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Causes and Control Measures of Apple Replant Problem

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Abstract

Replant problem is a situation resulting in suppression of growth and poor productivity of the trees planted on old orchard sites and makes the plantations un-economical. It is a serious malady throughout the world in some fruit crops where the new plantations are done at the old orchard sites. Although replant problem is known to exist for many decades but greater attention was paid to this phenomenon only when Thompson (1959) while working at East Malling Research Station, United Kingdom observed poor growth of apple and cherry on old plantation sites. This observation strongly stimulated 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 out lived 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. It is comparatively easy to prevent the replant problem than to control it because of unknown exact etiology and complex nature of malady due to the presence of different biotic and abiotic factors associated with the problem. Nature and intensity of the incidence is highly variable from country to country and even region to region and there is lack of quick diagnostic methods. The problem is difficult to control with one method and require integrated management practices for effective control.

Keywords: Apple, replant problem, causes, biotic stress, control measures

1. Introduction

Amongst fruit crops, apple is an important crop of temperate regions of the world. Its plants fail to survive or show poor growth when planted on a site where apple was grown earlier. This is a serious problem all over the word for the establishment of new apple orchards on old sites. The problem becomes more serious in the present context when there is a trend towards high-density plantations, using dwarf scion and stock combination. The economic life of such dwarf trees is very short and need to be replanted after a short span of 15-20 years. Apple replants problem is a complex problem that reduces survival, growth and yield of replanted trees and is often encountered in establishing new orchards on old sites (Yao et al., 2006). It is a common problem typified by stunted growth and reduced yields in successive plantings of apple on old orchard sites (Leinfelder and Merwin, 2006). The disease is a complex syndrome that affects young trees in replanted orchard sites causing necrotic lesions on feeder roots, stunted tree growth and reduced cumulative yields

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(Rumberger et al., 2007). According to Laurent et al. (2008), apple replant problem is a soil-disease syndrome of complex etiology that affects apple tree roots in replanted orchards, resulting in stunted tree growth and reduced yields.

Buszard and Jensen (1986) reported the more conspicuous effect of the disease in soil samples from beneath trees than alleyways. The incidence is common all over the world and a plant growth reduction of 30-73 and 40-63 per cent has been observed in glasshouse pot trials and subsequent field trials, respectively along with 50 per cent reduction in average yield (Brown and Schimanski, 2002). However, the incidence of apple replant problem has been found 25-70 per cent in Himachal Pradesh (Bhardwaj and Sharma, 2004).

2. Causes of the Problem

The currently accepted concept of poor apple growth as a "specific replant disease" is considered unjustified and a possible barrier for the identification of the cause. The causal agents of apple replant problem must be either bacteria or actinomycetes, probably the latter as their temperature tolerance agreed with that of the disease (Otto, 1972). Experimental evidence indicated that the cause might be a common, widespread but variable soil malaise affecting many plants (Sewell, 1979). Pathogenicity of replant disease agents is considerably influenced by environmental conditions especially microbiological factors in the soils (Sewell et al., 1982). In apple orchards or nurseries, different biological agents have been implicated in disease development e.g. nematodes like *Pratylenchus penetrans* were found to attack the roots of every size and age but difficult to diagnose by above ground symptoms (Mai et al., 1994). The infected apple roots showed discoloured, stunted and sometimes 'witches-broom' symptoms (Hoestra, 1994). Among the identified potential factors responsible for apple replant problem, most important are low soil pH, poor irrigation practices and arsenic spray residues in the soil, soil compaction, nematodes and nutrient deficiencies (Willett et al., 1994). The aetiology of apple replant disease is biological in origin, complex and site-specific and involves a shift in soil microbial community composition towards pathogens dominating the soil microbial profile (Mazzola, 1999). The disease is attributed to biotic and abiotic factors and highly variable by sites, making it difficult to diagnose and overcome (Leinfelder and Merwin, 2006). The possible causes attributed to apple replant problem are as under:

2.1. Fungi/actinomycetes

Fungi or actinomycetes are considered as the major causal organisms responsible for apple replant problem. Pythium species may be involved in poor apple growth i.e. apple replant problem (Sewell, 1979). Several lines of circumstantial evidence collectively indicated that poor early growth of apple (replant disease) might be associated with the effects of soil-borne pythiaceous fungi (Sewell, 1981). Sewell et al. (1982) related the apple replant problem to that of *Pythium sylvaticum* and reported that *Pythium sylvaticum* isolates inhibit root growth of apple and contain diffusible toxins. The association between the fungus and replant disease in soil contained a growth-suppressing factor of non-biological origin. Utkhede and Li (1989) collected nineteen fungal isolates from the soil of an orchard with apple replant problem and identified them as *Mortierella sp*., *Torulomyces lagena* and *Trichoderma hamatum*. Interactions between soil fungi such as *Phytophthora* species and *Pratylenchus penetrans* are involved in apple replant problem (Utkhede et al., 1992). Braun (1995) observed that replant disease-like symptoms in apple which were caused by *Cylindrocarpon lucidum* and *Pythium* species. According to Mazzola (1998) fungi viz., *Phytophthora cactorum*, *Pythium* species and *Rhizoctonia solani* are the dominant causal agents of apple replant problem. Isutsa and Merwin (2000) isolated various *Pythium, Cylindrocarpon, Fusarium, Rhizoctonia* and *Phytophthora* species from roots of apple plants grown in the replant test soil. While analyzing the etiology of apple replant problem, Rabie et al. (2001) reported a complex of fungal genera, i.e. *Rhizoctonia, Cylindrocarpon, Pythium* and *Phytophthora* as the dominant causal agents for the disease.

Apple replant problem is a soil-borne disease that may be caused by nematodes, bacteria and fungi viz., *Rhizoctonia, Pythium* and *Phytophthora* (Brown and Schimanski, 2002). However, Mazzola (2003) suggested *Pratylenchus* species as the causal organism of this disease. Molnar *et al*. (2003) detected *Rosellinia necatrix* in the roots of plants grown on apple replanting sites and reported it as the causal organism of the disease. Fungi and oomycetes belonging to the well-known root rot complex, *Rhizoctonia solani, Phytophthora* species., *Cylindrocarpon* species and *Pythium* species were also shown to be an important factor of replant disease (Manici et al., 2003; Manici and Caputo, 2010; Kelderer et al., 2012). Otto and Winkler (1977) detected actinomycetes in the damaged feeder roots and microscopically visible injury of apple trees and considered actinomycetes as a causal organism of this disease. Westcott et al. (1986) established an association between infectious actinomycetes and apple replant problem and reported that actinomycetes may be important in the aetiology of the disease. Westcott *et al*. (1987) found high levels of infection of the Actinomycete-like organisms in soil conducive to apple replant problem. Catska and Taube (1994) found phytotoxic micromycetes to cause apple replant problem.

Jensen and Buszar (1988) identified the involvement of Oomycetes in apple replant problem. Root pathogenic actinomycetes are the primary cause of specific apple replant problem (Otto and Winkler, 1993; Winkler and Szabo, 1995; Szabo et al., 1998). Otto et al. (1994) from their studies concluded that root exudates, as determined by the metabolism of growing terminal buds contain signal substances, which switch on the activities of root-pathogenic actinomycetes and lead to root infection. Otto and Winkler (1998) confirmed infection of woody plants of the family Rosaceae in soil with specific replant disease by actinomycetes resulting in damage of the cortical cells and finally in the death of the rootlets. Light microscopic investigation of rootlets of young apple seedlings grown in soil suffered from apple replants problem revealed the colonization of actinomycetes in cortical cells (Szabo et al., 1998). Various researchers have reported *Rhizoctonia, Phytophthora, Pythium* (Caruso *et al.*, 1989), *Alternaria, Cylindrocarpon, Fusarium, Rhizoctonia* and *Verticillium* (Kowalik, 1999), *Dematophora necatrix, Fusarium oxysporum, Phytophthora* spp. and *Pythium* spp. (Kumar *et al.*, 1998) to cause apple replant problem.

2.2. Bacteria

Fluorescent pseudomonas may act as growth inhibitors in apple seedlings and possibly a causative factor in the development of replant disease (Bunt and Mulder, 1973). Catska et al. (1982) found *Pseudomonas putida* as a cause of apple replant problem in Czechoslovakia. Two strains of *Bacillus subtilis* have been reported to be associated with stunting growth of apple seedlings in British Columbia by Utkhede and Li (1988). Waechter (1988) isolated bacteria from the soils of apple orchards with different levels of replant disease and reported it as a causal organism of the disease. Bacteria alone or in combinations with fungi and nematodes may contribute towards the occurrence of apple replant problem (Utkhede et al., 1992). However, contrary to this, Rumberger et al. (2007) reported that potentially antagonistic neither *Pseudomonas* nor rhizosphere cyanide concentrations appeared to be involved in the apple replant problem complex.

2.3. Nematodes

Winkler and Otto (1972) indicated that nematodes are not the main factor responsible for apple replant problem. Similarly, Mazzola (1998) found minor or no role of plant-parasitic nematodes in development of apple replant problem. Contrary to this, Szczygiel and Zepp (1998) reported that root parasitic nematodes (*Pratylenchus penetrans*) are responsible for the unspecific type of replant disease. Two agents, nematode and unknown organism present in field soil contribute to apple replant problem by inducing stunting and root discolouration symptoms (Jaffee et al., 1982). Isutsa and Merwin (2000) isolated phytophagous nematodes from roots of apple plants grown in the replant test soil.

2.4. Fungus and nematode interaction

Utkhede et al. (1992) suggested that interactions between soil fungi such as *Phytophthora* species and *Pratylenchus penetrans* are involved in apple replant problem. Histopathological studies have shown the presence of nematodes and hyphae of *Rhizoctonia*, *Phytophthora* and *Pythium* in the roots of apple trees in replant soil (Caruso et al., 1989). According to Mazzola et al. (2009) *Pythium* species and *Pratylenchus penetrans* were predominant components of the apple replant problem.

2.5. Phytotoxins

There are various evidences that the allelopathy has a drastic effect over the seedling and plant growth. The allelochemicals impair the physiological function of the cell directly or indirectly thus retard the plant growth and cause soil sickness in apple (Ajsaadawi and Rubeaa, 1985).

2.6. Role of variety

Different apple varieties respond differently in replant soil and show varying degree of replant disease. It is due to the growth and vigour pattern of the scion/stock, the root system of the stock and water and nutrient absorption capacity of the plant. O'Kennedy and Kavanagh (1980) found more severe effects of replant disease on Golden Delicious than Cox on M.9 rootstock. Northern Spy seedlings showed severe stunting and root discolouration symptoms when grown in untreated field soil obtained from an orchard with a history of apple replant disease (Jaffee et al., 1982).

2.7. Orchard soil properties

Poor growth of young apple trees on replant sites has been thought to be due to arsenic toxicity (Covey et al., 1979). Benson et al. (1978) established a negative correlation of seedling growth with soil arsenic concentration and reported that zero growth occurs at about 450 ppm total arsenic concentration. According to Willett et al. (1994) and Potter (1999), low soil pH, poor irrigation practices, arsenic spray residues, soil compaction, nutrient deficiencies and selection of an inappropriate orchard system contribute to low soil fertility and the apple replant problem.

Low soil pH prevents the specific apple replant disorder (Jonkers and Hoestra, 1978). Contrary to this, Buszard and Jensen (1986) failed to establish any correlation between soil pH and apple replant problem. Apple replant problem appears to be more frequent in light sandy soil than heavy soils, however, growth improvement with control measures was reported to be better in light rather than heavy soils. The disease has been reported more frequent in neutral or slightly acidic soils than in more strongly acid soils. Szczygiel and Zepp (1998) observed more frequent occurrence of apple replant problem in light and neutral or slightly acidic soils than in heavy and acidic soils.

Deficiency of N, P and K in the soil cause physiological stresses that lead to replant problem (Merwin and Stiles, 1989). Li and Utkhede (1991) established positive relationships of major nutrient elements (N, P and K) with plant height in apple replant soils. Moyls *et al*. (1994) found phosphorus deficiency as a nutritional factor associated with apple replant problem. Toxicity caused by the excess of Mn and Al (Hoyt and Neilsen, 1985) and heavy metals such as arsenic derived from pesticides (Benson, 1976) have also been implicated in replant problem of apple.

2.8. Role of plant growth regulators

Growth regulators, 1-naphthylacetic acid (NAA) and benzylaminopurine (BAP) spray promoted root infection very strongly in replant soils, whereas, gibberellins reduced infection at the lower level of apple replant disease (Otto et al., 1994).

3. Control Measures

Soil fumigation, increased recognition of soil physical/chemical/moisture problems, reduced reliance on seedling rootstocks and an increase in the use of dwarfing as well as precocious rootstocks could be a management tool for better apple tree growth and production at old apple orchard soils (Willett et al., 1994). The disease may be controlled by the application of broad-spectrum fumigants, but environmental concerns necessitate the investigation of the organic alternative. Since the disease develops mainly through changes in soil microbial populations, the integration of biological soil amendments into production systems may shift the population balance towards a more beneficial microbial community (Barea et al., 2005; Cohen et al., 2005; Yao et al., 2006). Due to the adverse effects of disease on root proliferation and development, stimulation of root growth can also play an important role in managing it. Various control measures which have been found effective are discussed below:

3.1. Chemical control

Fumigation greatly increased the growth of apple trees at replanting site (Jackson, 1973). In most soils fumigation resulted in better tree growth than in untreated soil (Ross and Crowe, 1973). The growth of apple tree can be significantly improved by effective control of replant disease with chloropicrin (Ryan, 1975). Sewell and White (1979) obtained the effective control of apple replant problem using pre-planting soil treatments with chloropicrin, propylene oxide, steam or formalin. Application of formalin @ 150 ml/m^2 soil provides an economical and less hazardous alternative to chloropicrin for the control of apple replant problem (Sewell, 1979). Oehl (1980) reported that pre-planting fumigation of replant soil with chloropicrin @ 281 l ha^{-1} resulted in increased shoot numbers, trunk girth and total yield. Control of replant disease has typically relied on pre-plant application of broad-spectrum soil fumigants (Mazzola and Gu, 2000). Brown and Schimanski (2002) recommended the use of Basamid (dazomet) for soil fumigation to control the disease.

Williams (1984) recorded significantly higher girth increment, total extension growth and fruit yield in trees planted into replant soil that was treated with chloropicrin (injections @ 28 ml/m^2) and mulched with black polyethene film after planting. Slykhuis and Li (1985) effectively treated the soil infested with apple replant disease using methyl bromide (0.5 g litre^{-1}), captan (1 g litre^{-1}), chloropicrin (0.2 g litre^{-1}), formalin (2 ml litre^{-1}), dazomet (0.25 g litre^{-1}), mancozeb (0.5 g litre^{-1}), efosite-al (0.1 g litre^{-1}) and urea formaldehyde solution containing 10% N (1 ml litre^{-1}). Methyl bromide has been the fumigant used most widely to control apple replant problem (Szczygiel and Zepp, 1998). Gur et al. (1991) applied pre-planting soil fumigation with methyl bromide, chloropicrin, 1, 3-dichloropropene, 1, 2-dichloropropane and Vorlex (methyl isothiocyanate + 1, 3-dichloropropene, 1, 2-dichloropropane) either singly or in combinations in replanting apple sites and found that fumigation with a small amount of methyl bromide was much less effective than double fumigation, first with chloropicrin and then with methyl bromide.

Ross et al. (1983) reported that fumigation with vortex (methyl isothiocyanate) significantly increased the trunk cross-sections of apple trees in replant sites. Covey et al. (1984) recommended the use of formaldehyde (0.06-0.43 mg kg^{-1} soils) instead of chloropicrin or methyl bromide for effectively alleviating growth suppression indicative of an apple replant problem. Jensen and Buszard (1988) found post-planting applications of metalaxyl @ 0.312/0.600 mg a.i./litre at weekly or biweekly intervals as effective as steam sterilization for controlling apple replant disease. Application of the fungicides difenoconazole or metalaxyl enhanced the growth of apple plants in replant soils (Mazzola, 1998). Bavistin (0.2%), Jkstein (0.2%) and Dithane Z-78 also found to improve growth of apple plants in replant soils but not as effective as formalin. Line et al. (2003) compared the efficacy of Telone C35 (chloropicrin), Basamid (dazomet) and the standard methyl bromide at apple replant sites and reported significantly greater control of replant problem with methyl bromide and Telone C35 than the untreated control and the Basamid treatments.

3.2. Cultural control

Costante (1990) had outlined a programme of cultural practices to reduce losses due to diseases at apple replanting sites. Since, apple replant problem has been recognized as a soil borne problem, the attention is needed towards modification of cultural practices such as to dig the pit slightly away from the old one, take out old roots before replanting, destroy them, removal of hardpan at sub-soil level and avoid water logging. Different cultural practices reported to control apple replant problem are as under:

3.2.1. Application of soil amendments and fertilizers

The organic amendments have a variety of beneficial properties in addition to their ability to supply nutrients and improve soil water holding capacity. The disease-suppressive effects of compost have been established (De Ceuster and Hoitink, 1999; Noble and Coventry, 2005) and mechanisms of disease suppression have been attributed mainly to the microbial activities inherent to them (Ristaino and Thomas, 1997). Compost or earthworm humus added to the soil placed in planting holes of replanted apples considerably increased growth rates (Gur et al., 1998). Organic substances may not only influence soil structure and its moisture but can also modify the composition of microflora in a direction beneficial to young roots (Szczygiel and Zepp, 1998). The general biological activity of the soil is stimulated by addition of an available carbon source (Campbell, 1989; Magarey, 1999) and soils with a diversity of beneficial microorganisms are more likely to be suppressive to disease development (Lazarovits, 2001). Mazzola et al. (2001) suggested the use of *Brassica napus* seed meal amendments for the management of apple replant disease (*Rhizoctonia* species) as this amendment controlled the disease by mechanisms other than the production of glucosinolate hydrolysis products. Wilson et al. (2004) had grown apple plants for 4 weeks in a soil-less potting mix before transplanting into replant soil pasteurized or amended with various levels of organic matter and found to produce markedly longer extension growth than trees planted directly into replanting soil. While comparing fumigation and compost treatment for control of apple replant problem, Yao et al. (2006) recorded longer lateral extension growth in trees growing in compost-treated soil as compared to those under fumigation treatment. Mazzola et al. (2007) suggested the use of a composite *Brassica juncea* and *Brassica napus* seed meal mixture for effective control of the pathogen complex inciting apple replant disease relative to either seed meal used alone. Applications of compost and compost extracts were identified as promising practical tools for managing replant disease. In pot trials, the application of compost and sterilized as well as unsterilized compost extracts to apple replanting soil was found to significantly increase the growth of apple seedlings (Schoor et al., 2009).

Hudska et al. (1987) recorded 2.17 fold higher growth with liquid fertilizer and 1.76 fold higher growth with potassium sulphate at replant sites and suggested soil acidification and sulphuric acid treatment of old orchard soils for control of replant disease. Fertilization with mono ammonium phosphate corrected stunting effect and effectively promoted the growth of apple plants at replanting sites (Utkhede and Li, 1989; Utkhede and Smith, 1993). Utkhede and Smith (1991a) recorded a significant increase in seedling height with the application of N and P fertilizers in soil infested with fungi and bacteria causing replant disease. They further reported that N and P promoted the growth of bacteria antagonistic organisms associated with replant disease. Mono ammonium phosphate was found more effective than *Bacillus subtilis* and formalin in increasing total shoot length and trunk cross-sectional area of 2-year-old McIntosh plant on M.26 rootstock (Utkhede and Smith, 1994). Szczygiel and Zepp (1998) recommended the use of bio-humus amendment at 10-20 per cent and mono ammonium phosphate at 2 g litre^{-1} of soil for effective control of apple replant problem. Wilson et al. (2004) examined the response of young apple trees to amendment of apple replant problem soils using mono ammonium phosphate, organic matter or replacement soil and reported that mono-ammonium phosphate at 1 and 2 g l^{-1} of soil resulted in a significant improvement in first year radial growth, but higher rates of mono-ammonium phosphate were found toxic. Wojcik and Klamkowski (2008) mixed the mono ammonium phosphate with soil @ of 1, 2 and 3 g l^{-1} before planting and recommended the application of mono-ammonium phosphate @ of 1 g l^{-1} for coarse-textured soils with low P status in the soil solution to increase precocity of apple trees. In replanting, soils absence of mycorrhiza leads to the unavailability of phosphorus due to soil absorptive complex. In such situations, mono ammonium phosphate application reduces the negative effect of replant disease and enables young roots to use phosphorus without mycorrhiza.

Use of plastic mulch against apple replant problem was as effective as fumigation with methyl bromide, chloropicrin or formalin (Jensen and Buszard, 1988). Engel et al. (1994) recommended the planting of two-year-old nursery plants than one-year-old plants in replant disease affected soils for higher growth and vigour. Application of peat and drip irrigation enhanced shoot growth in replant soils (Dencker and Hansen, 1995). Szczygiel and Zepp (1998) suggested that activated charcoal controls replant disease to some extent. The ethylene content in the soil and root environment of replanted apple plants was reduced by adding activated charcoal to the soil or by soil fumigation with methyl bromide (Gur et al., 1998). Leinfelder and Merwin, (2006) studied the effect of planting position on tree growth and reported that trees planted in old grass lanes perform better than those in the old tree rows. According to Rumberger et al. (2007), avoiding replanting into the old tree rows coupled with the use of tolerant rootstocks appeared to be the best strategy for reducing apple replant problem. Addition of slow-release fertilizers, compost and mulch extracts significantly increased the growth parameters and survival of apple seedlings in replant soil (Engel et al., 2001; Schoor et al., 2009).

3.2.2. Intercropping

Antagonistic activity of marigold and grasses like red fescue and red top has been recorded against *Pratylenchus penetrans* by Townshend et al. (1984). Intercropping with herbaceous crops greatly improves the apple seedling growth in replanting soils (Vrain and Yorston, 1987). Crops like mustard, radish, cabbage etc are effective in controlling the soil borne pathogens. These crops release volatile gases, which are effective against the soil borne pathogens (Gamliel and Stapleton, 1993). Edwards et al. (1994) conducted field trials to test the effectiveness of antagonistic plants on the populations of *Pratylenchus penetrans* and *Pythium* species in replant soils and found that marigold *(Tagetes patula,* cv. Harmony), creeping red fescue *(Festuca rubra)* as well as red top *(Agrostis alba)* substantially decreased the population of *Pratylenchus penetrans* and *Pythium* species, whereas, canola crop substantially increased the population of these pathogens.

In greenhouse studies, cultivation of wheat in replant orchard soils prior to planting suppressed disease development. Under controlled conditions, cultivating replant soils with wheat prior to planting apple resulted in reduced root infestation by *Pythium* species, *Rhizoctonia* species and *Pratylenchus* *penetrans* and enhanced seedling growth (Mazzola and Gu, 2000). The microbial community resident in a wheat field soil was shown to suppress components of the microbial complex that incites apple replant problem (Mazzola et al., 2002). Wheat cultivation prior to planting, modified the genetic and species composition of the fluorescent *pseudomonas* population resident to orchard soil and substantially enhanced apple seedling growth (Gu and Mazzola, 2003). Contrary to this, Mazzola, (2003) observed no significant impact of cultivation of replant orchard soils with a perennial/annual ryegrass mixture prior to planting of Gala seedlings. Mazzola and Mullinix (2005) evaluated the influence of cultural practices including cover crops and incorporation of *Brassica napus* seed meal on the control of apple replant problem and reported that *napus* seed meal significantly enhanced vegetative growth and yield of Gala/M.26 compared to methyl bromide soil fumigation. Contradictory to this, Mazzola and Mullinix, (2005) observed that *Brassica napus* green manure neither suppressed disease development nor enhanced tree growth. Mazzola et al. (2006) advocated the *Brassica napus* seed meal induced control of *Rhizoctonia solani* because it enhanced the activity of resident soil microorganisms, specifically *Streptomyces species*.

3.2.3. Use of resistant/tolerant rootstocks

Rootstock selection and row repositioning have been found to be more beneficial than soil fumigation or compost amendments in controlling apple replant problem. Development of replanting resistant rootstocks for apple is a slow and lengthy process and sometimes the resistance obtained is lost by the time plant comes into a productive stage. In replant apple soils, Ryan (1975) suggested the use of M.12 rootstock for sites susceptible for root diseases, MM.115 and M.793 for lighter soils and M.793 for heavier soils with chloropicrin fumigation. Costante et al. (1985) reported that apple rootstock MM.111 roots in clay had fewer *Pratylenchus penetrans* than MM.106 roots. Rootstock genotypes modified their rhizosphere environments which differed significantly in their bacterial, Pseudomonas, fungal and oomycetes communities. Although none of the apple accessions has found completely resistant to replant disease in the test soil, however, seedling accessions of *Malus sieversii* and *Malus kirghisorum* had some tolerance and three clonal rootstock accessions viz., CG.65, CG.6210 and CG.30 and four other clones like *Malus baccata* 1883, *Malus xanthocarpa* Xan, *Malus spectabilis* PI 589404 and *Malus mandshurica* 364 had good tolerance (Isutsa and Merwin, 2000). Rootstock genotype had the dominant influence on root lifespan and distribution, whereas pre-plant soil fumigation, compost amendments and replanting positions had a little apparent impact on root characteristics despite their influence on above-ground tree growth and yield (Yao *et al*., 2006). Leinfelder and Merwin (2006) recorded better growth and higher yield of apple on CG.6210 and CG.30 clonal rootstocks than those on other rootstocks and reported that clonal rootstocks were more beneficial than soil fumigation or compost amendments in controlling apple replant problem. Yao et al. (2006) evaluated the response of five clonal rootstock genotypes (M.7, M.26, CG.6210, G.30 and G.16), in an apple replant site and recorded highest growth and yield on CG.6210 rootstock, while trees on M.26 rootstocks had the least growth and lowest yield. They categorized the rootstocks M.7, M.26 and CG.16 as susceptible, while CG.30 and CG.6210 as tolerant to apple replant problem. Use of apple replant problem tolerant rootstocks is an emerging control strategy (Rumberger et al., 2007). Out of seven rootstocks studied, Angelika *et al*. (2010) found CG.30 and CG.6210 clonal rootstocks relatively tolerant to the apple replant problem on the basis of root-zone soil microbial consortia and the relative severity of apple replant problem. The genotype-specific interactions with soil microbial consortia were linked with apple rootstock tolerance or susceptibility to replant problem by Laurent et al. (2010). Auvil et al. (2011) from their studies on 65 rootstocks and three scion cultivars (Gala, Fuji and Honeycrisp) in modern, high-density systems at replant sites concluded that trees on G.41 and G.11 rootstocks had less vigour than trees on G.935, CG.4214, G.202, and CG.4814. Wang et al. (2011) evaluated adaptability of five rootstocks viz., *Malus sieversii, M. micromalus, M. hupehensis, M. baccata* and *M. micromalus* to replant soils with pot trials and concluded that *M. hupehensis* had a better tolerance to replant problem and plants on this rootstock exhibited the lowest decrease in photosynthesis rate, chlorophyll and carotenoids contents. Various research workers have reported the susceptibility of MM.106, MM.111 (Mazzola, 2003), M.26 (Mazzola, 2003; Rumberger et al., 2004; Laurent et al., 2010), M.7, CG.16 (Rumberger et al., 2004) and G.65 (Laurent et al., 2010) to the disease. However, G.30, CG.210 (Isutsa and Merwin, 2000; Rumberger et al., 2004; Laurent et al., 2010), CG.5935, CG.4202 (Robinson et al., 2004) and M.793 (Soni et al., 2011; Singh and Sharma, 2017; Singh at al., 2017; Singh et al., 2018) have been reported as tolerant rootstocks to apple replant problem.

3.2.4. Use of mulches

Soil solarization with polyethene mulch alone or in combination with soil fumigation with certain fumigants like formaldehyde is effective against the soil-borne pathogens. In controlling replant disease, plastic mulches as a cultural treatment have been found as effective as methyl bromide, chloropicrin and formalin (Jensen and Buszard, 1988). Cultural practices of deep ploughing and use of grass mulch between the rows have been found effective against apple replant problem by Engel (1988).

3.3. Biological control

Although soil fumigation and chemicals are most adaptive mean to control replant problem but not attractive as they disturb natural equilibrium between pathogen and antagonistic microorganisms in the soil. Utkhede and Smith

(1991b) recorded an increase in tree growth of apple in the replanting site by soil drenching with Bacillus subtilis. *Agrobacterium radiobacter* improves the growth of apple plants grown in soil with the apple replant problem (Catska and Taube, 1994).

Parasitism of pathogenic fungi by other fungi is generally termed as "Mycoparasitism". Some of these mycoparasites, such as *Trichoderma spp*., have a very broad host range while others, such as chytrids are host specific. When a mycoparasite is grown with its host in dual culture, hyphae may coil around the host and hook-like structure (appressoria) are formed. The recognition phenomena involving agglutinin (lectin) from the host binds to carbohydrate residues on the cell walls of *Trichoderma spp.* was supported by fluorescent indicators and enzyme studies which provided evidence for enzymatic activity leading to penetration of host hyphal cell by mycoparasites. Mycoparasites produce hydrolytic enzymes; β-1, 3 glucanases, cellulase and chitinase in appropriate to the cell wall substrate. Involvement of numerous separate genes and gene products has been reported in mycoparasitic interactions by Harman et al. (1989) and suggested the involvement of chitinase and β- 1, 3 glucanases in Trichoderma mediated bio-control.

Bacterial strain EBW-4 of *Bacillus subtilis* and Strain B8 of *Enterobacter aerogenes* were found to have potential for field control of apple replant problem in orchards. Application of BACT-1 and EBW-4 under field conditions leads to increase shoot growth in unfertilized and unpasteurized apple replanted soils (Utkhede and Li, 1989). The post planting drench application of strain EBW-4 of Bacillus subtilis alone or in combination with formalin fumigation effectively increased trunk cross-sectional area, shoot growth and fruit yield of apple, which showed the potential of this bacterium for biological control of replant disease (Utkhede and Smith, 1992). Mycorrhizal fungus *Glomus mosseae* used alone or in combination with *Enterobacter aerogenes* and peat significantly increased their growth in replanted apple soil and effectively control the replant problem (Utkhede et al., 1992). Two mycorrhizal fungi, *Glomus species* D13 and *Glomus intraradices* increased total shoot length and the number of shoots per rootstock in apple replant soils (Taube and Baltruschat, 1993). Utkhede and Smith (2000) recorded increase in growth and fruit production of apple in soil conducive to replant disease with the application of biological agents (strain B8 of *Enterobacter agglomerans*, strain EBW-4 of *Bacillus subtilis* and *Glomus intraradices*).

A radiobacter may affect the plants by changing the composition of the rhizosphere microflora and by reducing the number of colony-forming units of phytotoxic micromycetes contributing to replant disease (Catska and Hudska, 1993). Inoculation of apple seedlings and rootstocks with *Agrobacterium radiobacter* improved the growth of apple plants grown in soil with replant problem (Catska and Taube, 1994). Similarly, inoculation with the vesicular-arbuscular mycorrhizal fungus *Glomus etunicatum* successfully controls the apple replant problem. Apple replant problem was suppressed by inoculation of apple-tree seedlings with *Glomus fasciculatum* and *Glomus macrocarpum* (Catska, 1994), which showed that the use of some VAM fungi could replace chemical treatments of soil against apple replant problem. The strain EBW4 of *Bacillus subtilis* has potential for biological control of the apple replant problem (Utkhede and Smith, 1994). The application of *Enterobacter agglomerans* (B8), *Bacillus subtilis* (EBW-4), *Glomus intraradices* (GI), significantly increased fruit yield and tree trunk growth and reduced infection by *Phytophthora cactorum* and *Pythium ultimum* in the soil conducive to replant disease (Utkhede and Smith, 2000). Rabie et al. (2001) suggested the use of biological formulations and soil composts for the control of the replant problem. Bharat and Bhardwaj (2001) studied the interaction between five species of VAM and *Dematophora necatrix* and found that local isolate of Glomus species was most effective in reducing disease severity, increasing VAM root colonization and increasing different plant growth parameters of six-month-old apple seedlings. Arbuscular mycorrhizae colonisation of apple roots at planting in different replant problem soils resulted in increased arbuscular mycorrhizae population in chloropicrin fumigated or fungicide treated pot soils (Kandula et al., 2006). Development of fungal and pseudomonas communities in the rhizosphere of the different rootstock genotypes may be important factor influencing tree growth and yield at apple replant sites (Yao et al., 2006). Raj and Sharma, (2009) tested four isolates of VAM and two isolates of *Azatobacter chrococcum* on seeds and seedlings of Golden Delicious against *Dematophora necatrix* (root rot of apple) and found that AZUHF1 isolates of *A. chrococcum* and AMUHF1 (*Glomus fesiculatum*) were the best treatments in increasing the shoot and root length.

3.4. Thermal control

Soil steaming at 60 °C or above for 45-60 minutes is required to remove growth-inhibiting agents from replant apple orchard sites (Winkler and Otto, 1972). Soil steaming temperatures up to 50ºC did not alter the growth suppression induced by replant disease, whereas, 60 °C steaming improved subsequent shoot growth and 70ºC permitted normal growth of plants (Otto, 1972). According to Moyls et al. (1994), steam heat treatments of soil reduced the effects of apple replant disease and steam for 1 minute showed 68 per cent better growth, while steaming for 2 minutes showed 120 per cent growth improvement. Mazzola (1998) reported that soil pasteurization enhanced the growth of apple plants and resulted in the change in the composition of the fungal community.

3.5. Integrated management

The exact cause of the replant problem is difficult to investigate as it can vary from region to region. Therefore, it is difficult to control the problem with only one method of management hence, integrated management could be an effective tool for the management of replant problem. Baxter (1977) reported that soil treatment with Vertafume and mulching with sawdust or plastic, markedly increased tree growth (total shoot length and trunk cross-sectional area) at replanting sites. Utkhede and Li, (1989) suggested the use of bacterial strain B8 in combination with mono-ammonium phosphate and lime in combination with fumigation and bacterial strains (EBW-4 of *B. subtilis* and strain B8 of Enterobacter aerogenes) for effective control of the disease. Utkhede and Smith, (1993) reported that although the application of mono-ammonium phosphate alone may be sufficient to alleviate the replant problem but the addition of *Bacillus subtilis* strains BACT-1 or EBW-4, or Enterobacter aerogenes strain B-8 to this treatment may be beneficial to increase tree growth. Granatstein and Mazzola (2001) advocated the integration of cultural and biological methods for control of apple replant problem. Use of topsoil + additional P + formalin drench was found the most effective control of apple replant problem by Bhardwaj and Sharma, (2004) in Kullu valley of Himachal Pradesh. Soil fumigants helped in controlling apple replant problem when applied in combination with biological and cultural practices (Angelika et al., 2004). Wheat cropping controlled apple replant problem and enhanced fruit yield, whereas, *Brassica napus* seed meal amendment in concert with a post-plant mefenoxam soil drench was found as the sole treatment to provide a growth and yield response equivalent to soil fumigation (Mazzola et al., 2006). Avoiding replanting into the old tree rows coupled with the use of tolerant rootstocks appeared to be the best strategies for reducing replant problem in apple orchards (Rumberger et al., 2007). Kandula et al. (2010) reported improvement in growth of apple in replant site with commercial *Trichoderma* formulations and nitrogen, phosphorus as well as potassium (NPK) supplements.

4. Conclusion

Apple replant problem is a serious problem in the establishment of new orchards at old sites. The disease is a complex syndrome, caused by various biotic and abiotic agents and results in poor survival, growth and yield of young replanted apple trees. The soil fumigation and solarization have been found more effective in its control, but due to complex nature of the problem, integrated management practices combining chemical, cultural and biological methods should be given preference as control measures. The detailed research on quick and correct diagnosis of biotic and abiotic causes of the problem and management through eco-friendly techniques is the need of the present time.

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