# Reduced Incidence of Purple Blotch and Cercospora Leaf Spot in Garlic Through Relay Cropping and Spatial Crop Management

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## ABSTRACT

Ecological pest management is an approach that uses compatible pest control techniques to promote sustainable production under varying environmental conditions. This study aimed to identify the effective management techniques and crop assemblages that sustain the performance of the garlic production system. The effectiveness of habitat management was evaluated using different relay cropping systems, planting distances, and trap and band crops to manage diseases, such as purple blotch *(Alternaria porri)* and cercospora leaf spot *(Cercospora duddiae)*, and to improve yield. Results showed that planting six rows of garlic every two rows of tomato effectively controls purple blotch occurrence at bulb development (65.39%) and maturity stage (57.15%). Cercospora leaf spot was also reduced by up to 32.50% at maturity under a similar relay cropping system, followed by planting of six rows of garlic and one row each of tomato and corn. The inclusion of tomato and corn served as an effective biological control agent and a physical barrier because tomato exhibits antifungal properties and corn has tall height and broad leaves, which help reduce disease incidence and spread and lead to higher yields and net profits. These systems yielded 3.77 and 3.90 t ha$^{-1}$, respectively. Planting distance also significantly influences disease incidence and yield. Those garlic plants planted at a distance of 20 cm x 15 cm produced the highest yield of 2.55 t ha$^{-1}$, with an increase of 18.43% compared to other distances. The use of trap and band crops, such as marigolds and corn, also decreases pest occurrence and improved crop quality as well as attract natural enemies and pollinators. Overall, the use of relay cropping, planting distances, and integration of band and trap crop reduces disease incidence and severity, increases yield and profitability, and enhances ecological stability. Thus, reduces the use of synthetic pesticide and promotes long-term sustainability and productive garlic farming.

***Keywords****: Ecological pest management, garlic farming, relay cropping system, planting distance, trap and band crops*

## Introduction

Ecological Pest Management (EPM) is a holistic approach that controls the population of pests through ecologically balanced and environmentally sustainable practices (Vasuki and Kavipriya, 2024). It is associated with the principles of Integrated Pest Management (IPM), which involve the combined application of compatible pest control techniques, such as cultural, mechanical, physical, biological, and, when necessary, chemical methods to maintain pest populations below the economic injury level while safeguarding human, animal, and environmental health. Within this framework, the EPM promotes the cultivation of healthy crops through the establishment of natural and cultural processes that include host plant resistance, habitat manipulation, and biological control. Using these approaches will strengthen the natural regulatory mechanisms of agroecosystems as well as reduce the dependence on synthetic pesticides and promote long-term sustainability. Chemical interventions are only employed when these natural regulations fail to effectively suppress the pest population (Frison et al., 1998; Climate Technology Center and Network, n.d.).

The EPM is based on the biodiversity of the agroecosystem, where high biodiversity stabilizes natural enemies, which subsequently reduces pest populations, while biodiversity loss results in more severe infestations (Pesticide Action Network America, 2009; Climate Technology Center and Network, n.d.). The conventional agriculture characterized by monocropping and excessive use of synthetic pesticides has led to several environmental issues, such as water pollution, biodiversity loss, soil degradation, and pesticide resistance. These practices disrupt the crop and the environment's natural control mechanisms and compromise long-term productivity.

The ecological practices, which include the use of relay cropping, crop spacing, and inclusion of traps and band crops in the field, could enhance on-farm biodiversity and provide habitats for beneficial organisms. Among these practices, relay cropping is a technique where succeeding crops are introduced into an existing standing crop several weeks before the first crop is harvested (Queen et al., 2009; Tanveer et al., 2017). This approach increases farm productivity and allows two or more crops to be harvested within a single growing period, and effectively addresses the time gap between planting schedules. It also improves soil quality, increases net return, and maximizes land-use efficiency. Moreover, it reduces weed infestations and other pest incidences, thus reducing reliance on chemical pesticides (Jabbar et al., 2011; Bandyopadhyay et al., 2016; Tanveer et al., 2017).

Planting distance is another important cultural factor that influences disease development and crop productivity. It is necessary to determine the most appropriate plant spacing and number of plants per unit area of soil to achieve optimal yield, as this improves air circulation, enhances light penetration, and inhibits disease progression and the spread of foliar diseases (Fathi, 2006; Fakhar et al., 2019). Optimized spacing can also affect the resource competition and soil conditions, hence making it a vital consideration in the development of ecologically based management strategies.

In the Philippines, particularly in the Ilocos Region, garlic (*Allium sativum* L.) is known as “White Gold” for it is a high-value crop and an important source of income for farmers (Department of Agriculture, 2021). Despite its economic significance, the garlic industry continues to face several constraints that include low yield potential of the existing varieties, limited access to high-quality planting materials, post-harvest losses (Elias and Camalig, 2023), and the increasing incidence of pests and diseases. Fungal pathogens such as cercospora leaf spot *(Cercospora duddiae)* and purple blotch *(Alternaria porri),* as well as root rot caused by either *Fusarium* or *Sclerotium sp.*, along with viral diseases, insect pests (mites, thrips, and storage pests), and weeds, have resulted in yield reductions of up to 78%.

In view of the above challenges, there is a need to develop and implement ecologically based pest management strategies that enhance the stability and resilience of the garlic production system. Therefore, this study aimed to identify effective management techniques and crop assemblages that sustain the performance of the agroecosystem. Specifically, it sought to (1) determine the relationship between plant ecosystem composition and the fluctuation of pest and natural enemy populations, and (2) develop eco-friendly control techniques using cultural and biological approaches that suppress pest populations while maintaining environmental balance.

## Methods

### Locale of the Study

The study was conducted at Mariano Marcos State University in the City of Batac, Ilocos Norte, and comprehensively divided into three major experiments.

***Experiment 1. Habitat Management through Manipulation of the Farm Ecosystem using Relay Crops.***

The effectiveness of tomato (*Solanum lycopersicum* L.) and corn (Zea mays L.) as relay crops was evaluated to manage major fungal diseases of garlic, including purple blotch and cercospora leaf spot. This was done from November 2020 to February 2021. The following relay cropping system serves as the treatments: (a) three rows of garlic every one row of tomato; (b) three rows of garlic every one row of corn; (c) six rows of garlic every two rows of tomato; (d) six rows of garlic every two rows of corn; (e) six rows of garlic every one row of tomato and two rows of corn; and (f) garlic monocrop (Control).

The Ilocos White garlic variety was used as the planting material. Garlic cloves were planted on November 15 at a distance of 20 cm x 20 cm. Fertilization followed the recommended rate of 120-60-60 kg $ha^{-1}$. Organic fertilizer was applied at 40 bags $ha^{-1}$ supplemented with 14-14-14 applied as basal and 21-0-0 as side-dress.

Tomato was selected as a relay crop due to its characteristic odor and antifungal properties. Its leaf volatiles and non-edible parts contain an antimicrobial compound that inhibits fungal growth and development (Buttlery et al, 1987; Zhang et al., 2008; Kim et al., 2014; Kim et al., 2019). Tomato MMSU Tm 1 variety was relay-cropped 30 days after planting (DAP) with a row spacing of 1.5 m and a spacing of 1 m between crops. Organic fertilizer (8-12 bags ha-$^{1}$) was applied, with 14-14-14 applied as basal at 20-30 g per plant. Side-dressing was carried out at three, seven, and 11 weeks after transplanting (WAT) using 46-0-0 and 0-0-60 at 10 g and 5 g per plant, respectively, equivalent to approximately 12 bags of 46-0-0 and 6 bags of 0-0-60 per $ha^{-1}$ (Nalundasan et al., 2019).

The corn MMSU Glut-1 variety was evaluated as a potential physical and biological barrier crop to reduce pest movement and disease spread. Corn was relay-cropped at 45 DAP with 1.5 m space between rows, 0.5 m between crops, and 40 cm per hill. Complete fertilizer was applied at the rate of 60-60-60 kg NPK $ha^{-1}$ as basal during planting and 60 kg N $ha^{-1}$ as side-dress at 21 days after emergence (DAE) (Remolacio and Constante, 2018).

Standard management cultural practices were uniformly applied across treatments. Mulching was done in all garlic plots, while weeding and irrigation were performed as needed to maintain consistent crop conditions. No chemical spraying was applied throughout the experiment.

Tomatoes and corn were relayed at 30 and 45 DAP, respectively, to allow garlic plants to establish and grow without being shaded by these taller crops and to ensure optimal light interception during early growth and development.

The incidence of garlic diseases was recorded from 30 DAP and monitored at different growth stages of the crop, particularly during vegetative (0-44 DAP), bulb initiation (45-60 DAP), bulb development (61-75 DAP), and bulb maturity (76-90 DAP). The following disease rating scales were used:

Purple Blotch Rating Scale

0- No symptoms
1- Low disease intensity (one or a few small spots)
2- Intermediate intensity (30-50% of the total leaf area blighted)
3- High disease intensity (more than 50% of the total leaf area)
4- All leaves blighted

Cercospora Leaf Spot

0- No disease symptoms
1- Few spots toward tips covering 10% leaf area
2- Several dark brown spots covering 20% leaf area
3- Several spots with paler outer zone covering up to 40% leaf area
4- Leaf streaks covering up to 75% leaf area or breaking the leaves
5- Complete drying of the leaves or breaking of the leaves at the center

***Experiment 2. Habitat Management using Appropriate Planting Distance.***

Crop density and distance can significantly influence and affect the development and spread of pests and diseases in garlic. Higher plant densities tend to increase disease incidence by facilitating the transfer of inoculum between adjacent plants, increasing leaf contact, and creating favorable microclimate conditions. Proper planting distance improves air circulation and reduces humidity, thus establishing an environment less conducive to the proliferation of pests and diseases.

During field visits, farmers have been observed adopting different planting distances, which may also affect garlic productivity and susceptibility to pests and diseases. Some of the planting distances used by the farmers and methods described by Fakhar et al. (2019), with slight modifications, were adopted in the experiment, wherein three planting distance treatments were established: (a) 15 cm x 15 cm; (b) 20 cm x 15 cm; and (c) 20 cm x 20 cm (Control). The experiment was set up from November 2021 to February 2022.

All the management cultural practices for garlic done in Experiment 1 were followed in this study, except for planting distance, which was used as the main experimental variable. Data on pest and disease incidence, agronomic and yield components, and cost and return analysis were documented using the same procedures and statistical methods described in Experiment 1. Weather data were also recorded throughout the cropping period.

***Experiment 3: Enhancing the Activities of Biological Control Agents Using Trap and Band Row Crops.***

Biological control involves the use of natural enemies, such as predators and parasitoids, to control pest populations. Its main goal is not to eliminate pests, but to maintain their populations below economic threshold levels. Therefore, ecological balance is preserved, and natural enemies that depend on these populations are sustained. The effectiveness of biological control as an ecosystem service is highly dependent on farm design and cultural practices used to conserve beenficial microorganisms.

For habitat manipulation in this study, trap-and-band row crops, such as marigold (*Tagetes erecta* L.) and corn, were integrated around the garlic experimental plots in experiments 1 and 2. These crops were considered to improve the habitat diversity and provide structural and floral resources that support the activity of natural enemies and pollinators within the garlic ecosystem. Along the borders, marigolds were transplanted, while corn was planted at the outer periphery. Both crops had been planted asynchronously with garlic to ensure their presence during the critical period of disease occurrence.

Marigold was sown at a distance of 30 cm and fertilized following the recommended rate of 45-90-75 kg NPK $ha^{-1}$ as basal and 45 kg N $ha^{-1}$ as top dressing 45 DAP (TNAU Agritech Portal, 2021). Weeding and irrigation were applied to these crops as needed. Corn was planted at a 0.5 m spacing, consistent with the spacing in the relay crop setup in Experiment 1, and similar cultural practices were followed.

Although quantitative data on the population and activity of natural enemies were not recorded. Their presence was observed at various stages of garlic crops, such as vegetative, bulb initiation, bulb development, and bulb maturity.

## Results and Discussion

### Experiment 1. Habitat Management through Manipulation of the Farm Ecosystem Using Relay Crops

Manipulation of the farm ecosystem using relay crops can produce direct and indirect effects on the occurrences of fungal diseases, as well as agronomic and yield characteristics of garlic.

#### *Fungal Diseases*

Purple Blotch. The incidence of purple blotch was first observed in older leaves, typically the third or fourth lower leaves of garlic at the bulb initiation stage, mainly during 45 to 60 DAP. However, significant differences among treatments were noted from bulb development to maturity, indicating that the various relay cropping systems used as habitat manipulation strategies effectively influence disease occurrence (Table 1). Among the treatments, the relay cropping system of six rows of garlic with every two rows of tomato exhibited the lowest incidence of infection, ranging from 12.00% to 20.00%. This was followed by six rows of garlic with one row of tomato and one row of corn, with a 26.67% infection rate at bulb maturity. These findings indicated that the use of tomato and corn as relay cropping decreased the incidence of purple blotch by 26.94 to 57.15% as compared to other treatments. This might be due to the fact that tomatoes have antifungal properties that may have contributed to the suppressive effect. Tomato leaf volatiles (TLVs) exhibit potent antifungal activity against several plant pathogenic fungi, including *Botrytis fuckeliana, Colletotrichum cingulatum*, *Fusarium oxysporum f. sp. melonis, Fusarium oxysporum f. sp. lycopersici, Glomerella cingulata,* and *Rhizoctonia solani.* Furthermore, the leaves of tomato plants contain pesticidal phenolic compounds and alkaloids that enhance their antifungal potential (Kobayashi et al., 2015; Kim et al., 2014; Kim et al., 2019).

Thus, their presence in the garlic relay cropping system may also function as a biological control agent against the causal organism of purple blotch*, Alternaria porri,* and reduce the need for hazardous pesticides.

**Table 1**. Incidence of Purple Blotch *(Alternaria porri)* and Cercospora leaf spot *(Cercospora duddiae)* at different growth stages of garlic as affected by relay cropping to manipulate the farm ecosystem.

| Relay Cropping System | Purple Blotch | | | | | | | | | Cercospora Leaf Spot | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bulb Initiation Stage | | | Bulb Development Stage | | | Bulb Maturity Stage | | | Bulb Development Stage | | | Bulb Maturity Stage | | |
| | %D | RS | %C | %D | RS | %C | %D | RS | %C | %D | RS | %C | %D | RS | %C |
| | ns | | | ** | | | ** | | | ns | | | * | | |
| 3 rows of garlic every 1 row of tomato | 2.67 | 1 | 100.00 | $20.00^{bc}$ | 1 | 42.31 | $30.00^{bc}$ | 2 | 35.72 | 21.33 | 2 | 11.13 | $37.33^{b}$ | 3 | 30.00 |
| 3 rows of garlic every 1 row of corn | 0.00 | 0 | 0.00 | $17.33^{bc}$ | 1 | 50.01 | $38.33^{ab}$ | 2 | 17.87 | 25.33 | 2 | -5.54 | $40.00^{ab}$ | 3 | 25.00 |
| 6 rows of garlic every 2 rows of tomato | 0.00 | 0 | 0.00 | $12.00^{b}$ | 1 | 65.39 | $20.00^{c}$ | 2 | 57.15 | 21.33 | 2 | 11.13 | $36.00^{b}$ | 3 | 32.50 |
| 6 rows of garlic every 2 rows of corn | 0.00 | 0 | 0.00 | $26.67^{ab}$ | 1 | 23.07 | $30.00^{bc}$ | 2 | 35.72 | 20.00 | 2 | 16.67 | $46.67^{ab}$ | 4 | 12.49 |
| 6 rows of garlic every 1 row of tomato and 1 row of corn | 1.33 | 1 | 100.00 | $25.33^{abc}$ | 1 | 26.94 | $26.67^{c}$ | 2 | 42.85 | 12.00 | 1 | 50.00 | $36.00^{b}$ | 3 | 32.50 |
| Garlic monocrop | 2.67 | 1 | - | $34.67^{a}$ | 2 | - | $46.67^{a}$ | 2 | - | 24.00 | 2 | - | $53.33^{a}$ | 4 | - |
| CV (%) | 79.54 | | | 9.99 | | | 5.63 | | | 20.10 | | | 7.94 | | |

**Legend:** %D- Percent Damage; RS- Rating Scale; %C- Percent Control; ns- not significant; **- significant at 1% level Vegetative stage- 0-44 days after planting (DAP); Bulb initiation stage- 45-60 DAP; Bulb development stage- 61-75 DAP; Bulb maturity stage- 76-90 DAP

**Purple Blotch Rating Scale**

0- No symptoms
1- Low disease intensity (one or a few small spots)
2- Intermediate intensity (30-50% of the total leaf area blighted)
3- High disease intensity (more than 50% of the total leaf area)
4- All leaves blighted

**Cercospora Leaf Spot**

0- No disease symptoms
1- Few spots toward tips covering 10% leaf area
2- Several dark brown spots covering 20% leaf area
3- Several spots with paler outer zone covering up to 40% leaf area
4- Leaf streaks covering up to 75% leaf area or breaking the leaves at the center
5- Complete drying of the leaves or breaking of the leaves at the center

Additionally, corn plants can further suppress the disease by altering microclimate conditions and acting as physical barriers that reduce spore dispersal due to their taller height and larger leaf size. They can modify canopy humidity and air movement, as well as disrupt the favorable conditions needed for *A. porri* infection and sporulation. Corn also serves as a non-host barrier crop that intercepts pathogen inoculum and limits the spread of pathogens from infected garlic leaves to neighboring plants. Barrier crops have been used to reduce disease spread and insect attack (Dicksen, n.d). The physical and ecological roles of corn thus work synergistically with the biochemical actions of the tomato and create a more effective and efficient integrated pest management strategy. On the other hand, monocropped garlic consistently had the highest infection rate ranging from 34.67% to 46.67% with a disease rating of 2, where 30-50% of the total leaf area was affected by blight. These findings were significantly higher than those of all other relay cropping systems with tomato and corn.

The disease incidence was also associated with prevailing weather conditions (Table 2).

**Table 2.** Correlation analysis between disease incidence and weather conditions at different growth stages of garlic as affected by relay cropping to manipulate the farm ecosystem.

| Weather Parameters | Purple Blotch | | Cercospora Leaf Spot | |
|---|---|---|---|---|
| | Computed R-Value | Rel | Computed R-Value | Rel |
| Air Temperature ($^0$C) | 0.130$^{ns}$ | very weak effect | 0.102$^{ns}$ | very weak effect |
| Minimum Temperature ($^0$C) | 0.153$^{ns}$ | very weak effect | 0.121$^{ns}$ | very weak effect |
| Maximum Temperature ($^0$C) | 0.129$^{ns}$ | very weak effect | 0.188$^{ns}$ | very weak effect |
| Rainfall (mm) | 0.813** | high effect | 0.725* | high effect |
| Relative Humidity (%) | 0.893** | very high effect | 0.935** | very high effect |
| Wind Speed (m/sec) | 0.263$^{ns}$ | weak effect | 0.145$^{ns}$ | very weak effect |
| Solar Radiation (MJ/m2) | 0.538$^{ns}$ | moderate effect | 0.860** | very high effect |

**Legend:** Rel- Relationship; ns- not significant; *- significant at 5% level; **- significant at 1% level

Among the environmental conditions, temperature showed a very weak relationship, whereas rainfall, relative humidity, and solar radiation had high, very high, and moderate effects on disease development, respectively. The influence of solar radiation suggests that light intensity plays an important role in disease expression in the field, and these confirm the results of Dar et al. (2020), who reported that the main environmental factors affecting purple blotch development were relative humidity, temperature, and light. Higher incidences were consistently recorded during bulb development up to maturity and coincide with the period of increased relative humidity (84.29%) and rainfall (3.57 mm) (Table 3).

**Table 3.** Weather data taken from the MMSU-PAGASA-PCAARRD Meteorological Station during the growing period of garlic.

| Growth Stages | Temperature ($^0$C) | | | Rainfall (mm) | Relative Humidity (%) | Wind Speed (m/sec) | Solar Radiation (MJ/m$^2$) |
|---|---|---|---|---|---|---|---|
| | Air | Min | Max | | | | |
| Vegetative Stage | 27.56 | 23.42 | 31.70 | 0.18 | 84.07 | 0.62 | 16.05 |
| Bulb Initiation Stage | 26.53 | 21.25 | 31.79 | 0.00 | 83.64 | 0.68 | 21.02 |
| Bulb Development Stage | 26.32 | 21.05 | 31.58 | 3.57 | 84.29 | 0.65 | 16.66 |
| Bulb Maturity Stage | 25.15 | 18.70 | 31.59 | 0.47 | 84.86 | 0.41 | 18.19 |

**Note:** Min – Minimum; Max – Maximum; Vegetative stage- 0-44 days after planting (DAP); Bulb initiation stage- 60 DAP; Bulb development stage- 61-75 DAP; Bulb maturity stage- 76-90 DAP

These factors significantly contribute to disease buildup as moisture and splashing rain promote spore germination and pathogen dispersal. The pathogen thrives at high relative humidity, ranging from 80 to 90%, and at temperatures between 21 to 30°C (Dar et al., 2020; Vikaspedia, 2020). Although the temperature results showed a weaker correlation, the occurrence of high relative humidity, frequent rainfall, and moderate light intensity led to an environment highly favorable for purple blotch development.

*Cercospora Leaf Spot.* Initial symptoms of Cercospora leaf spot were first observed during the bulb development stage of garlic, mostly between 61 and 75 DAP; however, their occurrence became more evident only during bulb maturity, as significant differences were observed among treatments, as shown in Table 1. Monocultured garlic had the highest infection rate of 53.33% which is comparable to six rows of garlic and two rows of corn (46.67%) and three rows of garlic and one row of corn (40.00%). Monocultures are more vulnerable to diseases due to a lack of biodiversity that promotes a homogeneous environment, which facilitates rapid pathogen buildup and spread (Ekroth et al., 2019; Kaur et al., 2014). However, integrating tomatoes into the relay cropping system has a notably lower infection rate as it is particularly advantageous due to its natural antifungal compounds and volatile substances that suppress fungal growth. This diversified plant composition can notably reduce inoculum movement, disrupt the pathogen disease development, and thus provide a biologically and environmentally sound alternative to pesticide use for safer garlic production.

The development of the disease, Cercospora leaf spot in garlic planted in different relay cropping systems, was also affected by various weather conditions (Table 2). Factors such as rainfall, relative humidity, and solar radiation showed a high-to-very-high relationship with disease incidence. Favorable conditions, mainly relative humidity between 81% to 90% (Lutap et al., 2018), adequate moisture from rainfall, overhead irrigation, or dew, and warm temperatures of >21 to 31°C, increase the rate of pathogen development and spread (Table 3). Warm temperatures often lie between 25-35 °C, coupled with adequate leaf wetness, strongly favor growth, sporulation, and infection (Dongre, 2023; Gardenia Creating Gardens, 2025). life cycle, contribute to less favorable

***Agronomic and Yield Characteristics of Garlic***

*Plant Height, Number of Leaves, and Leaf Size.* The different relay cropping systems used to manipulate ecosystems have affected garlic growth in terms of plant height, leaf number, and leaf size (Table 4). At 60 DAP, significant differences were observed in the height of the garlic plants, where the tallest were found in the monocropped garlic (51.17 cm), followed by six rows of garlic every two rows of corn (50.60 cm), and three rows of garlic every one row of corn (49.53 cm). Similarly, the monocropped garlic produced the highest number of leaves and the widest leaf width, measuring 12 and 1.37 cm, respectively, which may be attributed to lesser competition among plants for nutrients, water, and sunlight.

**Table 4.** Plant height, number of leaves, and leaf size of garlic plants as affected by relay crops to manipulate the farm ecosystem.

| Relay Cropping System | Plant Height (cm) | | Number of Leaves | | Leaf Size (cm) | |
|---|---|---|---|---|---|---|
| | 30 DAP | 60 DAP | 30 DAP | 60 DAP | Length | Width |
| | Ns | ** | ns | * | ns | ** |
| 3 rows of garlic every 1 row of tomato | 34.37 | 44.30$^{b}$ | 5 | 10$^{b}$ | 34.90 | 1.25$^{c}$ |
| 3 rows of garlic every 1 row of corn | 35.33 | 49.53$^{a}$ | 5 | 11$^{ab}$ | 36.73 | 1.32$^{abc}$ |
| 6 rows of garlic every 2 rows of tomato | 34.17 | 47.3$^{ab}$ | 5 | 10$^{b}$ | 35.33 | 1.31$^{abc}$ |
| 6 rows of garlic every 2 rows of corn | 35.20 | 50.60$^{a}$ | 5 | 11$^{ab}$ | 37.33 | 1.35$^{ab}$ |
| 6 rows of garlic every 1 row of tomato and 1 row of corn | 33.60 | 48.70$^{ab}$ | 5 | 10$^{b}$ | 36.87 | 1.27$^{bc}$ |
| Garlic monocrop | 37.07 | 51.17$^{a}$ | 5.07 | 12$^{a}$ | 37.23 | 1.37$^{a}$ |
| cv (%) | 6.12 | 3.51 | 2.25 | 2.71 | 4.70 | 2.34 |

**Legend:** DAP- Days after planting; ns- not significant; *- significant at 5% level; **- significant at 1% level

On the other hand, the study by Lui et al. (2014) found that intercropped garlic inhibits the growth of spring tomato, although this inhibition is reduced after garlic harvest. Interestingly, the result of the current experiment showed that as the garlic plants mature, the effect of tomato in certain relay cropping systems appeared to contribute positively to plant growth. This might be because tomatoes are relatively shorter than corn, have less light competition, and may have served as a potential natural deterrent to pests and diseases. The reduced biotic stress may have allowed the garlic plants to allocate their available resources to support improved and more resilient vegetative growth, especially when plants are already in their maturity stage.

*Bulb Size.* The garlic bulb size, as measured through polar and equatorial diameters, was significantly influenced by the presence of relay crops (Table 5). The bulb diameters were relatively larger in those planted with six rows of garlic every two rows of tomato, followed by monocropped garlic, and in six rows of garlic every one row of tomato and one row of corn. The increased bulb size in garlic plants relayed with tomato crops may be attributed to the more favorable growing environment, which allows garlic plants to efficiently absorb the essential resources such as nutrients, light, water, and air that are needed for optimal growth and development. In contrast, garlic plants planted in three rows of garlic every one row of corn, and six rows of garlic every two rows of corn, produced smaller bulbs, which could be due to a lack of resource absorption. Corn plants with deeper, more extensive root systems and taller canopies may have overshadowed garlic plants, limiting their access to light and reducing photosynthetic activity and bulb expansion.

*Yield.* The highest yield was obtained from the relay cropping system of six rows of garlic in every one row of tomato and one row of corn (3.90 t $ha^{-1}$) and six rows of garlic every two rows of tomato (3.77 t $ha^{-1}$). These treatments have significantly surpassed the monocrop and other relay combinations (Table 5). The higher yield performance in these systems can be attributed to reduced pest and disease incidence and improved resource use, including increased sunlight interception and enhanced nutrient uptake. The complementary growth habits of tomato and corn likely enhanced microclimatic conditions and soil nutrient balance, contributing to improved garlic vigor and bulb development. All other relay cropping treatments were statistically comparable, except for three rows of garlic every one row of corn, which produced the lowest yield of 3.10 t $ha^{-1}$. The reduced yield in this treatment may be due to the greater competition for light and nutrients, as the corn canopy may have partially shaded the garlic plants during critical growth stages, hence limiting the photosynthetic activity and bulb development. Taller corn plants could limit light penetration, creating shaded conditions that reduce photosynthetic activity. Since garlic thrives under full sunlight and cool temperatures (Hansen, 2025), excessive shading from corn may have constrained its vegetative growth and development. The relative plant heights of different crops grown in association in a relay cropping system are important as taller crops can dominate light capture and reduce photosynthesis in shorter crops (Tranbath, 1974; Abou-Keriasha, 2012). Light is one of the important growth factors affecting crop yields. Low light availability reduces photosynthetic activity and crop growth rate, and, eventually, leads to a drastic reduction in yield (Abou-Keriasha, 2012).

**Table 5.** Bulb size and yield of garlic plants as affected by relay crops to manipulate farm ecosystem.

| Relay Cropping System | Bulb Size (cm) | | Yield | |
|---|---|---|---|---|
| | Polar | Equatorial | t ha$^{-1}$ | % Increase |
| | ** | ** | * | |
| 3 rows of garlic every 1 row of tomato | 3.25$^{bc}$ | 3.30$^{a}$ | 3.40$^{ab}$ | 29.41 |
| 3 rows of garlic every 1 row of corn | 3.10$^{d}$ | 3.12$^{b}$ | 3.10$^{b}$ | -6.45 |
| 6 rows of garlic every 2 rows of tomato | 3.36$^{a}$ | 3.37$^{a}$ | 3.77$^{a}$ | 12.47 |
| 6 rows of garlic every 2 rows of corn | 3.20$^{cd}$ | 3.18$^{b}$ | 3.47$^{ab}$ | 4.90 |
| 6 rows of garlic every 1 row of tomato and 1 row of corn | 3.30$^{abc}$ | 3.31$^{a}$ | 3.90$^{a}$ | 15.38 |
| Garlic monocrop | 3.33$^{ab}$ | 3.37$^{a}$ | 3.30$^{ab}$ | - |
| cv (%) | 1.18 | 1.15 | 2.91 | |

**Legend:** *- significant at 5% level; **- significant at 1% level

### *Cost and Return Analysis*

Table 6 reveals that the garlic grown under the relayed cropping system of six rows of garlic every one row of tomato and 1 row of corn recorded the highest net return of PhP 361,311.94. It was primarily due to the higher productivity of garlic, combined with the additional income from the relayed crops of tomato and corn. Relay cropping not only diversifies farm income but also enhances total land productivity by allowing multiple harvests within a single cropping cycle. In contrast, monocropped garlic recorded the lowest net income of PhP 127,335.98 despite having a moderate yield of 3.3 t ha$^{-1}$. This may be due to the absence of secondary crops and higher vulnerability to disease pressure. The unit cost of production in the monocropping system was PHP 41.41/kg. Although slightly lower than the other treatments, this resulted in limited profit due to reduced total income.

**Table 6.** Cost and return analysis of growing garlic as affected by relay crops to manipulate farm ecosystem.

| Relay Cropping System | Yield t ha$^{-1}$ | | | Gross Income | Net Income | Production Cost | Unit Cost of Production |
|---|---|---|---|---|---|---|---|
| | Garlic | Tomato | Corn | | | | |
| 3 rows of garlic every 1 row of tomato | 3,400.00 | 14,240.00 | | 414,400.00 | 176,273.14 | 238,126.86 | 47.32 |
| 3 rows of garlic every 1 row of corn | 3,100.00 | | 4,740.00 | 342,800.00 | 168,574.78 | 174,225.22 | 52.01 |
| 6 rows of garlic every 2 rows of tomato | 3,770.00 | 15,880.00 | | 460,400.00 | 222,273.14 | 238,126.86 | 42.64 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6 rows of garlic every 2 rows of corn | 3,470.00 | | 3,870.00 | 355,000.00 | 180,774.78 | 174,225.22 | 49.09 |
| 6 rows of garlic every 1 row of tomato and 1 row of corn | 3,900.00 | 24,100.00 | 4,200.00 | 637,000.00 | 361,311.94 | 275,688.06 | 48.20 |
| Garlic monocrop | 3,300.00 | | | 264,000.00 | 127,335.98 | 136,664.02 | 41.41 |

**Farmgate Price-** PhP80.00

## Experiment 2. Habitat Management using Appropriate Planting Distance

Planting distance can be a significant factor influencing the population growth of purple blotch and cercospora leaf spot. Similarly, it can significantly affect plant yield.

### *Fungal Diseases*

*Purple Blotch.* Plant spacing had a significant influence on the incidence and severity of purple blotch in garlic (Table 7). The disease was observed to increase as plant spacing decreased, particularly at 15 cm x 15 cm, where infection started at the vegetative stage and continued up to bulb maturity. This closer spacing produced a disease rating of 3 at maturity, having a high disease intensity where more than 50% of the total leaf area was affected. The higher disease intensity observed in narrow spacing can be due to the limited air movement and increased canopy humidity, which are favorable for fungal development. Dense foliage creates a humid microenvironment that favors spore germination, mycelial growth, and conidial dispersal of *A. porri,* resulting in rapid disease development and spread within the crops. On the contrary, planting distances of 20 cm x 15 cm and 20 cm x 20 cm resulted in lower disease incidence and severity ratings because the reduced plant density may have allowed improved aeration and faster drying of the leaf surfaces, which inhibits fungal sporulation and infection. These findings suggest that planting distance can be used as an effective method to minimize the incidence while ensuring the establishment of optimal plant population and yield potential.

**Table 7**. Incidence of Purple Blotch *(Alternaria porri)* and Cercospora leaf spot *(Cercospora duddiae)* at different growth stages of garlic as affected by planting distance to manipulate the farm ecosystem.

| Relay Cropping System | Purple blotch | | | | | | | | | | | | Cercospora leaf spot | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vegetative Stage | | | Bulb Initiation Stage | | | Bulb Development Stage | | | Bulb Maturity Stage | | | Bulb Initiation Stage | | | Bulb Development Stage | | | Bulb Maturity Stage | | |
| | %D | RS | %C | %D | RS | %C | %D | RS | %C | %D | RS | %C | %D | RS | %C | %D | RS | %C | %D | RS | %C |
| | * | | | * | | | * | | | * | | | * | | | ns | | | * | | |
| 15 cm x 15 cm | 41.33$^{a}$ | 1 | -47.61 | 66.67$^{a}$ | 1 | -41.49 | 69.33$^{a}$ | 1 | -18.17 | 92.00$^{a}$ | 3 | -16.94 | 14.67$^{a}$ | 1 | -119.94 | 22.67 | 2 | -41.69 | 72.00$^{a}$ | 3 | -35.01 |
| 20 cm x 15 cm | 33.33$^{ab}$ | 1 | -19.04 | 37.33$^{b}$ | 1 | 22.23 | 57.33$^{b}$ | 1 | 2.28 | 74.67$^{b}$ | 2 | 5.08 | 10.67$^{ab}$ | 1 | -63.49 | 18.67 | 1 | -16.69 | 50.67$^{b}$ | 2 | 4.99 |
| 20 cm x 20 cm | 28.00$^{b}$ | 1 | - | 48.00$^{b}$ | 1 | - | 58.67$^{b}$ | 1 | - | 78.67$^{b}$ | 2 | - | 6.67$^{b}$ | 1 | - | 16.00 | 1 | - | 53.33$^{b}$ | 2 | - |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cv (%) | 5.83 | | | 6.26 | | | 3.30 | | | 3.71 | | | 11.51 | | | 10.60 | | | 5.81 | | |

**Legend:** %D- Percent Damage; RS- Rating Scale; %C- Percent Control; ns- not significant; *- significant at 5% level
Vegetative stage- 0-44 days after planting (DAP); Bulb initiation stage- 60 DAP; Bulb development stage- 61-75 DAP; Bulb maturity stage- 76-90 DAP

**Purple Blotch Rating Scale**
0- No symptoms
1- Low disease intensity (one or a few small spots)
2- Intermediate intensity (30-50% of the total leaf area blighted)
3- High disease intensity (more than 50% of the total leaf area)
4- All leaves blighted

**Cercospora Leaf Spot Rating Scale**
6- No disease symptoms
7- Few spots toward tips covering 10% leaf area
8- Several dark brown spots covering 20% leaf area
9- Several spots with paler outer zone covering up to 40% leaf area
10- Leaf streaks covering up to 75% leaf area or breaking the leaves at the center
11- Complete drying of the leaves or breaking of the leaves at the center

In addition, the incidence of purple blotch was influenced by environmental conditions such as relative humidity and wind speed (Table 8). Disease severity increases with high relative humidity (>80%), whereas wind and rainfall serve as the major agents in the dispersal of spores from infected tissue to nearby healthy plants (Tables 8 and 9). The interactions among these environmental factors, as well as the planting distances, imply the importance of microclimate management in garlic production.

**Table 8.** Correlation analysis between disease incidence and weather conditions at different growth stages of garlic as affected by planting distance to manipulate the farm ecosystem.

| Weather Parameters | Purple Blotch | | Cercospora Leaf Spot | |
|---|---|---|---|---|
| | Computed R-Value | Rel | Computed R-Value | Rel |
| Air Temperature ($^0$C) | 0.0003$^{ns}$ | very weak effect | 0.0001$^{ns}$ | very weak effect |
| Minimum Temperature ($^0$C) | 0.001$^{ns}$ | very weak effect | 0.000$^{ns}$ | No effect |
| Maximum Temperature ($^0$C) | 0.141$^{ns}$ | very weak effect | 0.114$^{ns}$ | very weak effect |
| Rainfall (mm) | 0.009ns | very weak effect | 0.653$^{*}$ | high effect |
| Relative Humidity (%) | 0.915$^{**}$ | very high effect | 0.662$^{*}$ | high effect |
| Wind Speed (m/sec) | 0.929$^{**}$ | very high effect | 0.501$^{ns}$ | moderate effect |
| Solar Radiation (MJ/m$^2$) | 0.004$^{ns}$ | very weak effect | 0.365$^{ns}$ | weak effect |

Legend: Rel- relationship; ns- not significant; *- significant at 5% level; **- significant at 1% level

*Cercospora Leaf Spot.* Planting distance also had a pronounced effect on the incidence and severity of Cercospora leaf spot in garlic. The disease occured as early as the bulb initiation stage and continued to progress until bulb maturity across all plots (Table 7). The highest percentage damage was recorded at a distance of 15 cm x 15 cm, reaching up to 72.00% at bulb maturity, followed by the 20 cm x 20 cm and 20 cm x 15 cm. Increasing the distance between plants reduces disease development, which simultaneously lowers plant population and restricts pathogen spread among plants, hence slows the epidemic buildup. This was observed by Azene and Worku (2015), as cited by Ahmed et al. (2017), who indicated that increasing planting distance will decrease the development and prevalence of fungal diseases. Environmental factors, such as relative humidity and wind speed, also exhibited significant positive correlations with disease incidence and played an important role in disease development (Table 9). The rainy, warm, and highly humid conditions further promoted pathogen buildup. Although temperature showed weaker correlation, the range of 25-35 °C was found to be favorable for *C. duddiae* development (Egel, 2020). Moreover, the use of overhead irrigation, the occurrence of drizzling rain, and windy conditions enhanced the rate of spore dispersal and infection.

**Table 9.** Weather data taken from the MMSU-PAGASA-PCAARRD Meteorological Station during the growing period of garlic.

| Growth Stages | Temperature (°C) | | | Rainfall (mm) | Relative Humidity (%) | Wind Speed (m/sec) | Solar Radiation ($MJ/m^2$) |
|---|---|---|---|---|---|---|---|
| | Air | Min | Max | | | | |
| Vegetative Stage | 28.07 | 24.39 | 31.75 | 0.03 | 84.82 | 12.62 | 15.19 |
| Bulb Initiation Stage | 27.74 | 22.77 | 32.70 | 0.00 | 84.22 | 13.39 | 18.29 |
| Bulb Development Stage | 26.03 | 20.95 | 31.10 | 1.95 | 80.72 | 19.67 | 18.64 |
| Bulb Maturity Stage | 25.05 | 18.85 | 31.24 | 1.63 | 85.64 | 11.76 | 18.91 |

***Agronomic and Yield Characters of Garlic***

*Plant Height, Number of Leaves, and Leaf Size.* Garlic plants were also affected by the distance between plants, as it influenced plant height and the number of leaves at 60 DAP (Table 10). The tallest plant height of 51.07 cm and 48.67 cm was recorded from plots with a planting distance of 20 cm x 15 cm and 20 cm x 20 cm, respectively, while the shortest, with 43.33 cm, was observed in 15 cm x 15 cm. The reduced height at closer distances may be due to competition for light, nutrients, and moisture as a result of increased plant densities. These results corroborate the findings of Jones and Mann (1963) and Brewster (1994), as cited by Ahmed (2017), that garlic planted at wider spacing has less competition for light and other resources, hence promotes better vegetative growth.

**Table 10.** Plant height, number of leaves, and leaf size of garlic plants as affected by planting distance to manipulate the farm ecosystem.

| Planting Distance | Plant Height (cm) | | Number of Leaves | | Leaf Size (cm) | |
|---|---|---|---|---|---|---|
| | 30 DAP | 60 DAP | 30 DAP | 60 DAP | Length | Width |
| | ns | ** | ns | * | ns | ns |
| 15cm x 15cm | 33.07 | 45.33[b] | 5 | 10[b] | 34.00 | 1.19 |
| 20cm x 15cm | 34.47 | 51.07[a] | 5 | 11[a] | 36.43 | 1.21 |
| 20cm x 20cm | 32.67 | 48.67[a] | 4 | 11[a] | 34.50 | 1.21 |
| CV (%) | 3.71 | 2.25 | 6.40 | 2.59 | 4.35 | 4.38 |

**Legend:** DAP- days after planting; ns- not significant; *- significant at 5% level; **- significant at 1% level

Conversely, the least number of leaves was recorded in a closer distance of 15 cm x 15 cm where this observation supports the findings of Teshale and Tekeste (2021), who reported that plants spaced farther apart produce more axillary branches than in the closely spaced plants because of increase of competition among plants for water, soil nutrients, space, light, etc., thus decreases their photosynthetic efficiency as well as leaf production.

On the other hand, no significant differences in leaf size, both length and width, were found among the various planting distance treatments.

*Bulb Size.* Different planting distances also influenced garlic bulb size, with results other distances (Table 11), These findings support the observations of Om and Srivastava (1977), Rahman and Talukdar showing that both polar and equatorial diameters were larger at planting distances of 20 cm x 20 cm and 20 cm x 15 cm than at 15 cm x 15 cm, which produced a smaller bulb (Table 11). The larger bulb size may be attributed to less competition among plants for essential growth requirements. Consequently, plants cultivated at a wider distance were perceived to have more vigorous growth and better bulb development.

*Yield.* Planting distance also had a significant effect on yield t ha$^{-1}$ where the highest yield as obtained in plants planted at 20 cm x 15 cm distance, producing 2.55 t ha$^{-1}$ with an increment of 18.43% compared to

(1986), Anwar et al. (1996), and Alam et al.

,

(2008), where crops grown at wider distances exhibit an improved yield performance due to less competition between plants in obtaining growth resources. In contrast, the lowest yield was obtained in plants planted at a 15 cm x 15 cm distance. This might be because higher plant density led to shorter plants, fewer leaves, smaller bulbs, and lower yield. Moreover, higher disease incidence was observed in plants grown at shorter distances, contributing to yield reduction.

**Table 11.** Bulb size and yield of garlic plants as affected by planting distance to manipulate farm ecosystem.

| Planting Distance | Bulb Size (cm) | | Yield | |
|---|---|---|---|---|
| | Polar | Equatorial | t $ha^{-1}$ | % Increase |
| | ** | ** | ** | |
| 15cm x 15cm | $2.88^{b}$ | $2.92^{b}$ | $1.84^{c}$ | -13.04 |
| 20cm x 15cm | $3.10^{a}$ | $3.15^{a}$ | $2.55^{a}$ | 18.43 |
| 20cm x 20cm | $3.26^{a}$ | $3.26^{a}$ | $2.08^{b}$ | - |
| CV (%) | 2.39 | 1.94 | 4.76 | |

**Legend:** **- significant at 1% level; CV – Coefficient of Variation

### *Cost and Return Analysis*

Among the three planting distances evaluated, the 20 cm x 15 cm produced the highest net income of PhP180,285.98, followed by 20 cm x 20 cm with PhP133,735.98, as shown in Table 12. The garlic planted at a closer distance of 15 cm x 15 cm incurred the highest production cost per hectare and per kilogram, resulting in the lowest marginal rate of return of 56,635.98. The higher production cost was mainly due to an increased use of planting materials (approximately >78%), greater labor requirements for planting and harvesting, and higher input consumption. Although closer spacing allows more plants per unit area, the associated expenses and the reduced bulb size and yield led to lower profitability. Thus, it is important to optimize planting distance in garlic production; wider distance, particularly 20 cm x 15 cm, offers a balance between plant population and resource efficiency, resulting in improved yield performance and economic returns. Farmers are therefore encouraged to adopt this spacing for sustainable and cost-effective garlic cultivation.

**Table 12.** Cost and return analysis of growing garlic as affected by relay crops to manipulate the farm ecosystem

| Planting distance | Yield kg | Gross Income (Php) | Net Income (Php) | Production Cost/ Hectare (Php) | Unit of Production Cost (Php/kg) | Additional Resources Needed (%)* |
|---|---|---|---|---|---|---|
| 15cm x 15cm | 1,840.00 | 239,200.00 | 56,635.98 | 182,564.02 | 99.22 | 78 |
| 20cm x | 2,550.00 | 331,500.00 | 180,285.98 | 151,214.02 | 59.30 | 33 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 15cm | | | | | | |
| 20cm x 20cm | 2,080.00 | 270,400.00 | 133,735.98 | 136,664.02 | 65.70 | |

***Additional resources** include seed materials and preparation, days of planting, harvesting, drying, sorting, and bundling
**Farm Gate Price**- PhP130

**Experiment 3: Enhancing the Activities of Biological Control Agents Using Trap and Band Row Crops**

The use of marigolds and corn as trap and band row crops can effectively protect garlic plants from pest infestations and enhance the activity of biological control agents. These crops were planted along the field margins and provided numerous advantages such as improved crop quality, increased attraction of natural enemies and pollinators, and reduced pesticide use.

The marigold serves as a trap and repellent crop because of its strong odor, which repels insect pests and attracts beneficial organisms. It provides habitat and food resources for predators and pollinators. In Experiment 1 of this research, tomato plants were relayed to garlic plants to control the attack of fungal pathogens; however, tomato fruit worm *(Helicoverpa armigera, Hubn.)* is one of the destructive pests that causes significant yield loss by feeding on tomato fruits. The use of this trap crop aids in controlling the occurrence and population of this pest. Moreover, marigold also serves as an attractant for thrips and mites from garlic, which reduces direct infestation on the main crop (Chandio et al., 2020).

The corn planted in band rows served as both a physical and biological barrier, limiting pest movement and disease spread. It also contributed additional food or income sources and provided forage for livestock.

Several natural enemies were documented across the different growth stages of garlic, including the orange lady beetles *(Micraspis hirashimai Sasaji*), wolf spiders (Pardosa) *(Lycosa pseuannulata),* red fire ants *(Solenopsis geminate, Fabricius)*, crickets *(Metioche vittaticollis, Stal),* longhorned grasshoppers *(Conocephalus longipennis),* and pollinators such as butterflies and bees (Table 13, Figure 1).

*Orange lady beetles***,** both larvae and adults, are voracious predators of sap-feeding pests, such as aphids, mites, and thrips. Their presence from bulb initiation to maturity coincides with the absence of mite infestation, locally known as "Ayam," which causes tangle top incidences and other viral diseases, such as allexiviruses, thus suggesting their potential role in suppressing the pest population.

*Wolf spiders* were commonly observed on the soil surface and mulch during bulb initiation to development stages. As active hunters, they contributed to the natural control of leaf folders and other soft-bodied insects.

*Red fire ants* were observed mainly after irrigation or soil disturbance and acted as ground-dwelling predators feeding on larvae and eggs of several insect pests, including leaf folders.

*Crickets* were noted from vegetative to bulb initiation stage and served as a predator of stemborers, leaf folders, and armyworms. It was also found that adult and nymphal feed on small larvae and hoppers (Shepard et al., 1987).

*Longhorned grasshoppers* were noted from vegetative to bulb initiation stages. During the growing period of the garlic, adjacent fields were planted with rice, which was nearly ready for harvest, and they might be exploring for an alternative plant host to find food. These insects were predators of rice bugs and stem borers, as well as plant hopper and leafhopper nymphs. Moreover, their presence was also recorded on corn plants, which indicates movement between adjacent crops.

*Butterflies and bees* were mainly observed during the bulb development to crickets primarily prey on eggs but may also the maturity stage of garlic plants. It was the time when the flowers of the marigolds and tomatoes bloomed. These beneficial insects act as important pollinators and help improve crop yield and quality.

The presence and diversity of these natural enemies and pollinators proved that there are ecological benefits of trap and band rows crops for enhancing biological control activities in garlic production. These habitat management manipulations support the reproduction, growth, and survival of various beneficial organisms, thus provides a more sustainable garlic production system that reduces pest pressures and reliance on chemical pesticides.

**Table 13.** Natural enemies observed at different stages of garlic plant growth.

| Natural Enemies | Vegetative Stage | Bulb Initiation Stage | Bulb Development Stage | Bulb Maturity Stage |
|---|---|---|---|---|
| Orange Lady Beetle | | | | |
| Larva | X | / | / | X |
| Adult | X | / | / | / |
| Wolf spider (Pardosa) | X | / | / | X |
| Red Fire Ant | / | / | X | X |
| Cricket | / | / | X | X |
| Longhorned Grasshopper | / | / | / | X |
| Butterfly | X | X | / | / |
| Bees | X | X | / | / |

**Legend:** x-not present; /-present


**Figure 1.** Natural enemies observed in the field planted with garlic **a.** orange lady beetles *(Micraspis hirashimai Sasaji*) [***Image Source:*** Predators, n.d], **b.** wolf spiders (Pardosa) *(Lycosa pseuannulata),* **c.** red fire ants *(Solenopsis geminate, Fabricius)*, **d.** crickets *(Metioche vittaticollis, Stal),* **e.** longhorned grasshoppers *(Conocephalus longipennis),* **f.** butterflies, and **g.** bees [***Image Source g:*** Bumble Bee on Marigold (2017)].

## Conclusion

Garlic farming continues to face constraints that significantly reduce production, including the increased incidence of diseases, which has led to reliance on chemical pesticides for their control. This research highlights the importance of ecologically based pest management strategies in improving the stability and sustainability of garlic production systems. Based on the following objectives: (1) determine the relationship between plant ecosystem composition and the fluctuation of pest and natural enemy populations, and (2) develop eco-friendly control techniques using cultural and biological approaches, the findings show that strategic manipulation of the garlic farm ecosystem can improve crop health, productivity, and long-term sustainability.

Certain relay cropping systems such as six rows of garlic every two rows of tomato as well as six rows of garlic every one row of tomato and one row of corn can effectively suppress disease severity and damage caused by purple blotch and cercospora leaf spot diseases compared to monocropped garlic. Monocropping is vulnerable to disease outbreaks due to a lack of biodiversity, resulting in a homogeneous environment that enables rapid pathogen buildup and spread. The inclusion of tomato and corn in the garlic cropping system may serve as an effective biological control agent and a physical barrier because the leaves of tomato exhibit antifungal properties; at the same time, corn reduces spore dispersal due to its tall height and broader leaves, resulting in suppress disease development which leads to higher yields and net profit while reducing reliance on chemical pesticides. These results emphasize the importance of diversified crop assemblages in reducing pest populations, improving agroecosystem performance, and developing sustainable tools and strategies for managing garlic pests.

Planting distance was also found to influence disease incidence and yield significantly. Plants planted at 20 cm x 15 cm and 20 cm x 20 cm had lower disease incidence than those planted at 15 cm x 15 cm. These results can be attributed to reduced plant densities, which permit improved aeration and faster drying of leaf surfaces, thus inhibiting fungal sporulation and infection. Moreover, it is influenced by environmental factors such as relative humidity, wind speed, and rainfall. Notably, garlic planted at 20 cm x 15 cm distance produced the highest yield of 2.55 t $ha^{-1}$, which produced an 18.43% increase in productivity compared to other distances. It also generated the highest net income. These results show that planting distance proves to be effective in controlling diseases and contributes to increasing garlic production; however, it must be emphasized that there is a need to balance plant density with disease management considerations.

The use of trap crops and band rows, such as marigolds and corn, respectively is also encouraged to suppress the occurrence of destructive pests, enhance the activity of biological control agents such as natural enemies and pollinators, improve crop quality, and decrease pesticide use. A diverse assemblage of natural enemies was observed throughout the growing period of garlic, such as orange lady beetles *(Micraspis hirashimai Sasaji*), wolf spiders (Pardosa) *(Lycosa pseuannulata),* red fire ants *(Solenopsis geminate, Fabricius),* cricket *(Metioche vittaticollis, Stal),* longhorned grasshopper (*Conocephalus longipennis),* as well as pollinators like butterflies and bees. The occurrence of these beneficial arthropods varies across different growth stages. Additionally, it plays an important ecological role in regulating pest populations and pollinating plants, which underscores the need for the application of biologically informed farm design.

Based on the above findings, the effectiveness of the relay cropping system, planting distance, and conserving and managing biological control agents, such as natural enemies and pollinators, through trap and band crops, provides a safe, effective, and efficient as well as ecologically based strategy to manage pests in garlic. Such approaches enhance pest regulation by reducing disease incidence and severity, increasing yield and profitability, and sustaining environmentally friendly, resilient, and productive garlic farming.

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