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Diseases Infesting Forage Alfalfa (*Medicago sativa* L.) and Management

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***Abstract*:** Alfalfa or lucerne, *Medicago sativa,* is one of the important legumes grown as a fodder crop providing feed hay with valuable nutrients. It is the principal source of fibre and protein in animal diets, thus plays an important role in the dairy industry. Alfalfa can significantly accumulate nitrogen by its deep rooting system and fix atmospheric nitrogen by biological fixation. Alfalfa plant stand covers the soil to minimize erosion by water or wind. Also grown as a rotational crop, Alfalfa provides the soil with nutrients and organic matter and the foliage acts as soil manure. Alfalfa is produced in several countries such as the USA, Australia, Europe and the Middle East. Pests, including insects, diseases, and nematodes, affect alfalfa hay productivity, considerably reducing yield, plant stand life, and fodder quality. Alfalfa is subjected to several infectious diseases causing severe menace, that can limit forage production, decline the fodder quality and restrict stand persistence. Many times, they cause sudden stand loss, delayed regrowth after cutting, ultimately stunted alfalfa stand. Managing the diseases is an important aspect of economical alfalfa production. A thorough understanding of the disease status, their seasonal incidence, damage symptoms and management strategies is an important tool in effective alfalfa fodder production. The current review highlights the different types of diseases caused by diverse pathogens infesting alfalfa crop, the symptoms of their infestation and managing the diseases organically in an environmentally safe manner.

Keywords: Alfalfa, Lucerne, Legume, Fodder, Disease, Pathogen

Alfalfa, *Medicago sativa,* is herbaceous perennial legume belonging to the family Fabaceae, which is primarily cultivated as a forage crop to provide high quality forage, which can be grazed by animals or harvested as hay or silage to be used as an animal feed (Paolo et al 2015). It is a plant that has been grown as feed for livestock for hundreds of years. It is treasured for its maximum content of nutrients *viz.,* proteins, vitamins and minerals. It is highly valued as a legume fodder, where millions of acres are devoted to it (Graham et al 1972). Alfalfa is widely planted over 32 million hectares due to its high nutritive and biomass producing values (Heuzé 2016). Alfalfa has several other benefits apart from forage purposes. Several pharmaceutical industries especially homeopathic pharmacy utilizes it for producing a nutritional tonic. The higher content of protein (60.5 %), minerals, enzymes, vitamins etc. excel the utility of Alfalfa to use as a tonic (Anonymous 1962), which is of increasing demand for its added nutrition, which enhances appetite and digestion resulting in improved mental and physical vigour (Boericke 1927). Alfalfa is an abundant source of Vitamin A and E and rich in Vitamin C (1.78 mg/g), but as the foliage dries vitamin content is lost. Amylase, peroxidase, lipase, and pectinase are notable enzymes present in Alfalfa (Uphof 1968). Alfalfa sprouts are used in salad making, shoots are utilized as leafy vegetable and dehydrated Alfalfa is articulated as a tablet for dietary supplement (Capneura 2008).

Soil fertility conservation by enhancing organic matter content to improve soil fertility has gained attention in soil research these days (Kusvuran et al 2014). Alfalfa is recognized as soil building legume crop, as it is able to significantly accumulate nitrogen by its deep rooting system and biologically fix atmospheric nitrogen (Jarvis 2005). It effectively uses excess water by its high-water consumption capacity with its deep roots. Alfalfa in crop rotation or in a mixed cropping apart from enriching the soil with organic matter, additionally aid in physical and chemical fortification of the soil (Kusurvan et al 2014). The soil aeration and drainage are enhanced due to penetration of alfalfa roots in soil, thereby improving the symbiotic fixation of nitrogen and activity of free-living nitrogen fixers in the soil. Alfalfa, greatly contributes in achievement of sustainable agriculture, as it is cut for foliage, the root system dies, providing organic matter to soil which is degraded by soil micro-organisms and foliage regrows and root develops again (Vasileva et al 2015). Alfalfa removes more N, P, and K on a per acre basis than any other major crop. For example, a six-ton hay yield of Alfalfa removes about 350 lbs of nitrogen (N), 40 lbs of phosphorous

(P) and 340 lbs of potassium (K) (Hanson et al 2013).

Alfalfa pests significantly reduce forage productivity, quality and stand life, minimizing the economic outcomes in alfalfa production. Sufficient awareness of the factors that encourage the build-up of the pest and the skill to diagnose the signs and indications of insects, pathogens and nematodes that infest Alfalfa is a significant tool in successful alfalfa production.

Diseases cause major yield reduction in Alfalfa and reduce the feeding value of the foliage. Several pathogens were reported to infest Alfalfa the severity of which differs seasonally and geographically. Pathogens that cause fungal diseases include virus, fungi, bacteria and nematodes. For a plant to be infested by a disease, the variety must be susceptible to pathogen and the environmental conditions, temperature and humidity favor disease development. The major and minor diseases that infest Alfalfa are detailed as follows:

Major Diseases of Alfalfa

Seedling or damping off (*Pythium ultimum, Pythium irregulare, Pythium violae, Phtopthora megasperma, Rhizoctonia solani*): Damping off is an ailment of seedling, where seeds get infested and die before germination or the emerging seedling will be stunted or collapse or dyeing of seedlings dye shortly after emergence. The damaged seedling before germination is discoloured and soft, and necrotic lesions occur after germination. The lesions after germination girdle the root and stem leading to plant death (Laurine et al 2017). The girdled plants subjected to root tip necrosis may be stunted and yellowish in colour. In older seedlings, near the soil surface a discolored constricted area is seen. The extent of discolouration is dependent on the age of seedling and duration of environmental conditions that favours the progress of the disease. The disease-causing genus, *Pythium* and *Phythopthora* commonly occur in most soil conditions as the fungi is transported by water, infested soil particles and carry over by infected plants. Damping off in Alfalfa leads to *Pythium* sp. that occurs under cool soil temperature. The infestation due to *R. solani* is often influenced by soil organic matter content of the soil enriched by earlier crops, with the infestation increases with the level of organic matter content (Bucciarelli et al 2018). After emergence the seedlings show water-soaked appearance and no proper demarcation between healthy and infested tissues could be noticed. Typical root-tip necrosis as well as inhibition of lateral root formation is caused by infestation of *P. violae. Rhizoctonia solani* causes pre-emergent death of seedlings as well as post emergent necrosis of stem near the soil surface (Lamichhane 2017). *Phythopthora megasperma* is yet another soil borne pathogen, distressing poorly drained soils.

Seedling blight and seed rot (*Pythium, Phythopthora, Rhizoctonia, Aphanomyces, Fusarium* etc): The disease is favoured by several soil pathogens belonging to the genera *Pythium*, *Phythopthora*, *Rhizoctonia*, *Aphanomyces*, *Fusarium* etc. Cool and wet soil conditions will boost the infection. Seeds being destroyed or killed before germination is the major symptom of the disease, mainly caused by *Pythium* sp. The different plant parts display water-soaked lesions initially and collapse and die later (Al-Askar et al 2013). *Aphanomyces* can cause the cotyledons to turn to purple before the seedling dies and will not allow the seedling to die.

***Phythopthora* root rot (*Phythopthora megasperma* f.sp. *medicaginis*):** The soil borne fungus kind of microbe survives well in excess soil moisture with the hard spores in soil or infected plant debris, transported by irrigation water. Wet and cold weather along with heavy, poorly drained soil are favourable for *Phythopthora* development. The disease will be more abundant in water logged areas with excessive moisture and soil compaction increase the root rot problem and cause severe seedling loss (Linda et al 2002). The affected plants wilt and turn yellowish or reddish brown in high temperature. The roots develop numerous dark lesions on the taproot and ultimately the roots will rot. The root cortex shows yellowish discolouration. The affected plants display reddish discolouration which resembles phosphorus deficiency. A thin stand of alfalfa crop will be noticed in severely infested region. Regrowth of foliage will be very slow after harvest.

***Stagonospora* crown and root rot (*Stagnospora meliloti*):** The disease infests crown and root of Alfalfa influenced by cold weather. The spores of the pathogen that occurs as black pyncnidia is transported by irrigation water and spread as the water splashes to injected leaves, stem, plant debris etc. The fungus finds its path of entry into the plant through crown and progress its growth towards taproot slowly The disease will sustain in plant and will take around one to two years to spoil the plant; ultimately the plant will lose its vigour and growth. The crown will be infected anytime but leaves and stem after spring rain. The bark tissues of the infected roots and crowns being rough and cracked are the main symptoms. Red streaks occur in xylem in the middle of the root, down to the rotted portion of the crown. The affected crown tissues will be firm and dry or will lead secondary organisms to invade the tissue (Frate and Davis 2007). The infection causes irregular light shaded lesions with diffuse margins.

***Pythium* root rot (*Pythium ultimum; Pythium irregulare*):** The soil borne fungal pathogens, *Pythium ultimum* and *Pythium irregulare*, endure in soil and debris for several years

as oospores). They affect alfalfa seeds causing seed blight or rot and cause water soaking and eventually the roots and stem will be killed as they emerge. The pathogen can cause damage to mature plants by destroying the fine roots without any prominent symptom, but a measurable yield loss. *Pythium* and *Phytopthora,* causing damping off and root rots infest in acidic, poorly drained and soils of high organic matter content. *Phytopthora medicaginis* can affect alfalfa plants in all stages of development and is the common pathogen causing root rot in Alfalfa (Deborah and Laurine 2015). The infection due to *Phythopthora medicaginis* displays stunted growth, reddish purple colour change of leaves and ultimately wilted plants. The infected plants form brown lesions, which turn black with the centre of roots become yellow. The infested damped off tap roots results in pencil tip like appearance. Affected taproots are damped off below the crown region giving a pencil-point look, which can be easily uprooted from the soil in a single pull. The infested seedlings die rapidly making it difficult to distinguish between death due to *Phytopthora* caused by *Pythium*. In general, the whole tap root system of *Phytopthora* infected plants will be rotted and collapse, but only few roots of *Pythium* infested plants rots (Gray 2007).

***Fusarium* seed rot (*Fusarium* sp.):** Several *Fusarium* species cause several types of infections in Alfalfa such as seedling blight, root and crown rot of Alfalfa. *Fusarium* root rot is a chronic condition causing the plant to slowly decline. They spoil the fine roots of plants without causing perceptible decay, but with quantifiable yield reduction. The noticeable symptom is poor and stunted growth of plant above ground level. The roots have brownish or reddish-brown lesions that spoil the roots. *Fusarium* rot infection together with crown rot kills the plant (Ellis et al. 2013).

***Rhizoctonia* root rot or canker (*Rhizoctonia solani*):** *Rhizoctonia* root canker occurs in high temperature conditions causing serious seedling damping off globally. New stands are planted when temperature is ideal for disease development. Only few strains of fungus cause root canker. Occurrence of prominent elliptical lesions in roots at points where lateral roots emerge is a distinctive symptom of *Rhizoctonia* infestation. During winter season, when the fungus is inactive the lesions turn black and stay stable. If the infection is severe, the roots will be girdled leading to death of the plant. New roots will sprout in cold weather if the infestation is not severe.

Complex crown rot: It is a disease caused by the blend of several pathogens such as *Fusarium*, *Pythium, Rhizoctonia*, *Phoma* and *Stagonospora*. Infections in crown occurs, if the crown is injured by causes such as mechanical damage, insect injury, nematode infestation, frost etc., which permits access of pathogen to the crown. The appearance of brown necrotic dead tissues in crown region is a typical symptom, which leads to stunting of plant and yield reduction. Avoiding mechanical injury to the crown area hinders entry of the pathogen to the crown region (William 2016). Planting resistant varieties is yet another tactic.

Bacterial wilt (*Clavibacter michiganense* sub sp. *insidosum*): The bacterium penetrates taproots through wounds developed by insects like Clover root curculio. The disease appears in young plants of three years old. The infested plants are usually scattered and not clustered. The affected plants appear stunted with very slow regrowth after cutting. The plant parts turn to yellowish colour initiating from leaves. The infested roots display yellowish discolouration of the root vascular tissue. The internal root tissues show yellow compared to white in healthy tap roots. Planting resistant cultivars is the management strategy.

Fusarium wilt (*Fusarium oxysporum f. sp. medicaginis*): The disease is highly influenced by high soil temperature and warm climates. The damage can occur in all kinds of soil, but severe infestation is noticed in the soil with nematode activity. The foremost visual symptom of *Fusarium* wilt is shoot wilting, followed by stem blanching that leads to a reddish tint in the foliage (Peterson et al 2017). The disease leads to reddish brown discolouration of plants, especially in the inner parts of roots, that proliferates as the plant ages. *Fusarium* wilt causes dark discolouration, in contrast bacterial wilt shows yellowish brown discolouration (Antonopoulos and Elen 2008). Planting root knot nematode resistant variety will counterpart *Fusarium* wilt resistance, which lessens acquaintance of Alfalfa to pathogen by nematode feeding on the roots.

***Verticillium* Wilt (*Verticillium albo-atrum*):** *Verticillium* Wilt is highly favoured by warm temperature and seriously infest susceptible cultivars, reducing yield up to 50 per cent in the second year of production. The symptoms of wilt include yellowing of leaf tips in a V-shaped pattern, upward rolling of the edges of apical leaflets. As the symptoms progress, leaves turn reddish in shade and become desiccated, defoliated with an intact petiole left over (Göre et al 2011). The infested stem remain green until the leaves are dead. The intact xylem tissues of roots turn brown. The fungi can be carried through alfalfa seed and survives in alfalfa hay and in animal manure. The fungus enters alfalfa roots directly by roots and spread occurs through infection of stem cuts. Care should be taken to prevent importation of infected seed or plant materials. The harvesting equipment's should be cleaned when moving from infested fields into new fields. The infested field should be harvested separately to avoid spreading of pathogen. Care should be taken with irrigation

water from infested fields as pathogen spores can be carried in water.

Anthracnose (*Colletotrichum trifolli*): Anthracnose commonly occurs in established alfalfa stands. The development of disease pathogen is maximum in summer and the pathogen persists in debris and crown. Rainfall and irrigation water disperse spores, which is the inoculum source into plant parts such as stem and petioles. Spores also disperse through seeds contaminated in threshing process. Crown rot is the important phase of anthracnose disease which can be diagnosed by bluish black v shaped rot in the crown, which further infests stem and leaves (Harrison and Dixon 1993). The stem acquainted with the crowns turn bleached white and the crowns die and the leaves do not drop from the stem. Irregularly shaped large oval shaped blackened lesions with black borders are also produced due to anthracnose. Acervuli, black fruiting bodies will develop in the lesions, which enlarge, coalesce and wither the stem resulting in a typical 'shepherd crook' symptom on top of the stem.

Minor diseases: Apart from the major diseases, several other diseases are causes by numerous pathogens in alfalfa crop occurs on a regular basis, but most of them are not considered a major cause that limits yield and crop productivity. However, sometimes, they become a serious problem that affect the quality of alfalfa hay. The following are the list of few of those pathogens with minor importance in Alfalfa:

Alfalfa dwarf/Pierces disease (*Xylella fastidiousa*): The sharp shooter, *Homalodisca vitripennis* act as vector of the bacterium, *Xylella fastidiousa*, that cause alfalfa dwarf disease. The green and red headed sharp shooters are responsible for this disease in Alfalfa. The bacterium also causes Pierces' disease of grapes and almond leaf scotch. As the insects acquire the bacterium by feeding on infested plants, they spread the infestation by subsequent feeding of the non- infested alfalfa plants (Blua et al 1999). The disease is of minor importance in Alfalfa. The blue green sharp shooter transmits the disease from Alfalfa to grapes. The primary symptom is stunted growth after first cutting, which may not be apparent for certain period after initial infestation. The infested plants have smaller, darker, distorted, mottled or yellow-coloured leaflets. The tap roots sows yellowish wood with fine dark streaks on a diagonal cut. The yellowing occurs as a ring under the bark with no yellow or brown shades as in bacterial wilt infected by *Clavibacter insodiosum*. Dwarf disease slowly worsens and kill the plant in a year (Costa et al 1999). The green and red headed sharp shooters require grasses like bermuda grass, water grass etc. and hence preventing the growth of grassy weeds help to overcome the disease.

Alfalfa mosaic virus (AMV) and cucumber mosaic virus (CMV): These viruses are not economically important, but feed on Alfalfa and transmit the virus to other economically important food crops and causes severe yield losses. Tomato and potato are such infested crop being transmitted from Alfalfa. Cucumber mosaic virus acquires the virus from the infected plants and spread to beans plant. Alfalfa mosaic virus cause yellow mottling and streaking on leaves, but cucumber mosaic virus shows no specific symptoms (Abdalla et al 2012).

***Aphanomyces* root rot (*Aphanomyces eutriches*):** *Aphanomyces* root rot (APR) is a serious disease-causing severe yield loss in seeded and established alfalfa stands. The disease is caused by soil borne water mold, *Aphanomyces eutriches.* The disease occurs in alfalfa fields with poor drainage and fields with heavier compacted soils receiving excessive water. The disease occurs with variations in crops like soyabean, snapbean, fababean red kidney bean, pea, red clover etc (Wakelin et al. 2002). *A. euteiches* produce microscopic, long-lived resting spores in the roots of alfalfa plants and they remain dormant in soil for up to 10 years. If the spores come across a susceptible crop, oospores can germinate and directly infect plants or under wetter conditions produce several microscopic spores that can subsequently infest plants.

Crown wart (*Physoderma alfalfa*): *Physoderma alfalfa* is a soil borne fungus that will endure in soil forever as resting sporangia, that release zoospores under favourable conditions that penetrate crown buds. The disease is prevalent in wet, waterlogged conditions. The disease cause large knobby swellings on crown and roots and the plant shows stunted growth and often dies maintaining the soil with good drainage, avoiding excessive irrigation and avoid planting Alfalfa in fields with prior history aids to overcome the pests.

Common leaf spot (*Pseudopziza medicaginis*): The disease is caused by the fungus, *Pseudopziza medicaginis* hibernates in plant debris in the soil surface, and get discharged in air. The foliar disease proliferates under cool and wet conditions. The typical symptoms are occurrence of tiny, circular black spots on leaves which turn yellowish and drop. In circumstances of cold weather, apothecia, the fruiting bodies of the pathogen are visible as circular raised bodies in the surface of spots. Though the disease does not destroy the plant but decreases vigour, hay quality and yield (Naseri and Marefat 2008). Severe yield loss is noticed. Early harvesting is recommended as the disease progress over time.

Downy mildew (*Peronospora trifoliorum*): The disease is a cold loving foliar disease, shows up when the temperature

Fig. 1. Damping off

is severely cold and humidity is extremely high for the pathogen to produce spores and infest the plant (Liatukas 2014). The abaxial side of the leaves show lighter shade and adaxial side yellowish in colour. The infected areas show

Fig .1. Seedling blight

Fig. 2. Seed rot

Fig. 4. *Stagonospora* crown and root rot

Fig. 3. *Phytopthora* root rot

Fig. 5. *Pythium* root rot

Fig. 6. *Fusarium* seed rot

bluish gray mycelial mats and spores under microscopic view. Spore production is more pronounced in the dawn when high humidity is experienced (Mario and Lira 2018). The entire buds and leaves of the plant will be prone to attack resulting in distortion and yellowing of leaves leading to leaf drop and loss in plant vigour, which ultimately show reduction in yield and quality. Early harvest prevents yield losses.

Lepto leaf spot (*Leptospaerulina briosiana*): It is a fungal disease associated with leaf spots and dead areas surrounded by brown margins giving an 'eyespot'. The disease is said to be seed borne, but transmits by rain and wind. The spots later coalesce and fall out. The fungus builds up on leaves and stem and the spores spread to healthy plant (Feng et al 2016). Early harvest and crop rotation avoiding Alfalfa for more than a year will aid to overcome the disease.

Rust (*Uromyces straiatus*): The disease cause uredial lesions and chlorotic spots and reduce the market value of the foliage. The leafy spurge (*Euphorbia esula*) is an

Fig. 7. *Rhizoctonia* root canker

Fig. 8. Complex crown rot

Fig. 9. Bacterial wilt

Fig. 10. *Fusarium* wilt

Fig. 11. *Verticillium* wilt

Fig. 12. Anthranose

important weed in alfalfa ecosystem and a carrier of rust urediospores. The pycnial and aerial stage occur on spurge and the cycling or uredial stage and overwintering or telial stage occurs in Alfalfa. Therefore, alfalfa rust is a possible candidate for biological control of leafy spurge (Statler et al 1987). Severity of the disease varies from season to season as influenced by temperature and rainfall. Nitrogen deficiency also promote the disease. Destroying the alternate host, leafy spurge from alfalfa weed is the best management option.

Sclerotinia stem and crown rot or white mold (*Sclerotinia trifoliorum*): Two species of *Sclerotinia* causes stem and crown rot, both exposing similar symptoms and need similar environmental conditions for infection. *Sclerotinia sclerotiorium* has a wider range and *Sclerotinia trifolium* infests legumes. The disease is easily identified by white, cottony, mycelial growth on crowns and stems (Batura 2013). The first sign of the disease is wilting of stem. White moist mycelium can be found on stem in soil adjacent to infectious plants. The disease is a cold weather disease proliferate in wet and foggy winters which high humidity is favourable for the disease (Aurelija et al 2012). Weeds such as chick weed favours the disease by prolonging moist conditions in the canopy. Early planting will aid to escape the disease.

Spring black stem (*Phomo medicaginis*): The cool season foliar disease, produces brownish black fruiting bodies called pycnidia on typical stem and leaf lesions. Spores are released from pycnidia on dead stems during wet weather. The symptoms include development of small black to brown spots on underside of leaves, petioles and stems. Irregularly or triangularly shaped lesions coalesce and become light brown (Akamatsu 2008). The infested leaves turn yellow and wither before falling. The tender shoots will be girdled and killed. Most damage occurs before cutting. Management strategies include early harvesting and planting resistant varieties (Castell-Miller and Zeyen 2007). Using pathogen free seeds helps to minimize the infestation as the pathogen is seed borne. Crop rotation can eliminate accumulation of inoculum in the field.

***Stemphylium* leaf *spot* (*Stempylium botryosum*):** It is a cool-season foliar disease favoured by cold temperature and moist weather. The disease is prevalent in first and second cuttings as defoliation occurs under heavy disease pressure. An irregularly shaped lesion with dark border, with the spot increase in size as the damage extends is the typical symptom. It is not considered as an economic important disease as other leafspot infesting Alfalfa (Pablo 2005). No specific recommended management strategy, but early harvest aids to avoid infestation.

Summer black stem and leaf spot (*Cercospora medicaginsis*): The typical symptom of the disease is the plant forms dense canopy. As the plant is infested brown areas of spots with waxy margins arise, the spot appears gray or silvery as spores are produced on the spot and a diffuse yellow colour surrounds the spots. The disease is favoured by high temperature and humidity, early harvest before extensive defoliation minimizes yield loss (Naceur et al 2020).

Management of Alfalfa diseases

Major Diseases

Damping off: Usage of high-quality seeds under conditions of environment that favour rapid germination and seedling growth minimizes the inflectional chance. Excess irrigation to the seedling should be avoided. Planting of seedlings in compacted or poorly-drained soils should be avoided. Fast germinating cultivars planted in well-drained soil under ideal temperature and pH aid to overcome pathogen infestation, while in moist soil conditions, the pathogen destroy the seedlings (Laurine and Deborah 2015). Crop rotation is not recommended for *Pythium* rot because of its broad host range.

Seedling blight and seed rot: The seedling planted in a well-prepared seed bed not being cold or wet minimize the infestation. A natural product, hydroquinone, obtained from the leaves, bark and fruits of ericaceous shrubs such as cowberry, blueberry etc. inhibits the seed born fungi (El-Wakil and El-Metwally 2000) and sodium metabisulfite is an antiseptic and antimicrobial agent (Ash and Ash 2009). Treating alfalfa seedlings with 10mM hydroquinone and 12mM sodium metabisulfide minimizes seedling mortality and increases their survival rate by enriching photosynthetic pigments in plant parts thereby enhancing growth parameters (Al-Askar et al 2013).

***Phythopthora* root rot:** Selection of planting area with internal drainage without a history of *Phythopthora* root rot is the basic strategy in management of the disease. Planting resistant cultivars also help in root rot prevention. Improved soil moisture drainage is a pre-requisite in management. Avoid water logging in the field for more than two days. Rotation of Alfalfa with non-host crops of the disease will favour to avoid infection. Proper fertilization of the crop to promote luxurious growth will aid to resist infestation.

***Stagonospora* crown and root rot**: The disease is more severe during prolonged period of warm, moist weather; therefore, provision of optimum growing condition is an important strategy to avoid *Stagonospora* infection. Rotating with non-host crops for more than a year will eliminate the inoculum from the field. Resistant cultivars are not yet developed, but germplasm with moderate resistance has been released. Planting in firm seed bed with adjusted soil pH

and nutrient level with proper soil drainage favours rapid emergence of seedlings and vigorous growth (Deborah and Laurine 2015).

Pythium root rot*:* Management root rot of Alfalfa caused by *Pythium* and *Phythopthora* entails a many-sided tactic. Planting in field with good drainage and no root rot history avoids infection. Planting resistant cultivars for *Pythium* and *Phytopthora* will reduce the pest issue. Seed treatment with high quality seeds treated with fungicides controls seedling blight and early root rots. Rotating crops with non-host crops will aid for dismantling of inoculum stagnation in the soil (Bodah 2017). Regular fertilization of the crop for vigorous crop growth will aid to resist infestation.

***Fusarium* seed rot:** The sole management tactics of this infection is maintaining favourable growing condition. The natural inhibitors of hydroquinone and sodium metabisulphite are promising antifungal agents against these fungi (Al-Askar et al 2013).

***Rhizoctonia* root rot or canker:** Planting in well-drained soils, prepared by tillage, fertility management by supplementing nutrients and weed management aid in managing root canker or rot due to *Fusarium* sp. Planting of seedling in recommended seed rate to avoid overcrowding minimizes the disease pressure. Crop rotation helps to break the lifecycle of pathogen and improve soil fertility. Plant growth promoting bacteria such as *Bacillus pumilus* and *Pseudomonas putida* along with antagonistic fungi such as *Aspergillus awamori, Aspergillus niger* and *Trichoderma harzianum* were beneficial in management of *Fusarium* root rot in Pea plants (Foroud et al 2014).

Complex crown rot: Avoiding mechanical injury to the crown area hinders entry of the pathogen to the crown region (William 2016). Timely irrigation to avoid excess moisture helps to overcome the disease (Bowden 2014).

Bacterial wilt: Planting resistant cultivars is the management strategy. The cultivars Ranger, Agate, Iroquis, Oneida, 120, 532, Lahontan, Orestan, Ladak, Vernal, Caliverdi carry resistance genes against the pathogen. Resistant varieties have carbohydrate storage reserve to give vigor to plant. Maintaining good stand vigor by maintaining potassium level and general fertility helps to overcome the pathogen. Harvesting young stands before old ones and destroying debris from the field also aid in managing the pathogen. The plant stand should not be mowed when wet. Rotating non-host crops for 2-3 years removes the source the infestation entirely from the field (Stuteville and Erwin 1990).

***Verticillium* wilt:** Care should be taken with irrigation water from infested fields as pathogen spores can be carried in water. An irrigation management strategy with the available water maintained at 20 percent led to significant reduction in severity of the disease and extent of xylem colonization by the pathogen (Cabral and Marouelli 2020). The mycoparasite, *Hypocrea rufa*, the antagonist, *Trichoderma hamatum*, and the pathogen *Zygorhynchus moelleri* are efficient natural enemies against the pests (Acharya et al 1995). A meroditerpenoid metabolite isolated from brown algae *C. tamariscifolia* and characterized as methoxybifurcarenone possess antifungal agent against *Verticillium albo-atrum* (Bennamara et al 1999).

Anthracnose: Crop rotation with non-host crops other than Alfalfa and clover for at least two years will eliminate the source of inoculum to the field. In infested fields alfalfa can be harvested before losses become severe.

Minor Diseases

Alfalfa dwarf/Pierces disease: The bacterial pathogen is transmitted by xylem-feeding insects, sharpshooters and spittle bugs, but green and red headed sharp shooters spread the infestation. The green and red headed sharp shooters require grasses like bermuda grass, water grass etc. and hence preventing the growth of grassy weeds help to overcome the disease. Minimizing the attractiveness of sharpshooters by preventing weed growth manages the disease (Civerolo 2001). Hotwater treatment of alfalfa seedlings at 50^{o}C for 45 mins. sanitizes the plant materials against *phytoplasma* the causal agent of Pierces disease, without affecting seedling survival and development (EFSA 2015).

Alfalfa Mosaic Virus (AMV) and Cucumber Mosaic Virus (CMV): Alfalfa mosaic virus can be managed by controlling the vector, aphids by foliar spray of insecticides. Resistant cultivars to alfalfa mosaic virus provide a management tool. Regular roughing of plants manages weeds, which will avoid aphid attraction to alfalfa field (Olawale 2020). Foliar spray of melatonin (MTL) and Salicylic Acid (SA) (100 µM) act as eco-friendly antiviral compounds that causes significant increase in morphological characters such as shoot and root length, number of leaves, leaf area and biomass, chlorophyll and carotenoid compounds and antioxidant compounds, whereas reduces oxidative damages caused by the virus, by reduction in hydrogen peroxide, superoxide anions, hydroxyl radicals and malondialdehyde (Ahmed et al 2021).

***Aphanomyces root rot* (*Aphanomyces eutriches*):** The most effective means of managing the root rot is use of resistant cultivars. Maintaining proper drainage in the field is the significant management strategy. Avoiding stagnant water in the field prevent development of oospores. Minimizing soil compaction can help to overcome wet soil conditions. Increased concentration of calcium in soil is found to lower the severity of the incidence of the pathogen. Crop

rotation is not an effective management strategy as oospores of *A. euteiches* will survive in the soil for longer duration. Cover crops such as crucifers and green manure crops such as oats were found to lower the incidence of *A. eutriches*. Seed treatments aid to overcome the disease only until seedling emergence. Several fungicides, soil fumigants and biological control options is effective against the pathogen. The active ingredients of the dinitroaniline herbicides, Pendimethalin (Prowel®) and trifluralin (Treflan®) were detrimental to *A. eutriches* (Hughes and Craig 2007). The beneficial bacterium, *Bacillus velezensis* UCMB5113 and beneficial earthworm, *Lumbricus terrestris* positively enhance the health and growth of Alfalfa with taller plants and higher biomass and thereby enhance plant growth and biological control of root rot. Earthworm considerably reduce disease infestation as they consume the pathogen (Jan et al 2020)

Crown wart*:* Maintaining the soil with good drainage, avoiding excessive irrigation and avoid planting Alfalfa in fields with prior history aids to overcome the pests. Resistant cultivars are suggested to minimize infestation (Samac 2014). Soil should be levelled and tilled deeply to reduce compaction. Seedlings should be planted on beds to alleviate disease severity. Reduce the length and time of flood irrigation to avoid infestation (UK CAB International 1987)

Common leaf spot: Severe yield loss is noticed. Early harvesting is recommended as the disease progress over time. Though the disease wont severely infests the plant, it reduces vigour, hay quality and yield. Resistant cultivars are an option. Crop rotation reduce inoculum in the field. The fungicides, Raclostronin@6–9 fl oz/acre and Azoxystrobin@6–15.5 fl oz/ acre offers a solution (Qin et al 2016).

Downy mildew*:* Early harvest prevents yield losses as the inoculum as well as susceptible host tissues of downy mildew were removed, as they are short lived and will be dead allowing new susceptible tissues to be grown. Early cutting minimizes humidity among crop canopy reducing risk of infestation (Skinner and Stuteville 2015). Seed treatment with a systemic fungicide, metalaxyl and mefenoxam protects seedlings from downy mildew infestation. Foliar spray of fungicides Ridomil (metalaxyl) and Curathane (cymoxanil) significantly reduce the infestation. The Ridomil applied alfalfa fields showed 29.94 per cent greater yield than control and Curathene applied fields show 28.37 percent greater yield (Mario and Lira 2018).

Lepto leaf spot: Early harvest can prevent leaf loss and accumulation of spores. Crop rotation avoiding Alfalfa for more than a year will aid to overcome the disease. Choosing well-adapted high yielding alfalfa varieties and using certified high yielding seeds aid in healthy crop stand. Plant in warm, well-drained and well-prepared seed bed with balanced nutrients with adequate amount of phosphate and potash. Cut heavily infested strands in the mid to late bud stage for high yield, minimal leaf loss etc. Cut as the foliage is dry to avoid the spread of pathogen. Minimize weed and insect infestation (Jim 2011).

Rust (*Uromyces straiatus*): Destroying the alternate host, leafy spurge from alfalfa weed is the best management option. Cultivars resistant to alfalfa diseases are recommended. Early cutting of alfalfa foliage is suggested when the disease is severe. Foliar fungicidal spray of copper compounds such as Champ Formula, Kocide 2000, Nordox 75 WG, Nordox 75 WG are recommended (Statler et al 2017).

***Sclerotinia* stem and crown rot or white mold:** Early planting will aid to escape the disease. Management of the disease is based on adjusting planting date by spring which allows the plant to develop resistance to the disease. Deep ploughing bury the sclerotia in the soil and reduce disease incidence. Planting the seedlings in fields with no history of the disease and rotating with non-host crops for 2 to 3 years will aid in minimizing the infestation (Malvick 2001)

Spring black stem: Using pathogen free seeds helps to minimize the infestation as the pathogen is seed borne. Crop rotation can eliminate accumulation of inoculum in the field. Planting moderately resistant varieties can significantly reduce losses (Stephen 2011).

Stemphylium leaf spot: Early harvest aids to avoid infestation. Any systemic fungicide at 0.6 kg rate applied at 50% bloom; and repeated at 7-10 days later for maximum of three applications reduce the infestation (Pearse 2006).

Summer black stem and leaf spot: Adjusting the cutting schedule is the most practical and economical means of management. Any copper hydroxide fungicide can be applied 10-14 days or earlier to harvesting can reduce the loss (Stephen 2011).

CONCLUSION

Alfalfa is an important crop suitable for integrated pest management. Alfalfa can endure pest injuries to certain degree and not lose significant quantity or yield. The ecosystem of Alfalfa is tremendously complex with manifold interactions of crop, pest and the natural enemies occurring at various levels. Alfalfa is chiefly managed in farms with the growers taking several pest control decisions. A bulk quantity of alfalfa cultivated all around the globe is consumed in dairies where forage quality, timing of cutting etc gains more importance. Integrated pest management requires awareness to take decisions based on extensive knowledge

base of the insect pests, diseases, nematodes, weeds and wildlife in alfalfa ecosystem. IPM decision makers should be proficient not only in farm sciences, but should have an exhaustive knowledge and understanding of the ecological moralities that administer the fluctuations in pest and natural enemy species that impose considerable dynamics in the economics of alfalfa production and farm utilization as fodder.

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