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Research Article

Distribution of *Uromycladium acaciae* disease on *Acacia mearnsii* woodlots; response and farmers' cultural management practices in Fagita Lekoma district, Ethiopia

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ABSTRACT
Acacia mearnsii-based rotational cropping was introduced to Ethiopia's highlands in the past two decades for its charcoal production and soil enhancement benefits. However, since 2020, plantations have been threatened by disease infestation. This study examines the distribution of Uromycladium acaciae on Acacia mearnsii and its management options in Fagita Lekoma, Ethiopia. Using systematic sampling, 28 woodlots were established. Data collection employed transect walks, 140 household interviews, 11 informant interviews, and 3 group discussions. Plantation size was analyzed using analysis of variance, while the relationship between education level and disease management decisions was tested using chi-square with R-software. Results revealed that only 4.5-, 5.5-, and 6.5-year plantations were observed during field assessment. Plantations less than 4-year old were not observed. New plantings in the past three consecutive years were abandoned. Complete (100%) distribution occurred in woodlots aged 4.5 and 5.5 years, however, a slight reduction (90.3%) was observed in 6.5-year woodlots. Seedlings and younger trees were more damaged than mature trees. Tree producers did not implement any cultural control measures and lacked information about the occurrence, identity, and damage caused by diseases. Instead, they converted their younger plantations to other land uses and harvested older ones for fences, firewood, and charcoal. The disease was perceived as severe during the rainy seasons (74.6%). Most respondents (94.3%) were still interested in production and related activities, while 5.7% were strongly discouraged. Commencing plantations with a mix of non-target, fast-growing, and environmentally-friendly trees is ideal. Research on the integrated management of Uromycladium acaciae should be strengthened.

Keywords: *Acacia mearnsii; invasive disease; plantation; Uromycladium acaciae; woodlot.*

Introduction

Tree plantations can improve the income level of communities [1], reported that the monthly income of households was significantly improved after they enrolled in an expanded plantation program in Ghana. Similarly, the farmers' overall livelihood index increased after they started the *Acacia mearnsii* based agroforestry practice in Ethiopia [2]. However, monoculture plantations are increasingly susceptible to several invasive diseases and pests. The establishment of monoculture plantations (particularly exotic trees) requires intensive Integrated Pest Management strategies to minimize species-specific disease and pest susceptibility. Consequently, the plant species diversity index in natural forests is much higher than in exotic monoculture plantations [3], [4]. According to [5], establishing and expanding such monoculture exotic plantations in a landscape should be done cautiously due to the possibility of disease and pest occurrence and reduction in water availability. Some studies have noted the abandonment of exotic monoculture plantations due to disease problems [6].

Acacia mearnsii, commonly known as black wattle (sometimes erroneously referred to as *Acacia decurrens* in Ethiopia), is a widely cultivated tree species in Ethiopia. A recent survey conducted by Pham *et al* [7], in the main wattle-growing regions of Ethiopia identified it as *Acacia mearnsii.* Therefore, the local *Acacia decurrens-based* studies remain valid references for current work on *A. mearnsii.*

Acacia mearnsii is a highly preferred and promising tree species for soil erosion prevention, nitrogen fixation, soil fertility improvement, carbon sequestration, and water purification [8], [9]. In the Awi Zone, Ethiopia, it primarily serves charcoal production and provides associated spillover benefits such as job creation, firewood, fencing, and other by-products for both consumption and sale [9], [10].

The gross income generated from *A. mearnsii* plantations through charcoal production was estimated to be 2,469 USD (104,192 ETB) ha^{-1}, with a non-discounted net benefit of 297 USD (12,570.9 ETB) ha^{-1} $year^{-1}$, surpassing wheat and teff by 90.64% and 157.49%, respectively [10]. Moreover, [11] reported that charcoal production from *A. mearnsii* increased the net benefit by 478% on average compared to cereal crop production.

The initial planting spacings of *A. mearnsii* woodlots varied among farmers, ranging from 1m x 0.75m (16,000 seedlings ha^{-1}) to 0.50m x 0.50m (40,000 seedlings ha^{-1}) [10]. Local people traditionally practice monoculture planting in the study area, which is typically more vulnerable to diseases and insect pests than mixed tree plantation. Nevertheless, the plantation and expansion of *A. mearnsii* have recently started to diminish, mainly due to biological factors such as disease epidemic.

The disease occurrence in the plantations and nursery seedlings of *A. mearnsii* was first noticed by local communities, development agents, and researchers in 2020. Subsequently, the specific pathogen responsible for the disease was identified as *Uromycladium acaciae* by a team of researchers from the Forestry and Agricultural Biotechnology Institute, University of Pretoria, and Ethiopian Forest Development [7]. *U. acaciae* is an emerging and economically significant disease prevalent in *A. mearnsii* plantations in Australia and South Africa, leading to total tree mortality [12].

However, information about this threatening disease is limited in Ethiopia. The distribution of the disease, existing preventive or management options used by local communities, damage extent and seasonal variation have not been well documented. Therefore, the current study was initiated to (i) examine the distribution, extent of damage, and seasonal variation of *U. acaciae* disease occurrence, (ii) assess existing management options practised by local communities against disease occurrence in *A. mearnsii* smallholder plantations in the Fagita Lekoma district, Awi zone Ethiopia to raise awareness among decision-makers for the future implementation of potential management measures.

Materials and Methods

Description of the study area

The study was carried out in the Fagita Lekoma district in the Awi zone, the North-Western highlands of Ethiopia (situated between $10^{0}57'23''$N-$11^{0}11'21''$N latitude and $36^{0}40'01''$E-

37^{0}05'021''E longitude) (Figure 1), at a distance of 101 km from Bahir Dar, the capital city of Amhara National Regional State, in southwest, and 460 km from Addis Ababa, Ethiopia, in North direction. The elevation ranges between 1800 and 2900 meters above sea level (masl) [13], [14]–[15]. The district is bordered in the south by Banja district, in the west by Guangua district, in the north by Dangila district, and in the east by West Gojjam zone [10]. The district has a total area of 653.39 km^2. The study area was selected for this particular study due to an experience of plantation and expansion of *A. mearnsii* and the presence of disease in the district for the first time.

Table 1. The total population and growth rate of Fagita Lekoma district.

Year	Population size	Growth rate (%)
1984	53,552	0
1994	97,446	81.97
2007	126,367	29.68
2017	146,848	16.21

Source CSA (Control Self Assessment) 2017.

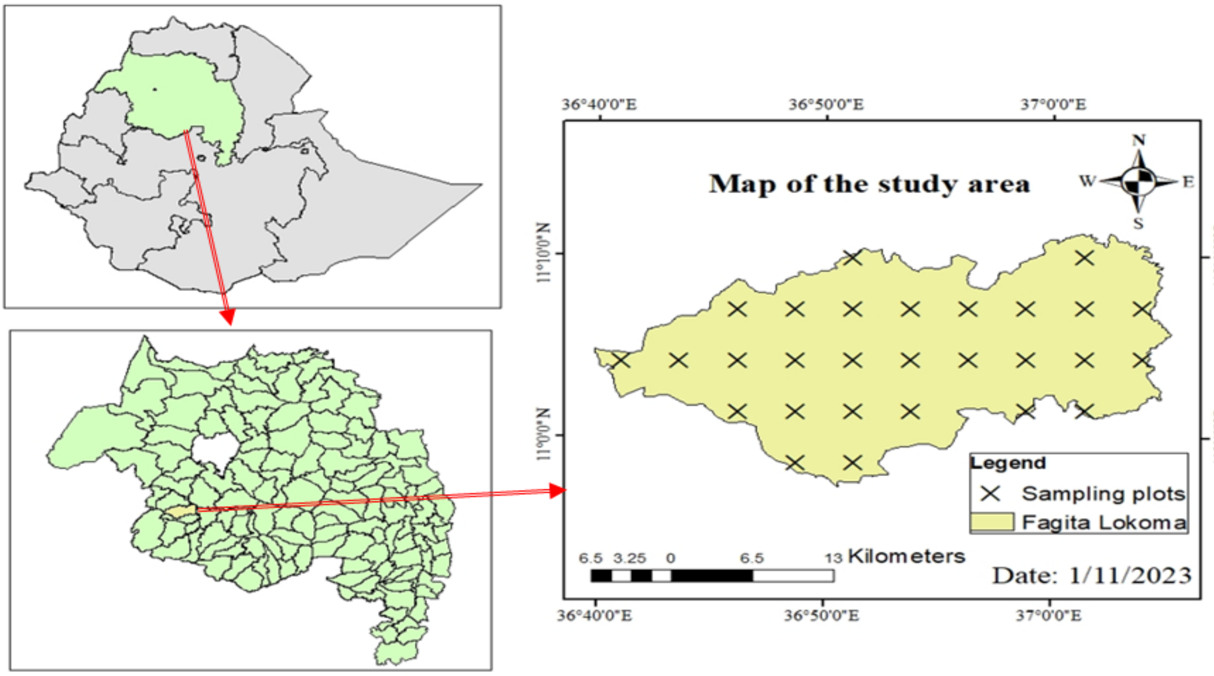

Figure 1. Location of the study area.

Population size

Ethiopia's national census of population and dwellings commenced in 1984 and continued in 1994, 2007, and 2017, estimated that the total population of Fagita Lekoma was 53552, 97446, 126367, and 146848, respectively (Table 1). The population growth rates, starting from the second census, were 81.97%, 29.68%, and 16.21%, expressed in percentage terms. During the recent census, approximately 90% of the total population (146,848) resided in rural areas with a population density of 224.7 per square kilometer [16].

Climate, edaphic, and topographic conditions

Fagita Lekoma district is categorized under the moist subtropical agroecological zone of the North-Western highlands of Ethiopia. Its mean monthly temperature ranges from 5^{0}c to 25^{0}c. It also has an average annual rainfall of 2495 mm, with the main rainy season lasting from June to September [17]. According to the [18] classification system, the major soil types of the district are Nitosols, Luvisols, and vertisols, covering 76%, 18%, and 6% of the study area respectively. These soil types are also characterized by shallow, moderate to very deep in-depth, and clay loam to clay in texture and of moderately acidic pH. The soil has medium to very erodible characteristics [19]. Topographically, the district is rugged and undulated [20].

Vegetation and cropping system

The natural vegetation cover of the district falls under the Afromontane Forest [16]. Woody plants and herbs are the major vegetation types in the study area. *A. mearnsii* and *E.globulus* are the predominant exotic tree species grown in the district for charcoal production [20]. The major land-use cover of the district was *A. mearnsii* woodlots (35.4 %), cropland (32.7 %), grazing land (13.4 %), another forest land (9.5 %), bushland (6.6 %), and settlement (2.4 %) [15].

The district's farming system is characterized by a mixed production system, combining rain-fed cropping with integrated livestock production for sustenance. Key crops cultivated in the district include teff (*Eragrostis tef Zucc*.), barley (*Hordeum vulgare L.),* wheat (*Triticum aestivum L.),* and potato (*Solanum tuberosum L.)* [17]. Additionally, smallholders engaged in teff cultivation in conjunction with *A. mearnsii* plantation as part of the taungya agroforestry system [8]. On the livestock side, the major domestic animals including cattle, sheep, goats, and other pack animals like horses, donkeys, and mules are reared in the district [17]. Farmers provide sustainable food items (meat, milk, and other animal products), cash income by selling them, and huge manure for fertilizer.

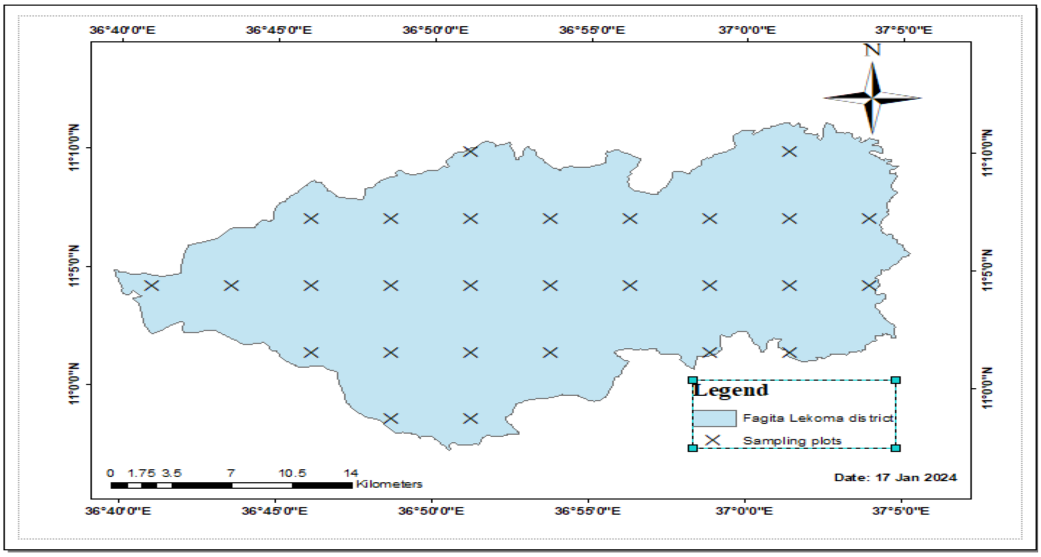

Figure 2. Systematic distribution of sampling plots in Fagita Lekoma district.

Sampling method

Acacia mearnsii woodlots were selected in a systematic random sampling manner [21], using parallel transects for the assessment of *U. acaciae* in the study area. Sampling plots were generated using the ArcGIS software (version 10.8). For evaluating the distribution of *U. acaciae* disease occurrence in *A. mearnsii* smallholder plantations, transect lines were laid out across the entire district. Circular plots, each covering an area of 100m^2, were utilized for data collection [20]. Considering the width of the study area, transect lines were set 5 km apart from each other, with plots placed at 4 km intervals based on [21], with a little modification. This led to the identification of 28 sampling plots for data collection (Figure 2). In cases where generated sample plots indicated different land-use covers, they were relocated to the nearest plantation sites.

Sample households were systematically selected for interviews. The use of systematic random sampling for household selection followed by those previously generated sampling plots was found to be the best option to establish correlations between actual disease occurrences and with perception of respondents as well as to obtain reliable information. Five households, including the owner of the sampled plantation (at the center), were considered for data collection. The remaining four households were selected from neighbouring areas of the systematically generated sampling plot. Consequently, a total of 140 sample households were chosen.

Data collection and source

Distribution of U. acaciae disease

The distribution of *U. acaciae* disease, data was obtained through assessment of symptomatic and asymptomatic individuals from woodlots. In circular plots measuring 100 m2, an average of 95.14 tree individuals (either healthy, recovered, or infected) were identified and counted using a meticulous visual assessment conducted by both the researcher and the smallholder plantation owner [20]. Trees that showed any disease symptom and/or sign were considered as symptomatic or infected individuals.

Perception and response of growers

The existing management or control practices against disease occurrence, variations in damage level related to the ages of trees, and seasonal variations of *U. acaciae* disease epidemic were determined through in-depth interviews. Household interviews (140), key informant interviews (11), focus group discussions (03), and field observations were conducted. Structured (set before data collection) and semi-structured questionnaires were employed for interviews during data collection. All household interviews were conducted on the farmers' *A. mearnsii* plantation sites, which enabled the researcher to crosscheck their answers with field observations. The whole data was collected between March and October 2023.

Method of data analysis Distribution of U. acaciae disease

Descriptive and text analysis methods were used to determine the spread of *U. acaciae* disease accordingly. The total number of healthy (asymptomatic) and infected (symptomatic) trees were identified and counted within each circular plot. Similarly, the number of healthy and infected plots was identified among the whole 28 plots. The number of trees that showed any disease symptoms and signs were counted as infected trees through careful visual assessment of both the researcher and respondents (owners of the smallholder plantation). Disease incidence (DI) and distribution (D) are determined as the presence or absence of disease on trees and plots respectively [22], [23]. As a result, disease incidence was calculated as the ratio of infected trees to the total number of trees observed (eq.1), and it can be expressed in percentage [24], mathematically. Similarly, the distribution was calculated as the ratio between the number of infected plots to the total number of plots observed (eq.2), and can also be expressed in percentage as follows [24].

$$Disease\ incidence\ (DI) = \frac{number\ of\ infected\ trees}{Total\ number\ of\ trees\ observed} \times 100 \quad (1)$$

$$Distribution\ (D) = \frac{number\ of\ assessed\ infected\ plots}{Total\ number\ of\ plots\ assessed} \times 100 \quad (2)$$

Furthermore, the data about possible management and preventive options against *U. acaciae* disease were analyzed by using multiple regression models, descriptive, and the text analysis methods. The farmers' knowledge of the disease, signs, and symptoms were analyzed in text, while their response on possible causes of the disease, measures taken after disease occurrence, and plans were described in frequency and percentage. Variation in *A. mearnsii* plantation size of respondents as well as their level of education and decisions made on control or management measures against disease occurrence were analyzed using analysis of variance (ANOVA) and chi-square tests respectively. All the collected data were carefully interpreted, analyzed, and visualized using R-studio computer programming language version 4.3 with different R-packages accordingly.

Results and Discussion

1. Acacia mearnsii plantation practice in Fagita Lekoma

Ninety-nine percent (99.3%) of sampled respondents had planted *A. mearnsii* tree species in the last five years before disease occurrence, while only a few (0.7%) respondents didn't, implying how much the communities depend on tree plantation-related activities. Moreover, on average they planted *A. mearnsii* woodlot 2.16 times (round of plantation) with a minimum of 1 and a maximum of 5 times [10]. The plantation size of households ranges from 0 to 1.5 ha with a mean plantation area of 0.57 ± 0.24 ha, indicating a significant difference among respondents (p-value: 0.000), which usually was determined by the total land size of households, suggesting the respondents having large total land size have allocated relatively large areas for *A. mearnsii* plantation. Similarly, the size of *A. mearnsii* plantation was positively and significantly increased (P-value: 0.000) with family size at a 95% confidence interval. This implies as the family size increased there was a better chance to perform different tasks related to the species cultivation. [10]. About (33.57 %) of the farmers had their nursery sites and they produced seedlings for their plantation and sold them to local communities, however, the remaining (66.43%) can access seedlings through purchasing.

Furthermore, all the interviews indicated that income diversification (charcoal and fuel wood selling), fuel wood, soil fertility improvement, prevention of flooding and wind damage, fence, construction, as well as amenities were among the motives for *A. mearnsii* plantation and expansion in the study area. This can indicate that the tree species is excellent for socio-economic and environmental purposes, which is expected and strengthens the results of [8], [10].

2. Distribution of U. acaciae on A. mearnsii woodlots

In the study area, only 4.5-, 5.5- and 6.5-year smallholder plantations were observed during the field survey. The sampled respondents stated that they abandoned new plantations for the past three years due to disease infestation and severe damage to their planted trees. All surveyed *A. mearnsii* woodlots in the district exhibited infection with *U. acaciae* disease, with every assessed tree aged 4.5- and 5.5 years within those plots being entirely affected as presented in Table 2. This result suggests a complete (100%) distribution and incidence of *U. acaciae* disease across the entire district, and hence the sustainability of the production system has been tackled by the disease. The distribution of *U. acaciae* in the Fagita Lekoma district is much greater in spread magnitude than [25]. Nevertheless, (9.27 %) of healthy individuals per hectare were observed in plantation woodlots aged 6.5 years (Table 2). This outcome can imply that *U. acaciae* disease might be comparatively more severe in young plantations than in mature individuals, or that older trees demonstrate greater resistance to the disease occurrence compared to their younger counterparts [26], [27].

The responses of all interviews also indicated the distribution of *U. acaciae* across the Fagita Lekoma district. The response of all respondents showed that *U. acaciae* disease was distributed to all areas of their village within a short period. Moreover, key informants also stated that after its occurrence for the first time in the nursery site at Amesha Shenikori kebele in 2018, it was distributed within a year across the entire district. Due to this, it is impossible to find healthy smallholder woodlots as well as healthy individual trees in the district, unless older plantations (>6 years).

Table 2. The distribution of *U. acaciae* on *A. mearnsii* in the Fagita Lekoma district

Species	Age	No. of sample plots		Healthy individuals Ha^{-1}	Infected individuals Ha^{-1}	Total Ha^{-1}	% of infected individuals
		Hlt	Inf				
Acacia mearnsii	4.5	0	15	0	10466.6 ± 1095	10466.6 ± 1095	100
	5.5	0	9	0	8800 ± 1016	8800 ± 1016	100
	6.5	0	4	700 ± 355	6850 ± 1701	7550 ± 1558	90.7

Notes: Hlt: Healthy, Inf: Infected

3. Response of local communities to U. acaciae

All the respondents had observed the signs and symptoms of *U. acaciae* disease on *A. mearnsii* tree species. When asked the name of the disease, all the sampled respondents named it 'Corona'. Similarly, when asked to mention the signs and symptoms of the disease occurrence, all the farmers indicated the presence of dark-spot on leaves and stems, production of exudates that matted leaves, gummosis, presence of lesions on leaflets, defoliation, discolouration, leaf wilting and dieback, stunted growth, and leaf crinkle (Figure 3). There is no difference between the responses of FGDs and KIs from HHs regarding signs and symptoms of *U. acaciae*, while when asked to indicate the name of the disease, they replied as 'fungus' [12]. When asked to mention all possible associated diseases and pests that could affect *A. mearnsii* trees, all the sampled respondents replied that they didn't observe any other disease or pest other than *U. acaciae*.

4. Response of local communities to U. acaciae

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5. Cause and seasonal variation of the disease

Immediately at the time of disease occurrence, the majority (67.1%) of sampled respondents perceived that the cause of *U. acaciae* disease on their plantations was due to divine pleasure, climate change (18.6%), the government planned to devastate their *A. mearnsii* plantation for crop production instead (4.3 %), seed and pot filling problem (2.1 %), lack of fertility (1.4 %) and (6.4) of them were not sure. However, two years later, all of the sampled respondents perceived that the damage to their plantation was due to disease occurrence. This disease has been given the name ‘Corona’, hence the occurrence of *U. acaciae* and the COVID-19 pandemic outbreak was during the same year. Due to this reason, all of the respondents perceived that COVID-19 was transmitted to their *A. mearnsii* plantations and attacked by corona.

When asked about the season that the disease becomes more severe, the majority of farmers (74.6 %) reported it was more severe and common in the rainy season (summer), although 21.3 % perceived the damage was common throughout the year. However, some of the respondents (4.1 %), were not sure about the seasonal variation in the damage level of *U. acaciae*, which is nearly consistent with the report of Angan *et al* [28].

A B

Figure 3. Pictures showing symptoms of *U. acaciae* (A) disease on *A. mearnsii* (B). This arrow is only used to indicate a specific point in the picture.

6. Impacts of the U. acaciae on Acacia mearnsii plantations

The impact of *U. acaciae* on the host tree plantations was initially not significant during the first year of disease occurrence. However, its severity gradually increased after one year, particularly affecting seedlings and young plantations. Within one- or two years post-disease occurrence, the seedlings at nursery sites and new plantations (one- or two-year plantations) completely dried up, leading to the total abandonment of plantation activities (Figure 4).

Seedlings and young plantation woodlots (less than three years old) experienced total mortality. In contrast, leaves and tops of three-year and older tree plantations became dried and heavily damaged, although not fatally. When asked about the damage level of *U. acaciae,* nearly all sampled respondents (98.35 %) who owned seedlings and young plantations during the disease occurrence reported total drying of their seedlings and young plantations. Only a small percentage (1.65 %) stated that their seedlings and new plantations at the time of disease occurrence were heavily affected. Among respondents with three-year plantations, 58.6% reported heavy damage, with total drying (24.1 %), partial death (10.3 %), and dieback (3.4 %). Similarly, respondents having four-year plantations during the disease occurrence reported dieback (50 %), reduced tree growth (46.9 %), and partial death (3.1 %). Furthermore, the response of sampled respondents who owned a five-year plantation woodlot at the time of disease occurrence also indicated that the damage of disease occurrence on their *A. mearnsii* was dieback (70.8 %), and reduced in tree growth (29.2 %) as illustrated in Figure 4. This result is consistent with the report of conducted on the gall-forming wasp on *Eucalyptus* tree species in Uganda, and can clearly show that the damage level of *U. acaciae* disease was different depending on the age of plantations [29]. As the age of plantation woodlots increased, the damage level of *U. acaciae* on *A. mearnsii* became reduced, and vice versa. This could suggest that mature tree species are more resistant to the disease than young tree individuals.

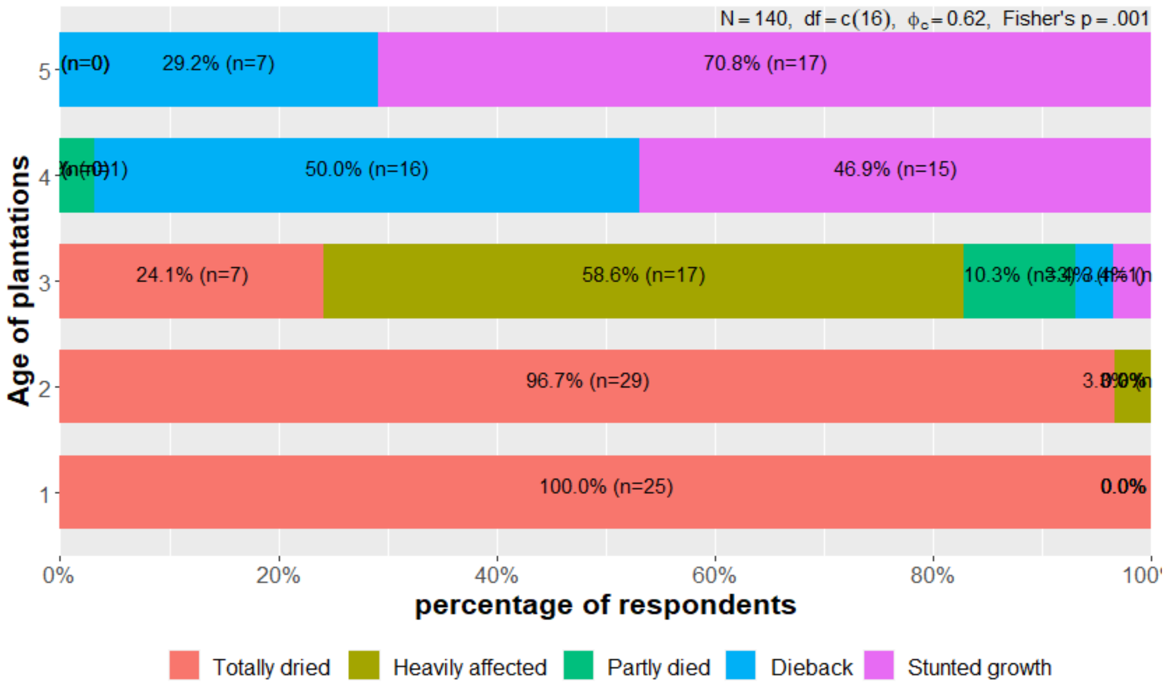

Figure 4. Response of households on the impact of *U. acaciae* disease occurrence on their plantations.

7. Local control measures, actions, and the future of A. mearnsii woodlot

All farmers had not attempted to practice any control measures against *U. acaciae* disease, due to a lack of knowledge on the available control methods and hence they believed that the cause of the disease was because of divine displeasure. Moreover, later they perceived that hence the cause of disease occurrence on their plantation was due to transmission of COVID-19 to their plantation, and one control measure against COVID-19 is lockdown for human beings, while it is impossible to lock down their trees. Therefore, all the sample respondents had not attempted to manage or control *U. acaciae* disease infestation. The educational level of respondents as well as their cultivation experience showed no difference in their decisions to control measures against *U. acaciae* disease on their woodlot plantation.

However, all the sampled respondents replied that depending on the age of their plantation woodlots, they converted their woodlots to other land uses rather than attempting control measures. Accordingly, all seedlings and young plantations (one or two years) were converted into another land-use type, mainly to cropland for the first one or two years, and later to grassland and other forest land. However, among three-year plantation owners, only 3.4 % of the respondents have produced charcoal, 31% of them harvest it to sell for firewood, and 17.2 % converted it to another land-use type, while about 48.3 % of them retained their plantation. Moreover, among four-year plantations, about 56.2 % retained their plantations and the remaining 43.8 %

of them produced charcoal. Furthermore, the five-year-old plantation was mainly harvested for charcoaling (87.5 %) and the remaining (12.5 %) of the farmers left their plantations without any actions taken (Figure 5).

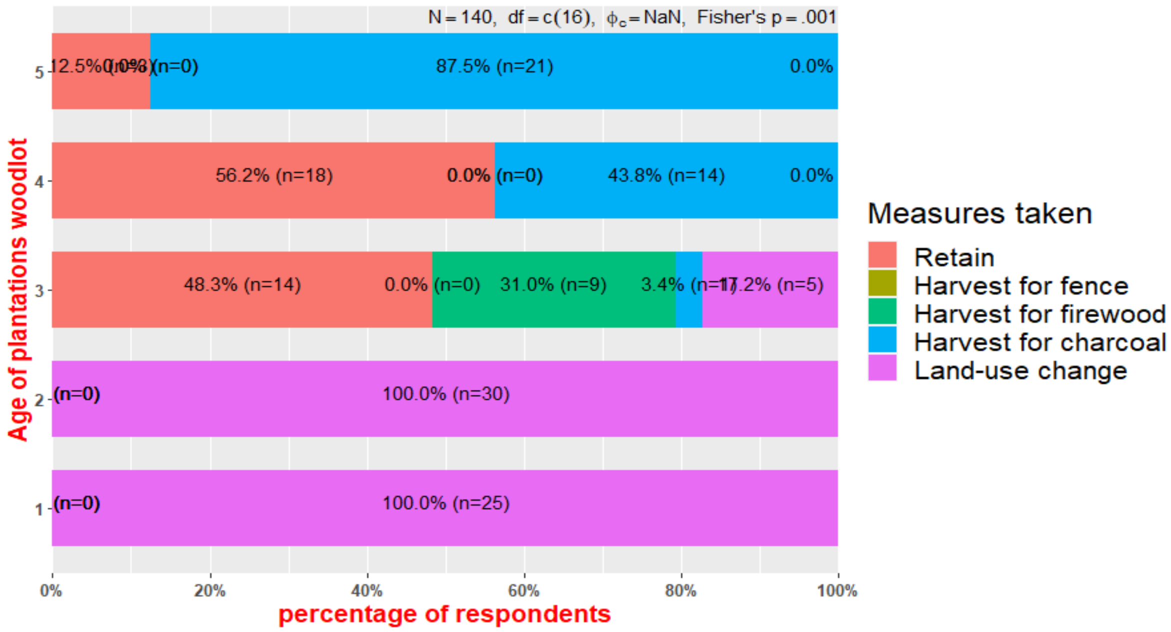

Figure 5. Measures taken for the affected smallholder plantations of *A. mearnsii.* Percentages are based on the number of specific year plantation owners.

When asked to indicate future actions to manage and control *U. acaciae* and ensure sustainable production of *A. mearnsii*, all sampled respondents emphasized that forest therapy or treatment, species substitution, and the aid of experts should be conducted. Additionally, key informants and group discussions highlighted that tree improvement, silvicultural treatment, wider initial plantation spacing, the introduction of and substitution with other equivalent tree species (such as *A. decurrens* and *Grevillea robusta)*) and mixed plantations should be practised. Specifically, they stressed that viable and quality seed should be collected from healthy-looking mother trees. Silvicultural treatments, appropriate initial plantation spacing, mixed planting, and seed collection from the right provenance and progeny can minimize the chances of the target species being affected and increase their resistance to the disease. These findings align with the results of [30 – 33].

When asked about their future plans regarding plantation activities, most respondents (94.3 %) expressed their willingness to return to plantation-related activities if control measures are implemented by the government. However, a few growers (5.7 %) were discouraged by the damage caused by the *U. acaciae* disease, and are not interested in engaging in *A. mearnsii* plantation-related activity in the future.

Conclusions

The results showed the complete distribution of *U. acaciae* across wattle-growing areas of the district and its severe damage, which led to a reduction in tree growth and productivity. This reduction in the production system has caused a potential shortage in charcoal supply, implying future pressure on natural forests to meet the high wood demand. The termination of *A. mearnsii* plantation in the study area has also contributed to the expansion of agricultural land, which subsequently showed a consistent reduction in land productivity after harvesting *A. mearnsii* plantations. This poses a future risk of food insecurity for communities relying on tree plantations. This study urges the strengthening of research on integrated disease management strategies for *U. acaciae* and the conducting of risk assessments and susceptibility trials before introducing and expanding exotic monoculture tree plantings. Planting a mix of fast-growing, non-target, and environmentally friendly tree species (such as *A. decurrens* and *Grevillea robusta)* is advisable to tackle potential challenges following the abandonment of *A. mearnsii* plantings. Raising awareness among tree growers about potential management and control strategies for *U. acaciae* disease can improve their livelihoods.

Conflict of Interest

We declare that there is no conflict of interest.

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