The development of pepper (*Piper nigrum* L.) foot rot disease on agroforestry

E Suhaendah¹, E Fauziyah¹ and G E S Manurung²

¹Research and Development Institute for Agroforestry Technology, Indonesia
²World Agroforestry (ICRAF), Indonesia

E-mail: endah_ah@yahoo.com

Abstract. Pepper foot rot is one of the most destructive diseases. There were three cropping patterns in the research area, i.e., agroforestry, pepper-cocoa and pepper monoculture patterns. As one of the most common cropping patterns, the observation of footrots in the agroforestry pattern compared to other cropping patterns. The study was conducted in Simbune Village, East Kolaka Regency, Southeast Sulawesi, from October 2013 to September 2014. The research was conducted by direct observation methods. In each cropping pattern, a permanent measurement plot was made by sampling 30% of the total pepper individuals. The intensity of the disease was observed monthly for 12 months. The observation revealed that the intensity of foot rot disease was getting more severe toward the end of observation. The intensity on agroforestry (26% - 33%) and pepper-cocoa (17% - 35%) patterns were lower than that on pepper monoculture pattern (85% - 90%). The infection rate was lowest on the agroforestry pattern with a value of 0.051. This finding suggested that the agroforestry pattern for pepper showed the best resilience against foot rot disease.

1. Introduction

Agroforestry is a land-use system in which forest plantation and agriculture are planted together. This land use can be combined with fodder plants and livestock. Agroforestry may be modified according to physical and socioeconomic conditions [1, 2]. Agroforestry practices have been prevalent for centuries in various parts of the world for the benefit of farm families [1, 3]. In agroforestry, there is a competitive and complementary interaction between trees, annual crops and fauna [4].

Recently, agroforestry is getting more recognized and has become a development agenda in developing countries to overcome various problems, i.e., increasing food demand, deforestation, land degradation and decreasing biodiversity [2, 3]. Agroforestry has various benefits, i.e., increasing yields, conserving soil, and recycling nutrients while producing fuelwood, animal feed, fruits and wood [1].

Agroforestry is an ecosystem that resembles a natural forest. This system allowed the preservation of biodiversity and might mitigate changes in temperature and precipitation [5]. The adoption of agroforestry might be influenced by household preferences, endowment resources, market incentives, biophysical factors, risks and uncertainties [6]. Farmers will likely invest in agroforestry if the benefits are higher than the alternatives [7]. [8] stated that risk, biophysical and resource factors significantly influenced agroforestry adoption behavior.

Multistory has been a common cropping system in Indonesia. In Indonesia, pepper plant is a
choice to be applied in the cropping system that can be developed on forest land with agroforestry patterns because pepper plants require shade [9]. Pepper is the oldest and most popular herb in the world. This plant is one of the superior commodities and has great potential in Indonesia's economic growth [10]. Pepper is the seventh foreign exchange earner in the plantation group and third pepper suppliers in the world [11].

One of the problems of pepper cultivation is the foot rot disease attack. Pepper foot rot was one of the most destructive diseases in Indonesia and other parts of Southeast Asia [12]. It had caused an annual loss in agroforestry applications in several countries in Southeast Asia [13]. Furthermore, certain cultivation practices might increase the plants' susceptibility to disease attacks. In monocultures, plant genetic diversity is limited. Moreover, the availability of other hosts in the tropics that continues throughout the year causes plants to produce large quantities of spores [14].

Information about the biology and the ecology of *P. capsici* is essential to develop ecology-based disease management strategies [15]. Management of this disease has been reported, including controlling using biological agents and cultivation techniques [1, 15, 16]. [21] stated that mulching, good drainage, and long-cycle rotation of plants might be employed to reduce pathogenic propagules and reduce their spread [15]. However, information regarding agroforestry cultivation as one of the management of foot rot is still limited. Therefore, studies on agroforestry systems as cultivation management is needed. The purpose of this study is to assess the development of foot rot pepper disease in agroforestry patterns.

2. Method

2.1. Location and time

The research was carried out in the people's pepper plantation in Lawonua Village, Besulutu District, Konawe Regency and Simbune Village, Tirawuta District, East Kolaka Regency, Southeast Sulawesi. The study was conducted from October 2013 to September 2014.

2.2 Data collection

The research was carried out by survey and interview methods. The survey was conducted using direct observation in the field on the development of foot rot attacks. The observed pepper plantation belongs to farmers. Interviews were conducted to obtain information about the conditions of pepper plantations at the study site.

The observations were carried out for one year. The pepper plant used belongs to the farmers. The *P. capsici* age observed was adjusted to the availability of pepper plants in the study location (assuming *P. capsici* attacks all stages of pepper). The observation location was chosen based on three pepper planting patterns, i.e., pepper monoculture, pepper monoculture, pepper with cocoa and pepper in mixed agroforestry. In each cropping pattern, a permanent measurement plot was made with a size of 20 m x 50 m. Samples were taken 30% of the total pepper individuals. In each village, the plot was repeated three times so that the number of plots used as research objects were nine plots.

Observation of the disease intensity was carried out every month for one year. Disease intensity was measured by the scoring method for the symptoms of the disease with the scoring method based on the Manohara [17] method as follows:

a. Attack on leaves (leaf spots)

Value 0: healthy plants, leaves appear fresh green
1: spotting occurs on the leaves ≤ 10%
2: leaf spots range between 10% – 50%
3: dead plants

b. Attack on foot (foot rot)

Value 0: healthy plants, leaves appear fresh green
1: most of the leaves turn yellow withered
2: the leaves remain green but most of the leaves
3: plants die, the foot is black
The disease intensity of *P. capsici* is calculated with the following formula:

\[
DI = \left( \frac{\sum(nv)}{Nv} \right) \times 100\% \tag{1}
\]

DI: Disease intensity (%)

n: score

N: the highest score (3)

v: total infected plants at every score

V: total plants in each plot

The data obtained were analyzed by variance at a confidence level of 95%.

The disease development model was obtained by regressing data on the intensity of the disease over time. The model of accuracy test or goodness of fit test was performed to determine the correct foot rot development model. The most widely used models are the mono-molecular, logistical, and Gompertz models [18]. The disease intensity data that has been obtained, each transformed into \( \ln \left\{ \frac{1}{1-x} \right\} \) for the monomolecular model, \( \ln \left\{ \frac{x}{1-x} \right\} \) for the logistic model, and \( \ln \left\{ -\ln (-\ln x) \right\} \) for the Gompertz model. The transformed data was regression linearly with time (t) disease progression, and then the goodness of fit was done by looking at the coefficient of determination (R²) and the square of error (SE). The coefficient of determination was the largest and the least square of error.

After knowing the appropriate model, the infection rate or \( r \) (infection rate) was calculated. The infection rate formula for each model is:

\[
r_m = \frac{1}{t} \left( \ln \frac{1}{1-x_t} - \ln \frac{1}{1-x_0} \right) \tag{2}
\]

\[
r_l = \frac{1}{t} \left( \ln \frac{x_t}{1-x_t} - \ln \frac{x_0}{1-x_0} \right) \tag{3}
\]

\[
r_g = \frac{1}{t} \left( -\ln(-\ln(x_t)) \right) + \ln(-\ln(x_0)) \tag{4}
\]

xt: the proportion of disease at the time t

xo: the proportion of disease at the beginning of the observation (t = o)

t: time

rm: the rate of Mono-molecular disease infection (per unit per time)

rl: the rate of Logistic disease infection (per unit per time)

rg: the rate of Gompertz disease infection (per unit per time)

3. **Results and Discussion**

3.1. **Condition of pepper planting at research sites**

The disease intensity survey was carried out in Simbune Village, East Kolaka Regency, which is located at S 4.00933 - S 4.02144 and E 121.8757 - E 121.8842 with an altitude of 106 - 128 m above sea level. The second location was Lawonua Village, Konawe Regency, located at S 3.98871 - S 4.01698 and E 122.2982 - E 121.88529 with an altitude of 34 - 66 m above sea level. The height in the two villages was suitable for pepper growth, as revealed by [8], which stated that pepper grew well at altitudes below 500 m above sea level.

The pepper plantations were rainfed dry land. The results of soil analysis at the study site showed soil conditions with very low to low fertility. The condition of the soil in the long term might cause plants to be susceptible to pathogenic infections [3].

Based on interviews, since the Gernas program, which began in 2009, most farmers in Simbune Village and Lawonua village had planted cocoa. However, due to the attack of pests on cocoa, farmers started to switch to planting pepper. There were three types of pepper management in Simbune and Lawonua Village, and those were monoculture (only planted with pepper using Gamal plant enforcer),
a mixture of pepper and cocoa and pepper agroforestry (with various types of plants).

The management of pepper cultivation in both villages tended not to be maintained intensively. This might be caused by farmers' perception that pepper would still bear fruit even without intensive maintenance (most farmers did not cultivate pepper and did not control pepper pests and diseases). In fact, unmaintained pepper plots were not healthy.

3.2 Pathogen, symptoms and intensity of foot rot disease

Foot rot disease is caused by *Phytophthora capsici* [19, 20]. According to [12], foot rot was a disease that is feared by farmers because it spread quickly and killed plants in a short time. Pathogenic *P. capsici*, which causes foot rot, is a soil-borne pathogen but can infect all parts of the plant. *P. capsici* could survive in the soil in the absence of a host for at least 18 months [19].

Symptoms of foot rot that attack pepper plants could be found in the leaves and foot parts. Pathogens that cause disease in the form of *P. capsici* fungus caused symptoms of spots on the leaves while the foot caused rot of foot so that the plants show wilting symptoms (Figures 1a and 1b). In newly infected plants, the lower leaves had round spots near the tips or edges of the leaves. The center of the spot was grayish-brown with a necrotic brown (dead) edge. Around the necrotic region, there was a 3-5 mm wet zone, which at the bottom had small yellowish drops. A few days later, the leaves fell. In the foot, infection occurred at the foot up to 30 cm high from the ground. If the foot was cut, it appeared brown to black. When plants began to show symptoms of wilting, their roots were still intact [21].

According to [17], foot rot symptoms in the foot is the most dangerous disease attack because it can cause plant death in a short time, while the symptoms of spots on the leaves are a source of inoculum for the occurrence of foot rot symptoms. [21] stated that the most striking symptom of foot rot disease is planted wilting. Often the leaves turn black, starting at the ends, after which the leaves fall. After wilting, the disease develops faster, so the plant dies. The dried leaves are attached to the tree, black, so the dead plants appear to have burned (Figure 1c).

![Figure 1. Symptoms of foot rot on pepper plants: (a) spotting symptoms, (b) withered symptoms and (c) dead pepper.](image)
absence of root contact between pepper plants. [22] said that one of the mechanisms for the spread of pathogens *P. capsici* is through root contact.

In December 2013 and in March 2014, there was a high increase in the disease intensity in the two villages. This is caused by several factors that cause the disease to develop rapidly. One of them might be due to the high rainfall in the two months. Pathogens may develop optimally at high humidity, which usually correlates to high rainfall. Rainwater splashes might help spread pathogens to plants. Pathogens can also be spread through the surface runoff because the gardens are clean from weeds [17, 21,23].

![Figure 2. The intensity development of foot rot in Simbune village.](image)

![Figure 3. The intensity development of foot rot in Lawonua village.](image)
Falling soil temperatures spurred wandering spores (zoospores) as a result of high rainfall [21]. The soil containing the spore was carried by rain sparks and attached to the leaves and caused an infection. The attack on the leaves allowed for infection at the foot to get larger.

The disease intensity in Simbune Village was lower than in Lawonua Village, both in leaf symptoms and foot symptoms in all three cropping patterns. This might occur due to different management in the two villages. In the Simbune village, weeds in the pepper garden were left while in Lawonua, weeds in the pepper garden were cleaned. The existence of weeds is a barrier to the spread of *P. capsici* through surface runoff or water splashes. The results of the study by [23] also show the same thing that on land with many weeds, the intensity of the disease is low compared to land with little weeds.

### 3.3 Model of Foot Rot Disease Development

The result of foot rot observations showed that the disease intensity increased over time. The model of accuracy test was performed to determine the disease development model by comparing the largest $R^2$ value and the smallest SE value from three disease development models (Monomolecular, Logistics and Gompertz). The model of accuracy test results are presented in Table 1.

| Location        | Pattern            | Parameter | Monomoleculer | Logistik | Gompertz |
|-----------------|--------------------|-----------|---------------|----------|----------|
|                 |                    |           | leaf | foot | leaf | foot | leaf | foot |
| Simbune village | Monoculture        | $R^2$ (%) | 73.5 | 85  | 68.8 | 84  | 70.5 | 84  |
|                 |                    | SE        | 0.01 | 0.08 | 0.78 | 0.29 | 0.32 | 0.15 |
|                 | Pepper with cocoa  | $R^2$ (%) | 95.06| 95  | 93.9 | 97  | 94.5 | 97  |
|                 |                    | SE        | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
|                 | Agroforestry       | $R^2$ (%) | 79.1 | 84  | 74.6 | 57  | 76.3 | 57  |
|                 |                    | SE        | 0.00 | 0.00 | 0.12 | 0.88 | 0.00 | 0.12 |
| Lawonua village | Monoculture        | $R^2$ (%) | 89   | 95  | 85   | 94  | 87   | 95  |
|                 |                    | SE        | 0.01 | 0.02 | 0.04 | 0.05 | 0.02 | 0.03 |
|                 | Pepper with cocoa  | $R^2$ (%) | 80   | 95  | 74   | 96  | 77   | 97  |
|                 |                    | SE        | 0.02 | 0.00 | 0.13 | 0.03 | 0.05 | 0.00 |
|                 | Agroforestry       | $R^2$ (%) | 74   | 82  | 68   | 85  | 69   | 85  |
|                 |                    | SE        | 0.02 | 0.00 | 0.26 | 0.24 | 0.06 | 0.03 |

Note: $R^2$ = coefficient of determination
SE = square of the error

Based on Table 1, for the most part, the disease development model followed the mono-molecular model. In Simbune Village, in the pepper+cocoa pattern with foot symptoms, the appropriate disease development model was the Gompertz model. In Lawonua Village, in the pepper+cocoa pattern and agroforestry pattern with symptoms of foot disease, the appropriate disease development model is the Gompertz model.

The pathogen development cycle occurred repeatedly and was influenced by the host plant and its environment pathogens developed in host plants and produce new inoculums as soon as possible. In turn, pathogens spread to new locations to start new infections. Pathogens that have only one development cycle (one cycle of infection) in each plant life cycle are called monocyclic. Meanwhile, pathogens that have more than one cycle of infection in each planting life cycle are called polycyclic.
The mono-molecular development model is included in the monocyclic cycle. However, the logistic model and the Gompertz model include the polycyclic cycle [24].

In the monocyclic cycle, the primary inoculum is the only inoculum available during the season. It is because there was no secondary inoculum and secondary infection. However, the number of inoculums produced at the end of the season was higher than the inoculums produced at the beginning of the season. Therefore, the number of inoculums increases continuously from year to year. Disease transmitted through the soil is one of the pathogens, including monocyclic. In the polycyclic cycle, the primary inoculum generally consists of sexual spores. The number of sexual spores and causes of infection is usually small. If the initial infection occurs, some asexual spores will be produced (secondary inoculum) on each infected part. It can cause new (secondary) infections, which can produce more asexual spores and more infections. Polycyclic pathogens are mainly dispersed by air or vectors (insects) [25].

*P. capsici* is a soil-borne pathogen. Soil-borne pathogens generally follow the monocyclic cycle because the inoculum remains throughout the year [24]. This could be seen from the disease development model, which mostly follows the Mono-molecular model. According to [26], the development model of certain diseases can be monocyclic (Mono-molecular) and can also be polycyclic (Logistic or Gompertz). It is because the development of the disease is strongly influenced by the surrounding environment so that it can change if the environment around the plant population changes. This is indicated by the presence of a polycyclic disease development model (Gompertz) in several patterns at the study site. The results of the Bande [23] study also showed the same thing. The development model of pepper foot rot disease followed the Monomolecular, Gompertz, and Logistic models depending on the appropriate environmental conditions.

In monoculture pepper patterns, all models of disease development in both leaf and foot symptoms followed the monocyclic cycle. Meanwhile, in monoculture patterns, the primary inoculum found on the land mainly caused by the availability of hosts for pathogens continuously. So that the pathogenic infections from one plant to another were easier and unobstructed by other types of plants. In the cocoa with pepper patterns and agroforestry patterns, the development of the disease occurred in the polycyclic. The presence of other plant types in both patterns caused the least number of primary inoculums that can infect plants. Eventually, it stimulated the formation of asexual spores (secondary inoculums) and made secondary infections.

The rate of infection is a number that shows how fast the pathogen population is developing. The rate of foot rot pepper infection in three patterns in two locations is presented in Table 2 and Table 3.

**Table 2.** The rate of foot rot infection disease in Simbune village.

| Observation period | Rate of infection (r) (per unit per month) |
|--------------------|-----------------------------------------|
|                    | Monoculture                             | Pepper with cocoa | Agroforestry |
|                    | Leaf | Foot | Foot | Leaf | Foot | Foot |
| 1                   | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2                   | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3                   | 0.084 | 0.002 | 0.013 | 0.019 | 0.027 | 0.000 |
| 4                   | 0.096 | 0.005 | 0.009 | 0.030 | 0.020 | 0.000 |
| 5                   | 0.077 | 0.004 | 0.009 | 0.024 | 0.016 | 0.000 |
| 6                   | 0.074 | 0.010 | 0.009 | 0.023 | 0.013 | 0.000 |
| 7                   | 0.074 | 0.156 | 0.009 | 0.050 | 0.016 | 0.006 |
| 8                   | 0.064 | 0.145 | 0.009 | 0.056 | 0.014 | 0.008 |
| 9                   | 0.057 | 0.139 | 0.008 | 0.053 | 0.013 | 0.008 |
| 10                  | 0.052 | 0.127 | 0.008 | 0.058 | 0.012 | 0.009 |
| 11                  | 0.047 | 0.122 | 0.009 | 0.055 | 0.012 | 0.012 |
Based on Table 2 and Table 3, the infection rate varied between locations. This is because the disease development model varies in each location. Based on the two tables, the infection rate with leaf spot and foot rot symptoms in the monoculture pattern was higher than other patterns. In leaf symptoms, in the third and fourth months, the rate of infection has increased. This might be due because there are quite a lot of available inoculums, enough host tissue to be infected, and the weather that supports infection. The next phase of infection rates began to decrease because healthy tissue begins to decline. In contrast to foot symptoms, infection rates tend to increase with increasing time. This might be due to the availability of inoculums and host tissue that can still be infected. The results of various analyses of cropping patterns' effect on infection rates were presented in Table 4.

The average rate of foot rot disease infection in three patterns was presented in Table 5.

### Table 3. The infection rate of foot rot disease in Lawonua village.

| Observation period | Monoculture | Pepper with cocoa | Agroforestry |
|--------------------|-------------|-------------------|--------------|
|                    | Leaf Foot   | Leaf Foot         | Leaf Foot    |
| 1                  | 0.000 0.000| 0.000 0.000       | 0.000 0.000  |
| 2                  | 0.000 0.000| 0.000 0.000       | 0.000 0.000  |
| 3                  | 0.000 0.049| 0.015 0.024       | 0.003 0.012  |
| 4                  | 0.083 0.093| 0.103 0.052       | 0.123 0.009  |
| 5                  | 0.080 0.078| 0.104 0.082       | 0.106 0.014  |
| 6                  | 0.077 0.149| 0.086 0.068       | 0.088 0.012  |
| 7                  | 0.078 0.168| 0.085 0.103       | 0.080 0.114  |
| 8                  | 0.068 0.153| 0.074 0.090       | 0.078 0.100  |
| 9                  | 0.061 0.138| 0.066 0.080       | 0.069 0.090  |
| 10                 | 0.064 0.147| 0.066 0.089       | 0.062 0.083  |
| 11                 | 0.061 0.139| 0.060 0.083       | 0.058 0.079  |
| 12                 | 0.057 0.134| 0.061 0.090       | 0.053 0.100  |
| Average            | 0.056 0.070| 0.008 0.035       | 0.013 0.005  |

### Table 4. Variance results in the effect of plant patterns on the rate of foot rot disease infection.

| Village | Symptoms | Source | Sum of squares | Free degree | Middle square | F     | Sig.    |
|---------|----------|--------|----------------|-------------|---------------|-------|---------|
| Simbune | Leaf     | Pattern| 0.017          | 2           | 0.008         | 25.35 | 0.000*  |
|         | Foot     | Pattern| 0.026          | 2           | 0.013         | 7.141 | 0.003*  |
| Lawonua | Leaf     | Pattern| 0.000          | 2           | 0.000         | 0.171 | 0.844   |
|         | Foot     | Pattern| 0.018          | 2           | 0.009         | 3.944 | 0.029*  |

Information: * significantly different
Table 5. The average rate of foot rot disease infection in three patterns.

| Location      | Pattern               | The average rate of infection per unit per Month | Leaf     | Foot     |
|---------------|-----------------------|-----------------------------------------------|----------|----------|
| Simbune       | Monoculture           |                                              | 0.0557 a | 0.0706 b |
| Village       | pepper with cocoa     |                                              | 0.0077 a | 0.0351 ab|
|               | Agroforestry          |                                              | 0.0128 a | 0.0047 a |
| Lawonua       | Monoculture           |                                              | 0.0524 a | 0.1040 b |
| Village       | pepper with cocoa     |                                              | 0.0600 a | 0.0634 a |
|               | Agroforestry          |                                              | 0.0600 a | 0.0511 a |

Information: Values followed by different letters (a) or (b) show significant differences (95% confidence level) according to Duncan’s Multiple Difference Test.

In both villages, the rate of infection of foot rot disease in both leaf symptoms and foot symptoms was significantly different in the three planting patterns except for symptoms in leaves in Lawonua Village. In Lawonua village, farmers are more intensively cleaning the garden, which likely to lessen the infection rate as the leaves that fall due to leaf spots were disposed of. Monoculture patterns showed the highest rate of infection among all patterns. The higher the infection rate, the shorter the period of disease progression have become. These results indicated that the presence of other types of plants might reduce the rate of disease development.

The presence of other types of plants may inhibit the spread of pathogens because there is no root contact between diseased pepper plants. This is due to the other type of roots plants not to become a pathogenic host. In addition to greater phylogenetic distances between plants, species can reduce the numbers of the two species are hosts for the same pathogenic species [27].

4. Conclusion
The intensity of foot rot disease with symptoms of leaf spot and foot rot symptoms continued to increase until the end of the observation. The attack intensity on agroforestry patterns (26% - 33%) and pepper + cocoa patterns (17% - 35%) were lower than that on pepper monoculture patterns (85% - 90%). On the agroforestry pattern, the infection rate of foot rot (with a value of 0.00-0.051) was the lowest among other patterns. Therefore, the agroforestry pattern for pepper cultivation is recommended to decrease foot rot disease.

Acknowledgments
The authors would like to thank Global Affairs Canada (GAC) implemented by the World Agroforestry Center (ICRAF) in the AgFor Sulawesi Project (2013 - 2017). We also would like to thank the Agroforestry Research and Development Institute for trusting us in doing research that was also supported by the available facilities.

Reference
[1] Ahmed A S, Sanchez C P, Egea C and Candela M 1999 Evaluation of Trichoderma harzianum for controlling root rot caused by Phytophthora capsici in pepper plants Plant Pathol 48 58–65
[2] Mayrowani H and Ashari 2011 Pengembangan agroforestry untuk mendukung ketahanan pangan dan pemberdayaan petani sekitar hutan Forum Penelit. Agro. Ekon. 29 83–98
[3] Nair P K R Agroforestry systems and environmental quality: Introduction 2011 J. Environ. Qual. 40 784–90
[4] Jose S, Gillespie A R and Pallardy S G 2004 Interspecific interactions in temperate agroforestry
[5] Tscharntke T, Clough Y, Bhagwat S A, Buchori D, Faust H and Hertel D Multifunctional shade-tree management in tropical agroforestry landscapes – a review 2011 J. Appl. Ecol. 48 619–29

[6] Mercer D E and Pattanayak S K 2004 Agroforestry Adoption By Smallholders. In: Sills EO K LA, editor. For. a Mark. Econ., Netherlands: Kluwer Academic Publishers p. 283–99

[7] Mercer D E 2004 Adoption of agroforestry innovations in the tropics: A review Agrofor. Syst. 61 311–28

[8] Pattanayak S K, Mercer D E, Sills E and Yang J-C 2003 Taking stock of agroforestry adoption studies Agrofor. Syst. 57 173–86

[9] Rajati T 2011 Lada perdu sebagai alternatif dalam pemanfaatan lahan kehutanan dan peningkatan kualitas lingkungan Gea.11 77–85

[10] Kurnianto D T, Suharyono and Mawardi K 2016 Daya saing komoditas lada Indonesia di pasar internasional (Studi tentang ekspor lada Indonesia tahun 2010-2014) J. Adm. Bisma 40 58–64

[11] Kardian A, Laba I W and Rismayani 2018 Peningkatan daya saing lada (Piper nigrum L.) melalui budidaya organik Perspektif 17 26–39

[12] Manohara D, Mulya K, Purwantaara A and Wahyuno D 2004 Phytophthora capsici on Black pepper in Indonisea in. Canberra, Australia: Australian center for international agricultural research

[13] Drenth A and Sendall B 2004 Economic impact of Phytophthora diseases in Southeast Asia ACIAR Monogr. 238

[14] Drenth A and Guest D I 2004 Diversity and management of Phytophthora in Southeast Asia ACIAR Monogr. 114 7–9

[15] Ristaino J B and Johnston S A 1999 Ecologically based approaches to the management of Phytophthora blight on Bell Pepper Plant. Dis. 83 1080–9

[16] Anith K N, Radakhrishnan N V and Manomohandas T P 2003 Screening of antagonistic bacteria for biological control of nursery wilt of black pepper (Piper nigrum) Microbiol. Res. 158 91–7

[17] Manohara D 2007 Bercak daun Phytophthora sebagai sumber inokulum penyakit busuk pangkal batang lada (Piper nigrum L.) Bul. Littro. XVIII 177–87

[18] Rivai F 2009 Dimensi waktu dan ruang penyakit tumbuhan. Padang: Universitas Baiturrahman;

[19] Lee B S and Lum K Y 2004 Phytophthora disease in Malaysia In: Drenth A and Guest DI (Eds). Diversity and Management of Phytophthora in Southeast Asia ACIAR Monogr. 238

[20] Truong N-V, Burgess L W and Liew E C Y 2008 Prevalence and aetiology of Phytophthora foot rot of black pepper in Vietnam Australas. Plant. Pathol. 37 431–42

[21] Semangun H 2000 Penyakit-penyakit Tanaman Perkebunan di Indonesia ke-empat Yogyakarta: Gadjah Mada University Press

[22] Ristaino J and Gumpertz M 2000 New frontiers in the study of dispersal and spatial analysis of epidemics caused by species in the genus Phytophthora Ann. Rev. Phytopathol. 38 541–76

[23] Bande L O S 2012 Epidemi Penyakit Busuk Pangkal Batang Lada di Provinsi Sulawesi Tenggara. Universitas Gadjah Mada

[24] Nirwanto H 2007 Pengantar Epidemi dan Manajemen Penyakit Tanaman. Surabaya: UPN "Veteran"

[25] Agrios G N 1996 Ilmu Penyakit Tumbuhan. ke-tiga. Yogyakarta: Gadjah Mada University Press

[26] Rivai F 2010 Dasar-Dasar Epidemi Penyakit Tumbuhan. Padang: Universitas Baiturrahmah

[27] Ampt E A, Ruijven J Van, Raaijmakers J M, Termorshuizen A J and Mommer L 2019 Linking ecology and plant pathology to unravel the importance of soil-borne fungal pathogens in species-rich grasslands Eur. J. Plant. Pathol. 154 141–56