BIODIVERSITAS
Volume 26, Number 11, November 2025
Pages: 5659-5670

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d261125

Vegetation composition and diversity in the habitats of Kikuyu grass (*Pennisetum clandestinum*) in West Java highlands, Indonesia

SARI SURYANAH[1,♥], IMAN HERNAMAN[2], MANSYUR[2], AGUNG KARUNIAWAN[3], DEDI RUSWANDI[3]
[1]Doctoral Program, Faculty of Animal Husbandry, Universitas Padjadjaran. Jl. Ir. Soekarno KM. 21, Jatinangor, Sumedang 45363, West Java, Indonesia. Tel./fax.: +62-22-7798241, ♥email: sari.suryanah@unpad.ac.id
[2]Department of Animal Nutrition and Feed Technology, Faculty of Animal Husbandry, Universitas Padjadjaran. Jl. Ir. Soekarno KM. 21, Jatinangor, Sumedang 45363, West Java, Indonesia
[3]Department of Agronomy, Faculty of Agriculture, Universitas Padjadjaran. Jl. Ir. Soekarno KM. 21, Jatinangor, Sumedang 45363, West Java, Indonesia

Manuscript received: 24 June 2025. Revision accepted: 3 November 2025.

Abstract. *Suryanah S, Hernaman I, Mansyur, Karuniawan A, Ruswandi D. 2025. Vegetation composition and diversity in the habitats of Kikuyu grass (*Pennisetum clandestinum*) in West Java highlands, Indonesia. Biodiversitas 26: 5659-5670.* *Pennisetum clandestinum* (Kikuyu grass) has the potential to be developed as pasture to feed livestock, yet it has the risk to be invasive, which might threaten native biodiversity. This study aimed to explore the ecology of Kikuyu grass in its habitats in highland areas across West Java, Indonesia. Vegetation analysis was conducted to examine the composition, structure, and diversity of plant communities in several of its habitats, thereby providing data on the vegetation coexisting with Kikuyu grass to infer whether this grass is invasive. A nested sample plot method was used to calculate the Importance Value Index (IVI) of all species and the biodiversity indicators for each plant habitus. The exploration recorded 18 accessions of Kikuyu grass in the highland areas (>1,000 m asl) in the districts of Bandung, West Bandung, Garut, and Subang. A total of 3,474 herbaceous plants (58 species, 19 families), 207 shrubs (20 species, 14 families), and 133 trees (11 species, 8 families) were recorded across the studied sites. The highest IVI for herbaceous species was *Axonopus compressus* (30.44%), shrub species was *Chromolaena odorata* (27.87%), and tree species was *Pinus merkusii* (117.49%). Analysis of biodiversity indices revealed that the research locations exhibited considerable floristic diversity (H′: 1.79-2.90), with a high evenness index (E: 0.71-0.85) and low dominance (D: 0.09-0.22) for all plant habitus. The species richness for herbaceous habitus was classified in the high category (R: 6.99), the moderate category (R: 3.56) for shrub habitus, and the low category (R: 2.04) for tree habitus. The highlands of Bandung District have an ideal ecological condition and vegetation community structure to support the natural growth of Kikuyu grass, characterized by balanced, stable, and species-rich vegetation. The study found that Kikuyu grass did not outcompete local species, indicating minimal ecological risks. These findings help identify suitable habitats for Kikuyu grass cultivation and provide valuable vegetation data for forage development efforts.

Keywords: Biodiversity, exploration, Kikuyu grass, vegetation analysis, West Java

INTRODUCTION

Indonesia is one of the world's mega-biodiversity countries for both flora and fauna. Among monocotyledons (including grasses), the National Research and Innovation Agency (BRIN) reports 7,584 species. Grass, a monocotyledonous angiosperm, occurs throughout Indonesia, with the highest diversity in Java, followed by Kalimantan and Sumatra (Retnowati et al. 2019). This remarkable resource warrants further study for sustainable management and utilization.

Grasses are widely used as forage, and efforts to ensure year-round feed increasingly emphasize local species. One promising species is *Pennisetum clandestinum*, or Kikuyu grass. Native to East and Central African highlands (Ethiopia, Kenya, Uganda, Tanzania, Rwanda, Zaire, and Congo), it thrives in cool, humid environments at 1,950-2,700 m asl (Arango-Gaviria et al. 2019). In Colombia's tropical highlands (2,200-3,000 m asl), it is a major dairy forage due to adaptability and productivity (Escobar-Charry et al. 2020; Enciso et al. 2021). Kikuyu grass produces high biomass, has excellent nutritional value, and is palatable for livestock. However, it is also highly invasive, spreading via long stolon and rhizomes exceeding 2 m, with roots formed at each node that enable dominance and strong competitiveness (Skerman and Riveros 1990; Muscolo et al. 2013; Marín-Santana et al. 2020; Alvarez-García et al. 2024). These traits facilitate rapid establishment and adaptation to highland environments.

Despite this potential, *P. clandestinum* remains little known in Indonesia, and research is limited. Local farmers commonly use it as field grass for feeding livestock, especially during the dry season, without recognizing its nutritional value or genetic potential. To date, there is no dataset reporting Kikuyu grass populations in Indonesia beyond information on its introduction (Holm et al. 1979; Hafliger and Scholz 1980; Bakar et al. 1990; Parker 2008; PIER 2011; Royani et al. 2021). Tracing detailed information on timing, pathways, or agents of introduction is challenging because historical records are scarce or unavailable; most knowledge derives from general references, regional reports, and recent field observations. Nevertheless, collaborative work by PT. Biofarma Persero, BPPT (currently BRIN), and Universitas Padjadjaran identified three accessions from mountainous and highland areas in Greater Bandung, West Java (Mount Burangrang, Tangkuban Perahu, and Bukit Tunggul) and examined their potential as a feed source for horses. Annual dry matter production ranged from 22.65 to 34.22 tons/ha/year, crude fiber from 20.51% to 20.85%, and crude protein from 18.18% to 21.48% (Royani et al. 2021; Mansyur et al. 2024). These values exceed reports from other countries, where dry matter yields range from 16.24 to 21.17 tons/ha/year and crude protein from 15.24% to 20.68% (Tsopgni et al. 2023; Alvarez-García et al. 2024). Kikuyu grass also shows higher nutritional potential than elephant grass (*Pennisetum purpureum*), a popular forage in Indonesia with dry matter yields of 30.84 to 44.56 tons/ha/year but crude protein of only 9.84% to 16.47% (Ernawati et al. 2023). These comparisons indicate the need for further exploration to evaluate Kikuyu grass as a potential superior forage.

A logical first step toward responsible utilization is to study Kikuyu grass ecology in suspected natural highland habitats. Vegetation analysis is central to evaluating forage ecosystems and provides information on species composition, community structure, diversity indices, and environmental factors linked to the adaptability, productivity, and resilience of Kikuyu grass as livestock forage. In naturally formed communities, biodiversity can positively promote multiple ecosystem functions (van der Plas 2019). Analyzing surrounding vegetation clarifies ecological interactions between Kikuyu grass and the broader plant community, helps detect early signs of invasion, such as displacement of local species or declines in floristic diversity, and supports evaluation of conservation value by documenting local species, diversity patterns, and potential disturbances. Fraser et al. (2017) noted that Kikuyu grass has excellent adaptability in marginal lands; its forage quality and quantity make it popular among dairy farmers and pastoralists. Nonetheless, its aggressive growth and invasive nature raise concerns in several regions; in parts of the USA, it has been classified as a dangerous weed because of its capacity to dominate and suppress native vegetation, threatening local plant diversity and the ecological balance of native habitats.

Effective biodiversity management integrates protection (conservation), research (study), and utilization (application) (Setiadi 2005). Biodiversity indicators also help interpret abiotic factors (soil type, altitude, and microclimate) that influence plant community dynamics (Zhang et al. 2021). Accordingly, this study aims to explore the ecology of Kikuyu grass in natural highland habitats of West Java to develop a comprehensive understanding of ecological balance; to evaluate how this species interacts with surrounding vegetation and potentially influences ecosystem composition and biodiversity; and to inform management practices that incorporate biodiversity conservation, ensuring that Kikuyu's potential dominance does not threaten nearby local species. The results can guide sustainable development and utilization of Kikuyu grass as a forage resource and support breeding efforts to improve feed quality and adaptability to diverse environments.

MATERIALS AND METHODS

Study area

The study was carried out in West Java Province, Indonesia, specifically in the highland areas above 1,000 m asl in Bandung District, West Bandung District, Garut District, and Subang District (Figure 1).

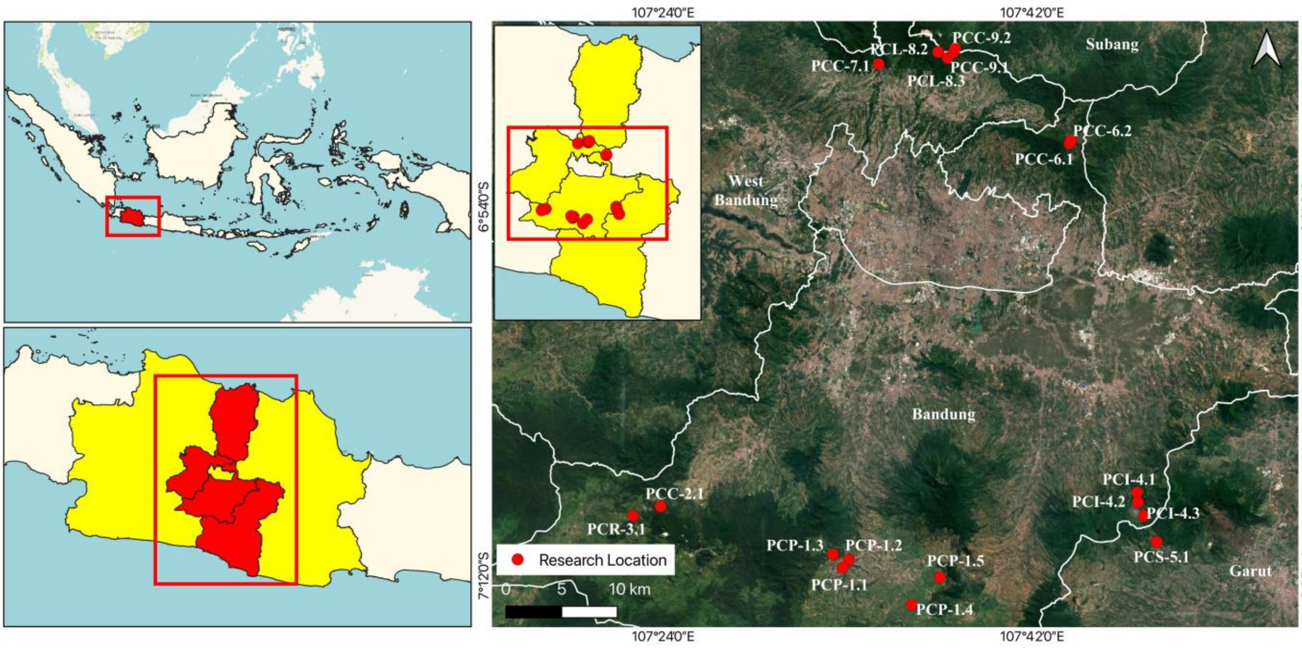

Figure 1. Map of study area in West Java Province, Indonesia showing the surveyed sites

Procedures

At each surveyed site, vegetation analysis was conducted using a square sample plot method with a nested design. Each main plot measured 10 m × 10 m for tree sampling, with smaller subplots of 5 m × 5 m for shrubs and 1 m × 1 m for herbaceous species placed within the larger plot (Malakar and Joshi 2020). The number of sample plots at each surveyed site varied from 2 to 3, depending on the availability of samples in the field. This is due to differences in habitat heterogeneity, accessibility, and study area size. Not all sites contained shrub and tree plants, therefore the total number of samples collected was 44 plots for herbaceous species, 31 plots for shrubs, and 35 plots for trees. All plant species within each plot were recorded and quantified. Species were identified using standard botanical references, including Flora Malesiana (van Steenis and de Wilde 1989), PROSEA (https://prosea.prota4u.org/), Plants of the World Online (https://powo.science.kew.org/), USDA Plants Database (https://plants.usda.gov/), and other regionally relevant floras and field guides. Unidentified species in the field were collected for herbarium preparation and later identified in the laboratory. All collected samples are dried, labeled, and stored for documentation and verification purposes. Soil pH was measured in situ using a soil analyzer tester, and the spatial coordinates (latitude, longitude, and altitude) of each site were recorded using a Global Positioning System (GPS) device.

Data analysis

Quantitative analysis was conducted to explain the composition, structure, and diversity of plant vegetation using Microsoft Excel 2021 with formulas and functions built into the software. The data obtained were analyzed by calculating the Importance Value Index (IVI) of each species recorded. The IVI for each tree species was calculated as the sum of Relative Density (RD), Relative Frequency (RF), and Relative Dominance (RDm) for a maximum value of 300, while for herbaceous plants (including grasses), shrubs, and vines, it was calculated by summing the RD and RF only, so that the maximum possible value is 200. The basal area was not calculated for the shrub and herbaceous layers due to the difficulty in measuring the exact diameter of small individuals (Curtis and McIntosh 1950; Mueller-Dombois and Ellenberg 1974; Malakar and Joshi 2020). The formulas are listed below:

$$\text{Density (AD)} = \frac{\text{Number of Individuals of a Species}}{\text{Total Area of the Sample Plot}}$$

$$\text{Relative Density (RD)} = \frac{\text{Absolute Density of a Species}}{\text{Sum of Absolute Densities of All Species}} \ x\ 100\%$$

$$\text{Frequency (AF)} = \frac{\text{Number of Plots Found a Species}}{\text{Total Number of Sample Plots}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Absolute Frequency of a Species}}{\text{Sum of Absolute Frequencies of All Species}} \ x\ 100\%$$

$$\text{Dominance (ADm)} = \frac{\text{Sum of Basal Area of Species}}{\text{Total Area of the Sample Plot}}$$

$$\text{Relative Dominance (RDm)} = \frac{\text{Absolute Dominance of a Species}}{\text{Sum of Absolute Dominance of All Species}} \ x\ 100\%$$

$$\text{IVI} = \text{RD}\ (\%) + \text{RF}\ (\%) + \text{RDm}\ (\%)$$

Several biodiversity indices were calculated following standard references (Odum 1971; Magurran 1988; Lilisti et al. 2021; Haryadi et al. 2024). Community structure was quantified using four metrics. Species diversity was measured with the Shannon-Wiener index (H′):

$$H' = -\sum Pi \ln Pi, \text{ where } Pi = ni/N$$

Where, ni: the number of individuals of species-i and N: the total number of individuals. Diversity was interpreted as low ($H'<1$), moderate ($1<H'<3$), and high ($H'>3$). Species evenness was assessed using the Pielou index:

$$E = H'/ H'max$$

Where, H′max: ln S, S: Number of species found. Evenness was categorized as low ($E<0.3$), moderate ($0.3<E<0.6$), and high ($E>0.6$). Species dominance was quantified with the Simpson index:

$$D = \sum pi2$$

Dominance was interpreted as low ($0<D<0.5$), moderate ($0.5<D<0.75$), and high ($0.75<D<1.0$). Species richness was estimated using the Margalef index:

$$R = (S-1)/\ln N$$

Where, richness was classified as low ($R<2.5$), moderate ($2.5<R<4.0$), and high ($R>4.0$).

RESULTS AND DISCUSSION

Environmental conditions

West Java Province features a complex geological landscape with steep mountainous areas in the south (over 1,500 m asl), gentle hillside areas in the middle (100-1,500 m asl), wide plain areas in the north (0-10 m asl), and river basin areas. The total land area is 37,040.04 km^2 and approximately 22.10% of its land is forested for conservation, protection, and production. The province receives high rainfall intensity, with annual rainfall ranges from 2,000 to 4,000 mm (BPS-Statistics of West Java Province 2025).

The field survey found 18 accessions of Kikuyu grass in the highland areas in Bandung District (Pangalengan Sub-district, Ciwidey Sub-district, Rancabali Sub-district, Ibun Sub-district, and Cilengkrang Sub-district), West Bandung District (Cisarua Sub-district and Lembang Sub-district), Garut District (Samarang Sub-district), and Subang District (Ciater Sub-district), at altitudes ranging from 1,383 to 1,778 m asl (Table 1). These accessions were mainly found along the roadsides in the Greater Bandung area, including pine forests, eucalyptus forests, and spruce forests. Several of these locations are pine forest areas that are also used as tourist areas. The discovery sites also include agricultural areas such as vegetable gardens, tea plantations, and coffee intercropped under pine tree stands.

The results showed that the observed Kikuyu grass accessions grew well in shaded and unshaded conditions (Figure 2), coexisting with surrounding herbaceous, shrub, and tree species. The growing sites were characterized by fertile soil with a pH level ranging from 5.7 to 7.0 and are located in areas with cool temperature suitable for the natural habitat of this grass. This aligns with Noreña-Grisales et al. (2024) observations that the recommended soil pH for optimal growth of many grasses fluctuates between 5.0 and 7.2, and the optimal pH for Kikuyu grass growth is between 5.4 and 6.4. These findings indicate that the observed environmental conditions are favorable for the establishment and sustained growth of Kikuyu grass in its natural habitats.

Fertilization and fertile soil greatly promote the growth of Kikuyu grass. Nevertheless, it exhibits an extraordinary ability to adapt to various ecological conditions, including marginal land, due to its resilience to abiotic stresses such as salinity, acidic soils, and drought (Muscolo et al. 2013; van der Colf et al. 2015; Fraser et al. 2017; Acero-Camelo et al. 2020). The growing locations were in mountainous and highland areas with fertile conditions similar to its native habitat. The fertility of these regions is supported by geological activity, including volcanic ash deposits (Wibowo et al. 2019; Minasny et al. 2021), climatic conditions with high rainfall and low temperatures that increase the accumulation of litter and humus (Ping et al. 2013), and diverse vegetation that encourages nutrient cycling and organic matter accumulation (Liu et al. 2024). These conditions greatly support the growth of this grass in West Java, even not being cultivated.

Vegetation analysis

In the surveyed sites where Kikuyu grass was found, 58 herbaceous species belonging to 19 families, 20 shrub species belonging to 14 families, and 11 tree species belonging to 8 families were identified. The highest Relative Density (RD) for herbaceous plants was *Axonopus compressus* (23.58%), followed by *Oplismenus compositus* (13.18%), *Centella asiatica* (6.91%), *Drymaria cordata* (6.88%), and *Calyptocarpus vialis* (4.98%). This finding indicates that these herbaceous species are abundant in the study areas. Herbaceous species with the highest Relative Frequency (RF) was *C. asiatica* (7.46%), followed by *A. compressus* (6.87%), *O. compositus* (5.37%), *Ageratum conyzoides* (5.07%), and *Ageratina riparia* (4.48%). This result indicates that these herbaceous species were present in most of the study area plots and evenly distributed across the observation areas.

Figure 2. Kikuyu grass grown in shaded conditions (A: PCI-4.2 accession) and grown in unshaded conditions (B: PCC-9.2 accession)

Table 1. Location and altitude of sampling plot areas of the habitats of *Penisetum clandestinum* in West Java highlands, Indonesia

Code	Coordinate	Altitude (m asl)	Soil pH	Description
PCP-1.1	7°11'36.7"S 107°32'45.3"E	1,421	6.5	Shaded, the Situ Cileunca tourist area
PCP-1.2	7°11'12.9"S 107°33'03.9"E	1,436	7.0	Unshaded, on the roadside at the vegetable garden area
PCP-1.3	7°10'57.7"S 107°32'17.1"E	1,446	6.5	Shaded, on the roadside at the coffee plantation area
PCP-1.4	7°13'25.1"S 107°36'07.8"E	1,530	6.0	Shaded, on the roadside at the Situ Gede area
PCP-1.5	7°12'04.9"S 107°37'29.8"E	1,684	6.5	Shaded, the Wayang Windu Pine Forest Park tourist area
PCC-2.1	7°08'37.0"S 107°23'52.5"E	1,778	6.5	Shaded, the Kawah Putih Ciwidey tourist area
PCR-3.1	7°09'04.2"S 107°22'31.5"E	1,705	6.5	Shaded, on the roadside at the tea plantation area
PCI-4.1	7°07'55.9"S 107°47'07.2"E	1,509	5.7	Shaded, on the roadside at the pine and coffee forest area
PCI-4.2	7°08'24.7"S 107°47'09.9"E	1,502	6.1	Shaded, at the Kamojang Geothermal Power Plant (PLTP) area
PCI-4.3	7°09'04.1"S 107°47'27.7"E	1,485	6.5	Shaded, on the roadside at the residential area
PCS-5.1	7°10'20.7"S 107°48'04.3"E	1,383	7.0	Shaded, on the roadside at the Mata Air Cimanuk Arboretum area
PCC-6.1	6°50'53.8"S 107°43'49.7"E	1,536	6.2	Shaded, on the roadside at the eucalyptus forest area
PCC-6.2	6°50'46.1"S 107°43'54.2"E	1,521	6.5	Unshaded, on an open field
PCC-7.1	6°47'01.8"S 107°34'30.8"E	1,481	6.7	Shaded, on the eucalyptus forest area
PCL-8.2	6°46'26.6"S 107°37'25.5"E	1,679	6.5	Unshaded, on the parking lot
PCL-8.3	6°46'44.0"S 107°37'52.7"E	1,554	6.0	Shaded, on the roadside in the pine forest area
PCC-9.1	6°46'27.7"S 107°38'09.8"E	1,517	7.0	Unshaded, the Mount Tangkuban Perahu tourist area
PCC-9.2	6°46'15.9"S 107°38'14.9"E	1,480	6.5	Unshaded, on the roadside at the tea plantation area

Note: PCP-1: Pangalengan Sub-district, Bandung District; PCC-2: Ciwidey Sub-district, Bandung District; PCR-3: Rancabali Sub-district, Bandung District; PCI-4: Ibun Sub-district, Bandung District; PCS-5: Samarang Sub-district, Garut District; PCC-6: Cilengkrang Sub-district, Bandung District; PCC-7: Cisarua Sub-district, West Bandung District; PCL-8: Lembang Sub-district, West Bandung District; PCC-9: Ciater Sub-district, Subang District

The values of RD and RF affect the Importance Value Index (IVI). In general, the IVI measures how dominant a species is in an area and helps to understand its ecological significance in community structure (Ismail et al. 2017; Oktavia et al. 2021). Species with the highest IVI was *A. compressus* (30.44%), followed by *O. compositus* (18.56%), *C. asiatica* (14.37%), *D. cordata* (9.57%), and *C. vialis* (8.56%) (Table 2).

Axonopus compressus is the most abundant non-native grass species from the Poaceae family and was found in almost every area where Kikuyu grass grew, even its IVI exceeds the IVI of *P. clandestinum* (21.68%). This is because *A. compressus* grass, also known as carpet grass, is a strong grass that spreads rapidly through stolon, resistant to biotic and abiotic stresses, and can grow in low fertile soil (He et al. 2021). As a result, this grass can grow naturally and adapt easily to various environments, making it frequently establishes itself as a dominant species in grassland ecosystems. The resilience of this grass to environmental stress and its ability to quickly cover land contributes to ecosystem stability by preventing erosion, maintaining moisture, and ensuring the availability of forage. It can coexist with Kikuyu grass which has higher nutritional value and productivity. The combination of the two creates a balanced forage community, where *A. compressus* maintains ecosystem resilience, while Kikuyu grass improves feed quality, thus together supporting forage sustainability in terms of both quantity and quality. Adams et al. (2022) reported that *A. compressus* and *P. clandestinum* are two of several exotic grass species commonly used to establish grasslands in the tropical Andes, particularly in Ecuador, as a substitute for local grasses that are not available in the pristine forests. Another Poaceae species, *O. compositus*, was also widely distributed in the surveyed areas. This species is native to Indonesia, commonly occurring in shaded and forested environments. The study by Fikadu (2023) showed that *O. compositus* is one of the most commonly found herbaceous species in the open forest area of East Oromia, Ethiopia, and has a higher IVI under tree stands.

Various wild plants commonly used by local communities were also found in the study area, including *C. asiatica*, known locally as *pegagan*. This species is native to Indonesia and commonly occurs in wet areas such as riverbanks and rice fields. The Sundanese people in West Java often use *pegagan* as a vegetable that is consumed raw (fresh), called as *lalapan* or traditional salad, because it provides health benefits (Amrinanto et al. 2019; Milanda et al. 2022). This tropical plant is also widely recognized as a traditional herbal medicine for treating various diseases and can be used as a skin conditioning agent in cosmetic products (Husaini et al. 2022; Johnson et al. 2023; Min et al. 2024).

Based on the data in Table 3, the highest RD value of shrub species was recorded for *Coffea arabica* (14.49%), followed by *Dracaena fragrans* (12.08%), *Musa paradisiaca* (11.59%), *Sida rhombifolia* (11.11%), *Manihot esculenta* (11.11%), and *Chromolaena odorata* (10.63%). The large number of these species is due to the characteristics of the study areas, which included forestry, plantation, and agricultural land. The highest RF value was recorded for *C. odorata* (17.24%), followed by *C. arabica* (12.07%), *S. rhombifolia* (12.07%), *M. paradisiaca* (10.34%), and *D. fragrans* (6.90%). This indicates that these species were evenly distributed in the study areas. Although *C. odorata* ranks sixth in RD value, its FR value is the highest because this plant species is almost always present in every observation plot. The highest IVI was recorded for *C. odorata* (27.87%), followed by *C. arabica* (26.56%), *S. rhombifolia* (23.18%), *M. paradisiaca* (21.94%), and *D. fragrans* (18.97%).

Chromolaena odorata, commonly known locally in West Java as *kirinyuh*, is a perennial shrub from the Asteraceae family, most often found in the study areas. The local communities believe this plant has many benefits as a traditional medicine that can heal wounds and various diseases (Olawale et al. 2022). This shrub species is an invasive weed native to tropical and subtropical America. It spread rapidly to countries in Africa, East and South Asia, and Australia, becoming one of the dominant agricultural weed species (Yu et al. 2016). This plant can grow under various ecological conditions, soil types, and climates due to its high growth and reproduction rate, efficient nutrient assimilation, ability to suppress other vegetation through light competition, and allelopathic properties (Uyi et al. 2014). However, the presence of *C. odorata* does not interfere the main crops, which are forestry and plantation crops, and the presence of Kikuyu grass acts as a counterbalance in the ecosystem. Kikuyu grass has allelopathic potential that can affect the growth of other plants. According to Chou and Wang (2023), allelopathy is a biochemical interaction between plants that releases toxic compounds (phytotoxins) into the environment, negatively impacting other plants in the surrounding area. However, allelopathy also plays a crucial role in both natural and cultivated ecosystems, particularly in increasing sustainable agricultural productivity. For example, in a pasture-forest intercropping system, Kikuyu grass effectively suppresses weeds without inhibiting the regeneration of Chinese fir trees, therefore it can be a win-win strategy for integrated ecosystem management.

The shrub plant with the second-highest IVI is *C. arabica*, a commonly cultivated coffee plant. This is because the study area mainly covered plantation areas, including coffee and tea plantations. Coffee is one of the plantation commodities that has long been cultivated in Indonesia, has high economic value, and is a source of foreign exchange for the country. One widely cultivated coffee type is Arabica coffee, which has a distinctive taste and special market value (Siahaan 2018; Shara et al. 2021). In Ethiopia, the country of origin of the coffee plant, coffee grows at various altitudes ranging from 550 to 2,750 m asl. Most Arabica coffee grows best between 1,300 and 1,800 m asl (Tadesse et al. 2020; Melese and Kolech 2021). This aligns with the study areas, which are located in a highland region.

Table 2. The Importance Value Index (IVI) of herbaceous species in the habitats of *Pennisetum clandestinum* in West Java highlands, Indonesia

Species name	Family	N (ind.)	Abundance category	RD (%)	RF (%)	IVI
Axonopus compressus	Poaceae	819	Abundant	23.58	6.87	30.44
*Pennisetum clandestinum**	Poaceae	297	Common	8.55	13.13	21.68
Oplismenus compositus	Poaceae	458	Common	13.18	5.37	18.56
Centella asiatica	Apiaceae	240	Common	6.91	7.46	14.37
Drymaria cordata	Caryophyllaceae	239	Common	6.88	2.69	9.57
Calyptocarpus vialis	Asteraceae	173	Frequent	4.98	3.58	8.56
Ageratina riparia	Asteraceae	124	Frequent	3.57	4.48	8.05
Ageratum conyzoides	Asteraceae	49	Uncommon	1.41	5.07	6.49
Murdannia nudiflora	Commelinaceae	85	Frequent	2.45	3.28	5.73
Alternanthera philoxeroides	Amaranthaceae	120	Frequent	3.45	2.09	5.54
Plantago major	Plantaginaceae	37	Uncommon	1.07	4.18	5.24
Arachis pintoi	Fabaceae	132	Frequent	3.80	0.90	4.70
Eleusine indica	Poaceae	31	Uncommon	0.89	3.28	4.18
Commelina diffusa	Commelinaceae	40	Uncommon	1.15	2.69	3.84
Cynodon dactylon	Poaceae	45	Uncommon	1.30	2.39	3.68
Bidens pilosa	Asteraceae	26	Uncommon	0.75	2.69	3.43
Pseudelephantopus spicatus	Asteraceae	40	Uncommon	1.15	2.09	3.24
Clinopodium gracile	Lamiaceae	62	Frequent	1.78	1.19	2.98
Paspalum conjugatum	Poaceae	58	Frequent	1.67	1.19	2.86
Richardia scabra	Rubiaceae	40	Uncommon	1.15	1.19	2.35
Cyperus rotundus	Cyperaceae	16	Uncommon	0.46	1.79	2.25
Paspalum dilatatum	Poaceae	16	Uncommon	0.46	1.79	2.25
Elephantopus mollis	Asteraceae	12	Uncommon	0.35	1.79	2.14
Artemisia vulgaris	Asteraceae	38	Uncommon	1.09	0.90	1.99
Oxalis latifolia	Oxalidaceae	17	Uncommon	0.49	1.49	1.98
Erigeron sumatrensis	Asteraceae	29	Uncommon	0.83	0.90	1.73
Galinsoga quadriradiata	Asteraceae	16	Uncommon	0.46	1.19	1.65
Salvia occidentalis	Lamiaceae	25	Uncommon	0.72	0.60	1.32
Brachiaria decumbens	Poaceae	13	Uncommon	0.37	0.90	1.27
Polygala paniculata	Polygalaceae	23	Uncommon	0.66	0.60	1.26
Panicum maximum	Poaceae	11	Uncommon	0.32	0.90	1.21
Setaria palmifolia	Poaceae	9	Rare	0.26	0.90	1.15
Cyperus kyllingia	Cyperaceae	15	Uncommon	0.43	0.60	1.03
Lycopodiella cernua	Lycopodiaceae	11	Uncommon	0.32	0.60	0.91
Thelypteris dentata	Thelypteridaceae	9	Rare	0.26	0.60	0.86
Imperata cylindrica	Poaceae	8	Rare	0.23	0.60	0.83
Rumex obtusifolius	Polygonaceae	7	Rare	0.20	0.60	0.80
Acmella caulirhiza	Asteraceae	6	Rare	0.17	0.60	0.77
Macrothelypteris torresiana	Thelypteridaceae	5	Rare	0.14	0.60	0.74
Spermacoce remota	Rubiaceae	4	Rare	0.12	0.60	0.71
Synedrella nodiflora	Asteraceae	2	Rare	0.06	0.60	0.65
Persicaria nepalensis	Polygonaceae	12	Uncommon	0.35	0.30	0.64
Stenotaphrum secundatum	Poaceae	12	Uncommon	0.35	0.30	0.64
Alternanthera sessilis	Amaranthaceae	9	Rare	0.26	0.30	0.56
Galinsoga parviflora	Asteraceae	8	Rare	0.23	0.30	0.53
Amaranthus tricolor	Amaranthaceae	7	Rare	0.20	0.30	0.50
Viola odorata	Violaceae	2	Rare	0.06	0.30	0.36
Emilia sonchifolia	Asteraceae	2	Rare	0.06	0.30	0.36
Impatiens platypetala	Balsaminaceae	2	Rare	0.06	0.30	0.36
Chloris gayana	Poaceae	2	Rare	0.06	0.30	0.36
Mitracarpus hirtus	Rubiaceae	2	Rare	0.06	0.30	0.36
Athyrium distentifolium	Athyriaceae	2	Rare	0.06	0.30	0.36
Thymus vulgaris	Lamiaceae	2	Rare	0.06	0.30	0.36
Arenaria serpyllifolia	Caryophyllaceae	1	Rare	0.03	0.30	0.33
Sonchus oleraceus	Asteraceae	1	Rare	0.03	0.30	0.33
Amaranthus blitum	Amaranthaceae	1	Rare	0.03	0.30	0.33
Richardia brasiliensis	Rubiaceae	1	Rare	0.03	0.30	0.33
Vigna luteola	Fabaceae	1	Rare	0.03	0.30	0.33
Total		3,474		100	100	200

Note: The abundance class used a fixed threshold-based approach because the data distribution is very wide and extreme (Abundant >500, Common 200-500, Frequent 50-199, Uncommon 11-49, and Rare 1-10). **Pennisetum clandestinum* grass is still included in the calculation because each plot taken contained this grass. IVI: Importance Value Index, RD: Relative Density, RF: Relative Frequency

Table 3. The Importance Value Index (IVI) of shrub species in the habitats of *Pennisetum clandestinum* in West Java highlands, Indonesia

Species name	Family	N (ind.)	Abundance category	RD (%)	RF (%)	IVI
Chromolaena odorata	Asteraceae	22	Common	10.63	17.24	27.87
Coffea arabica	Rubiaceae	30	Abundant	14.49	12.07	26.56
Sida rhombifolia	Malvaceae	23	Common	11.11	12.07	23.18
Musa paradisiaca	Musaceae	24	Common	11.59	10.34	21.94
Dracaena fragrans	Asparagaceae	25	Abundant	12.08	6.90	18.97
Manihot esculenta	Euphorbiaceae	23	Common	11.11	3.45	14.56
Camellia sinensis	Theaceae	13	Frequent	6.28	5.17	11.45
Duranta erecta	Verbenaceae	9	Uncommon	4.35	3.45	7.80
Solanum mauritianum	Solanaceae	6	Rare	2.90	3.45	6.35
Colocasia esculenta	Araceae	4	Rare	1.93	3.45	5.38
Yucca gigantea	Asparagaceae	7	Uncommon	3.38	1.72	5.11
Clidemia hirta	Melastomataceae	3	Rare	1.45	3.45	4.90
Dahlia pinnata	Asteraceae	6	Rare	2.90	1.72	4.62
Solanum pseudocapsicum	Solanaceae	2	Rare	0.97	3.45	4.41
Leucaena leucocephala	Fabaceae	2	Rare	0.97	3.45	4.41
Solanum betaceum	Solanaceae	3	Rare	1.45	1.72	3.17
Boehmeria cylindrica	Urticaceae	2	Rare	0.97	1.72	2.69
Lantana camara	Verbenaceae	1	Rare	0.48	1.72	2.21
Asclepias curassavica	Apocynaceae	1	Rare	0.48	1.72	2.21
Cinchona pubescens	Rubiaceae	1	Rare	0.48	1.72	2.21
Total		207		100	100	200

Note: The abundance class used a proportional approach because the data range is small and relatively even (Abundant 25-30, Common 19-24, Frequent 13-18, Uncommon 7-12, and Rare 1-6). IVI: Importance Value Index, RD: Relative Density, RF: Relative Frequency

Sida rhombifolia, known locally as *sidaguri*, is another shrub widely found in the study areas. Although this species is non-native to Indonesia, this plant has long been recognized and used in traditional medicine due to its antioxidant properties, with potential for treating various diseases (Sari et al. 2021). *Musa paradisiaca* (banana trees) and *D. fragrans* are also widely found in the area. This is because the local community commonly plants banana trees to optimize plantation and agricultural land use, while *D. fragrans* is often planted as a hedge, particularly along the roadsides where most Kikuyu grass accessions are found. According to Rojas-Sandoval (2020), *D. fragrans* is a popular ornamental plant generally cultivated for hedges, living fences, and windbreaks that often survives and grows into natural weeds. Once established, this plant behaves like a weed, growing naturally in neglected gardens, wastelands, pastures, disturbed sites, forest edges, roadsides, and riparian vegetation.

Based on the data in Table 4, the highest RD value of tree species was recorded for *Pinus merkusii* (36.84%), followed by *Eucalyptus* sp. (23.31%), *Casuarina junghuhniana* (12.03%), *Toona sureni* (11.28%), and *Swietenia macrophylla* (6.02%). The highest RF value was recorded for *P. merkusii* (31.82%), followed by *Eucalyptus* sp. (25.00%), *C. junghuhniana* (9.09%), *T. sureni* (9.09%), and *Araucaria heterophylla* (4.55%). The highest relative dominance (RDm) value was recorded for *P. merkusii* (48.83%), followed by *Eucalyptus* sp. (18.31%), *C. junghuhniana* (12.86%), *A. heterophylla* (7.09%), and *T. sureni* (5.95%). This indicates that these tree species have larger base diameters and occupy more space than others. The values of RD, RF, and RDm significantly influence the IVI. Based on the calculations, the highest IVI for tree species was recorded for *P. merkusii* (117.49%), followed by *Eucalyptus* sp. (66.62%), *C. junghuhniana* (33.98%), *T. sureni* (26.32%), and *A. heterophylla* (14.64%).

Pinus merkusii, known locally as *tusam*, is a pine species native to Southeast Asia, primarily found in the mountainous regions of northern Sumatra, Indonesia. It plays a vital role in forest ecosystems by maintaining ecological stability, preventing soil erosion, and providing habitats for diverse flora and fauna (Sulton et al. 2024). Typically, it grows in the highlands at over 1,000 m asl (Andini et al. 2022). This tree species exhibited a high IVI, indicating its strong dominance within the vegetation community. Such dominance can significantly shape the availability of light, soil nutrients, and microclimatic conditions, which in turn affect the growth and persistence of understory forages such as Kikuyu grass and other herbaceous plants. The study area was also mainly covered by *Eucalyptus* sp., which is cultivated to produce essential oils with various beneficial chemical compounds. Additionally, *C. junghuhniana* and *T. sureni* are also the most commonly found tree species.

In general, Kikuyu grass accessions can grow well alongside various other plants in forestry, plantation, and agricultural areas, both in shaded and unshaded conditions, without interfering with the main crops. Field observations indicated that Kikuyu grass was still able to grow under certain shaded conditions, as evidenced by its presence beneath tree stands. Funk and McDaniel (2010) found that in Hawaiian forest, canopy shading by native trees suppresses the growth of invasive grasses, including Kikuyu grass, more than it suppresses the growth of native shrubs and trees.

Table 4. The Importance Value Index (IVI) of tree species in the habitats of *Pennisetum clandestinum* in West Java highlands, Indonesia

Species name	Family	N (ind.)	Abundance category	RD (%)	RF (%)	RDm (%)	IVI
Pinus merkusii	Pinaceae	49	Abundant	36.84	31.82	48.83	117.49
Eucalyptus sp.	Myrtaceae	31	Common	23.31	25.00	18.31	66.62
Casuarina junghuhniana	Casuarinaceae	16	Frequent	12.03	9.09	12.86	33.98
Toona sureni	Meliaceae	15	Frequent	11.28	9.09	5.95	26.32
Araucaria heterophylla	Araucariaceae	4	Uncommon	3.01	4.55	7.09	14.64
Swietenia macrophylla	Meliaceae	8	Uncommon	6.02	4.55	1.17	11.73
Grevillea robusta	Proteaceae	2	Rare	1.50	2.27	3.62	7.40
Cedrela odorata	Meliaceae	3	Rare	2.26	4.55	0.52	7.32
Artocarpus heterophyllus	Moraceae	2	Rare	1.50	4.55	0.15	6.20
Callistemon viminalis	Myrtaceae	1	Rare	0.75	2.27	1.25	4.28
Cyathea contaminans	Cyatheaceae	2	Rare	1.50	2.27	0.23	4.01
Total		133		100	100	100	300

Note: The abundance class used a narrow and flexible classification approach because the total number of individuals is small, the data range is narrow, and empty classes are prevented (Abundant ≥40, Common 25-39, Frequent 11-24, Uncommon 4-10, and Rare 1-3). IVI: Importance Value Index, RD: Relative Density, RF: Relative Frequency, RDm: Relative Dominance

Future research is recommended to quantitatively assess the shade tolerance of Kikuyu grass by measuring parameters such as percentage of canopy cover, tree density, and light interception. Such studies would provide a clearer understanding of its growth performance, productivity, and nutritional quality under different levels of shade in agroforestry or silvopastoral systems. Koskey et al. (2021) reported that *P. clandestinum* is one of the grass species commonly found in the riparian zones of the Njoro and Kamweti rivers, Kenya, especially in agricultural areas. This grass can grow alongside other species such as *Cynodon dactylon* and *Leersia hexandra*. Under proper management, this grass does not spread aggressively, but under poor conditions (e.g., poorly managed plantations), it can spread and cause a decline in biodiversity. Akau et al. (2022) conducted research in the island of Maui, Hawaii, highlighting the important role of Kikuyu grass in the ecological relationship with the endemic tree *Acacia koa*. The results indicate that the combination of koa trees and Kikuyu grass has the potential to support forage productivity and ecosystem health. The combination in silvopastoral systems has been shown to provide benefits in terms of improved forage quality and ecosystem services such as carbon sequestration and soil conservation. Kikuyu grass plays a strategic role as an adaptive forage under various canopy conditions of koa trees. Therefore, integrating Kikuyu grass into silvopasture and agroforestry systems could be a strategic approach to increasing forage availability, improving soil health, and supporting biodiversity, provided its growth and distribution are managed carefully.

Biodiversity indices

Biodiversity indices are essential for measuring biodiversity, considering the number of species (richness) and the relative abundance of each species (evenness) in an ecosystem. Various biodiversity indices can describe the overall ecosystem health, the distribution, and species interactions within a community (Bollarapu and Ramarao 2021; Bhardwaj et al. 2023). Generally, based on the data (Figure 3), the Shannon-Wiener Index (H′) calculations showed diversity index values of 2.90 for herbaceous plants, 2.55 for shrubs, and 1.79 for trees. These values suggest that the diversity of all plant habitus is in the moderate category, indicating that the study area has diverse floristic composition. The evenness index (E) showed values of 0.71 for herbaceous plants, 0.85 for shrubs, and 0.75 for trees. These values indicate high evenness, indicating that the community is relatively stable. The dominance index calculations showed values of 0.10 for herbaceous plants, 0.09 for shrubs, and 0.22 for trees, which are included in the low category. This is because no species dominates the area when species are evenly distributed.

In term of species richness, the herbaceous habitus showed a value of 6.99 which is in the high category, while the shrub habitus with a value of 3.56 is in the moderate category, and the tree habitus with a value of 2.04 is in the low category. Field observations showed that the total number of herbaceous individuals found at the site was 3,474 plants, for shrub species was 207 individuals, and for tree species was 133 individuals. Not all locations had the occurrence of shrubs and trees, while the herbaceous habitus was always found in each research location.

Specifically, based on Figure 4, the diversity index values for herbaceous habitus across all districts are classified in the moderate category, with Bandung District ranking highest (H: 2.56, R: 5.82), indicating high species diversity and richness. This is because the number of accessions found in Bandung District is the highest among other districts, with a total of 12 accessions (PCP-1.1, PCP-1.2, PCP-1.3, PCP-1.4, PCP-1.5, PCC-2.1, PCR-3.1, PCI-4.1, PCI-4.2, PCI-4.3, PCC-6.1, and PCC-6.2), resulting in the highest number of observed plots. Therefore, the number of species obtained will also increase. Differences in the number of sample plots at each location can affect the consistency of diversity comparisons between locations. Subang, West Bandung, and Garut Districts also exhibited diversity index values within the moderate range, suggesting that these regions maintain a balanced level of herbaceous plant diversity. The evenness index in all districts showed values in the high category (E>0.6), while the dominance index showed values in the low category in all areas (D<0.5), indicating a healthy community with relatively equal contributions and no conspicuously dominant herbaceous. Based on the observations, Kikuyu grass can grow well alongside various herbaceous species, as reflected in the moderate biodiversity index across all districts. This indicates that although it is competitive, this grass does not completely dominate or suppress other species, but rather allows for the existence of various other herbaceous species around it. Research by Srinivasan et al. (2024) also revealed that *P. clandestinum* is the most dominant species in the Pulikulam cattle grazing pasture, but it still allows coexistence with 8-10 other herbaceous species in each district, indicating that the ecosystem is still in a relatively balanced condition and species diversity is maintained.

Shrub habitus showed a more varied pattern. Bandung District showed diversity and richness indices in the moderate category (H′: 2.48; R: 3.51), but other districts such as West Bandung and Subang have low richness, despite high evenness values. No shrub vegetation (all values: 0) grew in the Garut District, which may reflect ecological pressure or environmental conditions that do not support shrub growth. This does not mean that shrubs cannot grow in Garut in general, but rather that the observation site where Kikuyu grass was found does not have a shrub community. Kikuyu grass found in Garut District consisted of only one accession, PCS-5-1, found at the Mata Air Cimanuk Arboretum area, which had unique environmental conditions, located along a major road that may be regularly mowed, trampled, or physically disturbed. The area tends to be shaded, moist, and may have a closed canopy due to the presence of many trees. According to Yao et al. (2022), environmental factors such as temperature and precipitation significantly influence vegetation diversity. These factors influence plant metabolic processes and resource availability, thereby controlling ecosystem richness, evenness, plant coverage, and aboveground biomass.

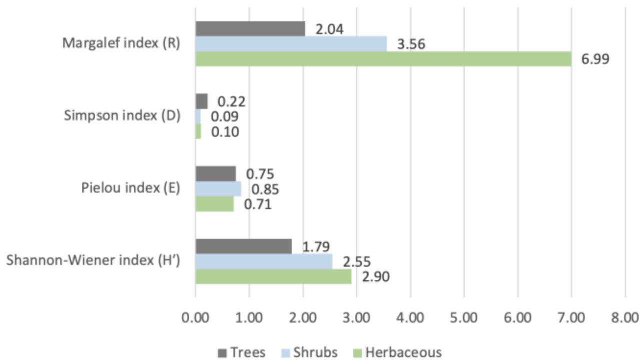

Figure 3. Biodiversity indices of herbaceous plants, shrubs, and trees in the habitats of *Pennisetum clandestinum* in West Java highlands, Indonesia

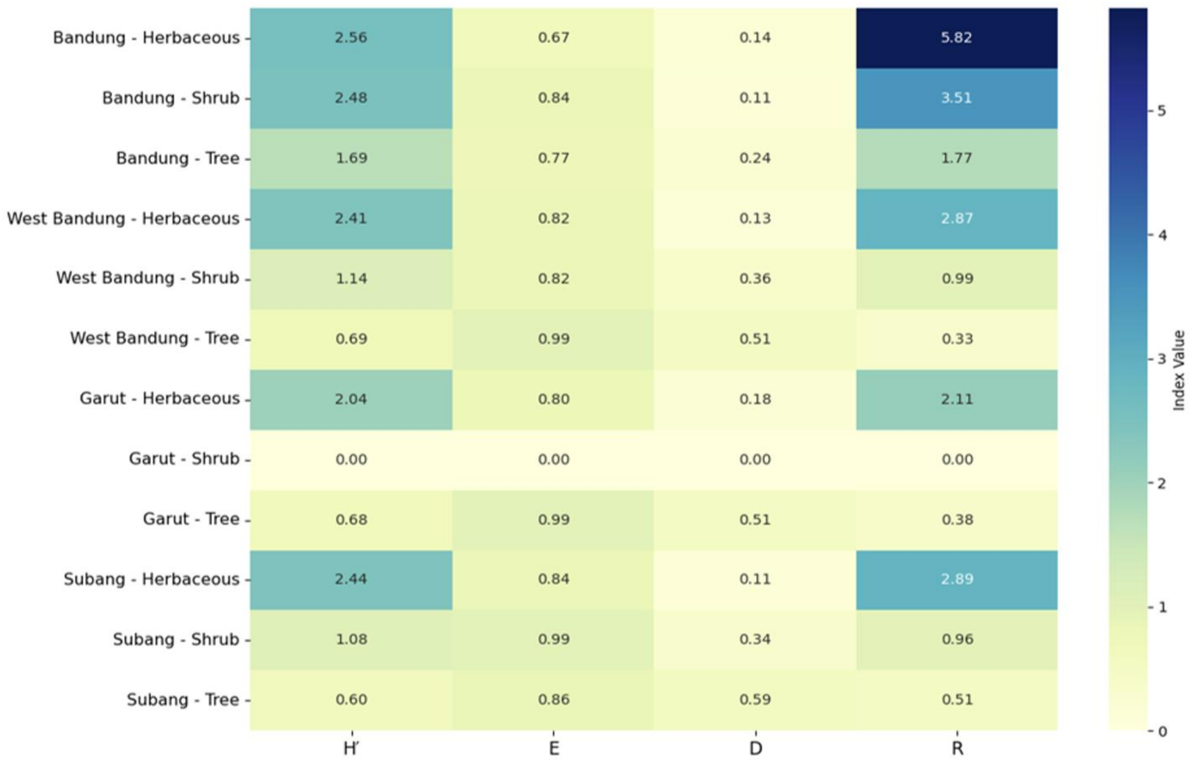

Figure 4. Heatmap of biodiversity indices by district and habitus in the habitats of *Pennisetum clandestinum* in West Java highlands, Indonesia

Tree habitus was the least diverse in all districts, except for Bandung District, which was slightly better. Despite high evenness, tree habitus had the lowest diversity and richness. Diversity in the moderate category was only found in Bandung District (H′: 1.69), while other districts were in the low category (H′<1). The evenness values were relatively high, especially in West Bandung and Garut District (E: 0.99). This is because the number of species found was very low (two species), but each species had nearly the same number of individuals. Dominance value for tree habitus in Bandung District was low, but in other districts tended to be high (D>0.5). Strong (2002) states that the relationship between dominance index and evenness is not always linear. Dominance is not simply the opposite of evenness in an ecological community. Although some districts have a balanced number of individuals among the species present (high evenness), the very low number of species causes dominance values to remain high. This aligns with research findings that only two tree species were found at discovery sites in West Bandung District (*P. merkusii* and *Eucalyptus* sp.), Garut District (*T. sureni* and *S. macrophylla*), and Subang District (*Cyathea contaminans* and *P. merkusii*), while nine species with 92 individuals were recorded in Bandung District.

In conclusion, Kikuyu grass can grow naturally in highland regions above 1,000 m asl and coexist with various plant types in forestry, plantation, and agricultural areas without significantly disturbing the main crops. Although this grass is competitive, its presence does not appear to substantially reduce the diversity of other plant communities in the study area. Intensive land management may help limit the dominance of this grass, highlighting the importance of proper cultivation techniques to reduce the risk of potential invasion. However, further long-term studies are needed to confirm this. It is important to note that this study is preliminary, with limitations including the relatively limited study area, short observation period, and limited assessment of seasonal dynamics. Future research should evaluate the ecological effects of Kikuyu grass over time, its potential invasiveness, and sustainable cultivation strategies that ensure productive use of this grass while minimizing ecological risks. Moreover, these findings provide valuable information that can guide future forage improvement and breeding programs.

ACKNOWLEDGEMENTS

We would like to thank the Center for Higher Education Funding (BPPT) of the Indonesian Ministry of Education, Culture, Research, and Technology, for the doctoral scholarship program (BPI Kemendikbudristek), and also the Indonesia Endowment Fund for Education (LPDP) for the financial support. The APC was funded by the Directorate of Research, Hilirization, and Community Engagement (DRHPM) of Universitas Padjadjaran, Indonesia.

REFERENCES

Acero-Camelo A, Pabón ML, Fischer G, Carulla-Fornaguera JE. 2020. Optimum harvest time for Kikuyu grass (*Cenchrus clandestinus*) according to the number of leaves per tiller and nitrogen fertilization. Rev Fac Nac Agron Medellín 7 (3): 9243-9253. DOI: 10.15446/rfnam.v73n3.82257.

Adams J, Samimi C, Mitterer C, Bendix J, Beck E. 2022. Comparison of pasture types in the tropical Andes: Species composition, distribution, nutritive value and responses to environmental change. Basic Appl Ecol 59: 139-150. DOI: 10.1016/j.baae.2022.01.005.

Akau G, Detlefsen G, Imbach A, Jenkins T, Villanueva C. 2022. Agronomic qualities of *Pennisetum clandestinum* in association with *Acacia koa* for the mitigation of the effects of ranching and promotion of conservation in a silvopastoral context on the island of Maui, Hawaii. Agroecol Sustain Food Syst 46 (7): 1047-1074. DOI: 10.1080/21683565.2022.2089940.

Alvarez-García WY, Diaz-Herrera A, Becerra Y, Vallejos-Fernández LA, Florián R, Carrasco-Chilón W, Cervantes-Peralta M, Quilcate C, Muñoz-Vilchez Y. 2024. Sustainability potential of Kikuyu grass (*Pennisetum clandestinum*) in livestock farming of Peru's highland regions. Sustainability 16 (24): 11021. DOI: 10.3390/su162411021.

Amrinanto AH, Hardinsyah H, Palupi E. 2019. The eating culture of the Sundanese: Does the traditional salad *(lalapan)* improve vegetable intake and blood β-carotene concentration? Future Food J Food Agric Soc 7 (2): 104. DOI: 10.17170/kobra-20190709593.

Andini R, Melinda V, Pardede E, Yanti LA, Hmon K, Moulana R, Indrioko S. 2022. Morphological variation of Aceh pinus (*Pinus merkusii*). IOP Conf Ser: Earth Environ Sci 951: 012091. DOI: 10.1088/1755-1315/951/1/012091.

Arango-Gaviria J, Echeverri-Zuluaga J, López-Herrera A. 2019. Diversity of Kikuyu grass (*Cenchrus clandestinus*): A review. Respuestas 24 (2): 81-88. DOI: 10.22463/0122820X.1834.

Bakar BB, Latief A, Puat NA. 1990. The genus *Pennisetum* in Peninsular Malaysia with particular reference to *P. setosum*, a new record for the weed flora. Biotrop Spec Publ 38: 71-79.

Bhardwaj M, Tiwari R, Bhardwaj VP, Bhardwaj S. 2023. A short review on various biodiversity indices. Intl J Adv Res Sci Commun Technol 3 (1): 385-389. DOI: 10.48175/IJARSCT-13153.

Bollarapu MJ, Ramarao KVSN. 2021. Biodiversity measures-Mathematical evaluation of various indices. Oecon Copernic 12 (4): 46-59.

BPS-Statistics of West Java Province. 2025. West Java Province in Figures 2025. BPS West Java, Bandung. https://jabar.bps.go.id. [Indonesian]

Chou C-H, Wang C-M. 2023. Allelopathy research: Past, present and future--II. Managed ecosystems. Allelopathy J 59 (1): 1-20. DOI: 10.26651/allelo.j/2023-59-1-1428.

Curtis JT, McIntosh RP. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31 (3): 434-455. DOI: 10.2307/1931497.

Enciso K, Castillo J, Albarracín LO, Campuzano LF, Sotelo M, Burkart S. 2021. *Avena sativa* AV25-T (Altoandina) supplementation as alternative for Colombia's high-altitude dairy systems: An economic analysis. Front Sustain Food Syst 5: 758308. DOI: 10.3389/fsufs.2021.758308.

Ernawati A, Abdullah L, Permana IG, Karti PDMH. 2023. Forage production and nutrient content of different elephant grass varieties cultivated with *Indigofera zollingeriana* in an intercropping system. Trop Anim Sci J 46 (3): 321-329. DOI: 10.5398/tasj.2023.46.3.321.

Escobar-Charry MA, Cárdenas-Rocha EA, Carulla-Fornaguera JE. 2020. Effect of altitude and defoliation frequency in the quality and growth of Kikuyu grass (*Cenchrus clandestinus*). Rev Fac Nac Agron Medellín 73 (1): 9121-9130. DOI: 10.15446/rfnam.v73n1.77330.

Fikadu T. 2023. The effects of tree species on herbaceous vegetation composition, distribution and diversity in Eastern Oromia, Ethiopia. J Biodivers Endanger Species 10 (11): 457. DOI: 10.37421/2332-2543.2022.10.457.

Fraser D, Sharp P, Ahmad N, Morris B, Trethowan R. 2017. Abiotic stress tolerance of kikuyu (*Cenchrus clandestinus*) and some related grasses and potential of kikuyu for agricultural and urban environments. Crop Pasture Sci 68 (3): 285-296. DOI: 10.1071/CP15380.

Funk JL, McDaniel S. 2010. Altering light availability to restore invaded forest: the predictive role of plant traits. Restor Ecol 18 (6): 865-872. DOI: 10.1111/j.1526-100X.2008.00515.x.

Hafliger E, Scholz H. 1980. Grass Weeds 1. CIBA-GEIGY, Switzerland.
Haryadi NT, Kurnianto AS, Dewi N, Sukma GAK, Devarigata ES, Suyitno YMR, Magvira NL, Firdaus AS. 2024. Exploring vegetation's role in enhancing ant-based coffee berry borer control in an agroforestry system. Biodiversitas 25 (2): 491-501. DOI: 10.13057/biodiv/d250207.
He L, Teng L, Tang X, Long W, Wang Z, Wu Y, Liao L. 2021. Agro-morphological and metabolomics analysis of low nitrogen stress response in *Axonopus compressus*. AoB Plants 13 (4): plab022. DOI: 10.1093/aobpla/plab022.
Holm L, Pancho JV, Herberger JP, Plucknett DL. 1979. A Geographical Atlas of World Weeds. John Wiley and Sons, New York.
Husaini IPA, Maulany RI, Nasri N, Ngakan PO. 2022. Diversity and use of traditional medicinal plant species in Bantimurung-Bulusaraung National Park, Indonesia. Biodiversitas 23 (11): 5539-5550. DOI: 10.13057/biodiv/d231101.
Ismail MH, Fuad MFA, Zaki PH, Jemali NJN. 2017. Analysis of importance value index of unlogged and logged peat swamp forest in Nenasi Forest Reserve, Peninsular Malaysia. Intl J Bonorowo Wetl 7 (2): 74-78. DOI: 10.13057/bonorowo/w070203.
Johnson W Jr, Bergfeld WF, Belsito DV, Hill RA, Klaassen CD, Liebler DC, Marks JG Jr, Shank RC, Slaga TJ, Snyder PW, Gill LJ, Heldreth B. 2023. Safety assessment of *Centella asiatica*-derived ingredients as used in cosmetics. Intl J Toxicol 42 (1_suppl): 5S-22S. DOI: 10.1177/10915818231158272.
Koskey JC, M'Erimba CM, Ogendi GM. 2021. Effects of land use on the riparian vegetation along the Njoro and Kamweti Rivers, Kenya. Open J Ecol 11 (11): 807-827. DOI: 10.4236/oje.2021.1111049.
Lilisti, Zamdial, Hartono D, Brata B, Simarmata M, 2021. The structure and composition of macrozoobenthos community in varying water qualities in Kalibaru Waters, Bengkulu, Indonesia. Biodiversitas 22 (1): 106-112. DOI: 10.13057/biodiv/d220115.
Liu H-B, Yang LP, Gao J-Q, Li Q-W, Li X-L, Feng J-G, Yu F-H. 2024. Increasing plant diversity enhances soil organic carbon storage in typical wetlands of northern China. Front Plant Sci 15: 1467621. DOI: 10.3389/fpls.2024.1467621.
Magurran AE. 1988. Ecological Diversity and Its Measurement. Springer, Berlin. DOI: 10.1007/978-94-015-7358-0.
Malakar S, Joshi HG. 2020. Vegetation structure, composition and species diversity in an age series of coal mine overburden dumps. Indian J Ecol 47 (2): 467-479.
Mansyur, Indriani NP, Nagara W, Wahyuni DS, Maulana S, Martono S, Herdis, Harper KJ, Rifianda NFD, Niderkon V, Yanza YR. 2024. Assessing the potential of indigenous Kikuyu grass (*Pennisetum clandestinum*) as high-quality equine forage from different accessions in tropical regions. Intl J Agric Biosci 13 (4): 701-708. DOI: 10.47278/journal.ijab/2024.173.
Marín-Santana MN, López-González F, Hernández-Mendo O, Arriaga-Jordán CM. 2020. Kikuyu pastures associated with tall fescue grazed in autumn in small-scale dairy systems in the highlands of Mexico. Trop Anim Health Prod 52: 1919-1926. DOI: 10.1007/s11250-020-02216-7.
Melese YY, Kolech SA. 2021. Coffee (*Coffea arabica* L.): Methods, objectives, and future strategies of breeding in Ethiopia—Review. Sustainability 13 (19): 10814. DOI: 10.3390/su131910814.
Milanda T, Febriyanti RM, Kusuma ASW, Diantini A. 2022. Antibacterial and cytotoxic activity of selected raw-consumed vegetables in West Java, Indonesia. Pharmacogn J 14 (2): 289-295. DOI: 10.5530/pj.2022.14.36.
Min D-H, Yu Y-B, Kim T-H, Kim H, Lee S. 2024. Pharmacological effects of pentacyclic triterpenoids isolated from *Centella asiatica*. Hortic Environ Biotechnol 65: 189-197. DOI: 10.1007/s13580-023-00561-8.
Minasny B, Fiantis D, Hairiah K, Van Noordwijk M. 2021. Applying volcanic ash to croplands - The untapped natural solution. Soil Secur 3: 100006. DOI: 10.1016/j.soisec.2021.100006.
Mueller-Dombois D, Ellenberg H. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York.
Muscolo A, Panuccio MR, Eshel A. 2013. Ecophysiology of *Pennisetum clandestinum*: A valuable salt tolerant grass. Environ Exp Bot 92: 55-63. DOI: 10.1016/j.envexpbot.2012.07.009.
Noreña-Grisales JM, Ramírez-Pisco R, Orosio-Vega NW. 2024. Soil quality indicators related to the deterioration of Kikuyu grass *Cenchrus clandestinus* (Hochst. Ex Chiov.) Morrone. Rev Fac Nac Agron Medellín 77 (3): 10811-10825. DOI: 10.15446/rfnam.v77n3.109829.
Odum EP. 1971. Fundamentals of Ecology (3rd ed.). W.B. Saunders Company, Philadelphia.
Oktavia D, Pratiwi SD, Munawaroh S, Hikmat A, Hilwan I. 2021. Floristic composition and species diversity in three habitat types of heath forest in Belitung Island, Indonesia. Biodiversitas 22 (12): 5555-5563. DOI: 10.13057/biodiv/d221240.
Olawale F, Olofinsan K, Iwaloye O. 2022. Biological activities of *Chromolaena odorata*: A mechanistic review. S Afr J Bot 144: 44-57. DOI: 10.1016/j.sajb.2021.09.001.
Parker C. 2008. *Pennisetum clandestinum* (Kikuyu grass). CABI Compendium 39765. DOI: 10.1079/cabicompendium.39765.
PIER. 2011. Pacific Island Ecosystems at Risk (PIER): *Pennisetum clandestinum*. Institute of Pacific Islands Forestry, USA. http://www.hear.org/pier/species/pennisetum_clandestinum.htm.
Ping C-L, Michaelson GJ, Stiles CA, González G. 2013. Soil characteristics, carbon stores, and nutrient distribution in eight forest types along an elevation gradient, eastern Puerto Rico. Ecol Bull 54: 67-86.
Retnowati A, Rugayah, Rahajoe JS, Arifiani D. 2019. Status Keanekaragaman Hayati Indonesia: Kekayaan Jenis Tumbuhan dan Jamur Indonesia. BRIN, Indonesia. [Indonesian]
Rojas-Sandoval J. 2020. *Dracaena fragrans* (corn plant). CABI Compendium 19898. DOI: 10.1079/cabicompendium.19898.
Royani JI, Utami RN, Maulana S, Agustina H, Herdis, Herry R, Sarmedi, Mansyur. 2021. Biodiversity of Kikuyu grass (*Pennisetum clandestinum* Hochst. Ex Chiov) in Indonesia as high protein forage based on morphology and nutrition compared. IOP Conf Ser: Earth Environ Sci 902: 012006. DOI: 10.1088/1755-1315/902/1/012006.
Sari ER, Suhatri N, Ismed F, Putra DP. 2021. Inventory, morphological and antioxidant profile of the *Sumatera sidaguri* (*Sida* Spp.) plants. Proc 2nd Intl Conf Contemp Sci Clin Pharm 2021 (ICCSCP 2021). Adv Health Sci Res 40: 65-74. DOI: 10.2991/ahsr.k.211105.010.
Setiadi D. 2005. The diversity of trees species in Taman Wisata Alam Ruteng, East Nusa Tenggara. Biodiversitas 6 (2): 118-122. DOI: 10.13057/biodiv/d060210.
Shara PN, Thomy Z, Anhar A, Harnelly E, Ramlan RR. 2021. Morphological characterization of some *Coffea arabica* L. varieties in Gayo Experimental Garden Bener Meriah. J Phys Conf Ser 1882: 012092. DOI: 10.1088/1742-6596/1882/1/012092.
Siahaan A. 2018. Identification of arabica coffee production in altitudes place in Lintong Ni Huta of Humbang Hasundutan. Intl J Environ Agric Biotechnol 3 (1): 249-255. DOI: 10.22161/ijeab/3.1.31.
Skerman PJ, Riveros F. 1990. Tropical Grasses. FAO Plant Production and Protection Series No. 23. FAO, Rome.
Srinivasan G, Chinnamani V, Chellapandian M, Leela V, Sathiamoorthy T, Arunachalam A. 2024. Floral diversity and nutritional value of forages in Pulikulam cattle breeding tract. Range Manag Agrofor 45 (1): 148-154. DOI: 10.59515/rma.2024.v45.i1.20.
Strong WL. 2002. Assessing species abundance unevenness within and between plant communities. Community Ecol 3 (2): 237-246. DOI: 10.1556/comec.3.2002.2.9.
Sulton MN, Aurina DM, Muhammad F, Fadzilah FPA, Hanun Z, Indrawan M, Budiharta S, Supriatna J, Nursamsi I, Setyawan AD. 2024. Predicting the current and future distributions of *Pinus merkusii* in Southeast Asia under climate change. Biodiversitas 25 (3): 1135-1143. DOI: 10.13057/biodiv/d250328.
Tadesse T, Tesfaye B, Abera G. 2020. Coffee production constraints and opportunities at major growing districts of Southern Ethiopia. Cogent Food Agric 6 (1): 1741982. DOI: 10.1080/23311932.2020.1741982.
Tsopgni LT, Lemoufouet J, Meutchieye F, Nounamo LWE, Kondo CN, Kana JR, Mouchili M, Feudjio BA. 2023. Nutritive value of forages consumed by ruminants during the dry season in the Western Highlands of Cameroon. Grassl Res 2 (2): 112-119. DOI: 10.1002/glr2.12051.
Uyi OO, Ekhator F, Ikuenobe CE, Borokini TI, Aigbokhan EI, Egbon IN, Adebayo AR, Igbinosa IB, Okeke CO, Igbinosa EO, Omokhua GA. 2014. *Chromolaena odorata* invasion in Nigeria: A case for coordinated biological control. Manag Biol Invasions 5 (4): 377-393. DOI: 10.3391/mbi.2014.5.4.09.
van der Colf J, Botha PR, Meeske R, Truter WF. 2015. Seasonal dry matter production, botanical composition and forage quality of kikuyu over-sown with annual or perennial ryegrass. Afr J Range Forage Sci 32 (2): 133-142. DOI: 10.2989/10220119.2015.1018945.
van der Plas F. 2019. Biodiversity and ecosystem functioning in naturally assembled communities. Biol Rev 94 (4): 1220-1245. DOI: 10.1111/brv.12499.

van Steenis CGGJ, de Wilde WJJO. 1989. Flora Malesiana: Series I, Spermatophyta. Kluwer Academic Publishers, Netherlands.

Wibowo H, Warna RN, Wulandari P, Prakoso T, Prasetyo D, Airlangga TA, Purwanto BH, Utami SNH, Sulistyaningsih E, Handayani S. 2019. Identification the availability of P in land planted with corn on volcanic, karst and acid soils in Indonesia. KnE Life Sci 4 (11): 179-188. DOI: 10.18502/kls.v4i11.3864.

Yao Z, Xin Y, Yang L, Zhao L, Ali A. 2022. Precipitation and temperature regulate species diversity, plant coverage and aboveground biomass through opposing mechanisms in large-scale grasslands. Front Plant Sci 13: 999636. DOI: 10.3389/fpls.2022.999636.

Yu F, Akin-Fajiye M, Thapa Magar K, Ren J, Gurevitch J. 2016. A global systematic review of ecological field studies on two major invasive plant species, *Ageratina adenophora* and *Chromolaena odorata*. Divers Distrib 22 (11): 1174-1185. DOI: 10.1111/ddi.12481.

Zhang Q-P, Wang J, Wang Q. 2021. Effects of abiotic factors on plant diversity and species distribution of alpine meadow plants. Ecol Inform 61: 101210. DOI: 10.1016/j.ecoinf.2021.101210.