FORESTRY IDEAS
An International Journal
ISSN 1314-3905 (Print)
ISSN 2603-2996 (Online)

ISSUES

Forestry Ideas, 2024, Vol. 30, No. 2

Issues: **1-5** | 6-9

SEASONAL GROWTH AND DEVELOPMENT OF TAXA OF THE GENUS *FORSYTHIA* VAHL IN THE CONDITIONS OF KYIV

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Abstract:

In the Right-Bank Forest-Steppe of Ukraine, 6 species, 2 hybrids, 2 varieties and about 10 cultivars of the genus *Forsythia* Vahl are cultivated. The phoenology of the species of the genus is not sufficiently covered in the literature. The available information is mostly about flowering and fruiting periods of individual species, varieties and cultivars at various points of introduction. Due to the lack of information on the rhythms of growth and development of plants of most taxa of the genus *Forsythia* in the Right-Bank Forest-Steppe of Ukraine, there was a need to conduct such studies. The purpose of the work is to recognize the features in seasonal rhythms of growth and development of *Forsythia* taxa in th Right-Bank Forest-Steppe of Ukraine and to study their con- sistency with the natural and climatic conditions of this region. The studied objects are within the normal limits of 3–4 phoenodata. Only *Forsythia ovata* Nakai, whose phoenophases are shorter than normal, does not fit into this range. 20 % of the research objects are within the normal range for all phoenodata, and 93.33 % are within the normal range for 3–4 phoenodata. *F. giraldiana* Lingelsh., *F. ovata* 'Tetragold', *F. suspensa* (Thunb.) Vahl, *F. suspensa* var. *fortunei*, and *F. suspensa* var. *sieboldii*, growing in the city of Kyiv, are within the norm for the dates of onset of all phoeno- phases and have an unused part of the growing season in reserve. In the majority of forsythias (86.67 %), the phoenological atypicality indicator is less than 1, which indicates the correspond- ence of the seasonal rhythms of growth and development of most of the studied forsythias to the climatic conditions of the Right-Bank Forest-Steppe of Ukraine.

Received: 07 February 2024 / Accepted: 14 July 2024 / Available online: 02 August 2024

(Forestry Ideas, 2024, Vol. 30, No. 2) [Download]

IMPACT OF SILVICULTURAL INTERVENTIONS ON GROWTH AND SURVIVAL OF *FAGUS SYLVATICA* L. SAPLINGS

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Abstract:

This study aims to examine the impact of silvicultural interventions on the height and diameter growth, survival, and canopy structure of naturally regenerated European beech (*Fagus sylvatica* L.) saplings. In a field study, a system of six experimental sites was set up across three areas in the West Stara Planina region, selected according to the various types of cutting regimes within them. At each area, we chose two experimental sites – one of them with silvicultural intervention (Group selection system, Group shelterwood system and Short-term shelterwood system cuttings) and the other one – without silvicultural intervention during the last minimum twenty years (control). Biometric measurements of sapling number, height, and diameter were taken in 2018 and 2022, alongside assessments of the leaf area index (LAI). The results showed that cutting regimes influence beech regeneration growth patterns. Small canopy gaps (0.111 and 0.125 ha) in the Group selection and Short-term shelterwood systems led to similar survival and growth changes, selecting resilient individuals and increasing sapling sizes compared to controls, with no significant change in LAI. In contrast, the Group shelterwood system, with a larger canopy gap (0.555 ha), resulted in similar sapling numbers and sizes to the control but increased LAI over four years without sapling size growth. This indicates that larger gaps may have a less stimulating effect on beech regeneration compared to smaller gaps.

Received: 07 June 2024 / Accepted: 31 August 2024 / Available online: 05 August 2024

(Forestry Ideas, 2024, Vol. 30, No. 2) [Download]

AGE-SIZE STRUCTURE AND GROWTH RATE OF *BARBUS STRUMICAE* (CYPRINIDAE) IN THE MESTA RIVER, SOUTHWEST BULGARIA

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Abstract:

The primary objective of this study was to determine the growth parameters of Thracian barbel in the middle zone of the Mesta River within the Aegean basin in Bulgaria. For this purpose, a total of 106 fish were caught and examined. The sample was collected by electrofishing along the Mesta River. Fish age was determined using scalimetry, while length and mass were calculated using scale length-radius and mass-length

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relationships, respectively. The study identified six age groups, with the majority of the sample comprising two and three-year-old fish. The lengths ranged from 46 mm to 242 mm. Growth analysis was performed by back-calculating the length using the equation $L = 3.0858 \cdot S + 20.759$ ($r2$ = 0.955). Furthermore, a relationship between gutted weight (W) and standard length (L) was established using the equation $W = 0.00001 \cdot L2.9799$ ($r2$ = 0.967).

Received: 24 June 2024 / Accepted: 07 October 2024 / Available online: 17 October 2024

(Forestry Ideas, 2024, Vol. 30, No. 2) [Download]

AGROFORESTRY COFFEE REDUCES HOUSEHOLD VULNERABILITY TO CLIMATE CHANGE

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Abstract:

Global climate change impacts all aspects of human life, including agriculture. Coffee is a major export commodity for Lampung Province. El Niño and La Niña can reduce coffee produc- tion by 80 %. Agroforestry coffee planting pattern is one of the steps to minimize the impact of climate change. This research, conducted from November 2022 to March 2023 in West Lampung Regency, focused on the Way Tenong, Air Hitam, and Batu Brak sub-istricts. A survey method was employed, and a sample of 233 coffee farmers was selected through random sampling. The samples in this research were divided into three groups, namely monocropping coffee systems (MCS), simple agroforestry systems (SAFS), and complex agroforestry systems (CAFS). The level of livelihood vulnerability of farm households was analysed using the Livelihood Vulnerability Index. Overall, farm households on monoculture coffee farms had higher livelihood vulnerability compared to farm households on SAFS and CAFS. Factors significantly affecting the vulnerability of coffee farming households to climate change include farmers' knowledge of climate change, drought, rainfall patterns, pest and disease outbreaks, as well as the adoption of SAFS and CAFS. Implementing agroforestry systems in coffee farming can help reduce this vulnerability.

Received: 18 July 2024 / Accepted: 09 October 2024 / Available online: 17 October 2024

(Forestry Ideas, 2024, Vol. 30, No. 2) [Download]

INDUCIBLE RESISTANCE OF *FALCATARIA FALCATA* (L.) GREUTER & R.RANKIN FOR GALL RUST DISEASE USING PLANT EXTRACTS AS ELICITORS

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Abstract:

Falcataria falcata is valuable species for timber production in Indonesia. Yields from this species, however, are reduced by gall rust caused by *Uromycladium falcatarium*. The aim of this research was to identify whether extracts of *Salix babylonica* and *Clerodendrum paniculatum* could induce systemic resistance of *F. falcata* to gall rust. Experiments were conducted at the nursery of Vocational College, Universitas Gadjah Mada. Three factors were tested, i.e. plant extract (*S. babylonica* or *C. paniculatum*), extract concentration (diluted or undiluted), and time of application (inoculated one day or seven days after elicitor application). Parameters measure were total phenolic compounds and the symptom of gall rust. The total phenolic compounds produced by seedlings treated with *C. paniculatum* extract were significantly lower than other treatments. After 5 months of observation, gall rust symptoms were only found on seedlings treated with *C. paniculatum* extract, i.e. stiff and bent shoot, stiff and slightly bent with a white stripe on branch, stiff and slightly bent leaf stalk, and gall formation.

Received: 07 June 2024 / Accepted: 14 October 2024 / Available online: 18 October 2024

(Forestry Ideas, 2024, Vol. 30, No. 2) [Download]

Source details

Forestry Ideas

Years currently covered by Scopus: from 2016 to 2024

Publisher: University of Forestry

ISSN: 1314-3905

Subject area: Agricultural and Biological Sciences: Forestry; Environmental Science: Nature and Landscape Conservation; Environmental Science: Ecology; Agricultural and Biological Sciences: Ecology, Evolution, Behavior and Systematics

Source type: Journal

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FORESTRY IDEAS, 2024, vol. 30, No 2 (68): 244–260

Agroforestry coffee reduces household vulnerability to climate change

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Abstract

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Key words: agroforestry coffee farmer, coffee production, Indonesia, West Lampung.

Introduction

In Indonesia, climate change is characterised by changes in average daily temperature, rainfall patterns, rising sea levels, seasonal shifts, and climate variability events, such as El Niño and La Niña which cause extreme drought and high-intensity rain. In plantation crops, these changes in rainfall patterns and intensity can lead to decreased productivity, shifts in flowering and harvest seasons, and changes in land suitability (Sarvina et al. 2023).

Indonesia ranks as the fourth-largest coffee producer globally, with an average annual production of 725,680 tons from

2016 to 2020, representing 7.21% of global coffee output. Lampung Province is a key robusta coffee-producing region, contributing 113,739 tons (14.68% of national production) in 2022. Within Lampung, West Lampung Regency is the largest producer, accounting for 55,080 tons or 48.43% of the province's robusta coffee production (Direktorat Jendral Perkebunan 2023).

Coffee is a climate-sensitive plantation crop (Bacon et al. 2017). Climate variability causes dynamics in coffee production (Chengappa and Devika 2016, Pham et al. 2019). Changes in climate variability as a result of climate change have a very significant effect on the growth and development of coffee plants, production, and economic life of coffee farmers. An increase in the intensity of climate anomalies due to climate change events such as El Niño has caused a decrease in coffee production by 34.79 %, as well as during La Niña, the output of coffee production decreased by 98.5 % (Supriadi and Pranowo 2015).

Climate change in West Lampung results in high rainfall variability which causes variations in coffee productivity (Fig. 1). When the weather is good, coffee productivity can reach above 1000 kg·ha^{-1}, but when the climate is unfavourable, productivity drops to 800 kg·ha^{-1}. Resulted in reducing farmers' income. To reduce the impact of climate change, active efforts are needed to anticipate it through mitigation and adaptation strategies. Coffee farming patterns with agroforestry systems, which add trees to the farming system or combine crops and trees, can be a solution to address climate change by adopting mitigation and adaptation measures (Nandakishor et al. 2022) and help farmers earn a sustainable income (Supriadi and Pranowo 2015, Meragiaw 2017).

It is common for agroforestry systems to alter the risk of drought and flood impacts (van Noordwijk et al. 2016). Trees can reduce the consequences of climate change, storing carbon in biomass, and

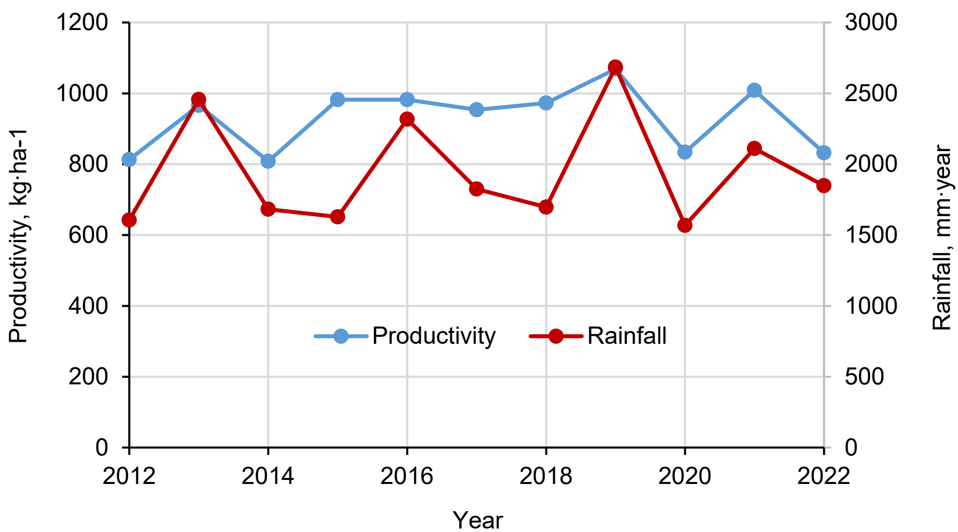

Fig. 1. West Lampung coffee productivity 2012–2022.
Sources: Badan Pusat Statistik (2022), BPS Provinsi Lampung (2023a, 2023b.)

soil and reducing atmospheric carbon dioxide (Hairiah et al. 2020). In addition, agroforestry can reduce land degradation (Mohebalian and Aguilar 2018). Agroforestry systems provide options to mitigate climate change with the possibility of increased crop yield and provide environmental benefits such as climate change adaptation (Coulibaly et al. 2017). Coffee agroforestry systems can mitigate projected climate change impacts by modifying the microclimate without reducing coffee productivity.

Coffee productivity with agroforestry systems tends to be more stable over the years than with coffee systems without shade (Nandakishor et al. 2022). According to Gidey et al. (2020), coffee production with agroforestry systems has a higher level of resilience in the face of climate change. Agroforestry systems can reduce the vulnerability of smallholders and act as a buffer for their livelihoods (Van Noordwijk et al. 2011, Minang et al. 2015).

In West Lampung Regency, not all farmers apply agroforestry systems on their coffee plantations. Prasmatiwi et al. (2010) reported that based on shade plants on coffee plantations, coffee cultivation was categorised into three: 1) monoculture or non-agroforestry coffee farming, 2) coffee farming with one type of intercropping plant or one type of dominant shade plant, and 3) coffee farming with complex or multi-strata agroforestry systems, namely coffee with various intercropping plants.

Coffee or cocoa plantations may be classified into monoculture without shade trees, monoculture with specialised shade trees (especially legume trees), and polyculture with complex shade trees (Somarriba and Lachenaud 2013). Pribadi et al. (2023) classified coffee plantations into monoculture (non-agroforestry), simple agroforestry, and complex agroforestry. More specifically, Mattalia et al. (2022) classified cocoa plantation as monocropping if cocoa is grown under the sun (without shade tree), SAFS if cocoa is grown under 1-3 shade tree species, and CAFS if cocoa is grown under more than 3 shade tree species.

Research analysing farmers' vulnerability due to climate change has appeared before, reported by Dias et al. (2023), Quiroga et al. (2020), and Rahn et al. (2014). However, research examining whether non-agroforestry (monocropping) coffee farmers are more vulnerable to climate change compared to agroforestry coffee farmers has not been conducted. This research aims to assess whether agroforestry systems in coffee plantations can mitigate the vulnerability of farming households to climate change in West Lampung Regency and to identify the factors influencing the level of vulnerability among coffee farmers.

Method

Field research was conducted from November 2022 to March 2023. Researchers employed a survey-based approach, gathering primary data through direct interviews with coffee cultivators. The research respondents were coffee farmers in 3 coffee production center sub-districts in West Lampung, Indonesia, namely Batu Brak, Way Tenong and Air Hitam sub-districts. We selected 8 villages for the research and a visual representation of these sub-districts geographical locations is provided in Figure 2.

This research included 233 coffee farmers, categorised into three groups based on the classification adapted from Mattalia et al. (2022): (1) monocropping

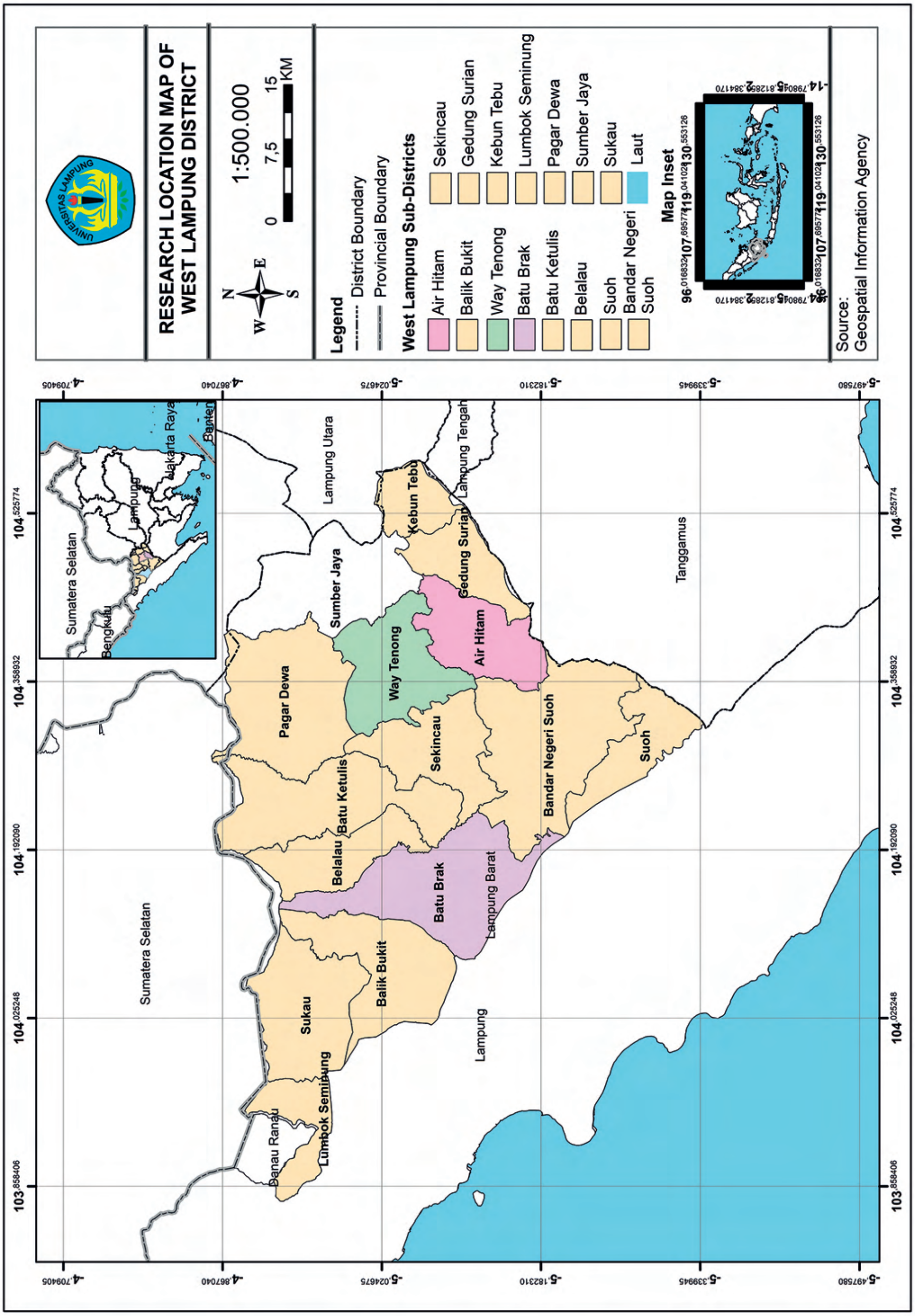

Fig. 2. Map of West Lampung District with the three sub-districts studied.

coffee systems (MCS), (2) simple agroforestry systems (SAFS), and (3) complex agroforestry systems (CAFS). In MCS (non-agroforestry system), coffee trees are grown alone without any shade. In SAFS, they are cultivated with up to three shade tree species. In CAFS, coffee trees are grown with four or more shade tree species. The number of respondents in each category is detailed in Table 1.

Table 1. Respondent categories.

Categories	Number of respondents
Monocropping coffee systems	69
Simple agroforestry systems	91
Complex agroforestry systems	73
Total	233

Researchers examined the susceptibility of coffee growers using the Livelihood Vulnerability Index (LVI), a framework established by Hahn et al. (2009). Vulnerability, as defined by Adger (2006), describes how prone individuals or communities are to disruptions in their way of life caused by social and environmental shifts. *LVI* methodology evaluates several crucial factors, including demographic characteristics, financial resources, educational attainment, consumption patterns, food availability, access to water, exposure to natural calamities, and fluctuations in climate conditions.

LVI analysis, as outlined by the Intergovernmental Panel on Climate Change (*IPCC*) (*LVI-IPCC*), indicates that vulnerability is determined by adaptive capacity, sensitivity, and exposure. This framework allows respondents to openly assess various questions related to these factors. The indicators used for *LVI* measurement are detailed in Table 2.

The data used in the index calculation has different units and weights so it needs to be standardised to equalise the weights using equations (1) to (5) (Hahn et al. 2009).

$$Index_{sd} = \frac{S - S_{min}}{S_{max} - S_{min}}, \quad (1)$$

where: $Index_{sd}$ is a standardised value of each subcomponent, S is the observed value of each subcomponent, S_{min} and S_{max} are the maximum and minimum values for each subcomponent.

After determining the subcomponent's value, the next step is to calculate the value of the main component using equation (2).

$$M_i = \sum_1^n \frac{Index_{sd}}{n}, \quad (2)$$

where: M_i is one of the eight main components, $Index_{sd}$ is the sum of the subcomponents, and n represents the number of subcomponents within each main component.

After calculating the values for each main component, they must be averaged to determine the overall *LVI* level using equation (3) (Manaye 2024).

$$LVI = \frac{\sum_{i=1}^{8} W_{mi} \cdot M_i}{\sum_{i=1}^{8} W_{mi}}, \quad (3)$$

where: *LVI* is vulnerability of each agroforestry system, determined from the weighted average of the eight main components, W_{mi} is the weight of each main component, and M_i is the main component.

LVI employs a scale ranging from 0 to 1, where the lower bound signifies minimal vulnerability and the upper bound represents maximum vulnerability. In calculating the *LVI-IPCC* index, researchers evaluate three main vulnerability factors as outlined by the IPCC: sensitivity, adaptability, and exposure. Although it uses the same indicators as *LVI*, *LVI-IPCC* index integrates them based on their contributing factors before combining the main

Table 2. Indicators for measuring vulnerability of farming households.

Parameter	Main component	Definition	Reference
Exposure	Natural disasters and climate variability	Natural disasters experienced by farmers in the last decade due to climate variability.	Hahn et al. (2009), Ho et al. (2022)
Adaptation	Socio-demographics	Farmer traits refer to the attributes of farmers, such as age and gender, that affect their understanding and reaction to climate change impacts.	Hahn et al. (2009), Shen et al. (2022)
	Education	The attributes of farmers that shape their understanding of and reactions to the consequences of climate change.	Hahn et al. (2009), Shen et al. (2022)
	Income	The various sources of revenue for farmers influence their vulnerability to climate change.	Hahn et al. (2009), Murniati et al. (2017)
	Consumption	Consumption encompasses the sources and factors related to farmer's dietary habits, such as rice consumption and staple food choices, which affect their vulnerability to climate fluctuations.	Hahn et al. (2009), Murniati et al. (2017)
Sensitivity	Agriculture	The characteristics of a farm and elements that affect the resilience of livelihoods to climate change, including farm size, shade-producing crops, and crops other than coffee.	Hahn et al. (2009), Murniati et al. (2017)
	Water	Availability of water for farmers to irrigate their fields amid climate change impacts.	Adu et al. (2018), Ho et al. (2022)
	Food	Food security and the elements influencing farmers' susceptibility to climatic shifts encompass crop diversification and the capacity to preserve crops.	Hahn et al. (2009), Adu et al. (2018)

components. The value for each contributing factor is determined using equation (4).

$$CF_{\mathrm{d}} = \frac{\sum_{i=1}^{n} W_{\mathrm{mi}} \cdot M_{\mathrm{di}}}{\sum_{i=1}^{n} W_{\mathrm{mi}}}, \tag{4}$$

where: CF_{d} represents an *IPCC* defined contributing parameter (adaptive capacity, sensitivity, and exposure) for region 'd', M_{di} denotes the main component for region 'd' indexed by i; W_{mi} is the weight of each main component, n is the number of main components within each contributing parameter.

After quantifying adaptive capacity, sensitivity, and exposure, the three contributing parameters are combined using equation (5).

$$LVI - IPCC = (e_{\mathrm{d}} - a_{\mathrm{d}}) \cdot S_{\mathrm{d}} \tag{5}$$

where: *LVI – IPCC* is for region 'd' based on the IPCC vulnerability framework. In this context, e_{d} denotes the exposure score calculated for region 'd' (including climate variability and natural disaster components), S_{d} denotes the sensitivity score (weighted average of the biophysical environment, agriculture, and water systems), and a_{d} denotes the adaptive capacity score (weighted average of assets and wealth, social networks, socio-demographics, and physical assets) (Asfaw et al. 2017). *LVI – IPCC* framework employs a scale ranging from -1 to +1, with -1 indicating minimal vulnerability (adaptive capacity exceeds sensitivity and exposure), 0 indicating moderate vulnerability (adaptive capacity and exposure are balanced), and +1 indicating high vulnerability (sensitivity and exposure exceed adaptability) (Hahn et al. 2009).

Factors influencing the vulnerability level of coffee farmers to climate change were analysed using binary logistic regression. This analytical approach examines the correlation between a binary or dichotomous dependent variable (*y*) and independent variable (*x*) which can be quantitative, qualitative, or a combination of both (Hosmer and Lemeshow 2000). In this research, the dependent variable (*y*) has two categories: 'not vulnerable' (*y* = 1) and 'vulnerable' (*y* = 0). The criteria for vulnerable and not vulnerable are determined by *LVI-IPCC* scale of -1 – -0.4 is not vulnerable, -0.41 – 0.3 is vulnerable, and 0.31 – 1 is highly vulnerable (Hahn et al. 2009). The independent variables include land area, education, climate change knowledge, age, drought level, rainfall, pest and disease attacks, number of adaptation strategies, simple agroforestry system, and complex agroforestry system. The logistic regression equation is based on the probability function $\pi(x) = E(Y|x)$, where $E(Y|x)$ represents the expected value of *Y* given *x*. The interpretation of this probability function is detailed in equation (6).

$$\pi(x) = \frac{e^{\beta_0+\beta_1 \cdot x_1+\beta_2 \cdot x_2+\ldots\beta_p \cdot x_p}}{1+e^{\beta_0+\beta_1 \cdot x_1+\beta_2 \cdot x_2+\ldots\beta_p \cdot x_p}}. \quad (6)$$

Then a logit transformation is performed to simplify equation (6) in logit form as in equation (7).

$$g(x) = h\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0 + \beta_1 \cdot x_1 + \ddot{u}\,\beta_p \cdot x_p, \quad (7)$$

where: β_0 is the intercept, β_p is the regression coefficient of *p*-th variable estimator, and *x* is the estimator variable.

The logistic regression model with predictor variables is a logit model, where the function is a linear function of the parameters. In assessing the impact of the independent variables on the dependent variable, the Likelihood Ratio (LR) test and Wald test are utilised.

Result and Discussion

Characteristics of respondents

The characteristics of coffee farms of sampled farmers are shown in Table 3. The average land size of MCS is 1.1 ha which is similar to land size of SAFS, while land size of CAFS is 1.51 ha. In this research, farmers of those three categories are the owner of the land. Age of the average coffee plants in the three categories is almost the same, range between 22–23 years. The number of coffee trees per ha of MCS is greater than those of SAFS and CASF. In SAFS and CAFS, beside coffee trees, there are intercrops including pepper (*Piper nigrum* L.) and banana (*Musa paradisiaca* L.), and shade trees including *Gliricidia sepium* (Jacq.) Walph., *Erythrina subumbrans* (Hassk.) Merr.), *Dalbergia latifolia* Roxb.), and *Maesopsis eminii* (Engl.).

Coffee productivity in CAFS was 948 kg·ha^{-1}, surpassing that in SAFS was 859 kg·ha^{-1} and in MCS 817 kg·ha^{-1}. Farmers typically sell their coffee to village intermediaries. The price at which coffee is sold varies based on its quality and the

Table 3. Coffee farming profile.

Description	Monocropping coffee systems			Simple agroforestry systems			Complex agroforestry systems		
	mean	max	min	mean	max	min	mean	max	min
Land area, ha	1.11	4.00	0.25	1.16	4.00	0.50	1.51	7.00	0.40
Number of coffee trees	2552	4000	1250	2472	3000	1000	2390	3100	1000
Age of coffee plant, years	23.90	60.00	5.00	22.42	50.00	3.00	23.73	20.00	4.00
Number of intercrops, trees per ha	-	-	-	236	198	584	349	295	669
Coffee price, IDR·kg^{-1}	24,159	27,000	21,000	24,016	27,000	21,000	24,236	27,000	21,000
Coffee productivity, kg·ha^{-1}	817	1350	300	859	1510	467	948	1690	400

Note: 1 IDR = 60,085,037·10^{12} € and 1 € = 16,645.3 IDR.

selling location. The average selling price of coffee was IDR 24,159–24,236 per kg.

Income from agroforestry coffee farming is derived from two sources: revenue from coffee plants and earnings from intercropped plants. In MCS, farmers earned intercropping income of IDR 435,628 per ha in total. In SAFS, farmers get income from pepper plants climbed on gliriside plants and banana and chili plants. The total revenue of intercropping simple agroforestry systems is IDR 2,528,968. In the CAFS, farmers get additional income from avocado (IDR 267,428), pepper (IDR 1,201,228), banana (IDR 760,928), cloves (IDR 96,285), jengkol (IDR 248,571), petai (IDR 85,714), durian (IDR 232,857), and chili (IDR 113,571). The income of intercropping complex agroforestry systems is IDR 3,296,728 per ha.

The average income of coffee farming in CAFS was the highest compared to other systems at IDR 21,247,112. The findings of this research align with Huhasna et al. (2021), which indicate that the average net income from coffee agroforestry systems is higher compared to that from coffee agroforestry systems with a single plant type (monoculture).

Farmer's knowledge of climate change

Overall, farmers' insights on climate change is mainly linked to the impact of the rainy and dry seasons. The most striking climate change felt by farmer households in the three agroforestry systems is the increase in rainfall. The increase in rainfall that was felt by farmers occurred in April and May, which amounted to 27.27 % and 136.09 % (Badan Pusat Statistik 2022). The increase in rainfall was felt by farmers, considering that this month was the coffee harvest season. Increased rainfall can cause flowers, pistils, and fruit to rot and hamper the harvest process (Evizal et al. 2019). In addition, due to increased rainfall, farmers need more time to spend drying coffee. Farmers need about more than two weeks. As much as 81.16 % farmers of MCS felt the increased rainfall more than the other two agroforestry systems.

The impacts of climate change most commonly experienced by farmers in monocropping coffee systems as well as in simple and complex agroforestry systems include pests and plant diseases. According to Syakir and Surmaini (2017), climate change can exacerbate the prevalence of coffee pests and diseases, such as coffee fruit borer and leaf rust. Additionally, changes in rainfall intensity are among the most noticeable impacts of climate change for farmers. In monocropping systems, 81.16% of farmers reported experiencing more significant effects from changes in rainfall intensity compared to those in agroforestry systems. This is because monocropping systems do not use shade, so increased rainfall directly impacts the coffee plants, potentially reducing flower and fruit production due to decreased photosynthesis from increased cloud cover. In addition, farmers also experienced crop failure as a consequence of climate change. Most MCS coffee farmers (53.62 %) experienced a production decline. In contrast SAFS coffee farmers (36.56 %) and CAFS (26.03 %) experienced a production declining. This crop failure is due to coffee fruit fall and coffee fruit drive disease due to increased rainfall. Harvest failure can also refer to the percentage of farmers who experienced a decreased production.

Exposure index

The purpose of calculating the exposure index is to have a closer sense of the impacts of climate change experienced by farming households. Based on Table 4, MCS coffee farmers have a greater exposure index (0.44) than SAFS and CAFS (0.36 and 0.30). A higher exposure index indicates that coffee SAFS farmers in MCS are more vulnerable to climate change compared to those in SAFS and CAFS. Indicators that influence this are the increased risk of landslides and climate extremes. Climate extremes reported by farmers in the research location refer to increased rainfall and a prolonged rainy season. SAFS and CAFS have a lower exposure index because the shade trees help mitigate the impacts of climate change. Additionally, climate change can increase the risk of landslides. MCS coffee farming is more vulnerable to landslide risk (0.72) than SAFS (0.49) and CAFS (0.30). Agroforestry systems play a very important role in retaining run-off, which significantly reduces the occurrence of floods and landslides.

Another impact of increased climate extremes due to increased rainfall and prolonged rainy seasons is increased pest and plant disease attacks. Increased rainfall can reduce the ambient temperature, making coffee berry borer pests and rust disease spread faster. MCS coffee farmers are more susceptible to pests (0.52) than SAFS and CAFS (0.48 and 0.38). Pests spread more rapidly in coffee farms without shade plants. However, the use of shade plants in coffee farms can help reduce the rate at which pests and diseases spread (Rice 2018).

Sensitivity index

The calculation of the sensitivity index is intended to evaluate how susceptible farm households are to climate change. Results of Table 5 show that in the main component of agriculture, farm households on MCS have a higher sensitivity (0.23) than farm households on CAFS (0.39). This sensitivity is because the average farm household in MCS does not have farms other than coffee. MCS coffee

Table 4. Subcomponent, main component, and exposure index values due to climate change.

Main component	Subcomponent	Subcomponent value			Main component value		
		MCS	SAFS	CAFS	MCS	SAFS	CAFS
Natural disasters and climate variability	Households not aware of climate change information	0.32	0.18	0.14	0.44	0.36	0.30
	Number of drought-affected households	0.28	0.27	0.27			
	Frequency of climate extremes increases	0.46	0.51	0.43			
	Heat and soil drying out early	0.34	0.24	0.25			
	Crop failure	0.41	0.36	0.33			
	Landslide risk	0.72	0.49	0.30			
	Pests and diseases	0.52	0.48	0.38			
Exposure index					0.44	0.36	0.30

Table 5. Subcomponent, main component values, and sensitivity of farm households to climate change.

Main compo-nent	Subcomponent	Subcomponent value			Main component value		
		MCS	SAFS	CAFS	MCS	SAFS	CAFS
Agricul-ture	Land area cultivated	0.10	0.11	0.15	0.23	0.23	0.39
	Percentage of households with income other than agriculture	0.65	0.62	0.66			
	Number of shade plants that produce yields	0.10	0.12	0.12			
	Percentage of households with farms other than coffee	0.12	0.16	0.11			
Food	Percentage of households that grow food crops	0.50	0.52	0.56	0.43	0.42	0.39
	Percentage of households that have savings	0.04	0.05	0.03			
	Share of households that never store their harvest	0.75	0.70	0.59			
Water	Water availability is limited	0.20	0.28	0.06	0.41	0.40	0.26
	Using water wisely	0.49	0.47	0.38			
	Apply irrigation	0.38	0.30	0.23			
	Number of households with artificial water sources	0.38	0.35	0.22			
	Share of households that use water not from natural sources for household needs	62.32	59.34	41.10			
Sensitivity index					0.36	0.35	0.34

farmers depend solely on coffee farming as their main source of income. If both quantity and quality of farm production diminished due to climate change impacts, farm households on MCS are more affected by other agroforestry systems (Minai et al. 2014).

Based on the main component values for the food indicator, MCS coffee farmers exhibit higher sensitivity (0.43) compared to farm households in other agroforestry systems (0.42 and 0.39). This higher sensitivity is due to most MCS coffee farmers not storing their crops or planting food crops, resulting in a lack of food reserves. Consequently, if climate change impacts reduce the quantity and quality of farm production, MCS coffee farmers are more significantly affected in meeting their food needs compared to those in SAFS and CAFS systems. In the water indicator, the sensitivity level of the main component for farm households in MCS is higher (0.41) compared to those in other agroforestry systems, which have sensitivity levels of 0.40 and 0.26, respectively. This sensitivity is because most of MCS coffee farmers do not have a fixed water source such as a well compared to farm households in other agroforestry systems. MCS coffee farmers mostly rely on rain-fed systems, thus vulnerable to droughts and water shortages (Gidey et al. 2020).

Adaptability index

Calculating the adaptive capacity index is essential for understanding how farming households make efforts to cope with climate change. Based on Table 6, CAFS coffee farmers have better adaptability (0.42) compared to MCS (0.37) and SAFS coffee farmers (0.39). The most influential main component for farm households on CAFS in adaptability is income. Households in CAFS farms earn more income than farm households in other agroforestry systems because most of them have income from non-farm sources. Thus, in the event of climate change that affects their farming activities, complex agroforestry systems farming households still have income reserves. According to (Purboningtyas et al. 2018) livelihood diversification is one of the economic adaptations carried out by farmers.

Livelihood vulnerability of farming households using the *LVI* method

The vulnerability status of farm households from climate change can be determined through *LVI* values formulated by Hahn et al. (2009). Table 7 shows that MCS coffee farmers (0.46) experience natural disasters and climate variability more than SAFS (0.38) and CAFS coffee farmers (0.30). Both areas have relatively moderate values because they are not disaster-prone areas. The losses experienced are economic losses caused by climate variability in coffee farming activities. Generally, MCS coffee farmers have higher livelihood vulnerability than in SAFS and CAFS coffee farmers. This result is indicated by *LVI* values of 0.39 for MCS coffee farmers, 0.35 for SAFS, and 0.33 for CAFS. Both regions have relatively moderate livelihood vulnerability relative to the *LVI* scale of 0 to 0.5.

Livelihood vulnerability of farming households using the *LVI-IPCC* method

The calculation of livelihood vulnerability to climate change using the *LVI-IPCC* involves combining the values of the seven main components. A higher *LVI-IPCC* value indicates greater livelihood vulnerabil-

Table 6. Subcomponent, main component values and farmer household adaptation to climate change.

Main component	Subcomponent	Subcomponent value			Main component value		
		MCS	SAFS	CAFS	MCS	SAFS	CAFS
Socio-demographics	Number of female household heads	0.01	0.00	0.01	0.24	0.22	0.25
	The average age of household head	0.47	0.47	0.50			
	Number of unproductive family members	0.25	0.47	0.22			
Income	Total household income	0.14	0.17	0.31	0.40	0.39	0.55
	Number of households with off-farm income	0.65	0.62	0.79			
Education	Household head education < 9 years	0.52	0.59	0.42	0.33	0.39	0.31
	Number of household members with > 9 years of education	0.14	0.18	0.19			
Consumption	Amount of household rice consumption per day	0.18	0.21	0.20	0.50	0.56	0.56
	Whether or not there is a combination of staple food consumption	0.96	1.00	1.00			
	Number of staple food combinations	0.37	0.48	0.49			
Index adaptive					0.37	0.39	0.42

Table 7. *LVI* value, farm household livelihood vulnerability index to climate change.

Main component	Main component value		
	MCS	SAFS	CAFS
Natural disasters and climate variability	0.46	0.38	0.30
Socio-demographics	0.24	0.22	0.25
Income	0.40	0.39	0.55
Education	0.33	0.39	0.31
Consumption	0.50	0.56	0.56
Agriculture	0.24	0.26	0.39
Food	0.43	0.42	0.39
Water	0.41	0.40	0.26
LVI	0.39	0.35	0.33

ity due to climate variability. According to the results in Table 8, farmer households in MCS exhibit higher livelihood vulnerability (0.03) compared to those in SAFS (-0.01) and CAFS (-0.04). The elevated exposure and sensitivity indices (0.44 and 0.36, respectively), coupled with a lower adaptability index (0.37), demonstrate

Table 8. Farm household *LVI-IPCC* value.

LVI-IPCC parameter	MCS	SAFS	CAFS
Exposure	0.44	0.36	0.30
Adaptability	0.37	0.39	0.42
Sensitivity	0.36	0.35	0.34
LVI-IPCC	0.03	-0.01	-0.04

that monoculture coffee systems are more severely impacted by climate change and less capable of adapting to its effects. This limited adaptability in monoculture systems makes farmers more vulnerable in terms of their livelihoods.

Factors affecting the level of vulnerability of coffee farmer households

The analysis results in Table 9, show that farmers' knowledge of climate change has a negative coefficient and is significant at the 1% level. This indicates that the vulnerability index for farmer households with knowledge of climate change is 0.2186 lower than for those without such knowledge. The lack of awareness about climate change means that uninformed farmers are less likely to implement adaptation strategies during disasters. Consequently, farmers who are unaware of climate change are more vulnerable than those who are informed. The level of drought related to climate change has a positive coefficient and is significant at the 5% level. This means that each unit increase in drought severity raises the vulnerability index by 1.2922. The direct impact of drought on farmers is a reduction in crop production, which lowers their income and increases their vulnerability to climate change. Additionally, the lack of awareness among farmers about the importance of building water reservoirs during the dry season hampers their ability to adapt to climate change.

Rainfall related to climate change has a positive coefficient and is significant at the 1% level. This indicates that each unit increase in rainfall raises the vulnerability index by 3.4513. Erratic rainfall significantly impacts household exposure levels, as inconsistent rainfall can reduce crop production. In fact, 53.62 % of farmers in monoculture coffee systems reported a decline in yields due to increased rainfall associated with climate change.

Table 9. Factors affecting the level of vulnerability of coffee farming households.

Variable	Coefficient	Std. Error	z-statistic	Prob.	Odds ratio
Constant	-0.5791	2.0608	-0.2810	0.7787	0.5604
Land area	-0.3217	0.2529	-1.2723	0.2033	0.7249
Education	0.0547	0.0576	0.9508	0.3417	1.0562
Climate change knowledge	-1.5205***	0.4202	-3.6185	0.0003	0.2186
Age	-0.0136	0.0143	-0.9549	0.3396	0.9865
Drought level	0.2564**	0.1289	1.9886	0.0467	1.2922
Rainfall	1.2387***	0.2785	4.4477	0.0000	3.4513
Pest and disease attacks	1.3492***	0.2874	4.6938	0.0000	3.8544
Total adaptation strategy	-0.4486	0.2420	-1.8532	0.0639	0.6386
Simple agroforestry systems	-0.8467**	0.4141	-2.0449	0.0409	0.4288
Complex agroforestry systems	-0.9850**	0.4665	-2.1117	0.0347	0.3734

Note: *** – significant at the α 1%, ** – significant at the α 5%, * – significant at the α 10%; z-statistic is coefficient/std error, Prob. is the probability of error for β_0 or β_1 predicted separately.

Pest and plant disease attacks have a positive coefficient and are significant at the 1% level against climate change. It means that every one time increase in pest and plant disease attacks will increase the vulnerability index by 3.8544. More than 60 % of farmers in the three agroforestry systems experienced increased pest and plant disease attacks due to increased temperature and rainfall. Increased pest infestation and plant diseases make farmers more vulnerable to crop failure.

Simple and complex agroforestry systems have negative coefficients and are significant at the 5% level against climate change. It means that the vulnerability index of households of simple and complex agroforestry systems is 0.4288 and 0.3734 lower than that of monoculture farmer households. Paudel et al. (2022) said that agroforestry practices contribute to climate change mitigation and adaptation while reducing their vulnerability to climate impacts. This statement is consistent with the *LVI-IPCC* values (Table 8), which indicate that complex and simple agroforestry systems are less vulnerable to climate change compared to monocropping coffee systems.

Conclusions

Overall, farm households engaged in monocropping coffee systems exhibit higher livelihood vulnerability (0.03) compared to those in simple (-0.01) and complex agroforestry systems (-0.04). In other words, incorporating agroforestry systems in coffee farming can reduce the vulnerability of farm households to climate change. The use of shade crops plays a significant role in both mitigating and adapting to climate change. Factors that significantly impact the vulnerability of coffee farming households to climate change include farmers' knowledge of climate change, drought levels, rainfall patterns, pest and plant disease infestations, and the use of simple and complex agroforestry systems. Climate change leads to adverse social, economic, and environmental effects.

To reduce the vulnerability of coffee farming households to climate change, it is recommended that farmers implement a coffee agroforestry system by planting shade trees and economically valuable plants, such as spices and fruit trees.

Acknowledgement

The authors gratefully acknowledge the Faculty of Agriculture, University of Lampung for the funds and facilities provided to carry out this research.

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