**Field management of dry root rot/wilt of acid lime (*Citrus aurantifolia* Swingle) incited by *Fusarium solani* (mart.) sacc**

**Abstract:**

Acid lime (*Citrus aurantifolia* Swingle) is one of the four commercially important citrus fruit crop grown in India among the citrus species. It belongs to the family Rutaceae and genus *Citrus aurantifolia* (Swingle). Among many soil borne diseases of acid lime, dry root rot/wilt is considered to be a severe disease caused by *Fusarium solani* which is prevalent in northern Karnataka in acid lime areas. *Fusarium solani* is primarily responsible for causing dry root rot in citrus, which is one of the most serious fungal diseases affecting citrus. Studies on management of wilt disease of acid lime under field conditions of natural infection revealed the efficacy of different fungicides and bio-agents with organic amendment tested in reducing the disease. Reduction in rotting of roots was highest at 90 days after treatment in trees drenched with carbendazim 50 WP @ 2 g /l (59.45 %). The second highest per cent reduction in rotting of roots was recorded in trees drenched with propiconazole 25 EC @ 2ml /l (53.67 %) which was on par with trees drenched with tebuconazole 250 EC @ 2ml /l (51.96 %). Among neem cake and bio-agent combinations, soil application of neem cake @ 10 kg/plant and FYM enriched with *Trichoderma* @ 30 kg/plant was most effective in reducing the root rot per cent (36.50 %) followed by treatment with neem cake @ 10kg /tree and FYM enriched with *Trichoderma* and *Paecilomyces @* 30 kg /plant (30.14%). Application of these fungicides can be achieved through drenching and bio-agents through soil application along with farm yard manure which would help in promoting healthy root development.

**Key Words**: Acid lime, dry root-rot/wilt, carbendazim 50WP, propiconazole 25EC, *Trichoderma harzianum, Paecilomyces lilacinus*

**Introduction**

Acid lime (*Citrus aurantifolia* Swingle) is one of the four commercially important citrus fruit crop grown in India among the citrus species. It belongs to the family Rutaceae. South East Asia is the origin of acid lime. It requires tropical and dry tropical climate, well drained soil with optimum temperature ranging from 20-30°C. Globally, citrus fruits are grown over an area of 11.42 million ha with 179.0 million tonnes of production (Anon., 2020a). India ranks third in the global citrus production after China and Brazil. In terms of area under cultivation, citrus is the third most important fruit crop after Banana and Mango. Citrus fruit production in India has increased from 1.79 million tonnes in 1971 to 14 million tonnes in 2020 with an average annual growth rate of 5.16 per cent. In Karnataka, the area under citrus fruits was 18400 ha in 2016-17 which accounted for only 4.50 per cent of the total area under fruits with production of 4.08 lakh tonnes and productivity of 22.19 tonnes per ha. The fruit is grown in most of the districts of Karnataka *viz*., Vijayapura, Chikkamagalur, Kodagu, Raichur, Kalburgi, Chitradurga, Hassan etc. Acid lime is majorly growing in Vijayapura and Bagalkote districts of northern Karnataka whereas; sweet oranges and mandarins are being cultivated in Kodagu, Chikkamagalur, Hassan and other districts of Karnataka. Among the citrus fruits, acid lime occupies first place with respect to area and production and is gaining popularity because of regular income, market access and export opportunities both in domestic and international markets (Anon., 2020b). In particular, Vijayapura district contributes more than 50 per cent of area and production of acid lime in Karnataka. Diseases cause serious problem to citrus cultivation which can be etiologically grouped under diseases caused by fungi, bacteria, viruses, viroids, phytoplasma and nematode. The crop is affected by many soil borne diseases like root-rot or gummosis, dry root rot and citrus decline. Among fungal diseases, the soil borne diseases of citrus are destructive and wide spread resulting to reduction in the yield of the fruits or complete decline of the crop, whereas other foliar diseases are climate dependent.

*“Fusarium* sp., is among the most prominent genera in the kingdom fungi, incorporating a broad spectrum of morphologically and phylogenetically diverse fungi. These fungi are soil borne saprophytic organisms, which colonize both living and dead plant tissue as an endophytes or epiphytes. *Fusarium* spp. produce a wide range of mycotoxins that contaminate food, thereby reducing its quality and posing a threat to the health of citrus trees” ([Mihlali Badiwe](https://pubmed.ncbi.nlm.nih.gov/?term=%22Badiwe%20M%22%5BAuthor%5D) *etal*., 2025). Dry root rot, caused by *Fusarium* species, is one of the worst fungal diseases of citrus and can be a serious threat in many countries (Ploetz *et al.,* 2007). “*Fusarium* dry root-rot is a sporadic but destructive disease, occurs in citrus orchards that are usually affected by some other factors, biotic like: *Phytophthora* spp. and nematode infections, or abiotic like: drought, water logging, temperature, mechanical root injury, excessive nitrogen, salinity, etc. and the symptoms are similar to those caused by *Phytophthora* but could be distinguished as they usually appear as decay of larger roots and trunk below the bud union without oozing any gum, *i.e*., dry rot” (Yaseen and D’Onghia, 2010). “The disease can be symptomless for years, but once enough root tissue has been destroyed, sudden collapse can occur under dry hot conditions. Due to dry root rot disease, about 10-15 per cent of the infected trees are being killed every year” (Vishwanath *et al.*, 2009). The disease is severe in the areas of north Karnataka as well which is caused by *Fusarium solani* (Mart.) Sacc. The pathogen was confirmed from Indian Type Culture Collection (ITCC), IARI, New Delhi. *Fusarium solani* is an opportunistic pathogen and a complex organism that can remain in the soil for a long time and is transmitted by wind, machinery, and water. On susceptible crops, the fungus produces a variety of destructive diseases, including wilt, gradual decline, and fruit rot. Dry root rot has been shown to cause a variety of symptoms, including wilt, gradual decline, fruit rot, and dieback over most citrus cultivars (Kaczmarek *et al*., 2019).

Based on effectiveness of various fungicides and bio-agents under *in-vitro* conditions against *F solani*, present studies were carried out under natural field conditions to know the best effective chemical such as carbendazim 50 WP, hexaconazole 5 SC, propiconazole 25 EC, tebuconazole 250 EC*,* (hexaconazole 5 % + captan 70 %) WP and bio-agents such as *Trichoderma harzianum and Paecilomyces lilacinus* singly and in combination, for eco-friendly management of the disease which would help in managing the disease thereby helping the farming community.

**Material and methods**

Isolation and identification of fungal pathogen from roots

Collected soil samples and infected plant parts such as roots, twigs, and from the plant showing disease symptoms were used for isolation of pathogen. For fungal isolation, after cleaning in the water, infected rotted roots were cut into pieces and were surface sterilized with sodium hypochlorite solution dipping it for 1 min and then washed serially three times in sterilized distilled water to remove the traces of chemical. The cut pieces were inoculated in Petri plate containing Potato Dextrose Agar media and were kept in incubator. The plates were observed periodically for growth of pure fungal colonies. The pure colonies were transferred to PDA slants and incubated at 28 ±1oC for 15 days. Then such slants were used for further studies**.**

The fungal culture obtained was compared with original characteristics of pathogen and it was sent to Indian Type Culture Collection (ITCC) IARI, New Delhi for species identification. On the basis of morphological characteristics, the pathogen and spore production it was identified as *Fusarium* spp. Further the species was confirmed as *Fusarium solani* (Mart.) Sacc. from Indian Type Culture Collection (ITCC), IARI, New Delhi.

The microscopic examination of mycelium revealed the production of micro conidia, macro conidia and chlamydospores. The micro conidia were hyaline, round to oval shape and produced abundantly on 10 days old culture. The macro conidia developed in 15 days old culture from well developed conidiophores. They were also hyaline, sickle shaped, three to four celled, slightly curved with blunt or round ends. Chlamydospores were produced in cultures 30 days after incubation. They were round to spherical and single celled produced either singly or in chains terminally or intercalary.

For management of wilt of acid lime caused by *Fusarium solani* experiment was laid out during 2021-22 on 12 years old orchard with wilt incidence at farmer’s field (Pirappa S Metri, Indi taluk, Vijayapur district, Karnataka state) adopting completely randomised block design (CRBD) with nine treatments replicated three times.

Fungicides were applied as a soil drench in rainy season @ 10 l /tree. Second, third drench was given at 15 days interval. For assessing the incidence of rotted roots, all roots from one sq.ft area upto one ft depth were collected from all the four corners of each tree basin. The roots were dried for 48 h and the proportion of healthy and rotted roots were calculated by weighment. The per cent rotting was assessed before imposing treatments (initial rotting %) and 90 days after treatment imposition (final rotting %). The percent reduction in rotting was calculated by the formula.

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| --- | --- | --- |
| Per cent reduction in rotting = | Initial rotting (%) - Final rotting (%) | × 100 |
| Initial rotting % |

**List 1: Treatment details**

|  |  |
| --- | --- |
| **Treatments** | **Details** |
| **T1** | Drenching of carbendazim 50 WP @ 2 g /l of water |
| **T2** | Drenching of hexaconazole 5 SC @ 2 ml/l of water |
| **T3** | Drenching of propiconazole 25 EC @ 2 ml/l of water |
| **T4** | Drenching of hexaconazole 5 % + captan 70 % WP @ 2 g /l of water |
| **T5** | Drenching of tebuconazole 250 EC 2 ml/l of water |
| **T6** | Soil application of neem cake @ 10 kg/plant, FYM enriched with *Trichoderma* @ 30 kg/plant (2 kg of *Trichoderma* enriched with 100 kg of FYM) |
| **T7** | Soil application of neem cake @ 10 kg/plant, FYM enriched with *Paecilomyces* @ 30 kg/plant (2 kg of *Paecilomyces* enriched with 100 kg of FYM) |
| **T8** | Soil application of neem cake @ 10 kg/plant, FYM enriched with *Trichodermaharzianum* and *Paecilomyceslilacinus*@ 30 kg/plant (1kg each in 100 kg of FYM) |
| **T9** | Control (Untreated) |

**Statistical analysis**

The data obtained was statistically analysed using completely randomized block design (CRBD). Observations of per cent reduction rotting were converted into angular transformation values.

**Results**

Results from the experiment conducted on management of wilt disease of acid lime under field conditions of natural infection revealed the efficacy of different fungicides and some bio-agents with organic amendment tested in reducing the disease. Among the different treatments tested, all the treatments significantly reduced the per cent root rotting compared to control. Drenching of carbendazim 50 WP @ 2 g/l was found to be significantly superior over other treatments in reducing the rotting of roots. Reduction in rotting of roots was the highest in trees drenched with carbendazim 50 WP@ 2 g/l (59.45%) followed by drenching of propiconazole 25 EC@ 2 ml/l (53.67%) which was on par with drenching of tebuconazole 250 EC @ 2 ml /l (51.96 %) (Table 1:Fig.1).

Among the bio-agents, Soil application of neem cake @ 10 kg/plant and FYM enriched with *Trichoderma harzianum* @ 30 kg/plant was found to be effective in reducing percentage root rotting (36.50) followed by treatment with neem cake at 10kg /tree with FYM enriched with *Trichoderma harzianum* and *Paecilomyces lilacinus* at 30 kg /plant (30.14 %) (Table 1:Fig.1).

**Discussion**

Among various fungicides used in this experiment under field conditions such as carbendazim 50 WP, hexaconazole 5 SC, propiconazole 25 EC, tebuconazole 250 EC and *(*hexaconazole 5 % + captan 70 %) WP though found effective under *in-vitro* but surprisingly carbendazim 50 WP was still found effective in reducing per cent root rotting against dry root rot at one litre chemical fluid per sq.m area comparing to new generation triazole fungicides. In a similar study, Suhag (1976) found that the guava trees affected with root-rot could be regenerated by severe pruning followed by a drench with Benlate or Bavistin (0.2%) using 20-30 g of fungicide dissolved in 40-60 litres of water per tree, depending upon age and canopy of the tree four times in a year in March, June, September and December.

Satyanarayana and Reddy (1994) reported that “dry root rot of sweet orange can be effectively checked by drenching the tree basins with 0.1 per cent carbendazim followed by another drenching of 0.25 per cent mancozeb or 0.2 per cent chlorothalonil 12-24 h after irrigation at monthly intervals”.

Results are also in agreement with Jayachandra (1999) who reported that the root-rot affected sweet orange trees drenched with Bavistin (0.2%) followed by either Dithane M-45 @ 0.25 per cent or Daconil @ 0. 2 per cent has recorded the highest per cent reduction in rotting of roots *i.e.*, 79.21 and 75.31 per cent respectively, Vijayakumar (2001) also also concluded drenching of fungicides like carbendazim (0.2%) and captafol effective against *F. solani*, causing dry root rot of acid lime. The results are also in accordance with Verma and Navtej Singh (1999) who reported that post-emergence drenching with carbendazim (0.2 %) gave 86 per cent of dry root-rot control. Drenching of carbendazim (0.2 %) and captafol (0.25%) were found effective against *F. solani* causing dry root-rot of acid lime as reported by Vijayakumar, 2001.

In a similar way, Sumana *et al.* (2012) studied on *Fusarium* wilt and root-knot complex disease of tobacco under field conditions which revealed that, among chemicals propiconozole and carbendazim (0.2 %) controlled the wilt disease to 60.29 per cent and 61.47 per cent respectively and among bio-agents, *T. viride and P. fluorescens* controlled the disease to 58.46 per cent and 60.15 per cent respectively. Similarly, sodium tetra thiocarbomate and *P. fluorescens* affected 49 per cent and 52 per cent control of root-knot nematode over the check respectively.

Narayanan *et al*. (2015) reported that soil drenching of carbendazim (0.1 %) recorded minimum incidence of mulberry wilt caused by *F. solani*.

Bubici *etal*. (2019) also controlled *Fusarium* wilt in banana by using *Trichoderma sp.* who reported 70 per cent biological control efficiency using the *Trichoderma.* Alamri *et al.*(2019) reported *Trichoderma* mediated control by enhanced growth (height and weight), enhanced levels of photosynthetic pigments and primary metabolites and enhancing plant defense mechanisms in managing root rot in lettuce. Results are in accordance with Hafiz Muhammad Usman *et al*. (2024) who narrated Bio-control agents, such as *Trichoderma species* (*harzianum and viride*), have been used to manage several phytopathogens, including the causal agent of dry root rot, *Fusarium*, to promote eco-friendly practices instead of using harmful chemicals in agriculture.

Additionally, the management of dry root rot disease caused by *Fusarium solani* necessitates the optimization of irrigation and fertilization inputs. Along with sanitation practices, pruning, regular scouting and monitoring of key pests and diseases play a crucial role in enhancing control methods and minimizing fungicides usage.

**Table 1: Effect of different treatments in reducing percentage root rotting in wilted acid lime orchard at 90 days after treatment**

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| --- | --- |
| **Treatments** | **Mean per cent reduction in rotting (%)** |
|
| T1: Drenching of carbendazim 50 WP @ 2 g/l of water | 59.45  (50.45) |
| T2: Drenching of hexaconazole 5 SC @ 2 ml/l of water | 48.43  (44.10) |
| T3: Drenching of propiconazole 25 EC @ 2 ml /l of water | 53.67  (47.10) |
| T4: Drenching of hexaconazole 5% + captan 70% WP @ 2 g/l of water | 44.55  (41.87) |
| T5: Drenching of tebuconazole 25 EC @ 2 ml/l of water | 51.96  (46.12) |
| T6: Soil application of neem cake @ 10 kg/plant, FYM enriched with *Trichoderma* @ 30 kg/plant (2 kg of *Trichoderma* enriched with 100 kg of FYM) | 36.50  (37.17) |
| T7: Soil application of neem cake @ 10 kg/plant, FYM enriched with *Paecilomyces* @ 30 kg/plant (2 kg of *Paecilomyces* enriched with 100 kg of FYM) | 28.97  (32.57) |
| T8: Soil application of neem cake @ 10 kg/plant, FYM enriched with *Trichoderma* and *Paecilomyces*@ 30 kg/plant (1 kg each in 100 kg of FYM) | 30.14  (33.30) |
| T9: Control (Untreated) | 0.00  (0.00) |
| CD at 5% | 3.20 |
| S.Em± | 1.07 |
| CV(%) | 5.71 |

Figures in parenthesis indicate angular transformed value

**Fig.1: Graph showing the Effect of different treatments in reducing percentage root rotting in wilted acid lime orchard**

**Per cent reduction in rotting**

**Treatments**

**Conclusion**

Studies on management of wilt disease of acid lime under field conditions of natural infection revealed the efficacy of different fungicides and some bio-agents with organic amendment tested in reducing the disease. Reduction in rotting of roots was highest at 90 days after treatment in trees drenched with carbendazim 50 WP @ 2 g /l (59.45 %). The second highest per cent reduction in rotting of roots was recorded in trees drenched with propiconazole 25 EC @ 2ml /l (53.67 %) which was on par with trees drenched with tebuconazole 250 EC @ 2ml /l (51.96 %). Among neem cake and bio agent combinations, soil application of neem cake @ 10 kg/plant and FYM enriched with *Trichoderma* @ 30 kg/plant was most effective in reducing the root rot per cent (36.50 %) followed by treatment with neem cake @ 10kg /tree with FYM enriched with *Trichoderma* and *Paecilomyces* @ 30 kg /plant (30.14 %). A suitable plant protection measure is a key to manage this disease on acid lime. In addition, as the fruits having export value, [green management](https://www.google.com/search?sca_esv=7e391c2c0531b813&cs=0&sxsrf=AE3TifMETuu3uGFTwS7y_WokEJniTpRcYg%3A1754031753422&q=green+management&sa=X&ved=2ahUKEwjujbW8hemOAxUuxjgGHcuBLvIQxccNegQIAhAB&mstk=AUtExfCupcTzhDPQH2v_Aon8XtARegQIB6_sFSReZrNzBxYpEPcMgHCB6DIc4cGF1NAdfgP2IxTEz4cFqYnZT2rmtuDEKzf3Hbq0odY9vBHGJtKE0kNYtW3L_V-nBe_5cWQUFwI9xO6IMSiw1WhmBpJzNoHQDNJ9b6OVnTufdW_fuyv_sdE&csui=3)/eco-friendly management is of need in order to minimize negative impacts.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, manuscript.

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