CarakaTani
Journal of Sustainable Agriculture
ISSN 2613-9456 (Print) 2599-2570 (Online)

Caraka Tani: Journal of Sustainable Agriculture, 39(2), 451-464, 2024
URL: https://jurnal.uns.ac.id/carakatani/article/view/90003
DOI: http://dx.doi.org/10.20961/carakatani.v39i2.90003

Enhancing Agroecology in Pepper (*Piper nigrum* L.) Cultivation with *Centrosema pubescens* Ground Cover: A Study from Central Bangka, Indonesia

Ani Kurniawati[1*], Sitti Nurul Aini[2], Nyayu Siti Khodijah[3] and Adriyade Reshi Gusta[4]

[1]Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor, Indonesia; [2]Agrotechnology Study Program, Faculty of Agriculture, Fisheries and Marine, Universitas Bangka Belitung, Bangka, Indonesia; [3]Magister Agricultural Science, Faculty of Agriculture, Fisheries and Marine, Universitas Bangka Belitung, Bangka, Indonesia; [4]Department of Plantation Cultivation, Politeknik Negeri Lampung, Bandar Lampung, Indonesia

[*]*Corresponding author:* ani_kurniawati@apps.ipb.ac.id

Abstract

Pepper cultivation in Bangka Island primarily takes place on sandy land. Legume cover crops, such as *Centrosema pubescens*, which has been widely used as a ground cover, are anticipated to improve land quality by maintaining soil temperature and humidity, increasing soil organic carbon content, increasing soil porosity, and improving soil fertility. This research aims to analyze the agroecosystem of pepper plants, by comparing the use of the cover plant *C. pubescens* as a soil treatment and the absence of using these cover plants as a control. The research was conducted in farmers' pepper gardens in Perlang Village, Central Bangka Regency, Bangka Belitung Province. The research employed a randomized block design, with *C. pubescens* and natural vegetation as treatments, each replicated 3 times. The variables measured were soil temperature and humidity; abundance of microorganisms; weed density, frequency, and dominance; chlorophyll a, chlorophyll b, and anthocyanin content of pepper leaves; photosynthesis rate; transpiration rate; stomatal conductance; soil chemical and physical properties. The results showed that *C. pubescens* as ground cover could reduce the dominance of the *Bidens pilosa* weed (relative dominance of 36.16%) but led to an increase in the dominance of *Chromolaena odorata* (relative dominance of 38.7%). *C. pubescens* ground cover could also maintain stable soil temperature and moisture, and increase P, K, Ca, and Mg soil content by 100%, 100%, 43.6%, and 48.3%, respectively. Furthermore, pepper plants grown with *C. pubescens* exhibited 25%, 23.7%, and 16% higher chlorophyll a, total chlorophyll, and carotenoid content, respectively, compared to those grown without the cover crop.

Keywords: cover crops; fertilizer recovery; soil temperature; weed dominance

Cite this as: Kurniawati, A., Aini, S. N., Khodijah, N. S., & Gusta, A. R. (2024). Enhancing Agroecology in Pepper (*Piper nigrum* L.) Cultivation with *Centrosema pubescens* Ground Cover: A Study from Central Bangka, Indonesia. *Caraka Tani: Journal of Sustainable Agriculture*, *39*(2), 451-464. doi: http://dx.doi.org/10.20961/carakatani.v39i2.90003

INTRODUCTION

One of the reasons for the decline in pepper production on Bangka Island is commodity conversion to palm oil. This commodity shift has caused pepper plants to be cultivated on marginal land, including sandy land. According to Hengl et al. (2017), land is categorized as sandy if it has a sand content of more than 50% and a clay content of less than 20%. The characteristics of this land are poor nutrient content, organic material, water-holding capacity, and low cation

* *Received for publication July 10, 2024*
Accepted after corrections August 27, 2024

exchange capacity (CEC). Therefore, the cultivation of plants requires intensive fertilization and irrigation. On the other hand, intensive crop cultivation systems cause environmental pollution and degradation because they contribute to greenhouse gas emissions and dangerous compounds (Bishnoi, 2018).

A conservative agricultural system is a solution for cultivating plants by paying attention to balance and environmental sustainability to create sustainable agriculture. One part of conservative farming is the use of ground cover, whether in the form of inorganic, organic, or plant materials. Not all plants can be used as ground cover. According to Baligar et al. (2021), plants that can be used as ground cover must have the criteria of perennial plants that do not propagate, are tolerant of low nutrient conditions, are productive, have good soil coverage, and have few diseases. The types of plants that can be used as cover crops vary depending on the soil type, climate, and main crop. Based on taxonomy, the plant families that are often used as ground cover are Brassicaceae, Fabaceae, and Poaceae (Haramoto and Gallandt, 2005; Mauro et al., 2015; Chozin et al., 2018; Yuniarti et al., 2018; Stanton et al., 2020; Silva and Bagavathiannan, 2023). Apart from that, plants identified as weeds can also be used as ground cover plants such as *Asystasia intrusa*, *Nephrolepis biserrata*, *Asystasia gangetica*, *Paspalum conjugatum*, and *Ageratum conyzoides* (Asbur et al., 2018; Satriawan et al., 2020).

Methods for improving the environment using cover crops depend on the type of cover crop used, the type of main crop, the season, fertilization measures, and field management. Scavo et al. (2022) divided the effects of cover crops into direct and indirect effects. Direct effects include nutrient provision (da Silva Alves et al., 2022), nutrient absorption by plants (Murrell et al., 2020), increasing soil C content (Novara et al., 2019), N fixation by legume cover crops (LCC) (Perrone et al., 2020; De Notaris et al., 2021), and reduced the soil C/N ratio (Singh et al., 2020). The indirect effects of LCC are increasing soil organic matter content (Wulanningtyas et al., 2021), increasing microbial biomass (Lange et al., 2015; dos Santos Cordeiro et al., 2021; Muhammad et al., 2021; Thapa et al., 2021), improving soil structure, porosity and conductivity (Blanco-Canqui and Jasa, 2019; Blanco-Canqui and Ruis, 2020), reducing erosion (Camargo Silva and Bagavathiannan, 2023), decreasing nutrient leaching (Mauro et al., 2015), modifying pH (Chozin et al., 2018), and suppressing weed growth (Mennan et al., 2009; Mauro et al., 2015; Chozin et al., 2018; Gerhards and Schappert, 2020). Furthermore, using cover crops can increase soil fertility and crop production (Daryanto et al., 2019). Also, using the legume plants *Centrosema pubescens*, *Mucuna* sp., *Crotalaria* sp. as a ground cover can act as a mercury bio-remediator on post-gold mining land (Dewi et al., 2023) while *Calopogonium mucunoides* and *C. pubescens* can reduce the metal content of Fe, Mn, and Zn on post-nickel mining land (Leomo et al., 2021).

The pepper cultivation system carried out in Bangka is still predominantly conventional and has yet to adopt operational standards (Pitono, 2020) as outlined in Regulation of the Minister of Agriculture Number 10/Permentan/2013. This includes monoculture planting, the use of dead stands, unbalanced fertilizer doses, and minimal use of organic materials. This causes a decrease in the quality of pepper cultivation land, such as having an acidic pH and relatively low organic N, P, and C nutrient content (Daras et al., 2012). Improving soil quality is crucial for enhancing pepper cultivation land and can be achieved using cover crops. In this way, there will be direct benefits to the land and the environment, because cover crops are also useful in increasing carbon sequestration and reducing CO_2 content in the atmosphere, reducing N fertilizer because they can fix N biologically (legume type) (Rose et al., 2019) so that the environment is more sustainable. The cover crop that is deemed suitable for use is *C. pubescent* because it has a high germination capacity in sandy areas (Fefirenta et al., 2023), and the seeds are easy to obtain in agricultural shops nearby and online shops. Therefore, this study aims to compare the effect of using a LCC on the physical and chemical characteristics of the soil and the physiological characteristics of pepper plants.

MATERIALS AND METHOD

The research was conducted in a farmer's pepper crop in Perlang Village, Central Bangka Regency, Bangka Belitung Islands Province, located at 106°31'47" E and 2°32'13" S. The research was conducted between July 2023 and February 2024, using a randomized block design with 3 replications. The treatments included pepper cultivation with *C. pubescens* as a ground cover plant and pepper cultivation without ground cover legumes (natural vegetation as control). Each experimental plot consisted of 48 pepper plants in a plot area of 8 m x 24 m. The pepper variety planted was Petaling 1 variety. *C. pubescens* was planted in rows between pepper plants, with a seed application rate of 1 kg 117 m^{-2}. Before planting, the seeds were treated by soaking in 1% KNO_3 solution for 24 hours.

Soil sampling

Soil samples for analysis of the biological and chemical properties were collected by digging the soil under the cover crops to a depth of 2 to 10 cm and taking 300 g with 3 replications. The soil samples were placed in a plastic zip-lock container and stored in a freezer at 0 °C. Soil samples were taken to analyze soil physical properties using a sample ring at a depth of 10 to 15 cm, both on land with and without ground cover. Soil biological analysis was conducted at the Microbiology Laboratory of the Faculty of Agriculture, Fisheries and Marine, Universitas Bangka Belitung. The chemical and physical properties of the soil were analyzed at the Indonesian Center for Biodiversity and Biotechnology Laboratory (ICBB, Bogor). The components, variables, and soil analysis methods are detailed in Table 1.

Calculation of the abundance of bacteria and fungi

Soil samples were collected from a depth of 2 to 10 cm, with a sample weight of 300 to 400 g. For the analysis, 10 g of soil was placed in an erlenmeyer flask containing 90 ml of sterile distilled water and then vortexed until fully homogenized. From this mixture, 1 ml of the suspension was transferred to another erlenmeyer flask containing 9 ml of sterile distilled water, resulting in a 1:10 dilution. Dilution was carried out to a dilution of 10^{-7}. Fungi were inoculated at dilutions 10^{-2}, 10^{-3}, 10^{-4}, and 10^{-5} while bacteria were inoculated from dilutions 10^{-4}, 10^{-5}, 10^{-6}, to 10^{-7}. From each dilution, 0.1 ml of suspension was taken and placed in a sterile petri dish containing solid media, which was spread evenly over the surface of the media using a spreading triangle. Bacterial cultures were grown on nutrient agar (NA) media while fungal cultures on potato dextrose agar (PDA) media. Incubation for bacteria was carried out for 1 to 2 x 24 hours while incubation for fungi lasted 5 to 7 days. All cultures were put in an incubation room (dark) at room temperature (25 °C). Colony counts were manually performed using a counting tool. Bacteria were counted only from petri dishes, which had 30 to 300 colonies, while fungi had 10 to 100 colonies. Colonies per milliliter were calculated using Equation 1.

Measuring vegetation distribution

Vegetation distribution was measured using the quadrant method measuring 1 m x 1 m. Quadrants were placed randomly into treatment blocks 3 times. The types and numbers of plants contained in the quadrants were recorded. Plants whose roots did not fall within the quadrant were not recorded.

Relative density, relative frequency, relative dominance, and Summed Dominated Ratio (SDR) were calculated based on the Equation 2, 3, 4, and 5. The weed species diversity index

Table 1. Components, variable, and soil analysis method

Component	Variable	Unit	Method
Soil physics	Bulk density	g cm^{-3}	Gravimetry
	Particle density	g cm^{-3}	Flask
	Total pore space	%	Counting
Soil chemical properties	pH		Potentiometry
	CEC	cmol(+) kg^{-1}	Titrimetry
	Organic C	%	Spectrophotometry
	Total N	%	Kjeldahl
	P_2O_5 available	mg kg^{-1}	Spectrophotometry
	P_2O_5 potential	mg 100 g^{-1}	Spectrophotometry-Olsen, Spectrophotometry-Bray I
	K_2O_5 potential	mg 100 g^{-1}	AAS
	K^+	cmol(+) kg^{-1}	AAS
	Na^+	cmol(+) kg^{-1}	AAS
	Ca^{2+}	cmol(+) kg^{-1}	AAS
	Mg^{2+}	cmol(+) kg^{-1}	AAS

Note: AAS = Atomic absorption spectrophotometry, CEC = Cation exchange capacity

$$\text{Colonies per ml (cfu}^{-1}) = \text{Number of colonies x } \frac{1}{\text{DP}} \quad (1)$$

Where, DP = Dilution factor

$$\text{Relative density (\%)} = \frac{\text{Absolute density of weed species}}{\text{Sum of absolute densities of all species}} \text{ x } 100\% \quad (2)$$

$$\text{Relative frequency (\%)} = \frac{\text{Absolute frequency value of weed species}}{\text{Sum of absolute frequency values of all species}} \text{ x } 100\% \quad (3)$$

$$\text{Relative dominance (\%)} = \frac{\text{Absolute dominance value of weed species}}{\text{Sum of absolute dominance values of all species}} \text{ x } 100\% \quad (4)$$

$$\text{SDR} = \frac{\text{Relative density + relative frequency + relative dominance}}{3} \quad (5)$$

$$H' = -\sum_{n=1}^{n} \left(\frac{ni}{N}\right) \ln \frac{ni}{N} \quad (6)$$

Where, H’ = Shannon-Wiener diversity index, ni = Number of important values of each species, N = Number of important values of all species, ln = Natural logarithm. The H’ value indicates low diversity if the value is less than 1 (< 1), medium diversity if the value falls between 1 and 3 (1 < H’ < 3), and high diversity if the value is more than 3 (> 3).

$$\text{Chlorophyll a (mg g}^{-1}) = \frac{(12.7 \text{ x A663}) - (2.69 \text{ x A645})}{10} \quad (7)$$

$$\text{Chlorophyll b (mg g}^{-1}) = \frac{(22.9 \text{ x A645}) - (4.68 \text{ x A663})}{10} \quad (8)$$

$$\text{Total chlorophyll (mg g}^{-1}) = \frac{(8.02 \text{ x A663}) - (20.2 \text{ x A645})}{10} \quad (9)$$

$$\text{Carotenoid } (\mu\text{mol g}^{-1}) = \frac{[\text{A480} + (0.114 \text{ x A663}) - (0.638 \text{ x A645})] \text{ V x } 10^2}{112.5 \text{ x W}} \quad (10)$$

Where, A480 = Absorbance at a wavelength of 480 nm, A663 = Absorbance at a wavelength of 663 nm, A645 = Absorbance at a wavelength of 645 nm, V = Volume of extract (ml), W = Sample weight (g).

was calculated using the Shannon-Wiener index (H’) (Equation 6).

Measurement of physiological variables in pepper plants

The physiological activity of pepper plants was measured by assessing variables such as photosynthesis rate, leaf transpiration rate, and stomatal conductance. These measurements were carried out using a Li-Cor 6400XT instrument on fully opened, mature leaves. Measurements were taken during the day when the leaves were dry.

Measurement of chlorophyll a, b, and carotene content

The pigment content of pepper plant leaves was measured by weighing 10 g of pepper leaves, which were then ground by adding 10 ml of acetone. The solution was then filtered using filter paper. The supernatant obtained was read using a Thermo Scientific Evolution 201

UV-vis spectrophotometer, at 480, 645, and 663 nm wavelengths with acetone as the blank. The pigment content of chlorophyll a (Equation 7), b (Equation 8), total chlorophyll (Equation 9) and carotenoids (Equation 10) was measured using the formula from Hendry and Grime (1993).

Statistical analysis

The data collected on soil physical and chemical properties, abundance of microorganisms, chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids were analyzed using the T-test with 95% confidence. The statistical analysis was performed using Microsoft Excel tools. The T-test was employed to determine whether there were significant differences between land with ground cover and land without ground cover on the observed variables.

RESULTS AND DISCUSSION

Based on climate data obtained from the Indonesian Meteorological, Climatological, and Geophysical Agency (2024), November and December 2023 marked the end of the dry season with daily temperatures ranging between 22 °C and 35 °C, air humidity at 81% (Figure 1c), total rainfall of 155 to 188 mm month^{-1}. Soil temperature and humidity varied between land with and without LCC. In land with ground cover, soil temperature remained more stable throughout the day and night. Ground cover helps to mitigate temperature increases during the day and maintains warmer temperatures at night. Specifically, maximum temperatures on land without ground cover reached up to 44 °C in November and December 2023, while land with LCC maintained temperatures below 34 °C (Figure 1a). Soil moisture levels showed minimal difference between land with and without ground cover, with moisture levels dropping to 29% during the day and rising to 90% at night (Figure 1b).

The use of cover crops has long been known to maintain stable soil temperature and maintain soil moisture. Blanco-Canqui and Ruis (2020) noted that legume ground covers keep soil temperatures cooler during the day and warmer at night, compared to soils without cover crops. This stabilization reduces the temperature amplitude, which is beneficial for plant growth, especially in tropical regions. The ability of ground cover plants is related to their ability to protect the soil from direct exposure to sunlight, reflect solar radiation, and reduce evaporation. Dabney et al. (2001) highlighted that the effectiveness of cover crops in regulating soil temperature is influenced by canopy closure and the amount of plant residue. Faster decomposition of plant residues generally reduces the ability to regulate soil temperature. It is often believed that legumes are less effective than cereal cover crops at temperature regulation due to their faster decomposition rates. Nonetheless, higher soil moisture observed in land with cover crops can be attributed to their ability to reduce evaporation rates, enhance water infiltration, and decrease runoff.

The conditions of the pepper cultivation are shown in Figure 2. In dry conditions (dry season), *C. pubescens* continues to grow despite its suboptimal coverage (Figure 2a). The dry season also limits weed growth on fields without ground cover (Figure 2b). However, *C. pubescens* as a ground cover significantly reduces both the number and types of weeds in pepper plantations. As depicted in Table 2, the number of individual weeds that can be reduced is 22. *Eleusine indica* is the dominant weed on the land, either with or without cover crops. The dominance level of each type of weed based on the SDR value is not much different in the 2 land conditions. The use of cover crops further suppresses the growth of the *Cynodon dactylon* weed. The effectiveness of legumes in controlling weed growth depends on the plant species used, legume diversity, environmental conditions, and cultivation techniques (Lorin et al., 2015; Pannacci et al., 2018; Elsalahy et al., 2019; Adeux et al., 2021). The mechanism for inhibiting weed growth carried out by cover crops is through 2 mechanisms, namely competition and non-competition (Camargo Silva and Bagavathiannan, 2023). Cover crops inhibit weeds through competition for growing space, water resources, nutrients, and sunlight. The mechanism for inhibiting weed growth is through the second mechanism, namely allopathy, decreasing soil temperature and decreasing the quality of sunlight. Cover crop suppression of weeds is related to their morphological, physiological, and phenological characteristics (Mennan et al., 2009; Rouge et al., 2022). The greater the biomass of cover crops, the greater the pressure on weed growth (Rouge et al., 2022).

The abundance of bacterial and fungal microorganisms did not show a statistically significant difference between soil with legumes

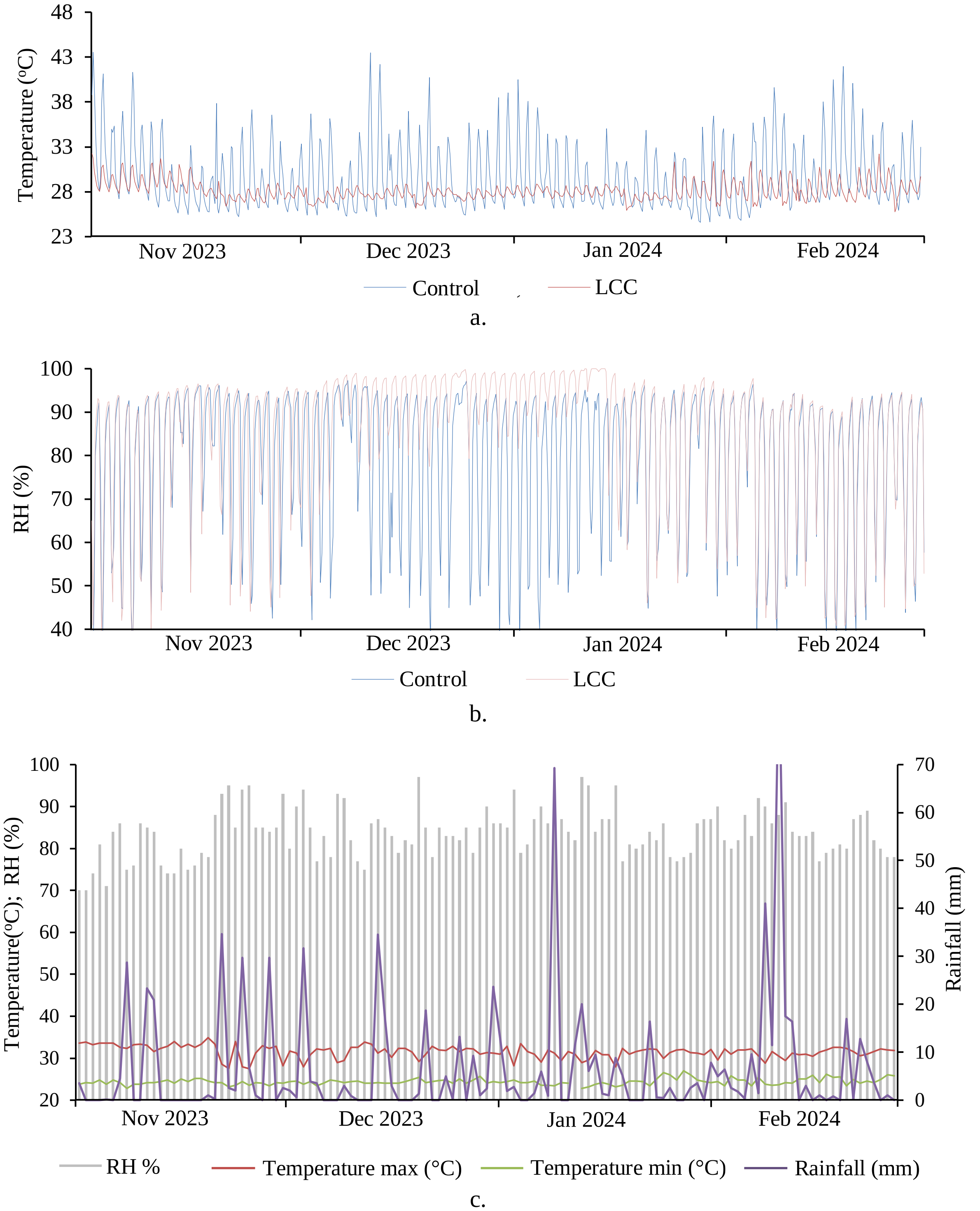

Figure 1. Temperature and humidity of pepper soil without ground cover (a), temperature and humidity of soil with ground cover (b), maximum temperature, minimum temperature, air humidity, and rainfall based on climate data (c)

Note: LCC = Legume cover crops, RH = Relative humidity

as cover crops and soil without ground cover (Table 3). Soil with ground cover has the potential to support a higher abundance of microorganisms compared to soil without ground cover. This is because cover crops contribute biomass that can alter microbial community structure, enhance soil enzyme activity related to soil organic matter, and support the N cycle (Thapa et al., 2021). Moreover, according to Inagaki et al. (2022), certain cover crops can enhance the functional biodiversity of arthropods in citrus orchards. The lack of difference in microorganism abundance between ground cover and no ground cover treatments in this study may be attributed to the dry season conditions and the relatively short observation period of 7 months following the planting of LCC. The dry season leads to low soil water content. Sandy soil types and low rainfall reduce the cover crop biomass formation and slow the rate of decomposition of plant residues. As highlighted by Muhammad et al. (2021), the impact of cover crops on microbial communities and their structure varies based on soil and climate conditions.

The use of cover crops did not significantly affect the physical and chemical properties of the soil tested (Table 4 and Table 5). However, there was a tendency for an increase in CEC and soil pH in soils with cover crops. This is thought to be related to the ability to form biomass from

Table 2. Types and number of individual weeds in 2 agroecosystems

Latin name	Local name	Number of individuals	Relative density (%)	Relative frequency (%)	Relative dominance (%)	SDR
Without LCC						
Ageratum conyzoides	*Babadotan*	8	9.87	7.69	2.96	6.84
Borreria laevis	*Rumput kancing ungu*	1	1.23	7.69	12.49	7.14
Eleusine indica	*Rumput belulang, rumput paragis*	33	33.33	15.38	0.77	16.49
Paspalum conjugatum	*Papaitan*	30	7.41	15.38	3.65	8.81
Cynodon dactylon	*Rumput bermuda*	1	37.04	15.38	1.53	17.98
Euphorbia hirta	*Patikan kebo*	2	1.23	7.69	32.88	13.93
Chromolaena odorata	*Kirinyu*	1	2.47	15.38	8.22	8.69
Bidens pilosa	*Ketul, ajeran*	5	1.23	7.69	36.17	15.03
Total		81				
H’				1.58		
With LCC						
Cyperus rotundus	*Rumput teki*	5	8.47	42.10	5.59	6.44
Elaeis guineensis	*Kelapa sawit*	1	1.69	5.26	21.29	9.42
Chromolaena odorata	*Kirinyu*	1	1.69	5.26	38.72	15.22
Eleusine indica	*Rumput belulang, rumput paragis*	26	22.03	5.26	9.59	15.80
Cynodon dactylon	*Rumput bermuda*	15	25.42	15.79	0.50	10.39
Eragrostis frangkii	*Rumput kemuncup*	10	16.94	5.26	0.26	7.49
Ageratum conyzoides	*Babadotan*	1	1.69	5.26	22.37	9.78
Total		59				
H’				1.73		

Note: LCC = Legume cover crops

Figure 2. Land with legume cover (a), land without legume cover (b), row of pepper plants with legume cover (c), row of pepper plants without legume cover (d)

cover crops to then produce organic material for the soil. The observed differences in soil physical properties between soils with and without ground cover are likely due to the dry season conditions and the short observation period, as ground cover plants may have experienced growth inhibition. Blanco-Canqui and Jasa (2019) noted that legume plants typically do not alter soil properties as much as grasses, which can produce larger biomass. Larkin (2024) confirmed that rye plants (family: Poaceae) can generate higher biomass than a combination of ground cover plants from the families Poaceae, Fabaceae, and Brassicaceae during 3 years of trials.

Soil organic carbon (SOC) content in these 2 types of land tested was categorized as medium. However, land without ground cover had a higher SOC content than land with *C. pubescens* ground cover (Table 5). The results are different from the outcomes of previous studies, that soil with ground cover has a higher SOC content (Novara et al., 2020). According to Acharya et al. (2022), the impact of cover crops on SOC in arid and semiarid regions is inconsistent and depends on soil and climatic conditions. This different response is thought to be related to high temperature and low moisture during this experiment. The microbial community has correlated with SOC content because it plays a vital role in soil C cycling (Jansson and Hofmockel, 2020). Environmental conditions such as high temperature and low soil humidity can reduce the activity of microbial enzymes, changing the composition of types and populations of microbes in the soil (Siebielec et al., 2020). This may explain why, despite the greater biomass of cover crops, the SOC content in land with ground cover was not significantly enhanced.

N is an essential nutrient that plants need in large quantities. Its availability in the soil for plant uptake is influenced by several factors, including the ammonium content released by diazotrophs, the decomposition of organic material which produces ammonium and nitrate, and ammonia oxidation activities by nitrifying and non-diazotrophic organisms in the rhizosphere (Lehnert et al., 2018). Soil type also influences the availability of N nutrients. Sandy soil has a low ability to hold N nutrients due to its relatively low organic matter content, as was the case in this study. N nutrients are low in sandy soil because they are easily leached and evaporated. In this experiment, the soil that used LCC had the same low N content as the soil that did not use a ground cover, although there were more types of N-fixing bacteria in the soil with a ground cover (Table 5). This is thought to be apart from N-fixing bacteria, it is also influenced by low organic C content as well as the presence of nitrifying bacteria and non-diazotrophic microorganisms. Research conducted by Rahayu et al. (2021) showed that applying low doses of silica and humic acid to sandy land could not increase soil N content. On the other hand, adding 1 ton ha^{-1} of silica from rice husks can increase the soil N nutrient content (Nwite et al., 2019).

The soil nutrient content analysis showed that the use of cover crops increased P nutrient availability, potential P nutrient content, potential K, Ca^{2+}, and Mg^{2+} (Table 5). The increase in P nutrient content with cover crops is likely related to organic material and increased alkaline phosphatase enzyme activity. *C. pubescens* plant

Table 3. Abundance of microorganisms in 2 types of agroecosystems

Agroecosystem type	Bacterial abundance (CFU ml^{-1})	Fungal abundance (CFU ml^{-1})
Without LCC	36.0 x 10^4	34.5 x 10^2
With LCC	176.5 x 10^4	54.0 x 10^2
T-test	ns	ns

Note: LCC = Legume cover crops, ns = Not significance

Table 4. Physical and chemical properties of soil

Agroecosystem	Bulk density (g cc^{-1})	Particle density (g cc^{-1})	Total pore space (%)	pH	CEC (cmol(+) kg^{-1})
Without LCC	1.40	2.62	46.62	5.0	1.87
With LCC	1.27	2.62	51.23	5.7	2.68
T-test	ns	ns	ns	ns	ns

Note: CEC = Cation exchange capacity, LCC = Legume cover crops, ns = Not significance

biomass, as an organic material, can boost the acid and alkaline phosphatase enzyme activities, thereby increasing the organic and inorganic P content of the soil. Phosphatase is an enzyme produced by root exudates of cultivated plants, cover crops, and microorganisms. The addition of cover crop biomass as organic material increases the Ca^{2+} nutrient content, as supported by research by de Medeiros et al. (2019), which proved that the increase in Ca^{2+} ion content is caused by the addition of organic material rather than the addition of P fertilizer. Cover crops also contribute to the K^+ nutrient cycle and improve the storage capacity of Ca^{2+} superscriptions (dos Santos Cordeiro et al., 2021; Wulanningtyas et al., 2021).

The synthesis of chlorophyll and carotenoids in plant tissue is influenced by internal factors (gene expression and enzymatic activity) and external factors (environment such as sufficient water, nutrients, and light). Carotene acts as an additional pigment to harvest light in the photosynthesis process (Hashimoto et al., 2016). Carotene also acts as a protector of chlorophyll from damage due to photo-oxidation under conditions of high light intensity. The use of cover crops in this study affects the availability of nutrients in the soil, thereby impacting the content of chlorophyll and carotenoid pigments (Table 5). Research by Arena et al. (2020) has proven that the higher the fertilizer dose, the more chlorophyll and carotene content is formed. Nutrients influence the biosynthesis of chlorophyll and carotenoids through the formation of the enzymes and compounds involved. According to the study by Quian-Ulloa and Stange (2021), carotenoids are formed through the methylerythritol phosphate (MEP) pathway from the compound geranylgeranyl pyrophosphate (GGPP) and require the activity of the enzyme geranylgeranyl pyrophosphate synthase (GGPPS) and the enzyme phytoene synthase (PSY). The higher availability of P nutrients in the treatment with ground cover is thought to contribute to the high carotene content in this treatment. Nutrients are needed in carotene biosynthesis as constituents of metabolically active compounds and enzymes. Similarly, the high chlorophyll content in the ground cover treatment is thought to be related to the high P and Mg^{2+} nutrient content in the treatment. Research by Yang et al. (2022) found that P-deficient wheat plants have low chlorophyll content. P is not needed for the formation of enzymes involved in chlorophyll biosynthesis but is required as an energy source in the form of ATP. In contrast, Mg is crucial for chlorophyll biosynthesis, as 8 of the 17 enzymes involved in this process require magnesium (Tripathy and Pattanayak, 2012).

The presence of limiting factors in the nutrient concept influences plant physiological activities. Essential nutrients cannot be replaced by other nutrients to carry out their specific function. In this study, the ground cover treatment had higher P and K, Ca, and Mg nutrient contents compared to those without ground cover. However, the N nutrient content of both is relatively low (Table 5). Therefore, despite the ground cover treatment having higher chlorophyll pigment content, total chlorophyll, and carotenoid levels (Table 6), the photosynthesis rate activity, stomatal conductance, transpiration rate, and intracellular CO_2 concentration are not significantly different from the treatment without ground cover.

The absence of differences in the physiological activity of pepper plants using ground cover and without ground cover is thought to be related to

Table 5. Soil chemical characteristics

Agroecosystem	C-Org	N total	P_2O_5 available	P_2O_5 potential	K_2O_5 potential	K^+	Na^+	Ca^{2+}	Mg^{2+}
	--- (%) ---		(mg kg^{-1})	--- (mg 100 g^{-1}) ---		------- (cmol(+) kg^{-1}) -------			
Without LCC	2.17 (m)^a	0.14 (l)^a	41.19^b	7.79 (vl)^b	5.08 (vl)^b	0.095^a	< 0.029	1.33^b	0.62^b
With LCC	2.02 (m)^b	0.13 (l)^a	97.66^a	26.17 (m)^a	10.67 (m)^a	0.155^a	< 0.029	1.91^a	0.92^a
T-test	*	ns	*	*	*	ns	ns	*	*

Note: Values followed by the same letter are not statistically different, LCC = Legume cover crops, ns = Not significantly different; m = Medium, l = Low; vl = Very low

Table 6. Content of chlorophyll a, chlorophyll b, and leaf carotenoid

Agroecosystem	Chlorophyll a (mg g^{-1})	Chlorophyll b (mg g^{-1})	Total chlorophyll (mg g^{-1})	Carotenoid (µmol g^{-1})
Without LCC	1.345^b	0.481	1.858^b	60.657^b
With LCC	1.656^a	0.513	2.300^a	70.374^a
t-test	*	ns	*	*

Note: Numbers followed by the same letter are not statistically different, LCC = Legume cover crops, ns = Not significantly different

non-photochemical quenching (NPQ). This is a mechanism that has been widely accepted as a determinant of photosynthetic productivity in plants that grow under conditions exposed to high light intensity (Wang et al., 2020). Excessive exposure to solar radiation can damage the photosynthetic apparatus. Soybean plants with faster NPQ induction and relaxation abilities have greater photosynthetic capacity and biomass formation (De Souza et al., 2023). NPQ expression, apart from genetics and solar radiation, is also influenced by low soil N nutrient content. In this study, the N nutrient content in both treatments was classified as low (Table 6). Soil N nutrient status did not differ between treatments using ground cover, causing NPQ expression not to differ between the 2 treatments, so both had physiological activities that were not significantly different. The benefits of using cover crops on plants cannot be seen in a short time. Research by dos Santos Cordeiro et al. (2021) indicates that the impacts of cover crops on crop yields and soil chemical fertility may become evident only in the third year after planting.

CONCLUSIONS

The use of *C. pubescens* as a LCC effectively maintains stable soil temperature and moisture during the dry season in pepper cultivation. It helps control the dominance of *Bidens pilosa* weed but increases the prevalence of *Chromolaena odorata* weed. Additionally, pepper plants grown with *C. pubescens* as ground cover shows a 25% increase in chlorophyll a, a 23.7% increase in total chlorophyll, and a 16% increase in carotenoid content compared to those without *C. pubescens*. Moreover, while *C. pubescens* ground cover can enhance soil nutrient levels of P, K, and Mg, it does not significantly increase soil N content over a short duration.

ACKNOWLEDGEMENT

The authors would like to express their gratitude for the research funding provided by the Indonesian Endowment Fund for Education (LPDP) through the Equity Program (DAPT), specifically under the national research collaboration scheme/Riset Kolaborasi Nasional (Ri-Na) (Grant No. 468/IT3.D10/PT.01.03/P/B/ 2023).

REFERENCES

Adeux, G., Cordeau, S., Antichi, D., Carlesi, S., Mazzoncini, M., Munier-Jolain, N., & Bàrberi, P. (2021). Cover crops promote crop productivity but do not enhance weed management in tillage-based cropping systems. *European Journal of Agronomy*, *123*, 126221. https://doi.org/10.1016/j.eja. 2020.126221

Arena, M. E., Pastur, G. M., Lencinas, M. V., Soler, R., & Bustamante, G. (2020). Changes in the leaf nutrient and pigment contents of *Berberis microphylla* G. Forst. in relation to irradiance and fertilization. *Heliyon*, *6*(1), e03264. https://doi.org/10.1016/j.heliyon.2020.e03264

Acharya, P., Ghimire, R., Cho, Y., Thapa, V. R., & Sainju, U. M. (2022). Soil profile carbon, nitrogen, and crop yields affected by cover crops in semiarid regions. *Nutrient Cycling in Agroecosystems*, *122*(2), 191–203. https://doi.org/10.1007/s10705-022-10198-1

Asbur, Y., Rambe, R. D. H., Purwaningrum, Y., & Kusbiantoro, D. (2018). Potensi beberapa gulma sebagai tanaman penutup tanah di area tanaman kelapa sawit menghasilkan. *Jurnal Penelitian Kelapa Sawit*, *26*(3), 113–128. https://doi.org/10.22302/iopri.jur.jpks.v26i3.69

Baligar, V. C., Elson, M. K., He, Z., Li, Y., Paiva, A. de Q., Almeida, A. A. F., & Ahnert, D. (2021). Impact of ambient and elevated [CO_2] in low light levels on growth, physiology and nutrient uptake of tropical perennial legume cover crops. *Plants*, *10*(2), 193. https://doi.org/10.3390/plants10020193

Bishnoi, U. (2018). Agriculture and the dark side of chemical fertilizers. *Environmental Analysis and Ecology Studies*, *3*(1), 198–201. https://doi.org/10.31031/EAES.2018.03.000552

Blanco-Canqui, H., & Ruis, S. J. (2020). Cover crop impacts on soil physical properties: A review. *Soil Science Society of America Journal*, *84*(5), 1527–1576. https://doi.org/10.1002/saj2.20129

Blanco-Canqui, H., & Jasa, P. J. (2019). Do grass and legume cover crops improve soil properties in the long term?. *Soil Science Society of America Journal*, *83*(4), 1181–1187. https://doi.org/10.2136/sssaj2019.02.0055

Camargo Silva, G., & Bagavathiannan, M. (2023). Mechanisms of weed suppression by cereal rye cover crop: A review. *Agronomy Journal*, *115*(4), 1571–1585. https://doi.org/10.1002/agj2.21347

Chozin, M. A., Nuryana, F. I., Guntoro, D., Sumiahadi, A., Badriyah, R. N., & Wibowo, A. P. (2018). Potency of *Arachis pintoi* Krap. & Greg. as biomulch in the tropical upland agriculture. *IOP Conference Series: Earth and Environmental Science*, *196*(1), 012011. https://doi.org/10.1088/1755-1315/196/1/012011

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using winter cover crops to improve soil and water quality. *Communications in Soil Science and Plant Analysis*, *32*(7–8), 1221–1250. https://doi.org/10.1081/CSS-100104110

da Silva Alves, M., da Gama, L. A., Leite, B. N., Pinto, K. G. D., de Souza, L. D. P. N., & Albertino, S. M. F. (2022). Nutrient cycling of cover crops in an Amazonian ecosystem. *Journal of Agricultural Science*, *14*(5), 41–52. https://doi.org/10.5539/jas.v14n5p41

Daras, U., Tjahjana, B. E., & Herwan. (2012). Status hara tanaman lada Bangka Belitung. *Buletin RISTRI*, *3*(1), 23–32. Retrieved from http://ejurnal.litbang.pertanian.go.id/index.php/bultri/article/view/1064

Daryanto, S., Jacinthe, P. A., Fu, B., Zhao, W., & Wang, L. (2019). Valuing the ecosystem services of cover crops: Barriers and pathways forward. *Agriculture, Ecosystems & Environment*, *270–271*, 76–78. https://doi.org/10.1016/j.agee.2018.10.021

de Medeiros, E. V., Silva, A. O., Duda, G. P., dos Santos, U. J., & de Souza Junior, A. J. (2019). The combination of *Arachis pintoi* green manure and natural phosphate improves maize growth, soil microbial community structure and enzymatic activities. *Plant and Soil*, *435*(1–2), 175–185. https://doi.org/10.1007/s11104-018-3887-z

De Notaris, C., Mortensen, E. Ø., Sørensen, P., Olesen, J. E., & Rasmussen, J. (2021). Cover crop mixtures including legumes can self-regulate to optimize N_2 fixation while reducing nitrate leaching. *Agriculture, Ecosystems & Environment*, *309*, 107287. https://doi.org/10.1016/j.agee.2020.107287

De Souza, A. P., Burgess, S. J., Doran, L., Manukyan, L., Hansen, J., Maryn, N., ... & Long, S. P. (2023). Response to comments on “Soybean photosynthesis and crop yield is improved by accelerating recovery from photoprotection.” *Science*, *379*(6634), 851–854. https://doi.org/10.1126/science.adf2189

Dewi, T., Sukarjo, Handayani, C. O., Hindersah, R., Waas, E. D., Kalay, A. M., & Zu’amah, H. (2023). The potential of legume cover crops and soil microbes for gold mine tailings revegetation. *Journal of Degraded and Mining Lands Management*, *10*(4), 4593–4600. https://doi.org/10.15243/jdmlm.2023.104.4593 dos Santos Cordeiro, C. F., Echer, F. R., & Araujo, F. F. (2021). Cover crops impact crops yields by improving microbiological activity and fertility in sandy soil. *Journal of Soil Science and Plant Nutrition*, *21*(3), 1968–1977. https://doi.org/10.1007/s42729-021-00494-0

Elsalahy, H., Döring, T., & Arends, D. (2019). Weed suppression in only-legume cover crop mixtures. *Agronomy*, *9*(10), 648. https://doi.org/10.3390/agronomy9100648

Fefirenta, A. D., Sunardi, & Prawestri, D. A. (2023). Perkecambahan empat jenis legume cover crop (LCC). *Gunung Djati Conference Series*, *18*, 101–112. Retrieved from https://conferences.uinsgd.ac.id/index.php/gdcs/article/view/1104

Gerhards, R., & Schappert, A. (2020). Advancing cover cropping in temperate integrated weed management. *Pest Management Science*, *76*(1), 42–46. https://doi.org/10.1002/ps.5639

Haramoto, E. R., & Gallandt, E. R. (2005). Brassica cover cropping: I. effects on weed and crop establishment. *Weed Science*, *53*(5), 695–701. https://doi.org/10.1614/ws-04-162r.1

Hashimoto, H., Uragami, & Cogdell, R. J. (2016). Carotenoids and photosynthesis. *Carotenoids in Nature: Biosynthesis, Regulation, and Function*, *79*, 377–414. https://doi.org/10.1007/978-3-319-39126-7

Hendry, G. A. F., & Grime, J. P. (1993). *Methods in comparative plant ecology*. London: Chapman and Hall. http://dx.doi.org/10.1007/978-94-011-1494-3

Hengl, T., De Jesus, J. M., Heuvelink, G. B. M., Gonzalez, M. R., Kilibarda, M., Blagotić, A., ... & Kempen, B. (2017). SoilGrids250m: Global gridded soil information based on machine learning. *PLoS ONE*, *12*(2), e0169748. https://doi.org/10.1371/journal.pone.0169748

Inagaki, H., Yuto, S., & Daiki, Y. (2022). The effects of different undergrowth vegetation pn the types and densities of functional ground-dwelling arthropods in citrus orchads. *Caraka Tani: Journal of Sustainable Agriculture*, *37*(1), 62–70. http://dx.doi.org/10.20961/carakatani.v37i1.56991

Indonesian Meteorogical, Climatolgical, and Geophysical Agency. (2024). *Data online – pusat database*. Retrieved from https://dataonline.bmkg.go.id

Jansson, J. K., & Hofmockel, K. S. (2020). Soil microbiomes and climate change. *Nature Reviews Microbiology*, *18*(1), 35–46. https://doi.org/10.1038/s41579-019-0265-7

Lange, M., Eisenhauer, N., Sierra, C. A., Bessler, H., Engels, C., Griffiths, R. I., ... & Gleixner, G. (2015). Plant diversity increases soil microbial activity and soil carbon storage. *Nature Communications*, *6*(1), 6707. https://doi.org/10.1038/ncomms7707

Larkin, R. P. (2024). Effects of different cover crops and amendments on soil and crop properties in organic vegetable production. *Agronomy*, *14*(1), 171. https://doi.org/10.3390/agronomy14010171

Lehnert, N., Dong, H. T., Harland, J. B., Hunt, A. P., & White, C. J. (2018). Reversing nitrogen fixation. *Nature Reviews Chemistry*, *2*(10), 278–289. https://doi.org/10.1038/s41570-018-0041-7

Leomo, S., Alam, S., Afrianto, E., Jamil, L. O., & Muhidin. (2021). Cover crop residue effects on soil and corn performance in ex-nickel mining soils. *Pakistan Journal of Biological Sciences*, *24*(8), 888–894. https://doi.org/10.3923/pjbs.2021.888.894

Lorin, M., Jeuffroy, M. H., Butier, A., & Valantin-Morison, M. (2015). Undersowing winter oilseed rape with frost-sensitive legume living mulches to improve weed control. *European Journal of Agronomy*, *71*, 96–105. https://doi.org/10.1016/j.eja.2015.09.001

Mauro, R. P., Anastasi, U., Lombardo, S., Pandino, G., Pesce, R., Restuccia, A., & Mauromicale, G. (2015). Cover crops for managing weeds, soil chemical fertility and nutritional status of organically grown orange orchard in Sicily. *Italian Journal of Agronomy*, *10*(2), 101–104. https://doi.org/10.4081/ija.2015.641

Mennan, H., Ngouajio, M., Isık, D., & Kaya, E. (2009). Effects of alternative winter cover cropping systems on weed suppression in organically grown tomato (*Solanum lycopersicum*). *Phytoparasitica*, *37*(4), 385–396. https://doi.org/10.1007/s12600-009-0048-1

Muhammad, I., Wang, J., Sainju, U. M., Zhang, S., Zhao, F., & Khan, A. (2021). Cover cropping enhances soil microbial biomass and affects microbial community structure: A meta-analysis. *Geoderma*, *381*, 114696. https://doi.org/10.1016/j.geoderma.2020.114696

Murrell, E. G., Ray, S., Lemmon, M. E., Luthe, D. S., & Kaye, J. P. (2020). Cover crop species affect mycorrhizae-mediated nutrient uptake and pest resistance in maize. *Renewable Agriculture and Food Systems*, *35*(5), 467–474. https://doi.org/10.1017/S1742170519000061

Novara, A., Minacapilli, M., Santoro, A., Rodrigo-Comino, J., Carrubba, A., Sarno, M., Venezia, G., & Gristina, L. (2019). Real cover crops contribution to soil organic carbon sequestration in sloping vineyard. *Science of the Total Environment*, *652*, 300–306. https://doi.org/10.1016/j.scitotenv.2018.10.247

Novara, A., Catania, V., Tolone, M., Gristina, L., Laudicina, V. A., & Quatrini, P. (2020). Cover crop impact on soil orgaic carbon, nitrogen dynamics and microbial diversity in a mediterranean semiarid vineyard. *Sustaiability*, *12*(8), 3256. https://doi.org/10.3390/su12083256

Nwite, J. C., Unagwu, B. O., Okolo, C. C., Igwe, C. A., & Wakatsuki, T. (2019). Improving soil silicon and selected fertility status for rice production through rice-mill waste application in lowland sawah rice field of southeastern Nigeria. *International Journal of Recycling of Organic Waste in Agriculture*, *8*(Suppl 1), 271–279. https://doi.org/10.1007/s40093-019-00299-3

Pannacci, E., Tei, F., & Guiducci, M. (2018). Evaluation of mechanical weed control in legume crops. *Crop Protection*, *104*, 52–59. https://doi.org/10.1016/j.cropro.2017.10.014

Perrone, S., Grossman, J., Liebman, A., Sooksa-nguan, T., & Gutknecht, J. (2020). Nitrogen fixation and productivity of winter annual legume cover crops in upper midwest organic cropping systems. *Nutrient Cycling in Agroecosystems*, *117*(1), 61–76. https://doi.org/10.1007/s10705-020-10055-z

Quian-Ulloa, R., & Stange, C. (2021). Carotenoid biosynthesis and plastid development in plants: The role of light. *International Journal of Molecular Sciences*, *22*(3), 1–16. https://doi.org/10.3390/ijms22031184

Pitono, J. (2020). Pertanian presisi dalam budidaya lada the precision farming on pepper cultivation. *Perspektif*, *18*(2), 1279–1300. https://doi.org/10.21082/psp.v18n2.2019.91-103

Rahayu, R. D., Mindari, W., & Arifin, M. (2021). Efektivitas pemberian silika dan asam humat terhadap ketersediaan nitrogen dan pertumbuhan tanaman padi pada tanah berpasir. *Agritrop : Jurnal Ilmu-Ilmu Pertanian (Journal of Agricultural Science)*, *19*(2), 99–106. https://doi.org/10.32528/agritrop.v19i2.5976

Rose, T. J., Kearney, L. J., Morris, S., Van Zwieten, L., & Erler, D. V. (2019). Pinto peanut cover crop nitrogen contributions and potential to mitigate nitrous oxide emissions in subtropical coffee plantations. *Science of the Total Environment*, *656*, 108–117. https://doi.org/10.1016/j.scitotenv.2018.11.291

Rouge, A., Adeux, G., Busset, H., Hugard, R., Martin, J., Matejicek, A., Moreau, D., Guillemin, J.-P., & Cordeau, S. (2022). Weed suppression in cover crop mixtures under contrasted levels of resource availability guillaume adeux. *European Journal of Agronomy*, *36*, 126499. https://doi.org/10.1016/j.eja.2022.126499

Satriawan, H., Fuady, Z., & Ernawita. (2020). The potential of asystasia intrusa weed of acanthaceae family as a cover crop in oil palm plantations. *Biodiversitas*, *21*(12), 5710–5717. https://doi.org/10.13057/biodiv/d211230

Scavo, A., Fontanazza, S., Restuccia, A., Pesce, G. R., Abbate, C., & Mauromicale, G. (2022). The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. *Agronomy for Sustainable Development*, *42*(5), 93. https://doi.org/10.1007/s13593-022-00825-0

Siebielec, S., Siebielec, G., Klimkowicz-Pawlas, A., Galazka, A., Grzadziel, J., & Stuczynski, T. (2020). Impact of water stress on microbial community and activity in sandy and loamy soils. *Agronomy*, *10*(9), 1429. https://doi.org/10.3390/agronomy10091429

Singh, G., Dhakal, M., Yang, L., Kaur, G., Williard, K. W. J., Schoonover, J. E., & Sadeghpour, A. (2020). Decomposition and nitrogen release of cover crops in reduced- and no-tillage systems. *Agronomy Journal*, *112*(5), 3605–3618. https://doi.org/10.1002/agj2.20268

Stanton, V. L., Haramoto, E. R., & Phillips, T. D. (2020). Summer survival is a major limitation to interseeding Poaceae cover crops in Kentucky. *Crop, Forage & Turfgrass Management*, *6*(1), e20004. https://doi.org/10.1002/cft2.20004

Tripathy, B. C., & Pattanayak, G. K. (2012). Chlorophyll biosynthesis in higher plants. *Photosynthesis: Plastid biology, energy conversion and carbon assimilation*, *34*, 63–94. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-1579-0_3

Thapa, V. R., Ghimire, R., Acosta-Martínez, V., Marsalis, M. A., & Schipanski, M. E. (2021). Cover crop biomass and species composition affect soil microbial community structure and enzyme activities in semiarid cropping systems. *Applied Soil Ecology*, *157*, 103735. https://doi.org/10.1016/j.apsoil.2020.103735

Wang, Y., Burgess, S. J., de Becker, E. M., & Long, S. P. (2020). Photosynthesis in the fleeting shadows: An overlooked opportunity for increasing crop productivity?. *Plant Journal*, *101*(4), 874–884. https://doi.org/10.1111/tpj.14663

Wulanningtyas, H. S., Gong, Y., Li, P., Sakagami, N., Nishiwaki, J., & Komatsuzaki, M. (2021). A cover crop and no-tillage system for enhancing soil health by increasing soil organic matter in soybean cultivation. *Soil and Tillage Research*, *205*, 104749. https://doi.org/10.1016/j.still.2020.104749

Yang, B., Chen, N., Dang, Y., Wang, Y., Wen, H., Zheng, J., ... & Qiao, L. (2022). Identification and validation of quantitative trait loci for chlorophyll content of flag leaf in wheat under different phosphorus treatments. *Frontiers in Plant Science*, *13*, 1019012. https://doi.org/10.3389/fpls.2022.1019012

Yuniarti, Y., Chozin, M. A., Guntoro, D., & Murtilaksono, D. K. (2018). Perbandingan *arachis pintoi* dengan jenis tanaman penutup tanah lain sebagai biomulsa di pertanaman kelapa sawit belum menghasilkan. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy)*, *46*(2), 215–221. https://doi.org/10.24831/jai.v46i2.16126