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Biological approaches for the management of replant disease: a mini review

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ABSTRACT

Replant disease in many temperate fruits is a serious and challenging issue that has been reported across almost all apple growing regions of the world including India where Himachal Pradesh is traced as a highly affected state. The symptoms includes abnormal growth and development, yield and quality decline of plants caused by continuous cultivation of same crops on same piece of land. The variations in growing habitat of exported and imported planting material, mono-cropping results in a decline in the ability to absorb water and nutrients, pH change coupled with persistence of soil borne pathogens, deviation in climatic conditions of fields and types of soil are ascribed as some of the amenable factors. Despite the heavy losses incurred on purchasing of new seedlings owing to continuous death in already established orchards, farming community of the state is desperately looking for a viable scientific solution. Furthermore, it leaves the youth no choice but to either replace apple by an alternative crop or to seek a job that provides them better income. Crop rotation or changing sites has been practiced since ancient times by some apple orchardists and could be a preferred strategy for mitigation of replant problem. Application of soil amendments for instance oilcakes, compost, mustard was reported to be effective in managing soil-borne fungi and plant parasitic nematodes along with the use of plant growth-promoting rhizobacteria which aggressively colonize the rhizosphere/plant roots, thereby enhancing the growth, and yield of plants when applied to seed or crops. Integrated management is helpful in combating this serious problem. Therefore, this review aims to describe different practices that pertains to reducing the replant problem in the old orchard sites.

Keywords: Replant disease, symptoms, management, soil amendments, crop rotation, intercropping, soil microflora

An introduction to replantation

Replanting is a burning problem across the major fruit growing areas of the world. Severity of this disease varies from region to region depending upon fields, type of soil and presence of pathogenic microbial species in rhizosphere [38, 34]. Both biotic and abiotic factors comes under replant problem. Replant disease is caused by the biotic community present in the rhizospheric soil [63]. Apple replant disease (ARD) is a soil sickness whose causes are unknown and uncertain [49]. Replant problem includes both the biotic and abiotic factors while replant disease pertains to biotic factors alone [63]. Disturbances related to soil nutrients, variation in soil pH and presence of phenolic compounds in the roots are the predominant abiotic factors whereas the biotic factors include only the soil microorganisms. This problem has been observed in other commercial crops like peach, pear, cherry, strawberry and rose.

Apple replant disease disturbs the overall micro-biome of the soil which causes difficulty in the establishment of new apple plantation at the old sites. There are two forms of replant diseases; specific and non-specific. Specific replant disease is species specific and affects the orchard when apple is replanted against apple crop whereas the non-specific replant disease affects crops of different species e.g., when apple is replaced with other stone fruits. Various definitions of the term "replant disease" or related phrases such as "replant problem", "soil sickness" or "soil fatigue" refer to such condition [12,14,63]. Fifty percent reduction in profitability of apple crop is due to low fruit bearing quality in ARD soils over the lifetime of an apple orchard [36,51]. Problems stemming from ARD are increasing day by day, as plant nurseries and orchards sites are concentrated over certain areas worldwide like the Pinneberg region in Germany, Pistoia in Italy etc. ARD is a serious problem both in nurseries and orchard soil which reduces the plant growth as well as fruit yield and fruit quality [38,34]. The change in the micro-biome of orchard soil occurs due to continuous cultivation of the same crop on the same piece of land. The incorporation of high-density plantation by using dwarf rootstocks results in a shorter life span of these orchards and consequently more frequent replanting [57,65]. A rapid improvement of this situation is difficult due to small land holdings in Himachal Pradesh, difficulty in crop rotation,

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installation costs etc. Apple orchards situated in the Western Himalayan states are facing replant issues with 25-70 per cent incidence of apple replant disease across various sites [55]. The complicating abiotic factors includes unbalanced and inadequate nutrient availability, impaired soil structure and loss of organic matter, herbicide residues, impervious soil layers and other site-specific problems [27]. In Washington state soils, the *Pratylenchus penetrans* number was below the damage threshold level across eight of the nine orchards surveyed and bacteria were not identified in the disease. The apple trees may grow poorly when planted in non-sterilised soil. Though ARD is specifically related to the species of *Malus domestica*, Rosaceae family crops such as cherry, peach, plum, strawberry and rose are also prone to it [49]. ARD is a very serious problem and though its management is very difficult, it can be reversed by transplanting apple plants to virgin or healthy soil.

This observation strongly simulated replant research in different parts of the world. Western Himalayan states of India are also facing the replant problem where majority of apple orchards have outlived their economic life and new plantations are being done at the same site. The incidence of apple replant disease on various sites has been observed 25-70 per cent. This observation strongly simulated replant research in different parts of the world. Western Himalayan states of India are also facing.

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ARD has become a serious threat and its management is a very challenging task. The application of soil sterilants such as methyl bromide and chloropicrin not only target the soil pathogenic organisms but also affect healthy soil microflora. Therefore, there is no specific treatment targeting pathogens without posing harm to beneficial microorganisms. Even the environmentally friendly approaches like addition of biocontrol agents, organic matter, fertilizers and use of healthy rootstocks are not reliable [70,48,47]. Apple cultivation has revolutionized the socio-economic status of the farmers and played a pivotal role in the economy in the state of Himachal Pradesh. According to statistical abstract of Himachal Pradesh 2021-22, the area under apple cultivation in the state is 1.15 lakh ha with an annual production of 7.97 lakh tones. Fifty to sixty-year-old apple orchards which were planted in the late sixties have completed their life span as these are showing symptoms of declining productivity. Owing to the limited land resources and crop types for diversification in hill states, orchardists are left with no alternative but to replant these old apple orchard sites, leading to drastic economic losses not only due to uprooting of old trees but also because of poor establishment of new plantation at the same site. This repeated cultivation of the same plant species on the same field/site is the primary factor leading to replant problem. As a result, a general decline in the growth and productivity of replanted apple orchard is commonly observed. Since, this problem is very common in other fruit crops of Himachal Pradesh as well such as cherry, strawberry, peach, pear etc., the present review summarizes current knowledge on the causes of ARD and critically evaluates the

contemporary lines of research aimed at developing mitigation strategies for the management of this problem. Since it is an intricate problem involving myriads of factors, its management is difficult using a unidimensional approach. It is against this background that we have attempted to explore various biological soil resources for the management of this disease.

Symptomatology of the Disease

Replant disease symptoms are visible within a year of plantation. Aboveground symptoms show difficulty in establishment of new seedling/ rootstock in the replanted soils, uneven growth of plants, stunting, shortened internodes etc. [14,58]. Belowground symptoms include discolored roots, root tip necrosis, and reduced root biomass (Figure 1). Planted trees die within one year of plantation and surviving plants yield poor quality fruits and reduced production. Replant disease affects the young, planted seedlings soon after plantation. Within one year of plantation, tender seedlings start facing difficulty in establishment. It is a debilitating soil problem which affects most orchards when they are replanted with the same crop. Due to its obscure nature, the orchardists sometimes unable to detect its presence and instead blame the rootstock or nursery for poor tree performance of replanted seedlings/rootstocks. Replant disease affects most fruit crops including pome and stone fruit.

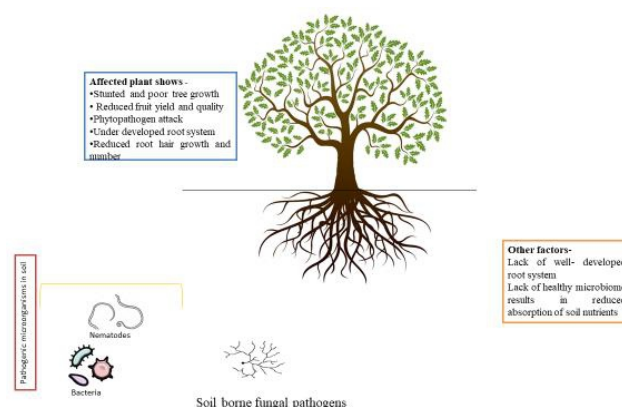


Figure 1 Overview of replant disease

Pathogens associated with the disease

The causal organisms vary from region to region and depend upon the presence of phytotoxic compounds secreted by plant roots, pH of the soil, nutrient imbalances in the soil etc. The important fungal pathogens associated with ARD were *Phytophthora cactorum*, *Pythium spp.*, *Cylindrocarpan destructans*, and *Rhizoctonia solani*. In addition, free-living nematodes of the genera *Aphelenchus*, *Cephalenchus* and an unidentified *Dorylaimida* were also found associated with replant disease [36]. Different fungal pathogens belonging to genera *Cylindrocarpon*, *Rhizoctonia*, *Phytophthora*, and *Pythium* are frequently isolated from replant affected soils [31,10]. The role of *Fusarium* species as a pathogen is controversial [59]. *Fusarium acuminatum* was non-pathogenic in ARD soil as reported by [32]. However, *F. oxysporum* and *F. solani* were shown to be aggressive pathogens of replanted trees [4,51]. [54] isolated different phytopathogenic fungi such as *Phytophthora cactorum*, *Pythium ultimum*, *Fusarium oxysporum* and *Dematophora necatrix*. These pathogens were isolated from old orchard soils across the temperate zones of Himachal Pradesh. Among fungal and bacterial genera, *Mortierella* and *Methylotenera* were most indicative of replanting problem as reported by [19] (Table 1).

Besides, over exploitation of the land for production of apple and stone fruit is the main cause of the problem. Although, the exact causes of replant problem are still unclear, the literature reported so far has shown that it is a complex problem occurring mainly due to disturbances in the old tree roots, water retention in the rhizosphere area and plant genotypes [71].

Table 1 Different pathogenic fungi/ nematodes associated with replant problem in different crops

Sr. No.	Fungi/ Nematodes associated	Reference
1.	<i>Phytophthora camivora</i> , <i>Phytophthora cactorum</i> , <i>Phytophthora cinamomi</i> , <i>Pythium ultimum</i> , <i>Pratylenchus penetrans</i>	[61]
2.	<i>Rhizoctonia</i> spp.	[41]
3.	<i>Pratylenchus penetrans</i>	[29]
4.	<i>Cylindrocarpon</i> , <i>Rhizoctonia</i> , <i>Phytophthora</i> , and <i>Pythium</i>	[32]
5.	<i>Phytophthora cactorum</i> , <i>Pythium ultimum</i> , <i>Fusarium oxysporum</i> and <i>Dematophora necatrix</i>	[54]
6.	<i>Pythium</i> spp., <i>Phytophthora cactorum</i> , <i>Cylindrocarpon- Ilyonectria</i> , <i>Fusarium</i> and <i>Rhizoctonia solani</i> , and the root-lesion nematode <i>Pratylenchus penetrans</i>	[35,60,30,45]
7.	<i>Aphelenchus</i> , <i>Cephalenchus</i> , <i>Mortierella</i> and <i>Methylothenera</i>	[19]
8.	<i>Prsimatolaimus</i> , <i>Acrobelles</i> , <i>Tylencholaimus</i> , <i>Acrobeloides</i> , and <i>Aphelenchus</i> , and associated fungi <i>Exophiala</i> , <i>Hohenbuehelia</i> , <i>Naganishia</i> , <i>Psathyrella</i> .	[19]

Disease Control strategies

Sustainable land management prior pre planting

It has been noticed that continuous cropping of the same crop on the same piece of land makes the soil unfit for that crop due to exhaustion of nutrients, disturbance in soil microflora, changing of soil structure, pH etc. Therefore, for the starvation and management of pathogens crop rotation has been exploited as an alternative method for effective management of soil borne pathogens. Hence, the most commonly used mitigation strategy against replant disease is crop rotation or changing sites [16,26]. Cultivation and production of American ginseng in China also faced replant disorders in the production sites. Authors documented that 5-year maize rotation significantly increased the abundance of beneficial soil bacteria [17].

Application of organic amendments alters the soil microbial communities by producing a disease-suppressive soil which reduces soil pollution and improves soil health. Bioactive compounds like those obtained from *Brassica*, *Azadirachta indica* and *Tagetes erecta* used as cover crop have potential role in mitigating apple replant problem [40]. Brassica plant releases volatile compounds, specifically isothiocyanates, effective in inhibiting soil-borne pathogens. Soil fungal community of apple trees was also improved by mixed cropping with *Brassica juncea* and *Allium fistulosum* as they proliferated the population of antagonistic fungi like *Trichoderma*, *Penicillium* in amended soil of orchards [75]. Crop rotation with wheat in ARD conducive sites increases the number of fluorescent pseudomonads and reduces the susceptibility of soils for ARD. The use of different strains of *Pseudomonas fluorescens* and *Pseudomonas putida* with biocontrol properties have been used against *Rhizoctonia* control [37]. It is important to use the biocontrol agents as these are environment friendly and safe for living beings. Carrier-based formulations were more effective in terms of establishment of new plants as they provided them the niche for performance [64]. The application of organic amendments can alter soil microbial communities by producing a disease-suppressive soil or growth medium [73] which reduces potential hazards and controls chemical pollution. Intercropping can help in managing replant disease to a certain extent by repelling nematodes or by increasing the diversity of soil microbiota. Also, the biodiversity in soil can be increased by application of soil amendments like compost. Anaerobic soil disinfection was also found to be an effective strategy of countermeasure against replant disease in apple and cherry. Another time consuming and difficult strategy involves breeding for replant disease tolerance. Soil disinfection by heat or chemical means is effective but ecologically harmful and expensive [11].

Preplant soil application of specific Brassicaceae sand meal formulations provide control of apple replant disease which is superior to that attained in response to preplant soil fumigation [67]. Application of soil amendments like oilcakes, compost, and mustard was reported to be effective in managing soil-borne fungi and plant parasitic nematodes. Mustard as green manure or seed meal cake was found toxic to root pathogens as well as nematodes [39]. The use of organic amendments like green manure crops having high organic matter content such as oats, barley, maize etc. improve the soil structure and fertility besides the population of soil-borne pathogens like *Fusarium*, *Pythium*, *Phytophthora* and *Rhizoctonia* [21]. Since isothiocyanates have a broad spectrum of antimicrobial activity, investigators have focused on the use of these plants as a 'biofumigant', where incorporation of plant residue into soil ultimately results in the release of active hydrolysis products [2]. Application of *Brassica napus* seed meal to the apple orchard soil and found that instead of killing the apple root pathogens *Rhizoctonia solani* AG-5, it increased the ammonia-oxidizing bacteria in the rhizosphere region that released nitric oxide which in turn is associated with the observed control of *Rhizoctonia* root rot in apple orchards [5]. Crop rotation typically has the potential to reduce the disease incidence by depriving the target pathogen of a susceptible host [37]. Use of mixed cropping such as allium and brassica species significantly improved the growth of the grafted apple seedlings and alleviated apple replant disease [75]. In addition, the analysis of clone libraries showed that *A. fistulosum* and *B. juncea* promoted the proliferation of antagonistic fungi such as *Mortierella*, *Trichoderma*, and *Penicillium*, and inhibited the proliferation of pathogens such as *Fusarium*. Biofumigation includes the addition of freshly chopped Brassicaceae crops like *Brassica juncea*, *Sinapis alba*, *Eruca sativa* or *Raphanus sativus* and Brassicaceae seed meal rich in glucosinolate to the soil in order to achieve natural isothiocyanate formation [12,9,44]. These fumes have microcidal effect on the pathogenic flora of the soils of the ARD sites [2,24,56].

Organic residue-based compost has been widely used as soil amendment for crop production [43,50]. Bioactive plant products like *Azadirachta indica* and *Tagetes erecta* including those of Brassicaceae family introduced either as cover crops or for soil amendment have been used as control measures for soil-borne diseases [15,42,69]. The volatile sulfur compounds secreted by genera *Allium* were very effective against pathogenic genera of bacteria, fungi, and insects [35,52]. Application of mustard seed powder in the replanted apple orchard soil not only curbed the growth of soil borne pathogenic fungi like *Pythium* spp. but also helped increase the diversity of

soil beneficial fungi like *Trichoderma* simultaneously reducing the infection of *Pythium* rot on apple roots and alleviated ARD for a long time [69]. The application of onion compost prepared by using byproduct not only inhibit the growth and reproduction of *Pythium*, but also significantly improved the yield of aloe vera and strawberry crops as they contain a large amount of dimethyl disulphide and dipropyl disulphide [3]. The dimethyl trisulfide present in leek volatiles was found to inhibit the growth of *Fusarium oxysporum* and could be used to control banana *Fusarium* wilt [74]. In today's scenario, organic residue-based soil amendments are useful in crop production because the active molecules of plant residues are easily volatilized or consumed [74,40]. Plant pathogenic microorganisms accumulate in the rhizosphere and roots of replanted apple plants within 1–2 years after the establishment of the orchard [41]. It has been documented that incorporation of spent mushroom compost in ARD soil increases the beneficial microbial activity which leads to a significant increase in shoot length; an effect being comparable to that of pasteurization of the soil [32,10].

Exploitation of indigenous soil microbial community

Exploitation of two-way positive interactions between the microbial endophyte and host plant can result in the growth promotion of both the partners and play a significant role in low-input sustainable agriculture applications for both food and nonfood crops. One of the efficient methods for low cost sustainable agriculture practices is the development of bio formulations of potential indigenous endophytes and rhizobacteria to promote plant growth and enhance the yield of crops. The endophytic microorganisms belong to common soil bacterial genera viz. *Bacillus*, *Pseudomonas* and *Burkholderia* which help in overall growth and development of host plants by producing plant growth promoting activities [25]. Inoculation of a biocontrol agent *Bacillus subtilis* in the replant site soil before plantation of apple increased the tree growth and fruit yield [62]. The bacteria showed biocontrol activities against various pathogens. Endosphere and rhizosphere colonization of *Crinipellis tabtim* M8, showed correlation with disease control of 84.95% against white root rot pathogen [46].

Two plant growth promoting fluorescent *Pseudomonas aeruginosa* strains An-E and An-F isolated from replant site of apple in Shimla district of Himachal Pradesh that suppressed major replant pathogens viz., *Dematophora necatrix*, *Phytophthora cactorum*, *Pythium ultimum* and *Fusarium oxysporum* [54]. *Pseudomonas aeruginosa* strains An-14-Mg and An-15-Mg on being tested in field conditions both individually and in consortium exhibited maximum increase in percent

survival, plant height, number of shoots, chlorophyll content and available NPK content of soil in consortial bioformulation after 3-year growth in apple orchards of Himachal Pradesh [53]. The antagonistic rhizobacteria produce different antibiotics and siderophores which indirectly help in plant growth promotion by killing the pathogenic microflora present in soil [1]. Plant growth-promoting rhizobacteria are free-living soil bacteria that aggressively colonize the rhizosphere/plant roots, and enhance the growth, and yield of plants when applied to seed or crops [23,28]. It has been reported that *Pseudomonads* and *Bacillus* spp. were very active in root colonization and production of metabolites ensuring better stress, tolerance mechanism and yield [20]. The colonizing ability of the binucleate *Rhizoctonia* population, having a non-pathogenic behavior, seems to act antagonistically to *Cylindrocarpon*-like fungi, having a role in growth reduction of replanted orchards [34]. Native plant growth- promoting rhizobacteria (PGPR) isolated from wheat rhizosphere and root-endosphere in the Himalayan region yielded four IGS patterns, one comprising *Bacillus* sp. which was not sequenced and other three types: one strain each was sequenced based on 16SrRNA gene. The PGPR isolate AJK-3 was identified as *Stenotrophomonas rhizophila* strain having 99% similarity with the reported gene sequence. AJK-7 showed 98% similarity with *Acetobactor pasteurianus*. However, isolate AJK-9 showed 95% similarity with *Stenotrophomonas* species. The new isolate, AJK-9, may be considered as a *Stenotrophomonas* species since many of its beneficial characteristics resembled those of *Stenotrophomonas* strain AJK- 3. The effect of these plant growth-promoting rhizobacteria (PGPR) under growth room conditions showed a significant increase in shoot and root length and shoots and root biomass whereas a significant increase of 76% in shoot nitrogen and 32% increase in root contents were observed in uninoculated control [28]. Table 2 depicts the antimicrobial activity of different bio control agents against replant pathogens. The application of plant growth promoting bacterial endophytes may increase the availability of nutrients and control the replant disease organisms. This would considerably regenerate, maintain and sustain the soil fertility and hence facilitate the establishment of apple rootstocks and yield. These will help in solving the apple replant problem in Himachal Pradesh and improve the economy of state by developing innovative cropping practices which will enable biodiversity preservation and increase soil health. The PGPR are highly diverse in nature benefitting through local antagonism to soil-borne pathogens and induction of systemic resistance against pathogens throughout the whole plant.

Table 2 Inhibitory effect of biocontrol agents against pathogenic microbes causing replant disease in apples.

Biocontrol agent	Pathogen	Mechanism	Reference
<i>Aspergillus aculeatus</i> strain C2, <i>Crinipellis tabtim</i> strain M8	<i>Dematophora necatrix</i>	Apple root colonization	[46]
Endophytic strain <i>Trichoderma asperellum</i> 6S-2	<i>Fusarium proliferatum</i> f. sp. <i>malus domestica</i> MR5	Antifungal effect of volatile substances and plant growth promotion	[66]
<i>Bacillus Licheniformis</i> XNRB-3	<i>Fusarium</i> sp.	Induce disease resistance	[72]
<i>Bacillus vallismortis</i> HSB-2	<i>Fusarium oxysporum</i> , <i>Fusarium moniliforme</i> , <i>Fusarium proliferatum</i> , and <i>Fusarium solani</i> .	Inhibitory effect on mycelial growth and fungal spore germination, improved plant growth	[7]
Indigenous arbuscular mycorrhizal fungi (AMF) (<i>Glomus</i> sp. and <i>Paraglomus</i> sp.)	Apple replant disease infested soil	Improve the resistance of the apple rootstock	[68]
<i>Bacillus amyloliquefaciens</i> QSB-6	<i>Fusarium oxysporum</i> , <i>Fusarium moniliforme</i> , <i>Fusarium proliferatum</i> , and <i>Fusarium solani</i>	Growth inhibition of pathogenic fungi	[8]
<i>Pseudomonas aeruginosa</i> strains An-14-Mg and An-15-Mg	Apple replant disease infested soil	Growth promotion	[53]

Future Research priorities

Apple replant disease is not due to known/identifiable microbial consortia in all growing regions of the world. Management of this problem is very difficult since it stems from multiple factors.

Major research areas will be plant induced soil microbiome that creates conducive environment for the growth and development of plants. Soil amendment based sustainable approaches favors indigenous soil microflora to establish in the orchard sites. Manipulation of plant genotype to attract more and more indigenous soil microbiome is an ecofriendly approach to maintain soil fertility in orchard sites.

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Declarations

Conflict of interest: None of the authors has any conflicting interests.

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