder twinning forms a dense network on the tea bush, as in Figure 4.16. Once dodder attaches to tea plants, it extracts vital nutrients and water, leading to reduced biomass and hence poor yield and quality (Yego *et al.*, 2022), henceforth economic losses (Ngare *et al.*, 2020; Masanga *et al.*, 2021).



Figure 4.17: Dried Tea Leaves as a Result of Dodder Attacks. Date taken 9th May 2023. GPS A (0.292181, 35.040082); B (0.293525, 35.053260); C (0.294221, 35.033749)

To test the variation in respondents' perceptions of the effects of dodder on tea, a Friedman Test was used. This Test was considered appropriate for testing the differences of multiple measures for the same subject. Therefore, the respondents vary in perception of the different effects of dodder on tea ($\chi^2_{\text{Friedman Test}} = 1621.314$, $df = 7$, $p = 0.000$, $n = 348$).



Figure 4.18: A Closer View of the Effects of Dodder on a Tea Leaf. Date taken 5th May 2023. GPS A (0.201323, 35.040790); B (0.200921, 35.041192)



Figure 4.19: A Buildup Network of Dodder Twines Interferes with the Hand Plucking of Tea Leaves. Date taken 3rd May 2023. GPS (0.078092, 34.880705)

4.5.2 General Knowledge of Dodder

General knowledge of dodder was essential for respondents to develop comprehensive and sustainable strategies to manage dodder infestation. Therefore, item no. 17 of the questionnaire was used to ascertain respondents' opinions on their general knowledge of dodder. On a 5-point Likert scale, the responses were recorded as shown in Table 4.14.

Table 4.14: Respondents' General Knowledge of Dodder (%)

		SD	D	N	A	SA	Total	N	Mean	Std. Dev.
1.	Threat to tea farming	0.3	0.0	0.9	1.1	97.7	100	350	4.97	0.26
2.	Medicinal plant	97.1	0.9	0.9	0.3	0.9	100	349	1.07	0.45
3.	Spreads faster after attachment	0.6	0.0	0.9	8.0	89.0	100	348	4.88	0.43
4.	C.V enhances the spread of dodder	3.7	10.0	34.4	26.0	25.8	100	349	3.61	1.08
5.	No guidelines from KTDA	0.6	0.0	0.9	4.3	94.3	100	348	4.92	1.40
6.	Chemicals are expensive to buy	0.6	0.0	4.0	13.8	81.7	100	349	4.77	0.54

SD= Strongly Disagree, D= Disagree, N= Neutral, A= Agree, SA= Strongly Agree, C.V= Climate Variability

The averages for the mean and the std. dev of the responses was computed as follows: 4.03 and 0.52 respectively for 348 respondents. The results in Table 4.14, show that the respondents were well conversant with the parasitic plant and understood the significant effect it has on the tea crop. The majority of the respondents (n= 342, 97.7%) were in support of dodder being a threat to tea farming, that dodder spreads faster once it has attached itself to the tea bush. 94.3% of the respondents strongly agreed that there were no guidelines provided by the KTDA on how to manage and control dodder and the chemicals used to buy dodder are quite expensive which was agreed by 81.7% of the respondents as the parasitic weed reemerge even after it has been sprayed. These were indicated by the high mean and little variability in responses noting that a high level of agreement among the respondents.

Dodder has different healing properties. It can cure spleen, jaundice, gallbladder, eczema, epilepsy and it has also anticancer properties. Therefore, the respondents were asked if they knew any medicinal uses for *Cuscuta*. However, in the study area, 0.9% of the respondents did not perceive dodder as a medicinal plant, indicated by a low mean of 1.07 (see Table 4.14). This is because the majority of the respondents did not know any medicinal potential of dodder. On whether climate variability (temperature and rainfall) enhanced the spread of dodder, 34.4% of the respondents could neither agree nor disagree with the average mean of 3.61, indicating they were neutral in their opinion.



Figure 4.20: Dodder Infestation on Tea Plantation. Date taken 18th May 2023. GPS (0.316937, 35.048588)

Further, a Chi Square Test showed that there was no significant difference in response among farmers in the two catchments (Chebut and Kaptumo) at ($\chi^2= 5.066$, $df= 3$, $p = 0.167$, $n= 348$). The household heads with dodder on their tea farms reported to the KTDA field officers during the field day visits but no actions have been taken to help them manage and control the infestation, this statement is in agreement with research done in other areas that dodder continues to spread and there is a little response to the respondents in managing dodder (Chepkirui, 2020). This conforms with the findings by Masanga *et al.*, (2021) that dodder is a threat to tea farming in Kenya as it leads to great economic losses as it is one of the most suitable dodder hosts (Chepkirui, 2020). The findings showed that despite dodder infestation being a threat to tea farming, there are no guidelines given by the KTDA to tea farmers on how to manage dodder on their tea farms this confirms the study done by Chepkirui (2020).

4.6 Management of Dodder

Uncontrolled dodder infestations pose a significant threat to tea production in Nandi County, leading to substantial economic losses for farmers. To address the challenge a comprehensive understanding of effective dodder control methods was essential for the study. Therefore, to determine the most used technique to control dodder, item no. 18 of the questionnaire was used to ascertain the respondents' opinions on the most to least used techniques as shown in Table 4.15.

Table 4.15: Methods of Dodder Control

Dodder Control Techniques	Mean	Std. Deviation	Rank
Herbicide application	1.26	0.83	VI
Handpicking twining	4.05	1.43	I
Slashing twining	1.35	0.87	V
Burning twining and infested plants	1.65	1.32	IV
Burying twining and infested plants	2.48	1.60	II
Uprooting infested plants	1.26	0.91	VII
Pruning-infested tea bushes	1.82	1.57	III

Results showed that handpicking dodder twines was the most commonly used method to control dodder among respondents. The respondents preferred this dodder control method as it effectively reduces dodder spread, especially when the infestation is not severe and targets dodder removal without affecting the entire tea bush. Since dodder

has not infested large areas within the farm, handpicking is the preferred method on both large- and small-scale farms.



Figure 4.21: Handpicking Dodder Twines on a Tea Farm. Date taken 17th June 2023. GPS A (0.184350, 34.985233); B (0.184170, 34.945084)

After the respondents handpick dodder from the infested tea bushes and throw them on bare ground or on the road, where couldn't find potential hosts to thrive. However, this method is not effective as the dodder tends to reemerge due to incomplete removal, as other parts of the dodder could remain on the tea bush and continue to grow in the presence of moisture which agrees with findings by Mierek *et al.*, (2021).



Figure 4.22: Handpicked Dodder Twining thrown by the roadside. Picture taken on 24th May 2023. GPS (0.108118, 35.1056737)

Besides incomplete removal of dodder parts, in the case of matured dodder plants could produce seeds which finds their way to the soil surface thus further spread of dodder within the plantation. In large-scale tea farms especially the multinationals- Siret, Chemomi, and Taito Tea estates; the field managers ascertained that labor costs

associated with handpicking dodder twinings were quite high, and much time was taken as this technique was a repetitive process to prevent the reemergence of dodder.

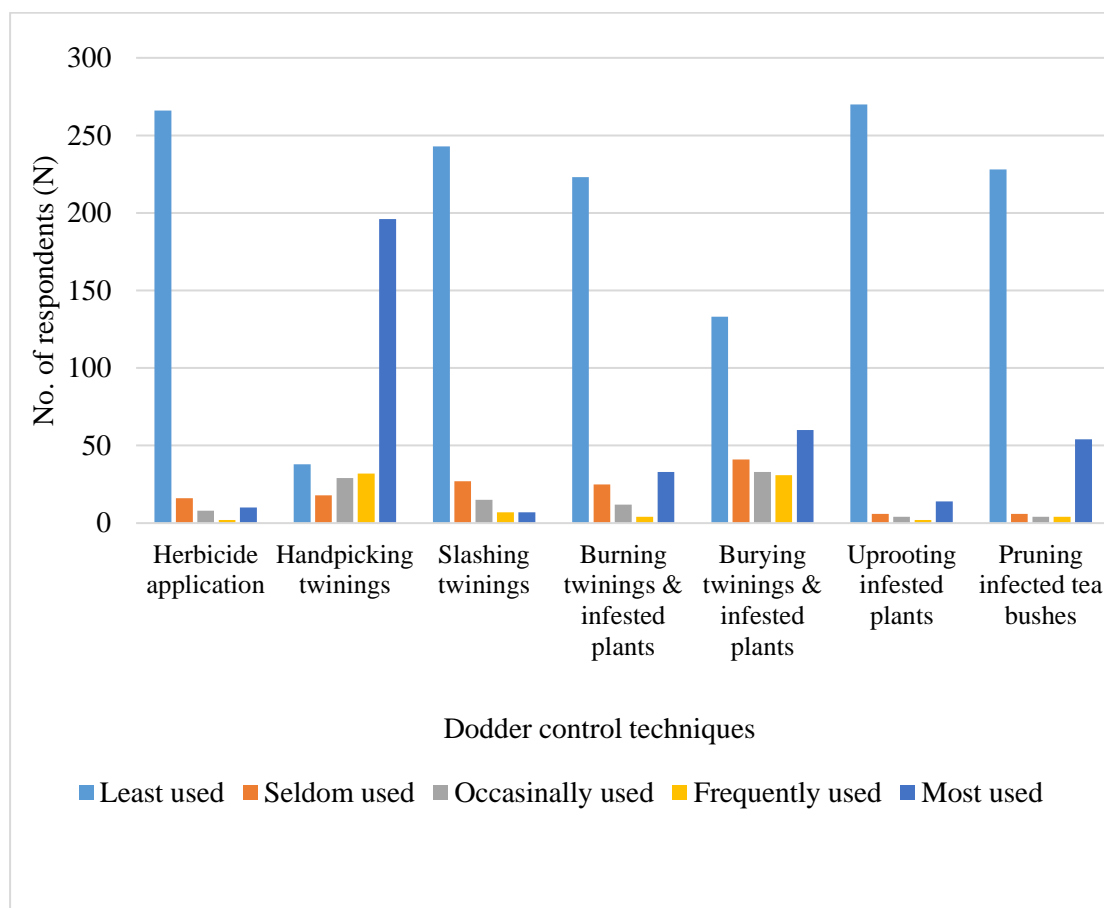


Figure 4.23: Dodder Control Techniques in Nandi County

After removal of dodder twining and infested tea bushes in both small and large scale farms, they were buried deep in the soil or burned outside the tea plantation. These methods were used to prevent further spread of dodder within the farm. On tea farms with extensive spread of dodder, the respondents were forced to prune their tea bushes in order to reduce dodder infestation, this method is highly recommended to tea farmers by Kenya Agricultural and Livestock Research Organization (KALRO) (Kamunya *et al.*, 2019).



Figure 4.24: Pruning-infested Tea in Progress. Date taken 12th June 2023. GPS A (0.064358, 35.021856); B (0.064827, 35.022334)

Further, in some households pruned infested tea and left the infected plants on the same plantation leading to the reemergence of dodder. This observation indicated that the methods used by the respondents were not sustainable thus cases of reemergence were reported. Pruned tea takes too long to grow therefore the households' heads considered this method not sustainable. A study done by Lanini *et al.*, (2019) found that burning of infected plants contains dodder spread as long as the host plants are burned too. However, this method was not effective since the respondents gave feedback that dodder continues to spread on their tea farms. This could be due to dodder seeds having already spread on the soil surface.

Herbicide application to control dodder was ranked second last as shown in Table 4.15. 5% of the respondents used Round-Up to spray on dodder twines. Farmers who used Round Up Turbo to spray the dodder twines led to severe leaf damage to tea bushes as it contains glyphosate which is a non-selective herbicide. One of the respondents used Glycel 480SL to spray on the infected tea bushes and after 3 weeks dodder remerged.

This method was found not to be effective as dodder species kept reemerging, thus correlating with the findings of Chepkirui, (2020) that dodder is difficult to control due to its reoccurrence. Other respondents used chemical control methods as they said that KTDA field extension officers had always discouraged the use of herbicides. This statement was confirmed to be true after an interview with a field officer situated at Kaptumo Factory.

Uprooting of infested plants as a way of dodder control was ranked the last see Table 4.15. Infested plants that were adjacent to the tea farm that as considered as a potential pathway of dodder into the farm was uprooted and burned.

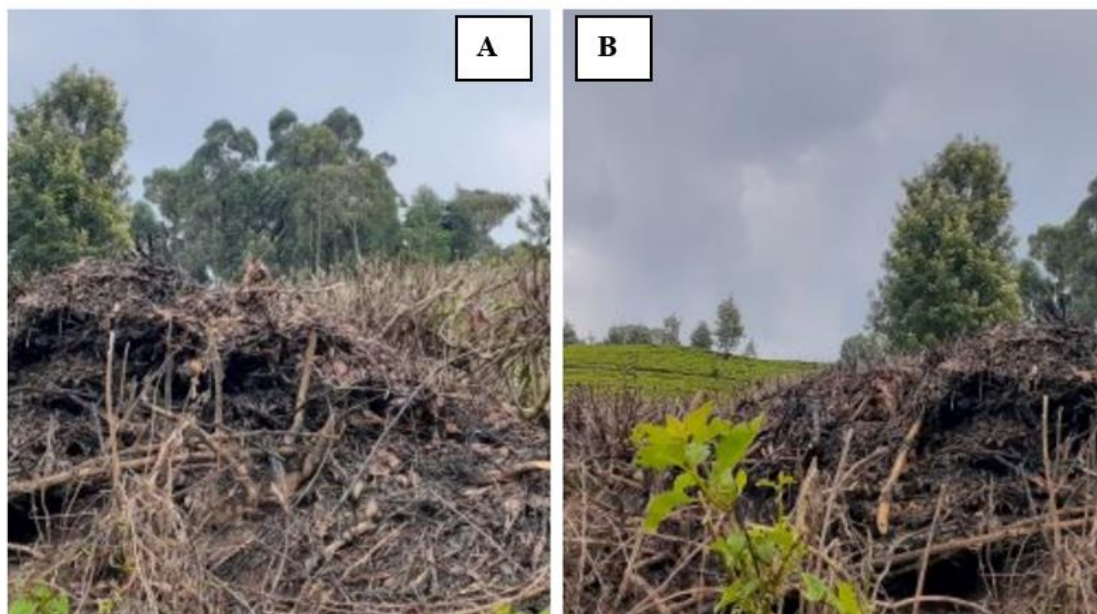


Figure 4.27: Burned Dodder Twining with Infested Tea Bushes. Date taken 29th May 2024. GPS A (0.016898, 35.020945); B (0.017384, 35.021202)

One or two tea bushes infested by dodder and adjacent to the neighboring plants were uprooted to curb further spread. Slashing dodder twining attached to the tea bush was considered impractical, thus the least used method of control, as this could cause damage. These plants were mainly Mauritius thorns and K-apples that surrounded most tea farms as shown in Figure 4.28.

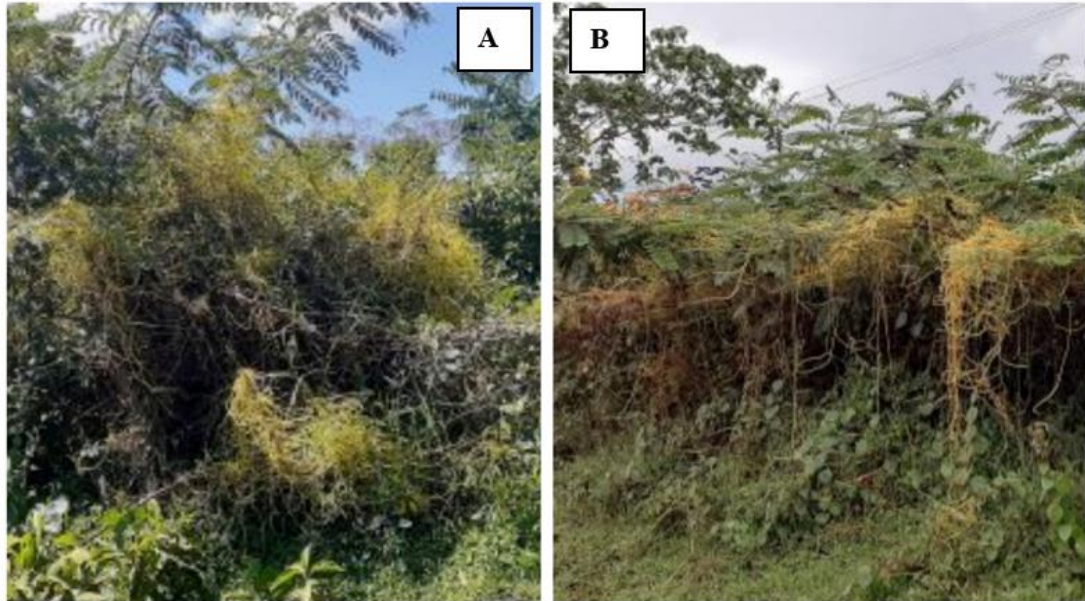


Figure 4.28: Infested Mauritius Thorn Adjacent to a Tea Plantation. Date taken 10th June 2023. GPS A (0.095892, 35.105386); B (0.095892, 35.108571)

To investigate the respondents' preferences on management methods, and the presence of dodder on tea farms. Dodder occurrence was cross-tabulated with the various techniques used. The results are shown in Table 4.16. The Chi-Square test showed no significant association between the presence of a dodder and the use of herbicide application, slashing, burning dodder twining, uprooting infested plants, and pruning tea as they had a greater p -value see Table 4.16. However, there was a significant association between farmers' awareness of dodder presence on their tea farms and their tendency to opt for handpicking ($\chi^2 = 15.835$, $df = 4$, $p = 0.003$) and burying of dodder twining alongside infested plants ($\chi^2 = 13.075$, $df = 4$, $p = 0.011$).

Table 4.16: Association of Presence Dodder with Methods of Dodder Control

Method	Sig.	Presence of dodder	Least used ←————→ Most used				
			Respondents (n)				
Herbicide application	$\chi^2= 4.745$	Yes	110	6	5	1	7
	$p= 0.314$	No	156	10	3	1	3
Handpicking twining	$\chi^2= 15.835$	Yes	18	8	6	6	94
	$p= 0.003$	No	20	10	23	26	102
Slashing twining	$\chi^2= 3.019$	Yes	103	11	7	5	4
	$p= 0.555$	No	140	1	8	2	3
Burning twining and infested plants	$\chi^2= 6.114$	Yes	91	10	7	3	19
	$p= 0.191$	No	132	15	5	1	14
Burying twining and infested plants	$\chi^2= 13.075$	Yes	64	12	7	16	30
	$p= 0.011$	No	69	29	26	15	30
Uprooting infested plants	$\chi^2= 1.785$	Yes	116	3	1	1	8
	$p= 0.775$	No	154	3	3	1	6
Pruning infested tea bushes	$\chi^2= 5.895$	Yes	92	3	1	2	31
	$p= 0.207$	No	135	3	3	2	23

These results suggested that the association between dodder presence and the choice of dodder control techniques varied across different strategies. For instance, respondents who had encountered dodder on their tea farms were more likely to consider handpicking and burying of dodder twining alongside infested plants as a control method compared to those who have no dodder on their farms.

To manage dodder, it was crucial to identify the types of species present within the study area. Five dodder specimens were sampled at random from different tea farms. Each specimen was carefully placed and labeled in different bags detailing the GPS and date of collection. The specimens were taken to the National Museums of Kenya for identification. The identification revealed of the 5 specimens, only two dodder species were present that is *Cuscuta reflexa* and *Cuscuta kilimanjari*. The findings highlighted a limited diversity of dodder species to accurately represent the overall distribution of dodder species in the study area as the sample size was too small.

CHAPTER FIVE: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1: Summary

This study aimed to assess the level of dodder invasion on tea in Nandi County, Kenya. Primarily, the study examined the trends of climate variability (rainfall and temperature) from 1992 to 2022. Respondents were asked about their perceptions of temperature and rainfall trends from 2012 to 2022, as it was easier for them to recall. Historical data from KMD were analyzed and compared with the perception by respondents. The trend analysis results using the Mann-Kendall test indicated a strong positive relationship for temperature, with Kendall's Tau (τ) = 0.554 at an increase of 0.031°C per year at $p < 0.0001$, and hence the null hypothesis of no significant changes in temperature was rejected. In contrast, rainfall had a weak positive correlation with Kendall's Tau (τ) = 0.123 and an increase of 6.6541 mm annually, but this was not significant $p = 0.341$. Thus, the null hypothesis on rainfall variations could not be rejected. Comparisons between KMD data and opinions of the respondents indicated a very strong match for temperature trends, where 98.7% of the respondents noted an increase. However, 99.4% of the respondents perceived a decrease in rainfall, a trend which was not supported by the KMD data.

The second objective sought to assess the extent of dodder infestation on tea in Nandi County. The sample frame of the study included KTDA tea farmers for small-scale farms and multinational tea estates for large-scale farms. The GPS software was used to extract the coordinates of the farmers with dodder present on their tea farms and map their spatial distribution. Out of 354 households sampled for the study, 149 (42%) had dodder on their tea farms. Additionally, 3 of the chosen 6 multinational tea estates recorded the presence of dodder in their farms. Sample specimens for dodder were taken to the National Museums of Kenya for species identification, revealing two species: *Cuscuta kilimanjari* and *Cuscuta reflexa*. These findings indicated that dodder had significantly infested both large- and small-scale tea farms in Nandi County.

The third objective of the study was to assess tea-growing farmers' perceptions of the influence of climate variability (temperature and rainfall) on the spread of dodder in Nandi County. Respondents were asked their opinions on the influence of rainfall and temperature on the intensity of dodder occurrence. The results revealed that 68.9% of

respondents noted increased dodder intensity during colder months (June to August) and 95.4% observed higher intensity during the long rainy seasons (March to May), attributing this to improved tea bush vitality due to better water availability. In contrast, dodder occurrence was reported as moderate during short rainy seasons (September to November) and moderately intense during dry spell seasons (December to January), with agreement from 94.8% and 69.8% of respondents, respectively.

The fourth objective was to assess tea farmers' perceptions of the effects and the methods used to manage dodder in the study area. On the effects of dodder on tea, respondents were to choose the selected observed effects of dodder on tea, ranging from lowering tea productivity, tea quality, reducing tea taste quality, interfering with leaf hand plucking, reducing tea bush vigor, interfering with machine leaf plucking, lower quantity of tea sales and increased financial expenditure to manage the parasitic plant. The results showed that dodder interfered with tea leaf hand plucking as it built a network on tea bushes; 97.1% reported that dodder is a threat to tea farming. To test the null hypothesis that tea farmers do not vary in perceptions of the impacts of dodder on tea, the Friedman Test showed that there were variations in perceptions of tea farmers on the effects of dodder on tea ($\chi^2_{\text{Friedman Test}} = 1621.314$, $df = 7$, $p = 0.000$, $N = 348$). Therefore, the null hypothesis was rejected.

In the second part of the fourth objective, the study assessed the methods used by tea farmers to control dodder. The results revealed that hand pulling of dodder twines was the most preferred method, utilized by 62.6% of farmers, followed by burying the twines after detachment at 20.1%. Depending on infestation severity, pruning tea was employed by 18.2% of respondents. Although herbicides were generally avoided due to their potential to harm tea plants, 3.3% of respondents used them as a control measure. The observed variations in control methods among respondents led to rejecting the null hypothesis, which stated that dodder control methods do not significantly vary among tea farms in the study area.

5.2: Conclusions

From the findings, the conclusion was made as follows;

1. Climate varied from 1992 to 2022 in Nandi County. The temperature had slightly increased, while rainfall showed minimal and statistically insignificant variations.
2. Dodder had infested both large- and small-scale tea farms in Nandi County. Out of the 354 respondents, 149 recorded dodder presence in the small-scale tea farms. In the large-scale farms, 3 out of 6 multinational tea estates, Chemomi, Taito, and Sireet, showed the presence of dodder.
3. Tea-growing farmers perceived that climate variability influenced the spread of dodder on tea farms. Increased dodder intensity was observed during colder months and the long rainy seasons due to improved tea bush vitality from better water availability.
4. Tea-growing farmers perceived dodder infestation as a threat to tea farming, affecting tea leaf plucking, productivity, and quality. They primarily used hand pulling as their preferred control method, with variations in control strategies across farms.

5.3: Recommendations

1. The government, through agricultural research institutions, should implement a program to identify and map areas with dodder for ease of monitoring and surveillance of dodder.
2. KTDA should partner with research institutions such as the Tea Research Foundation and KALRO to train and support tea farmers on integrated pest management (IPM) strategies to mitigate the impact of dodder.

5.4: Areas for Further Research

1. Research on the development and efficacy of new herbicides that target dodder without harming tea plants and environmental safety.
2. Further research is needed to identify the genetic diversity of dodder species in different regions of the Country.

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APPENDICES

Appendix I: Questionnaire

QUESTIONNAIRE TO KTDA TEA FARMERS

LETTER OF INTRODUCTION TO THE RESPONDENT

FAITH JEPCHIRCHIR MONGO,

P.O BOX 88-30300,

KAPSABET.

Dear, _____

I am a postgraduate student from Kenyatta University, pursuing a **Degree in Master of Environmental Studies (Climate Change and Sustainability)**. As a requirement for fulfillment for the award of a degree, I am required to identify a topic in my area, carry out data collection and write a project report on the same. My topic for research is **(EFFECTS OF DODDER INFESTATION ON TEA FARMING IN NANDI COUNTY, KENYA)**. I have therefore identified you as one of the respondents for this research. The information you provide to me will be invaluable in assisting with this report and in efforts to the conservation of tea farms and surrounding ecosystems. This will also be treated with utmost confidentiality and shall not be used for any other purpose except the one stated.

Questionnaire serial no. [_____]

Date 2023 _____

Ward _____

Village _____

GPS: Longitude _____ Latitude _____

Name of the interviewer _____

Part I Information about the household

Instructions to the interviewee:

Please Tick the brackets provided and fill the spaces provided appropriately.

1. Name of the household head _____
2. Age of the household head (years)_____
3. Gender of the household head: Male [] Female []
4. Total household annual income (Ksh.) _____
5. Name of the KTDA factory the tea grower is registered

6. Name of the tea buying center _____
7. Education level: None [] Primary []
Secondary [] Tertiary []
8. How long have you settled there? (Years) _____
9. What is the size of the household farm? (Ha) _____
10. What is the size of the household farm under tea? (Ha)

11. Land use plan (indicate):

S/N	Land use plan	Area in Acres
a	Grazing land	
b	Homestead	
c	Annual crops (Maize, beans, vegetables)	
d	Other perennial crops (bananas, coffee, sugarcane)	

Part 2 Climate Variability and Dodder

12. Do you know the dodder plant? Yes [] No [] (Show a freshly picked sample of a dodder plant approximately 40 cm long)

What do you call it in your local language?

s/n	Local name
a	
b	
c	

13. Have you experienced variations in the following climatic parameters (rainfall and temperature) in the past decade (2012 to 2022)? Yes [] No [].

On a scale of 1 to 5, kindly rate your opinion. (1=strongly disagree, 2=disagree, 3=neutral, 4= agrees, 5= strongly agree).

s/n	Climatic parameters	1	2	3	4	5
a	Rainfall have reduced in the past decade (2012 to 2022)					
b	Rainfall have increased in the past decade (2012 to 2022)					
c	Temperature have risen from the past decade (2012 to 2022)					
d	Is it colder than the last ten years (2012 to 2022)					

14. Temperature and rainfall is said to be an attribute to dodder infestation. On a scale of 1-3, give an opinion of your observations over time on the severity of infestation. (1 least intensive, 2= moderate, 3= very intensive).

S/n	Climate parameters	1	2	3
a	High temperatures			
b	Low temperatures			
c	High rainfall			
d	Low rainfall			

Part 3 Farmers' Perceptions on Dodder and Ways of Control

15. What is your perception on the pathways of dodder invasion in your tea farm?
 Brought about by birds and animals [] Children [] Poor handling of the infected farm tools [] poor handling of infected plants [] Not aware []
16. Dodder plant is said to have an effect on tea. On a scale of 1 to 5 give your opinion on the observed effects, (1= least effect...5= most effect).

s/n	Effects of dodder	Least effect ←————→ most effect				
		1	2	3	4	5
a	Lowers tea bush productivity					
b	Lowers tea leaf quality					
c	Lowers tea taste quality					
d	Interferes with leaf hand plucking					
e	It reduces tea bush vigor					
e	Interferes with leaf plucking by machine					
f	Lowers the quantity of tea sales					
g	Financial expenditure					

17. What are your general perceptions on parasitic dodder? On a scale of 1 to 5 kindly rate your answer. (1=strongly disagree, 2=disagree, 3=neutral, 4= agrees, 5= strongly agree).

s/n	General perceptions on dodder	1	2	3	4	5
a	Dodder is a threat to tea farming					
b	Dodder is a medicinal plant					
c	Dodder spreads faster once it has attached to tea bush					
d	Climate variability has enhanced the spread of dodder					
e	There are no guidelines provided to the farmer by KTDA on how to control dodder					

f	It is expensive to buy chemicals to control dodder					
---	--	--	--	--	--	--

18. Which of the following ways do you use to manage dodder weed. On a scale of 1 to 5, kindly give your opinion of the following methods used to manage dodder on tea plantation. (1= least used.....5=most used).

s/n	Method	Least used Most used				
		1	2	3	4	5
a	Herbicide application (name)					
b	Handpicking the dodder twines					
c	Slashing of dodder twining					
d	Burning of dodder twining					
e	Burying of dodder twining					
f	Uprooting infested plants adjacent to the plantation					
g	Pruning infested tea bushes					

THANK YOU!

ASANTE!

Appendix II: Interview Questions to the Tea Field Manager

FAITH JEPCHIRCHIR MONGO,

P.O BOX 88-30300,

KAPSABET.

Dear, _____

I am a postgraduate student from Kenyatta University, pursuing a **Degree in Master of Environmental Studies (Climate Change and Sustainability)**. As a requirement for fulfillment for the award of a degree, I am required to identify a topic in my area, carry out data collection and write a project report on the same. My topic for research is **(EFFECTS OF DODDER INFESTATION ON TEA FARMING IN NANDI COUNTY, KENYA)**. I have therefore identified you as one of the respondents for this research. The information you provide to me will be invaluable in assisting with this report and in efforts to the conservation of tea farms and surrounding ecosystems. This will also be treated with utmost confidentiality and shall not be used for any other purpose except the one stated.

Interview serial no. [_____]

Date 2023 _____

Ward _____

Tea Estate Group _____


GPS: Longitude _____


Latitude _____

Name of the interviewer _____

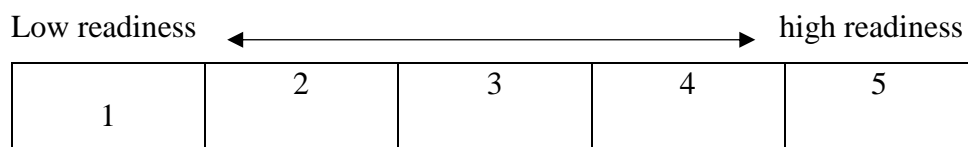
Part 1

1. Name of the tea estate _____
2. Name of the tea estate manager _____
3. Size of the tea estate (Ha) _____
4. Length of your service as a manager (years) _____
5. Do you have any challenges with weeds in the tea estate? Yes [] No []
6. Give three common weeds that maybe a challenge to your tea plantation
 a) _____ b) _____ c) _____

7. Dodder (*Cuscuta spp*) is said to be a challenge to agricultural and non-agricultural plants (showing a freshly pick dodder plant with a length of 30cm). Do you have any experience with the weed (dodder) (a) in the tea estate? _____ (b) outside the tea estate? _____
8. Dodder is a threat to crops and other vegetation in Nandi County. To what extent do you believe that dodder is a threat to your estate tea plantation? (Tick as appropriate).
 Low threat high threat


1	2	3	4	5
---	---	---	---	---
9. How frequently is dodder infestation reported in your tea estate? (In a scale of 1-5 below, rate your opinion on frequency).
 Low frequency high frequency


1	2	3	4	5
---	---	---	---	---
10. How prepared is the estate ready to control dodder? (In a scale of 1-5 below, rate the estate readiness)



11. Of the following dodder control methods, indicate in a scale of 1-5 how each of the following is applied in your tea estate;

s/n	Method	Least used ←————→ Most used				
		1	2	3	4	5
a	Herbicide application (name)					
b	Handpicking the dodder twines					
c	Slashing of dodder twining					
d	Burning of dodder twining					
e	Burying of dodder twining					
f	Uprooting infested plants adjacent to the tea plantation					
g	Pruning infested tea bushes					

12. What are the major pathways for dodder invasion on to tea farms? Build network from adjacent infected plants to the tea plantation [] Brought about by birds and animals [] Children [] Poor handling of the infected farm tools [] Poor handling of infected plants [] Others specify

13. Are there any observed effects of dodder on tea? Yes [] No []

14. In your own opinion what would be the effects of dodder on tea. Express your opinion in the scale below (1= least effect.....5= most effect).

s/n	Effects of dodder	Least effect most effect				
		←—————→				
		1	2	3	4	5
a	Lowers tea bush productivity					
b	Lowers tea leaf quality					
c	Lowers tea taste quality					
d	Interferes with leaf hand plucking					
e	It reduces tea bush vigor					
f	Interferes with leaf plucking by machine					
g	Lowers the quantity of tea sales					
h	Financial expenditure					

Appendix III: Interview Questions to the Key Informants

FAITH JEPCHIRCHIR MONGO,

P.O BOX 88-30300,

KAPSABET.

Dear, _____

I am a postgraduate student from Kenyatta University, pursuing a **Degree in Master of Environmental Studies (Climate Change and Sustainability)**. As a requirement for fulfillment for the award of a degree, I am required to identify a topic in my area, carry out data collection and write a project report on the same. My topic for research is **(EFFECTS OF DODDER INFESTATION ON TEA FARMING IN NANDI COUNTY, KENYA)**. I have therefore identified you as one of the respondents for this research. The information you provide to me will be invaluable in assisting with this report. This will also be treated with utmost confidentiality and shall not be used for any other purpose except the one stated.

Interview serial no. _____

Date: 2023/ _____

GPS: Longitude _____

Latitude _____

Name of the interviewer _____

Name of the interviewee _____

Organization _____

Designation _____

Part 1

1. Length of your service in the organization (years)

2. Do you have any challenges with weeds in Nandi County that lead to agricultural losses? Yes [] No []

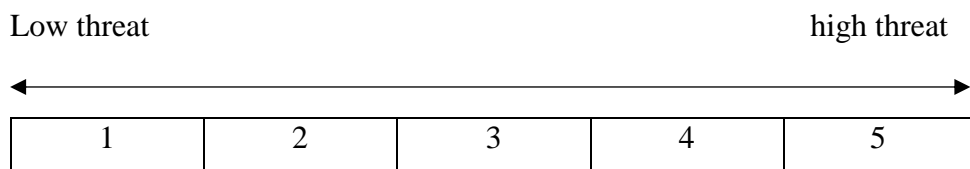
3. Give three common weeds that maybe a challenge to agricultural crops

a) _____ b) _____ c)

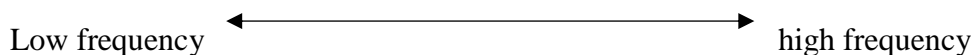
4. Dodder (*Cuscuta spp*) is said to be a challenge to agricultural and non-agricultural plants (showing a freshly pick dodder plant with a length of 30cm). Do you have any experience with the weed (dodder) (a) in the tea plantation?

_____ (b) outside the tea farms? _____

5. Dodder is a threat to crops and other vegetation in Nandi County. To what extent do you believe that dodder is a threat to tea plantations in the County? (Tick as appropriate).



6. How frequently is dodder infestation reported in the County tea? (In a scale of 1-5 below, rate your opinion on frequency).



1	2	3	4	5
---	---	---	---	---

7. How prepared is the organization ready to control dodder? (In a scale of 1-5 below, rate the organization readiness)

Low readiness ←————→ high readiness

1	2	3	4	5
---	---	---	---	---

8. Of the following dodder control methods, indicate in a scale of 1-5 how each of the following is commonly applied;

s/n	Method	Least used ←————→ Most used				
		1	2	3	4	5
a	Herbicide application (name)					
b	Handpicking the dodder twines					
c	The slashing of dodder twining					
d	Burning of dodder twining					
e	Burying of dodder twining					
f	Uprooting infested plants adjacent to the tea farm					
g	Pruning-infested tea bushes					

9. What are the major pathways for dodder invasion in the County and onto tea farms? Build network from adjacent infected plants to the tea plantation []
 Brought about by birds and animals [] Children [] Poor handling of the infected farm tools [] Poor handling of infected plants [] Others specify _____
10. Are there any observed effects of dodder on tea? Yes [] No []
11. In your own opinion what would be the effects of dodder on tea. Express your opinion in the scale below (1= least effect.....5= most effect).


s/n	Effects of dodder	Least effect most effect				
		←—————→	1	2	3	4
a	Lowers tea bush productivity					
b	Lowers tea leaf quality					
c	Lowers tea taste quality					
d	Interferes with leaf hand plucking					
e	It reduces tea bush vigor					
f	Interferes with leaf plucking by machine					
g	Lowers the quantity of tea sales					
h	Financial expenditure					

Appendix IV: Observation Checklist

CHECKLIST SERIAL No. _____ GPS _____

S/N	Parameters to observe	Observation
1.	Presence of dodder on the tea farm	
2.	Location of infestation (leaves, stem, buds)	
3.	Severity of infestation (no. of tea bushes affected)	
4.	Growth stage of dodder	
5.	Overall health of the infected tea bush (leaf damage and wilting)	
6.	Presence of other dodder hosts within the tea plantation	
7.	Presence of other weeds in the tea farm	

Appendix V: Approval of Research


KENYATTA UNIVERSITY
OFFICE OF THE EXECUTIVE DEAN, GRADUATE SCHOOL

E-mail: dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 020-8704150

Internal Memo

FROM: Executive Dean, Graduate School **DATE:** 23rd March 2023
TO: Faith Jepchirchir Mongo **REF:** NSO/20960/2021
C/O Environmental Sciences and Education

SUBJECT: APPROVAL OF RESEARCH PROPOSAL

=====

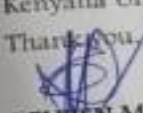
This is to inform you that Graduate School Board, at its meeting on 15th March 2023, approved your Research Proposal for the M.Env Studies Degree entitled, *Dodder (Cuscuta spp.) Infestation on Tea in Nandi County, Kenya.*

You may now proceed with your Data collection, subject to clearance with the Director General, National Commission for Science, Technology & Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking and Progress Report Forms per semester. The Forms are available at the University's Website under Graduate School webpage downloads.

Also, please ensure that you publish article(s) from your thesis before submitting it to Graduate School for examination as per the Commission for University Education and Kenyatta University guidelines.

Thank you.



REUBEN MURIUKI
FOR: EXECUTIVE DEAN, GRADUATE SCHOOL

CC. Chairman, Environmental Sciences and Education


Supervisors:

1. Dr. James K. Koske
C/o Environmental Sciences and Education
Kenyatta University
2. Dr. John Muriuki
C/o Environmental Sciences and Education
Kenyatta University

Appendix VI: Research Permit




REPUBLIC OF KENYA



NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **931245**
Date of Issue: **04/May/2023**

RESEARCH LICENSE




This is to Certify that Miss. Faith Jepchirchir Mongo of Kenyatta University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nandi on the topic: Dodder (cuscuta spp.) infestation on tea in Nandi County, Kenya for the period ending : 04/May/2024.

License No: **NACOSTI/P/23/25619**

931245


Applicant Identification Number



 Director General

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code



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See overleaf for conditions