DEVELOPMENT OF SUSTAINABLE DISEASE MANAGEMENT STRATEGIES IN STRAWBERRY PRODUCTION IN BENGUET, PHILIPPINE: A REVIEW

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ABSTRACT

Strawberry is grown only in Benguet Province because of its unique climatic conditions required by the crop. It has been a lucrative source of income for farmers adding revenue as well to the province of Benguet . However, diseases are important limiting factors in strawberry production in the area. This paper enumerated the fungal , bacterial and nematode diseases of strawberry, described their specific symptoms, and discussed the potential of the disease management strategies developed. Based on soil and plant samples collected from the strawberry- growing areas in Baguio City and Benguet Province, the following major diseases and nematode pests were identified: Verticillium wilt, red stele, leaf scorch, leaf spot, leaf blight, gray mold while the major nematode pests observed include the root lesion nematode (*Pratylenchus penetrans*) and strawberry crimp nematode (*Aphelenchoides fragariae*).

Among the six strawberry cultivars evaluated, only Sweet Charlie, the most preferred strawberry cultivar by the Benguet farmers was found to be resistant to some fungal pathogens and root lesion nematode. The following disease management options have shown potential in the management of the above diseases: use of indigenous mulching materials, crop rotation with broccoli, use of biocontrol agents, and application of baking soda.

Keywords: Benguet province, nematodes, cultivar, Sweet Charlie, pathogen, biocontrol

INTRODUCTION

Strawberry (*Fragaria x ananasa*) is among the most widely consumed fruits throughout the world. In the Philippines, strawberries are mostly grown in cool areas like Benguet and Baguio City and recently, in some parts of

Mindanao. Unlike strawberry growers in other countries, Benguet growers are production-oriented rather than market -oriented. Despite the available technology of ‘off season vegetable production, strawberry farmers are still on the open field technology using raised beds covered with plastic mulch. Strawberry farmers rely on volume sales during the regular season to make profit.

Benguet strawberries have become so popular that the province has gained the distinction, courtesy of the capital town of La Trinidad, as “Strawberry Capital of the Philippines”. La Trinidad has the biggest area planted to strawberry followed by Tuba and Tublay with 166, 5 and 1.5 hectares, respectively (Padua, 2010). However, strawberry production is relatively low compared to the yield potential of the crop which could be partly due to attack of insect pests and diseases. One of the major challenges facing strawberry growers is disease management. The losses in strawberry production due to diseases can be significant and in some cases can devastate the entire plantation. Diseases in plants occur when a pathogen is present, the host is susceptible, and the environment is favorable for the disease to develop. However, altering any of these three factors may prevent the disease from occurring. Organisms responsible for plant diseases include fungi, bacteria, nematodes, and viruses. If these organisms are present then manipulation of the environment and the host, to make it less susceptible, helps manage diseases in strawberries.

This paper enumerated the major diseases and nematode pests of strawberry in Benguet; described the symptoms produced by the specific pathogens; discussed the pathologic reaction of the different strawberry varieties/ cultivars to major plant pathogens, and elucidated the potential of the disease management strategies developed.

A. Foliar Diseases

There are three major leaf diseases of strawberry in Benguet. Leaf spot (*Mycospharella fragariae*), leaf scorch (*Marsonina earlianium)* and leaf blight / anthracnose (*Colletotrichum* spp.) as reported by Nagpala et al., (2003). All three diseases caused by fungi can occur singly or together on the same leaf (Figue 1). Under favorable environmental conditions, these three diseases cause serious yield reduction because of premature leaf death, reduction in fruit quality, general weakening of the plant, and in some situations, plant death (Nagpala et al., 2003). Other foliar diseases include powdery mildew (*Sphaerotheca macularis*) and angular leaf spot /bacterial blight (*Xanthomonas fragariae*).

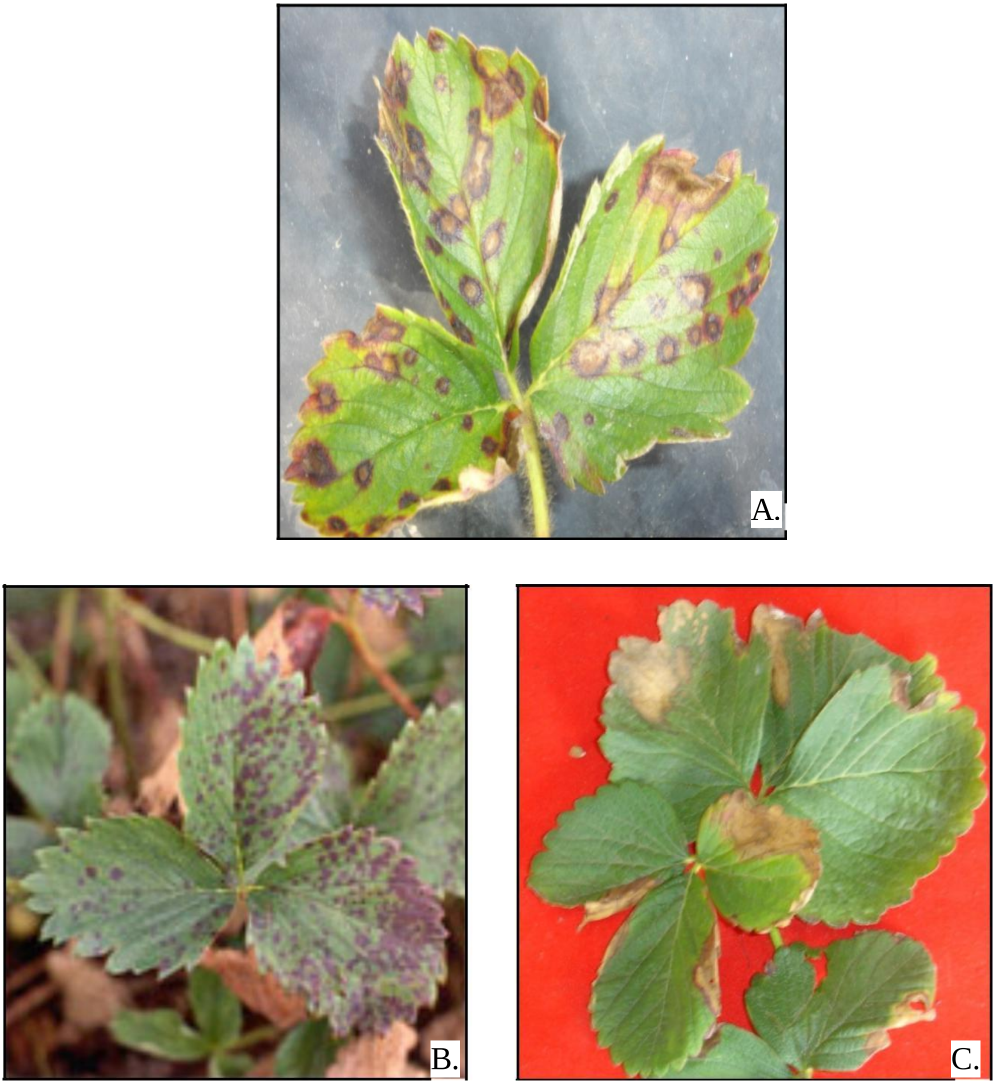


Fig. 1. Symptoms of major foliar diseases of strawberry in Benguet
A) leaf spot B) leaf blight and C) leaf scorch

B. Root Diseases

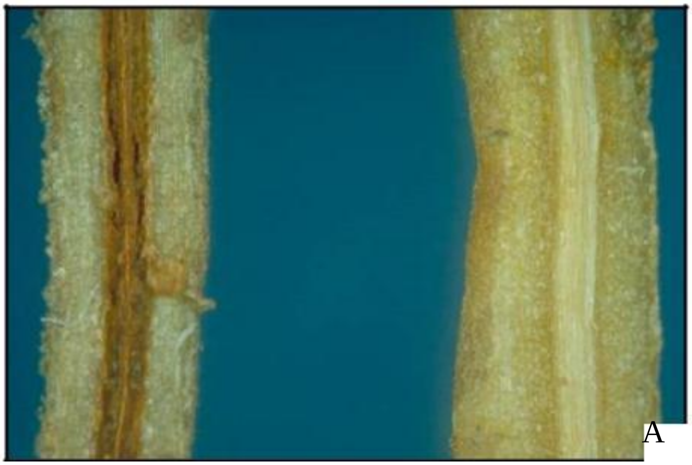
The following root diseases are very destructive to strawberry: red stele (Oloan and Villanueva, 2007), Verticillium wilt (Villanueva et al., 2006), and black root rot (Figure 2). Red stele caused by the soil-borne fungus *Phytopthora fragariae* is very common in the Swamp Area, BSU, La Trinidad, Benguet because of the continuous planting of strawberry. The disease is most destructive in heavy clay soils saturated with water during cool weather. Verticillium wilt caused by the fungus *Verticillium albo-atrum* is also a very serious disease of strawberry in the area. When a plant is severely infected, the probability of it surviving to produce a crop is greatly reduced. Another important soil-borne disease is black root rot, the general name for several root disorders producing similar symptoms. Although the exact cause of the black root rot is not known, one or more of the following is thought to be responsible: soil fungi (such as *Rhizoctonia* sp.and *Fusarium* sp.), nematodes, fertilizer burn, soil compaction, drought and excess salt, water or improper soil pH. Black root rot has been found in every strawberry growing area of Benguet (Nagpala et al., 2003).

C.Strawberry Fruit Rots

There are three important fruit diseases noted in the area: gray mold caused by *Botrytis cinerea,* Phytophthora rot (*Phytophthora* sp.) and anthracnose caused by *Colletotrichum* spp. (Figure 3). Among the three, gray mold is the most destructive. Under favorable conditions for disease development i.e. during prolonged rainy and cloudy periods during bloom and harvest. serious losses can occur. The gray mold fungus can infect petals, flower stalks (pedicels), fruit caps, and fruit (Nagpala et al., 2003).

D. Plant Parasitic Nematodes

Plant parasitic nematodes are microscopic round worms common in soils throughout Benguet and Mt. Province. Previous surveys conducted indicate the association of the following nematodes on strawberry in Benguet: *Meloidogyne javanica, M. hapla, Pratylenchus penetrans, Helicotylenchus* sp., *Trichodorus* sp., *Rotylenchus* sp., *Ditylenchus* sp., and *Aphelenchoides fragariae.* (Villanueva, Kiat-ong, and Pedroche, 2006; Kiat-ong, 2005; and Villanueva, 1994). These organisms restrict root growth by feeding directly on roots making the plants less efficient in taking up water and nutrients from the soil. Nematodes can also cause strawberry roots to be more susceptible to root- rooting fungi. The lesion nematode, *P. penetrans,* is probably the most destructive among the genera (Figure 4). High populations of this nematode cause areas of poor growth; plants are less vigorous; turn yellow; and cease to grow.



A

B

Fig. 2. Symptoms of most destructive root diseases of strawberry:
A) Longitudinal section of a healthy (left) and red stele infected (right) strawberry root,
B) Wilting caused by *Verticillium albo-atrum*,
C) Root rot

C

Fig. 3. Symptoms of important fruit rot diseases of strawberry:
A) anthracnose and B) gray mold

A

Necrotic lesions on the roots caused by *P. penetrans*

B

Small curled or crinkled leaves (crimp)

Deformed buds and flowers

Fig. 4. Symptoms of: A) root lesion nematode infection (*P. penetrans*) and B) foliar nematode (*A. fragariae*) on strawberry leaves and flowers respectively

DISEASE MANAGEMENT

Disease management strategies are very similar for both organic and conventional strawberry production systems. In both systems, it is important to develop and use an integrated disease management program that integrates as many disease control methods as possible, the more, the better. Major components of the disease management program include: use of specific cultural practices; developing appropriate knowledge of the pathogen and disease biology, use of resistant cultivars, and timely application of organically approved biofungicides or biological control agents or products when needed.

1.Cultural Practices

Cultural methods of disease control are commonly used in organic farms. The application of organic chemicals for disease control is often a last resort and is regulated while biological control is still not readily employed. The use of compost extracts, then present a simple, inexpensive, and potentially effective method to supplement the on-farm disease management program (Guerena and Born, 2007).

Crop Rotation

Crop rotation is one of the oldest and useful cultural control strategies. It means the planned order of specific crops planted on the same field and also the succeeding crop belongs to a different family than the previous one. The planned rotation may vary from 2 or 3 years or longer period. Many diseases build up in the soil when the same crop is grown in the same field year after year. Rotation can break the cycle and stop the buildup of disease organisms in the field (Ashley, 1994). The advantages of crop rotation are prevention of soil depletion, maintenance of soil fertility, reduction of soil erosion, management of pests and diseases, reduction of reliance on synthetic chemical and effeciency in controlling weeds.

In some production systems crop rotation can be considered as an economically viable means of reducing soil-borne propagules of *Verticillium* and yield losses from wilt disease. Effective management of Verticillium wilt in cauliflower has been reported with broccoli rotation and residue amendment (Subbarao et al., 1999; Xiao et al, 1998). Likewise, In California, USA strawberry plants grown in broccoli rotation showed the lowest disease severity rate among the rotation treatments and next to methyl bromide + chloropicrin in effectiveness. Njoroge *et al*., (2009) reported that yield of strawberry was greater in plots rotated with broccoli. In the Philippines, continuous planting of strawberry resulted in the occurrence of several fungal and bacterial diseases in strawberry growing areas in Benguet. Results of our initial trial at the Swamp Area, La Trinidad, Benguet indicate the significant effect of crop rotation on diseases caused by fungi and nematodes reflected as area under the disease progress curve (AUDPC) and root necrosis, respectively. The highest strawberry yield was obtained from broccoli-broccoli-strawberry treatment but this was at par with broccoli-strawberry and lettuce-lettuce-strawberry rotation (Villanueva and Agustin, 2008). Verification trials conducted at the Balili Experiment Station, BSU, La Trinidad, Benguet indicate that broccoli – broccoli – strawberry rotation had the highest marketable yield followed by broccoli - strawberry (Figure 5).

The least marketable yield was obtained from two croppings of strawberry. Twenty two weeks after planting, two croppings of broccoli followed by strawberry had the lowest disease severity rating of foliar diseases caused by fungi (Figure 6). Also, broccoli – strawberry rotation and two croppings of strawberry treated with fungicide reduced the disease severity as compared to two croppings of strawberry which had increased tremendously.

The foliar diseases are caused by several fungi, namely, *Colletotrichum* sp., *Fusarium* sp., *Diplocarpon* sp., and *Phomopsis* sp. (Villanueva and Agustin, 2010). The efficacy of two croppings of broccoli followed by strawberry is attributed to the toxic chemical, isothiocyanate, which is produced by broccoli residue during the process of decomposition (Subbarao *et al*., 1999).

Organic Mulches

In other countries, black plastic mulch is used in organic production primarily for weed control. Since the black plastic prevents the sun's rays from penetrating, the beds remain cool resulting in slower initial growth of the plants and reduced irrigation frequency as compared to clear plastic mulch. However, the use of plastic mulch has its own disadvantages too. Considering all the environmental costs to society, plastic culture is also not economically feasible in the long run. Research and grower experience in Ohio has shown that a good layer of straw mulch is very beneficial for controlling fruit rots, especially leather rot. Bare soil between the rows should be avoided and a good layer of straw mulch is highly recommended. The mulch keeps berries from contacting the soil where the leather rot fungus overwinters. In addition, it also aids in preventing infested soil from splashing onto the berries. On the other hand, Guerena and Born (2007) reported that plastic mulch (a layer of plastic) under the plants and /or between the rows increases splash dispersal of the pathogens that cause anthracnose and leather rot. Especially, where fruit rots have been a problem, the use of plastic mulch is not recommended. To verify this, Villanueva and Atew (2010) compared the efficacy of six organic mulches against major diseases in organic strawberry production. Fourteen weeks after transplanting (WAT), a much higher disease severity rating was obtained in plants mulched with polyethylene plastic as compared to sawdust, rice straw, grass, rice hull, and pine needles (Figure 7).

The highest marketable yield was recorded from plants mulched with rice hull while the least was obtained from plants mulched with pine needles (Figure 8). Mulching with dry grass resulted in higher non-marketable fruits followed by rice straw, rice hull, sawdust, pine needles, and polyethylene plastic. Non-marketable berries were due to infection of fungal pathogens, deformation, and slugs.

Sanitation

Any practice that removes old leaves and other plant debris from the planting is beneficial in reducing the amount of *Botrytis* inoculum. Leaf removal as innovation is highly recommended.

Irrigation practices

The application of supplemental water should be timed so that the foliage and fruit will dry as rapidly as possible. For example, irrigating early in the day is better than in the evening. If diseases such as gray mold, leather rot, anthracnose, or bacterial blight become established in the area, overhead irrigation should be minimized or avoided (Xiao et al., 1998) .

Control Movement of People

Movement of people (pickers) from infested area to a clean or uninfested field should be avoided. Diseases of primary concern are anthracnose, leather rot, and angular leaf spot/ bacterial blight. Diseases such as these are usually spread over relatively short distances by splash dispersal (rain or irrigation). Pickers moving from a field where the disease is present to a non-infested field can transport fungal spores or bacteria very efficiently on shoes, hands, and clothing. If people are working in fields where these diseases are a problem, they should complete work in non-infested fields before moving to infested areas.

2. Use of composts/ compost teas

Soil health and management are the keys for successful control of plant diseases. A soil with adequate organic matter can house numerous organisms such as bacteria, fungi, nematodes, protozoa, arthropods, and earthworms that may suppress soil-borne pathogens. This disease suppression is caused by either antagonism, competition for nutrients or competition for space around the root (the rhizosphere), and induced systemic resistance (ISR) or systemic acquired resistance (SAR) triggered in the plant. Increasing soil organic matter by incorporating cover crops or adding compost and organic fertilizers will help maintain these beneficial organisms (Johnson *et al.* , 1992).

The effectiveness of using compost for disease control, particularly against fungal pathogens has been studied extensively (Elad and Shtienberg, 1994; Weltzien, 1991). Composts of various kinds have been used to reduce the incidence of *Pythium* and *Rhizoctonia* in a variety of vegetables and fruits (Hoitink *et al*., 1997 ; Weltzien and Ketterer *et al.*, 1986). These results led to further work using filtered extract of composts. In some cases, the compost extracts were even more effective in controlling disease than conventional pesticides (Weltzien, 1991). Stindt and Weltzien (1988) at the University of Bonn achieved effective control of *Botrytis cinerea* in strawberries as well as blight in potatoes. Similarly, powdery mildew and root rot were significantly reduced in peas and beets in Germany (Thom and Moller, 1988). On the other hand, a` research from Ohio has shown that vermi compost applications increased strawberry growth and yields significantly (Arancon et al., 2004). Based on laboratory findings, this effect could have been due to production of plant growth regulators by microorganisms during vermicomposting. The foliar application of aerobically-prepared compost tea increased yields in British Columbia study (Welke, 2004). Besides reducing disease incidences of *Botrytis*, the compost tea treatment increased yields in strawberries by 20 percent as compared to the control and water sprays.

In the Philippines, Villanueva and Ramos (2008) reported that the use of biological control agents (BCAs) with compost teas was more effective in controlling foliar diseases of strawberry than BCAs alone. This practice resulted in significantly higher yield.

3. Resistant cultivars

In an integrated disease management program, the use of cultivars with resistance must be emphasized. Many commercial cultivars have resistance and /or tolerance to leaf spots, leaf scorch, red stele, Verticillium wilt, and powdery mildew. The more disease resistance within the program, the better. Studies conducted at Benguet State University showed that among the varieties imported from California,USA, three cultivars, Sweet Charlie, Camarosa, and Festival exhibited tolerance to the lesion nematode, *P. penetrans* (Villanueva, 2006). On the other hand, significant differences in the severity of leaf spot and anthracnose were observed among the six cultivars tested. Cultivar Camarosa was more sensitive to leaf spot and anthracnose followed closely by cultivar Sweet Charlie while Winterdawn, was more resistant followed by Earlibrite (Figure 9).

However, cultivar Whitney supported the highest nematode population which was significantly higher than in Camarosa, Winterdawn and Festival but comparable to Sweet Charlie and Earlibrite. Despite its moderate susceptibility to leaf spot, anthracnose, and the root lesion nematode, Sweet Charlie gave the highest yield followed by cultivars Festival and Earlibrite (Figure 10). Nevertheless, Winterdawn which showed some degree of resistance to the above diseases gave the lowest marketable yield (8.96kg/5m2). The berries of all the cultivars tested were observed to be infected with fruit rot caused by *Colletotrichum* sp. Sweet Charlie, Camarosa and Winterdawn showed gray mold infection caused by *Botrytis cinerea* while fruit rot caused by *Pestalotia* sp. was noted in Sweet Charlie and Camarosa (Villanueva and Ramos, 2008).

In Ohio, the reaction of Sweet Charlie to Verticillium wilt, red stele, foliar diseases, and powdery mildew was unknown. On the other hand, cultivar Camarosa was susceptible to foliar diseases and powdery mildew while its reaction to Verticillium wilt and red stele was unknown (http:// www.oardc.ohio-state.edu/fruit pathology).

4. Biocontrol agents

Many products are currently being introduced as “biological control agents” or “biopesticides”. These items include living organisms, natural chemicals such as plant extracts and plant activators that induce resistance in plants against diseases. For most of these products, independent evaluations are currently being conducted. However, their effectiveness under moderate to high disease pressure is uncertain. Although many of these new products have great potential for use with organic production systems, their effectiveness needs to be determined in field tests.

At the Benguet State University, the following biocontrol agents have shown promise for controlling strawberry diseases: *Pseudomonas* sp., *Bacillus subtilis, Flavobacterium* sp., *Bacillus pumilus,* and *Trichoderma harzianum* (Villanueva and Atew, 2010). Disease development in all the treatments was comparable from 7-12 weeks after transplanting (WAT). Nevertheless, after 12 WAT, disease severity of the untreated plants started to increase up to 15 WAT. This figure was much higher than the rest of the treatments except BCAs + VT 15 weeks after transplanting (Figure 11).

In terms of yield, plants applied with Tri- ace (1.2 g/ 24 liters) had the highest marketable fruit while those treated with T*richoderma + B. subtilis* had the least. On the other hand, more non- marketable fruits were harvested from plants applied with BCAs + VT and *Trichoderma + B. subtilis* (Fig. 12). Over the last few years, several studies abroad have successfully shown that honeybees can disseminate beneficial fungi to strawberries (http://nysipm.cornell.edu/publication/botrytis/default.asp?metatags_action=Find(‘PID’,2’). Their results showed that not only plant protection benefits can be achieved through the use of bees as pollinators of biologicals, but also higher yield can also be increased by the presence of these pollinators. In BSU, the use of honeybees to disseminate the biocontrol agent, *Trichoderma harzianum* has also been evaluated for the management of Botrytis fruit rot by Saclangan et al., (2008)

The potential of entomopathogenic nematodes (EPNs) for the management of soil insects and selected plant parasitic nematodes attacking strawberry has also been reported by Villanueva and Dugui-es, (2010).

5. Organic fungicides

Most organic fungicides are not highly effective against the overall disease complex on strawberry. A number of products including sulfur, salts, and oils will provide good control of powdery mildew if applied on a 7-10 day schedule.However, these materials have little or no activity against most of the leaf spot or fruit diseases.

Emphasis for controlling these diseases as well as powdery mildew should be placed on the selection and use of disease resistant cultivars. If a high level of resistance is not available in adapted varieties, growers should at least avoid the selection of highly susceptible varieties. Copper fungicides have limited use on strawberry since they are not highly effective against most of the leaf spot and fruit rot diseases. Copper fungicides have been recommended and used for control of angular leaf spot/bacterial blight with varying levels of success (Guerena and Born, 2007).

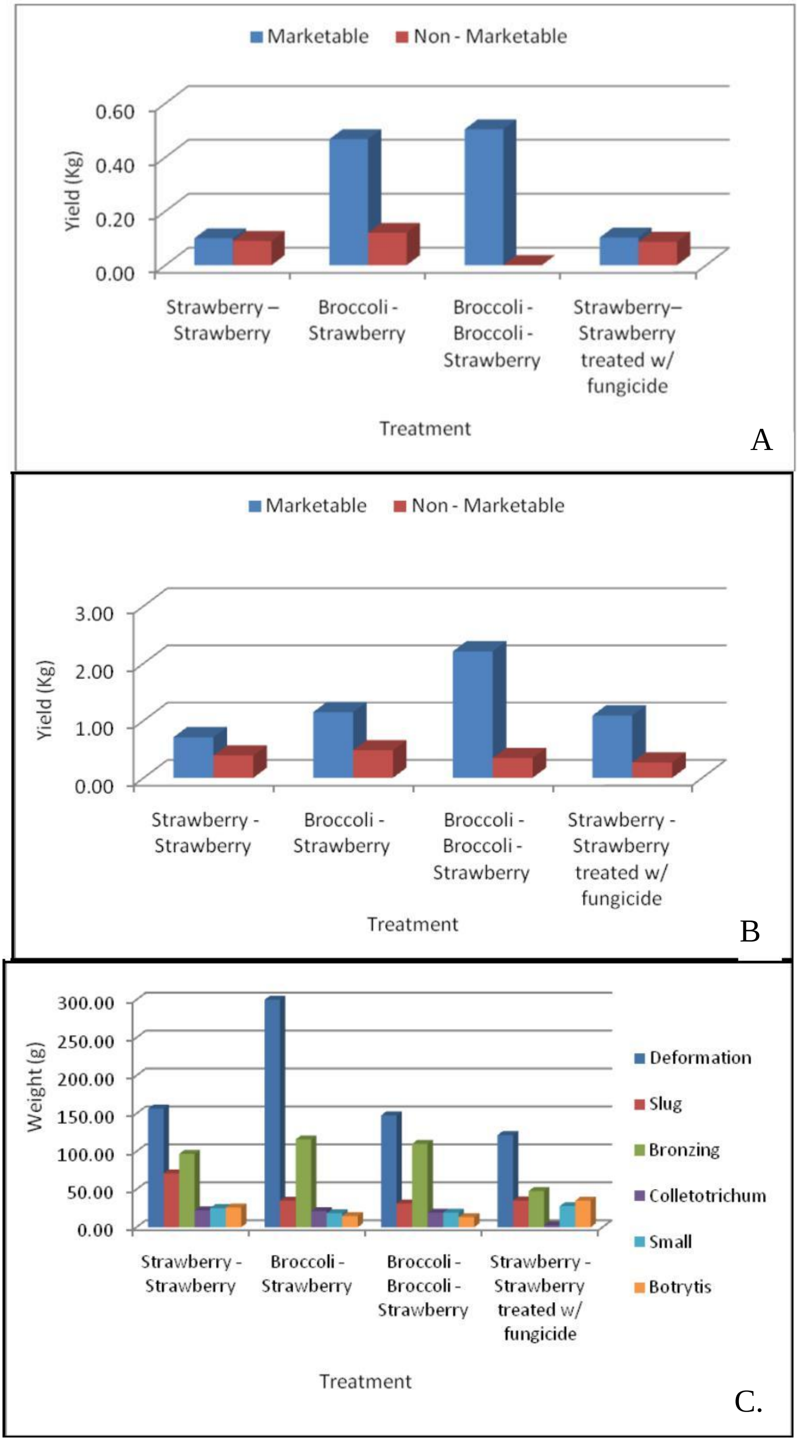


Fig. 5. Strawberry yield A) first cropping B) second cropping and C) causes of non–marketable yield during the second cropping

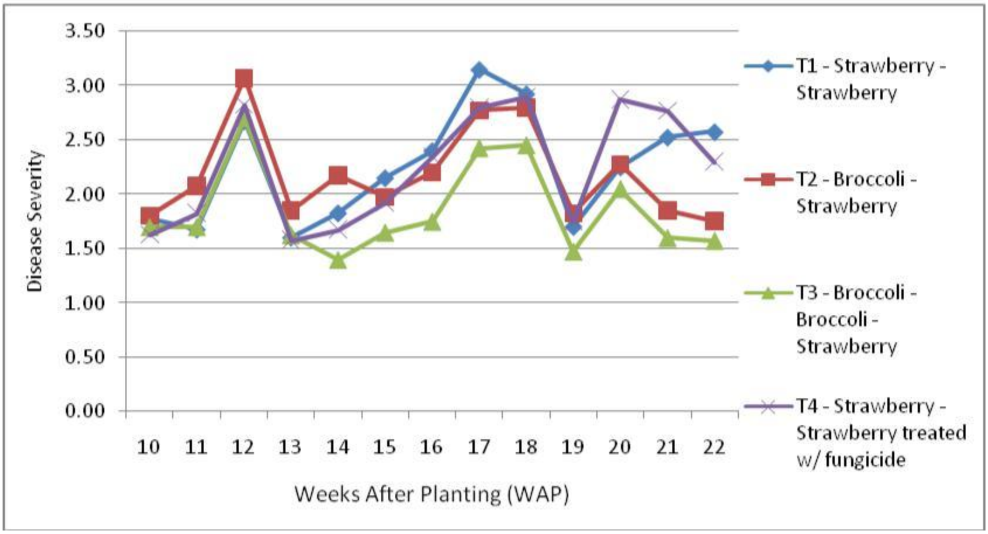


Fig. 6. Disease severity of fungal diseases of strawberry during the second cropping season

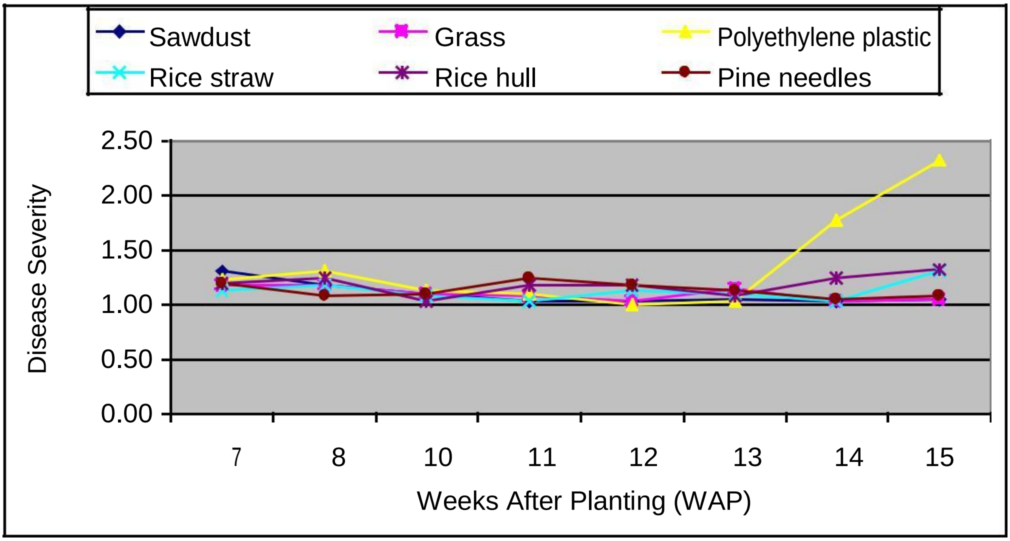


Fig. 7. Disease severity of foliar diseases of strawberry as affected by mulching materials

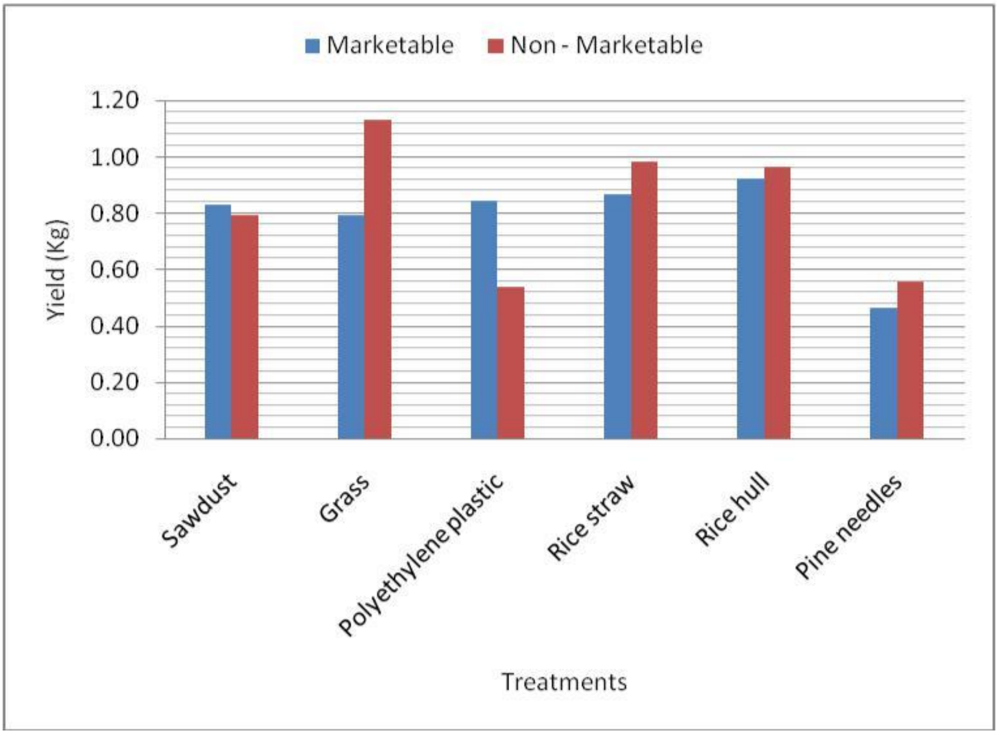


Fig. 8. Effect of mulching materials on the marketable and non-marketable yield of strawberry

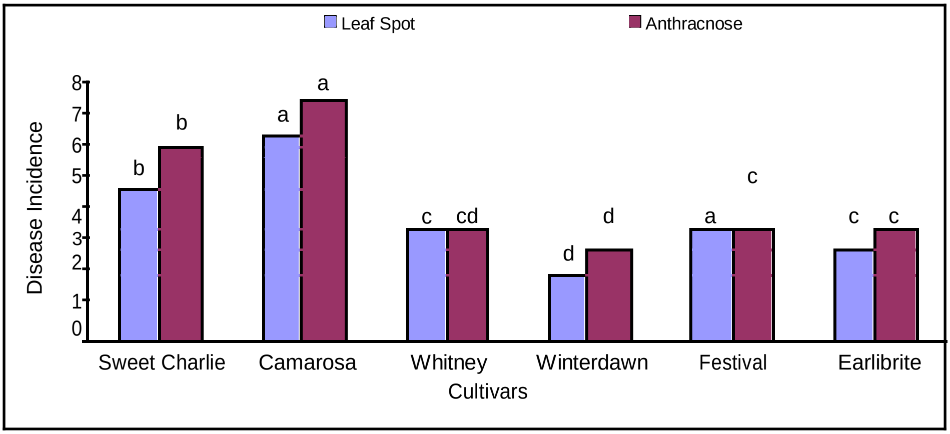


Figure 9. Disease incidence of leaf spot and anthrocnose on different strawberry cultivars

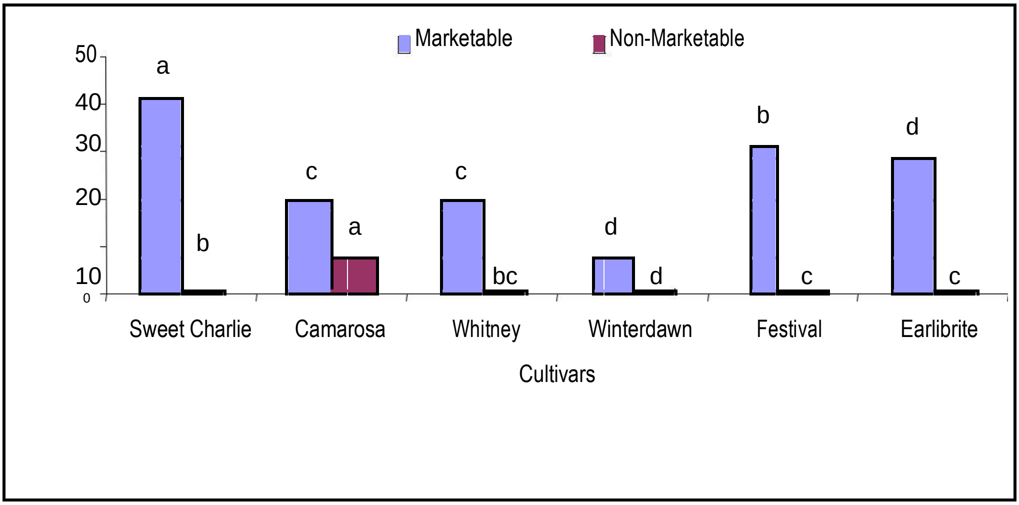


Fig.10. Yield of different strawberry cultivars (tons/ha) as affected by foliar diseases

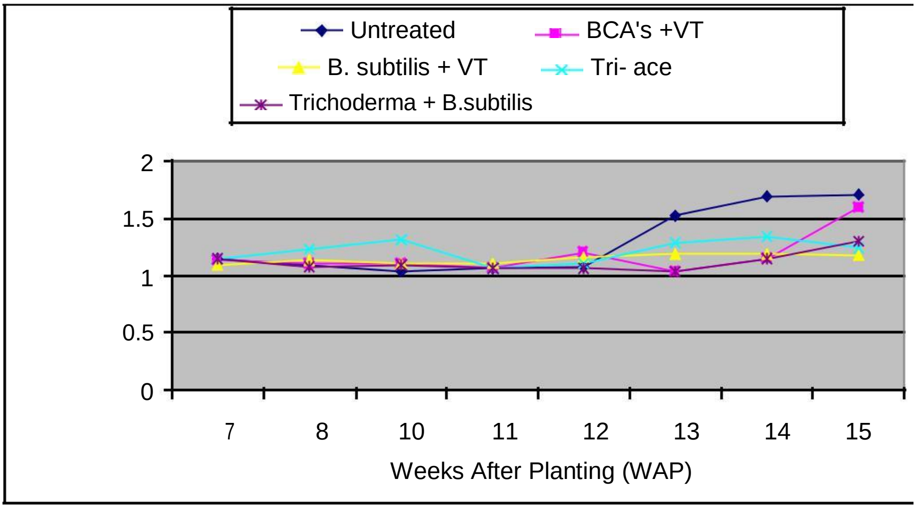


Fig. 11. Development of foliar diseases as affected by BCA's. (T1- untreated, T2- Bacterial antagonists (*Bacillus* sp. (131), *Bacillus* sp. (31), *Bacillus pumilus* (73), *Flavobacterium* sp. (94), *Pseudomonas* sp. (158) and Vermicompost tea (VT), T3-B. *subtilis* and vermicompost tea (VT), T4- Tri- ace (1.2 g/ 24 liters), T5- *Trichoderma* + *B. subtilis*)

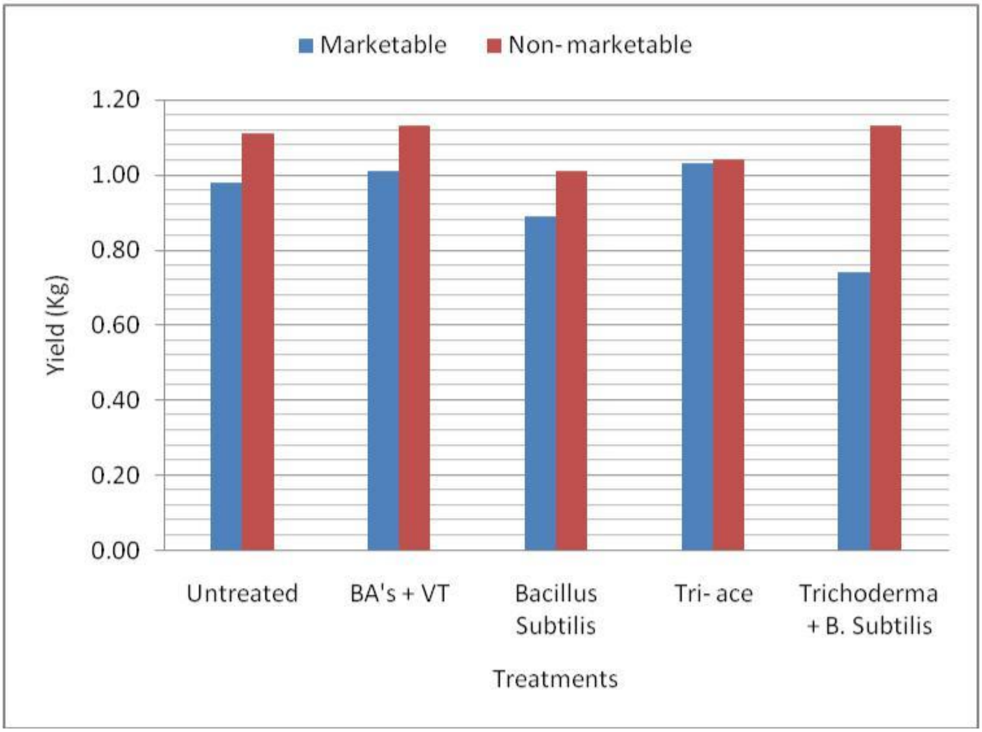


Fig. 12. Effect of BCA's on the marketable and non- marketable yield of strawberry. (T1- Untreated, T2- Bacterial antagonists (*Bacillus* sp. (131), *Bacillus* sp. (31), *Bacillus pumilus* (73), *Flavobacterium* sp. (94), *Pseudomonas* sp. (158) and Vermicompost \ tea 9VT), T3- B. subtilis and vermicompost tea (VT), T4- Tri- ace (1.2 g/ 24 liters), T5- *Trichoderma + B. subtilis*

CONCLUSION

Disease management in strawberry is relatively complex and challenging. In general, disease management strategies are influenced by numerous factors that may vary acrosss time and location. When choosing an appropriate management strategy, one must consider not only the disease in question but also factors directly and indirectly affecting the disease.

Two croppings of broccoli followed by strawberry significantly inhibited the growth of soil-borne diseases while the use of organic mulches like rice hull and rice straw protect the strawberry fruits from rotting.

There are available cultivars with tolerance to root lesion nematode and other fungal pathogens like Sweet Charlie , Camarosa and Festival . On the other hand, compost teas enhanced the efficacy of biocontrol agents.

In developing an effective and sustainable disease management strategies , integration of resistance , cultural and biological control methods is needed. Such an IPM strategy would reduce disease incidence, increase yield , minimize environmental damage, prevent build up of resistant pathogen strains, and produce high -quality products.

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