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Integrated Pest and Disease Management for Better Agronomic Crop Production

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Abstract

The disease and pest infestation is considered as one of the major constraints in better agronomic crop production for attaining anticipated yield to cater food security in the world. As agronomic crops (particularly cereals and pulses) are the leading sources of food in the world, management of their catastrophic pests and diseases needs special emphasis. At present, pests and diseases of agronomic crops are managed by various chemical control measures by using pesticides and fungicides. However, the disquiets regarding agronomic sustainability have instigated a wide and comprehensive utilization of integrated pest and disease management approaches. The said program is considered as an ecologically safer tactic for the control of various dreadful pests and diseases. Integration of approaches is aimed at reducing the health and ecological damages in response to chemicals by adopting certain cultural, mechanical, and biocontrol measures to manage various pests and diseases. However, efficacy of the control measure generally depends upon their effective utilization. Several cultural control measures such as cover crops, intercropping, trap crops, tillage practices, and planting time can reduce population of pests and disease severity but are not viable commercially under field conditions. Similarly, applicability of the biocontrol agents and plant extracts at large scale is also questionable. However, their efficacy may be increased by combination of other methods such as integrated use of the said cultural practices with reduced chemical applications. Therefore, in order to ensure better control and ecological sustainability, it is suggested that

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use of chemicals should be minimized by adopting integrated management strategies of pests and diseases.

Keywords
Agronomic crops · Biological control · Biofabricated nanoparticles · Deleterious pests · Food security

Abbreviations

AULRP	area under leaf rust progress curve
BioMA	biophysical model applications
CLCu	cotton leaf curl
CLCV	cotton leaf curl virus
CRISPR	clustered regularly interspaced short palindromic repeat
DNA	deoxyribonucleic acid
GMO	genetically modified organism
IBA	indolebutyric acid
JA	jasmonic acids
PGPR	plant growth-promoting rhizobacteria
PGR	plant growth regulators
SA	salicylic acid
PPO	polyphenol oxidase
POD	peroxidase
PCR	polymerase chain reaction
QTL	quantitative trait locus
RNAi	RNA interference
UV	ultraviolet

19.1 Introduction

The losses of agronomic crops due to diseases and pests are leading threats to the rural families for getting optimum income and to ensure worldwide food security (Savary and Willocquet 2014; Avelino et al. 2015). The information on quantitative loss in crop production is prerequisite for the understanding of the imperative pest and disease control drivers such as evaluation of crop protection practice efficiency; ecological system sustainability assessment; decisions for better adoption of the integrated pest and disease management schemes; and evaluation of the regulation of pest or disease control effectiveness as ecosystem sustainability regulation (Oerke 2006; Cooke 2006; Savary et al. 2006; Avelino et al. 2011).

Various types of pests and diseases have been reported affecting different crops from seeds to field conditions. Seed-borne, fungal, bacterial, and nematode-induced diseases as well as various types of insect pests are the major causes of reduced yield and increased losses of agronomic crops in the world. Moreover, occurrence and severity of various diseases and/or pests is generally associated with planting time, genotypes, and environmental conditions (Sharma and Sharma 1999). So, in order to reduce disease- and pest-induced agronomic crop losses, some appropriate and effective strategies are required (Sharma et al. 2015).

The pest and disease infestation is known as one of the leading limitations in achieving higher yield of agronomic crops to cater food security in the world (Igarashi et al. 2004). As agronomic crops (particularly cereals and pulses) are the major sources of food around the globe, management of their ruinous pests and diseases requires special importance. At present, pests and diseases of various crops are controlled or managed with different chemicals such as fungicides and pesticides (Rodrigues et al. 2013; Fromme et al. 2017). However, the disquiets regarding agronomic sustainability have instigated a comprehensive and wide application of integrated pest and disease management approaches. The said program is considered ecologically safe for control of dreadful pests and diseases of agronomic crops. Moreover, integrated pest and disease management has been known as one of the most robust paradigms to arise in agricultural production (Pretty and Bharucha 2015). It is an extensive strategy to cope with deleterious pests and diseases with wise utilization of cultural, mechanical, genetic, and biological ways by considering chemical control measures as a last option in a harmonious and compatible way to impede harmful inhabitants such as pests and diseases of agronomic crops (Barzman et al. 2015).

Different pests and diseases of agronomic crops can be controlled effectively. However, efficacy of the control measures generally depends on the used control measure. Several cultural control measures such as cover crops, intercropping, trap crops, tillage practices, and planting time can reduce population of pests and disease severity but are not appropriate as chemical applications at commercial scale under field conditions. Their control efficacy may be increased by combination of other control methods such as integrated use of the said cultural practices with reduced chemical applications. So, the present chapter summarizes various strategies and control measures for the integrated management of pests and diseases for the better production of agronomic crops.

19.2 Pest and Disease Effects on Global Food Security

Insect pests and plant diseases are anthropocentric perceptions. A microorganism or insect reduces (considered as a pest/pathogen) the quality and yield of food. These microorganisms, insects, and nematodes work synergistically to cause different diseases on the plants. These kinds of relationships are very dynamic and complicated for the food chain in nature. The global food security became a major threat to human population. Averagely, pests are moving about 3 km/year toward North and

South Pole, with an estimate of 10% to 16% loss in crop production globally. Rice has attained the 2nd position in global production and became more important since it is used as staple food for about half of the world's population. Every year, 10–30% loss in rice production has been recorded due to *Pyricularia oryzae*-induced rice blast disease (Talbot 2003). *Pyricularia oryzae* or other similar species (*P. setariae)* also affected the cereal crops including finger millet and wheat causing the complete loss of yield (Ekwamu 1991). Similarly, species of *Pyricularia* have been reported as a serious threat to wheat, and severe outbreaks have occurred with significant food losses (Igarashi et al. 2004). Several fungal pathogens also lead to production of mycotoxins, making the food, such as maize, unfit for human consumption. It has been reported that more than 700 identified plant viruses cause devastating diseases. Barley yellow dwarf viruses are spread globally and infect more than 150 Poaceae species, including most of the staple crops such as wheat, barley, oats, rye, rice, and maize (Gelderblom et al. 1988). So, pests and diseases of agronomic crops are the leading handicaps in securing global food security.

19.3 Pest and Disease Detection and Diagnosis

The crop losses can be minimized by timely identification and correct diagnosis of disease, followed by specific control measure. The visual examination is a traditional method for identification of plant pathogens. Mostly, it's possible only when major destruction has already been done to the crop; so treatments will be of limited or no use. For protection from these kinds of damages by pathogens, farmers should be able to recognize the infections at early stages. In addition to the traditional method, advance technology like direct microscopic observation of pathogens and their manipulation is essential for timely and effective control. The use of polymerase chain reaction (PCR) has a significant impact on plant disease diagnosis. Moreover, nucleic acid technology is the only option for detecting pathogens; yet, those have not been cultured. However, DNA-based methods have not completely replaced classical microbiology and visual inspection. These methods provide complementary evidence for accurate disease identification and diagnosis (Martinelli et al. 2015). Although the nucleic acid techniques based on PCR, hybridization, and biochemical assays are very accurate, sensitive, and effective for confirming the visual investigation, these are untrustworthy, as compared to screening tests to monitor the status of plant health before the appearance of the symptoms. These methods need detailed sampling techniques and expensive infrastructure and may garble the real status of infections. In addition, these techniques can only be efficient when used for a limited number of plants (Martinelli et al. 2015). Present and upcoming methods for plant disease detection include proximate detection, immunological and DNA-based assays, and study of volatile compounds and genes as biomarkers of disease diagnosis. Similarly, use of remote sensing technologies combined with spectroscopy-based systems and sensors based on phage display and bio-photonics could also be used (Schaad and Frederick 2002; Bock et al. 2010; Sankaran et al.

2010). In contrast, insect pests can be easily identified with visual observation in the field.

19.4 Integrated Pest and Disease Management

Integrated pest and disease management has been known as one of the most robust paradigms to arise in agricultural production science in the recent years. It is an extensive strategy to manage deleterious pests and diseases by wisely using the suitable skills, practices, and techniques including mechanical, cultural, genetic, and biological ways by considering chemical control measures as a last choice in compatible and harmonious manner to inhibit harmful inhabitants (pests and diseases) (Barzman et al. 2015; Pretty and Bharucha 2015). The effective integrated pest and disease management, however, depends upon the appropriate monitoring, inspection, and control. The integrated pest and disease management strategy has been recognized worldwide for attaining sustainable and ecologically stable agricultural production system. The increased globalization of the markets and enhanced traveling of the masses over the world allowed increased intensity and frequency of the invasive organisms to be brought into various other countries. Therefore, suitable and effective management strategies are required for these invasive pests and pathogens. For effective implementation of integrated pest and disease management program, it is also imperative to consider that the option chosen should be least threatening while bringing about maximum benefits to the farming community. The concept of integrated pest and disease management has progressively attained reasonable acceptance and has been adopted during the last two decades as an eco-friendly strategy which is considered important for the sustainable production of agronomic crops in the world.

19.5 General Principles of Integrated Pest and Disease Management

The integrated pest and disease management generally includes four major principles (Barzman et al. 2015). (a) The standardization of action thresholds is very critical before adoption of any disease or pest control measure. It is important to first find an optimum action threshold. The action threshold is a point where environmental conditions or pest populations indicate that a control action must be adopted. (b) It is important to know that not all weeds, insects, pests, diseases, and certain other organisms need to be controlled. Various organisms are either innocuous or even are surely beneficial for the crops of economic significance. So, it is imperative to monitor and thoroughly identify pests and diseases before adopting any control action. (c) As a first line of action in the control of pests and diseases, integrated approach works to efficiently manage outbreak of any pest or disease to prevent them becoming a major threat for the agronomic crops. It may be done by adopting certain cultural methods, e.g., rotation, planting resistant genotypes, and use of pest-/disease-free planting material. (d) Once monitoring, identification, and threshold action indicate that disease or pest control is indispensable and a preventive method is not available or effective, then certain control measures become essential. The control measures should be effective, ecologically viable, and environment friendly.

19.6 Modeling for Pest and Disease Prediction

The main focus of modern agricultural research is to increase the quality food production with reduced pest and disease attack. The "naked eye method" is usually used for detection and identification of pest and plant diseases at small scale with constant monitoring. In contrast, for a large farm, it's not precise and time-consuming. So, digital systems are widely used for inspection of plant diseases and pests. It generally identifies the affected area upon color changing. Automatic detection of plant diseases with the assistance of image processing technique offers more accurate pest detection and guidance for disease management (Rajan 2016). This software has been successfully used for detection of rice disease (Phadikar and Sil 2008). In this software, both image processing and soft computing skills are applied. The features include region segmentation and spot and boundary detection. Self-organizing map neural system has also been employed for classification. For satisfactory classification about test images, the simple computationally efficient technique is used for zooming algorithm extracts of the images. Likewise, BioMA modeling framework is composed of four extensible software libraries, targeting the modeling of generic fungal plant diseases. It provides input/output data structures and models to simulate a polycyclic fungal plant epidemic and to quantify its impact on crop growth. This technique has been used for major diseases of wheat (brown rust) and rice (leaf blast) to test model behavior under heterogeneous weather conditions according to changes in parameter values (Bregaglio et al. 2015). Bregaglio et al. (2015) documented a study about the extension and application of disease-based modeling that reproduces the field data of the annual fluctuations of disease epidemics for timely and accurate disease prediction.

19.7 Management of Pests and Diseases of Agronomic Crops

Pests and diseases of various agronomic crops can be managed with suitable control measures. The control measures could be cultural, chemical, biological, or combination of more than one strategy. However, the exact efficacy generally depends upon the nature of control measure being adopted. The pests and diseases of agronomic crops may be controlled/managed by employing different combinations of following measures.

19.7.1 Soil Fumigation

Soil-borne pests and diseases are the major cause of reduced yield and increased losses of agronomic crops in the world. So, in order to reduce disease- and pest-induced losses, some appropriate soil disinfestation treatments are required for getting higher yield (Rokunuzzaman et al. 2016; Mihajlović et al. 2017). Different chemicals such as ethylene dibromide, metham, and methyl bromide can effectively be used to disinfect soils from soil-borne pathogens. Soil fumigation with 1,3-dichloropropene or chloropicrin controlled the fusarium root-knot complex of nematode in cotton (Jorgenson et al. 1978). The combinational treatment with ethylene dibromide and fenamiphos significantly reduced the nematode population with concomitant higher yield of sugarcane (Chandler 1984). The application of methyl bromide reduced *Pythium*-induced infection with markedly improved vegetative growth and increased yield of grain in clean tilled winter wheat (Scott et al. 1992). The fumigation with paraformaldehyde efficiently reduced the leaf-cutting bee population of alfalfa (Goerzen 1992). The soil treatment with mancozeb strongly suppressed the dematiaceous root colonization and exhibited substantially higher sugarcane growth (Magarey and Bull 2003). Similarly, soil fumigation with methyl bromide markedly suppressed the nematode population of sugarcane having increased crop yield (Stirling et al. 2001). Likewise, soil fumigation with seed meal of mustard effectively checked the growth of soybean pathogenic fungi (Fayzalla et al. 2009). The combination of soil fumigation and *Trichoderma viride* significantly reduced the fungal diseases such as *Macrophomina phaseolina* and *Fusarium oxysporum* of sesame (Elewa et al. 2011). Soil fumigation with chloropicrin and methyl bromide showed reduced *Fusarium oxysporum*-induced infection in cotton (Bennett et al. 2011). In the same way, soil fumigation with methyl bromide efficiently reduced *Fusarium oxysporum* pathogens of chickpea (Mabrouk and Belhadj 2012). The Vapam soil fumigation suppressed *Plasmodiophora brassicae*-induced clubroot infection and enhanced the vegetative growth of canola (Hwang et al. 2014a, b). The soil treatment of sugarcane with silicon also reduced the incidence of stalk borer attack (Nikpay 2016). The bio-fumigation of the soil with *Brassica alba* extract suppressed *Fusarium* wilt of chickpea (Prasad and Kumar 2017).

19.7.2 Crop Rotation

Growing of same types of crops on same field over longer period of time ultimately leads to excessive disease outbreak or insect-pest infestation during the coming years. So, growing of suitable alternate crops is beneficial to reduce the pathogen or pest infestation in the forthcoming years (Bankina et al. 2015). Rotation scheme with corn/soybean/triticale-alfalfa/alfalfa checked the activity of carabid (O'Rourke et al. 2008). Growing of corn as a rotation practice markedly reduced the incidence of *Armadillidium vulgare* in soybean crop (Johnson et al. 2012). Adoption of fescue rotation and reduced tillage inhibited corn rootworm severity on peanut pods with increased population of collembolans, heteropterans, hymenopterans, and acarina under reduced till system (Cardoza et al. 2015). The rotation and summer fallow in combination with neonicotinoids seed treatment reduced wireworm incidence and increased yield of winter wheat up to 24–30% (Esser et al. 2015). Rotation of tobacco with rice significantly reduced plant hopper and brown plant hopper of rice (Zhang et al. 2015). Crop rotation of legumes and perennial sod or annual cereal grains in combination with moldboard or chisel plow cultivation system increased beneficial arthropods especially tiger and ground beetles in maize/soybean (Jabbour et al. 2016). A 3-year rotation as corn, soybean, and wheat resulted in reduced pests due to increased population of detritivore and granivore predators (Dunbar et al. 2016).

It has been reported that monoculture cultivation of wheat encourages aphids, thrips, wireworms, and some rust-related diseases in the cotton crop (Andow 1983; Cunfer et al. 2006). The crop rotation with corn, cowpeas, mung bean, rice, or sorghum increased yield and reduced *Pratylenchus zeae* infestation of rice (Aung and Prot 1990). The single year canola growing as rotation is suitable to efficiently reduce *Sclerotinia* stem rot and to prevent *Phoma* blackleg attack of canola (Kharbanda and Tewari 1996; Cunfer et al. 2006). The 4-year rotation by using canola, flax, and wheat significantly reduced diseased stem severity and incidence of canola blackleg under zero or conventional tillage system (Guo et al. 2005). The rotation of herbicide-tolerant canola reduced its maggot-induced root damage with better seed quality and yield (Dosdall et al. 2012). The rotation of lentil with cumin, anise, onions, and garlic considerably reduced root rot and damping-off disease with its substantially higher yield (Abdel-Monaim and Abo-Elyousr 2012). The 1-year sorghum and 2-year cotton rotation cultivation resulted in reduced *Verticillium* wilt of cotton under central pivot irrigation scheme (Wheeler et al. 2012). The rotation with barley, camelina, and spring pea showed reduced incidence of *P. thornei* and *P. neglectus* in winter wheat fields (Smiley et al. 2013). A cropping scheme of corn, soybean, and wheat combined with fungicide showed reduced *Fusarium graminearum* population; however, no effect was noted on *Fusarium oxysporum* or *Fusarium virguliforme* (Marburger et al. 2015). The cultivation of soybean with corn-soybean rotation scheme showed significantly reduced *Fusarium virguliforme*-induced sudden death syndrome of soybean (Navi and Yang 2016). The maize, pea, soybean, and sunflower growing scheme reduced Western corn rootworm infestation and *Fusarium graminearum* having better seedling health of maize (Benitez et al. 2017). The 1-year rotation of soybean with wheat crop increased its yield, whereas rotation with cotton had no positive effect (Ashworth et al. 2017).

19.7.3 Seed Treatment

Seed-borne diseases or pest infestation is the major cause of reduced yield and increased losses of agronomic crops in the world. So, in order to reduce disease- and pest-induced agronomic crop losses, some appropriate seed treatments are required for getting higher yield (Sharma et al. 2015). Several types of chemicals are being used for seed treatments (Table 19.1). Treatment of cotton seeds with metalaxyl and *Trichoderma virens* resulted in increased seedling stand and reduced disease

Table 19.1 Chemical compounds currently used as small grain cereal seed treatments

Captan	N-Trichloromethylthio-4-cyclohexene-1,2dicarboximide	Dicarboximide, Agrosol, Agrox, Granox, Orthocide
Carboxin	5,6-Dihydro-2-methyl-N-phenyl-1,4-oxathiin-3carboxamide	Vitavax
Difenoconazole	cis,trans-3-chloro-4-[4-methyl-2-(1H-1,2,4triazol-1-ulmethyl)-1,3-dioxolan-2-yl] phenyl 4chlorophenyl ether	Dividend
Imazalil	(+)-Allyl 1-(2,4-dichlorophenyl)-2-imidazol-1ylethyl ether	FloPro IMZ, Double R, Deccozil, Nuzone, Fungaflor
Mancozeb	Zinc manganese ethylenebisdithiocarbamate	Dithane M-45, Mankocide, Mansul, Penncozeb
Maneb	Manganese ethylenebisdithiocarbamate	DB Green, Granol NM, Trinox, Pro-Tex
Metalaxyl	Methyl N-(2-methoxyacetyl)-N-(2,6-xylyl)-DLalaninate	Apron, Allegiance
PCNB	Pentachloronitrobenzene	Terrachlor, Parflo, Terra-flo, Terrazan
Tebuconazole	(RS)-1-(4-chlorophenyl)4,4-dimethyl-3-(1H1,2,4-triazol-1-ulmethyl) pentan-3-ol	Raxil, Preventol, Tebuject
Thiabendazole	2-(4-Thiazolyl)-benzimidazole	TBZ, Mertect, Metasol
Thiram	Tetramethylthiuram disulfide	Arasan, Vertagard, Thiramad
Triadimenol	(1RS, 2RS; 1RS, 2SR)-1-(r-chlorophenoxy)-3,3dimethyl-1-(1H-1,2,4-triazol-1-yl) butan-2-ol	Baytan
Triticonazole	(+)-(E)-5-(4-chlorobenzylidene)-2-dimethyl-1(1H-1,2,4-triazol-1-ylmethyl) cyclopentanol	Charter

Source: Mathre et al. (2001) and Sharma et al. (2015)

incidence under field conditions (Howell et al. 1997). Seed and foliar treatment with fungicides controlled black point disease of wheat (Malaker and Mian 2009). Seed treatment with abamectin and sedaxane alone or in combination was highly effective in controlling *Pratylenchus penetrants* and *Rhizoctonia solani* disease complex under greenhouse conditions. The treatment also significantly enhanced seedling health as well as shoots and root growth of maize (Silva et al. 2017). Aerated steam therapy of sugarcane sets at 50 °C for 1 h showed high efficacy in controlling its grassy shoot disease with increased germination and cane yield (Viswanathan 2001). The incidence of anthracnose and sorghum smut was effectively reduced in response to metalaxyl seed treatment. It also increased the grain yield of sorghum particularly in late-maturing sorghum cultivars (Gwary et al. 2007). Similarly, seed treatment with *Trichoderma harzianum* reduced the incidence of *Macrophomina phaseolina* disease and increased its germination vigor index, plant height, and leaf growth characteristics under field conditions (Anis et al. 2013). Plant extract treatment of lentil seeds increased germination and reduced its associated mycoflora

(Mahal 2014). Similarly, combined treatment of seed with *Trichoderma hamatum* and metalaxyl reduced damping-off disease incidence of soybean along with increased germination percentage (Hudge 2015). The treatment of sugarcane sets with triadimefon and propiconazole effectively inhibited its smut incidence having higher harvestable yield under field conditions (Bhuiyan et al. 2015). Similarly, seed treatment with triadimenol alone or in combination with thiram effectively controlled leaf blight of spring wheat with higher grain yield (Sharma-Poundyal et al. 2016).

19.7.4 Planting Time

The occurrence and severity of various diseases and crop-specific pest attack is generally associated with planting time, genotype, growth stage, and environmental conditions. Atmospheric temperature and relative humidity are the key components for the epidemic spread of pests or diseases. Therefore, sowing date is of particular importance which determines the subsequent crop growth stages (Sharma and Sharma 1999).

The fall planting with lower plant density significantly decreased flea beetle attack with better growth and early maturity of canola (Lloyd and Stevenson 2005). Attack of thrips and *Maruca testulalis* was found to be higher during late sown crop of cowpea (Ezuch 1982). The incidence and severity of thrips was found maximum in early-planted crop, whereas lowest was noted on the late sown planting of black gram (Prodhan et al. 2008). Delayed planting in combination with insecticide spray showed reduced invasion of pod feeding bugs of cowpea (Kamara et al. 2010). Early sowing of soybean showed reduced or even escape of attack of whitefly and aphids when mixture of mung bean, sunflower, and maize was grown as border trap crop (Abdallah 2012). The population severity of dusky cotton bug was found lowest during 3rd week of July while surpassed economic threshold in August on transgenic cotton (Iqbal et al. 2017a, b). The early planting under high, medium, and low density as single, double, or triple rows showed higher incidence of cornstalk borer and armyworm in sweet sorghum (Cherry et al. 2013). Invasion of red cotton and dusky bugs was significantly higher in early sown, as compared to its normal or late plantation (Shahid et al. 2014). Early sown Bt cotton showed less incidence of sucking pests such as leaf hopper, aphid, and whitefly, in contrast to late-planted crop (Zala et al. 2014). However, early planting, combined with insecticide sprays during late July or mid-July, exhibited reduced thrips, legume pod borer, and pod sucking bugs in cowpea along with improved yield (Abudulai et al. 2017). The population of tobacco caterpillar was found to be substantially higher in the crop sown at 20 July, in contrast to 5 July or 20 June having increased leaf damage with lower yield of groundnut (Nath et al. 2017).

The cotton crop that was sown comparatively earlier during December had more yield than late cultivation (Gilio 2014). The incidence and severity of ramularia leaf spot of cotton was significantly lower when the crop was planted during the month of December, as compared to January sowing time (Ascari et al. 2016). Host fitness with environmental conditions during specific plant growth stage can be reduced by either change of sowing date or through costs of defense (Creissen et al. 2016). Ali et al. (2014) found that early sowing of cotton not only minimizes the CLCV incidence but also improved the boll weight, seed cotton yield, seed index, ginning out turn, number of nodes per plant, and other quality parameters of cotton crop. Moreover, Rashid et al. (2013) reported that disease incidence of mung bean yellow mosaic virus and cercospora leaf spot of mung bean was also associated with planting time. Early sowing (1 March) showed less disease infestation and high yield (2131.00 kg/ha), in contrast to late sowing (1 April). Similarly, Getaneh and Agu (2008) found significant loss of grain yield (6.9–40.2%), thousand kernel weight (5.9–27.6%), and kernels per spike (0–16.5%) caused by *Puccinia hordei* due to late sowing in barley. Leaf rust (*Puccinia triticina*) is a widely distributed fungal disease in wheat and is considered an unremitting dilemma due to its epidemic nature. Atiq et al. (2017) found that commonly used disease severity indicator “area under leaf rust progress curve (AULRP)” was minimum for early sowing (30 October) of wheat, while it was maximum for late sowing (30 November). In addition to this, certain diseases are spread through specific vectors (carriers) such as cotton leaf curl (CLCu) disease which is transmitted by whitefly (*Bemisia tabaci*) (Sharma et al. 2006), and this disease is responsible for low yield in cotton. Maharshi et al. (2017) found that besides changing the cultural practices, planting date is an effective method to avoid the excessive population of whiteflies, thus reducing the incidence of CLCu disease. It was also noted that Bt cotton hybrids are susceptible to CLCu virus and there is significantly positive correlation between sunshine with whitefly population and incidence of CLCuD. Hence, early plantation of Bt cotton minimizes the chances of coincidence of susceptible crop growth stage and CLCuD favorable environmental conditions.

19.7.5 Plant Spacing

Planting of sweet sorghum as single, double, or triple rows under high, medium, and low density either had no or little effect on population of cornstalk borer and armyworm (Cherry et al. 2013). Plants did not affect flowering thrips, sucking bugs, pod borers, and beetles in cowpea in response to different time of plantings (Alghali 1991). Planting of cowpea at 20 × 30 and 20 × 60 cm in combination with insecticide treatment controlled its pest infestation (Karungi et al. 2000). Reduced fall planting density decreased the attack of flea beetles with better growth and early maturity of canola crop (Lloyd and Stevenson 2005). Planting of cotton at 38 cm apart resulted in significantly reduced population of whitefly, jassid, and thrips. The incidence of the said pests was increased with decreased plant pacing (Arif et al. 2006). Planting of sunflower at 100 × 75 cm led to lowest incidence of beetle, variegated grasshopper, sunflower stem weevil, and spittlebug attack (Akinkunmi et al. 2012). The planting of cowpea at wider spacing significantly reduced the incidence of ramularia leaf spot of cotton with markedly higher vegetative growth and yield than closer planting scheme. Moreover, high plant density ensured high cotton productivity during the severe attack of CLCV (Iqbal et al. 2012; Singh et al. 2017). It has been observed that pest population (*Aphis craccivora*) enhances after 2 weeks of cowpea sowing, and this colony increases in size between 8 and 13 weeks after sowing to coincide with flower budding (Omongo et al. 1997). Most importantly, these colonies take the advantage of dense plantation to hinder below the leaves. Found that aphids (*Aphis craccivora*) and foliage beetles (*Ootheca mutabilis*) on cowpea can be controlled by regularly weeding after every 3–6 weeks and maintaining low plant density (152,174 plants/ha). Soybean was cultivated to optimize the rows and plant spacing. It was found that 40 cm row spacing with 5 cm plant spacing within a row can be used for high productivity and low weed infestation of soybean (Worku and Astatkie 2015). Akinkunmi et al. (2012) found that sunflower plants grown at normal distance (100 × 75 cm) had lowest population of various insects including sunflower beetle (*Zygogramma exclamationis*), spittlebug (*Poophilus adustus*), variegated grasshopper (*Zonocerus variegatus*), and sunflower stem weevil (*Cylindrocopturus adspersus*). Likewise, plant spacing at 65 × 75 cm damaged leaves, stems, and flower heads and caused severe economic loss to sunflower crop. However, Adipala et al. (1995) didn't found significant incidence of northern leaf blight (*Exserohilum turcicum*) incidence. Denser plantation caused high level of disease severity and subsequent loss in grain yield. Also reported similar observations about soybean crop which was cultivated at different plant-to-plant and row-to-row spacing. Plants with widest spacing (40 × 10 cm) produced lowest leaf area and shoot biomass. Chickpea crop also showed similar results under dense cultivation (Shamsi 2010). Rice sheath blight is a well-known devastating disease of rice which can be overcome by exogenous application of silicon with suitable plant geometry. The normal row spacing is 20 × 15 cm, and rice crop becomes prone to sheath blight easily. However, Khaing et al. (2015) found that widening the plant and row distance significantly enhances disease resistance and produced 32% more grain yield, than control.

19.7.6 Intercropping

Intercropping of maize, faba bean, and cabbage with sugar beet significantly reduced the population of aphid, whitefly, *Pegomyia mixta*, and *Cassida vittata*, as compared to non-intercropped field. However, no significant impact of relay intercropping was observed when winter wheat, alfalfa, and cotton were used as intercrops or green bugs and ladybeetles in sorghum (Phoofolo et al. 2010). Intercropping of basil in cotton significantly reduced the invasion of pink bollworm in cotton that eventually led to increased yield (Schader et al. 2005). Intercropping of groundnut, soybean, or common beans markedly reduced attack of termites with enhanced beneficial predatory nesting in fields of maize (Sekamatte et al. 2003). Intercropping of spring cereal in field beans significantly checked the attack and severity of black bean aphids (Hansen et al. 2008). Intercropping of sorghum resulted in markedly increased population of predatory lady beetles that eventually reduced the attack of sucking insects on cotton (Tillman and Cottrell 2012).

Intercropping has been extensively reported to reduce the incidence of various bacterial diseases (Yu 1999), fungal infections (Hao et al. 2010), and insect pests (Basha et al. 2017) during simultaneous growth of two or more component crops together. The intercropping of cowpea in cotton significantly reduced the incidence of ramularia leaf spot of cotton with markedly higher vegetative growth and yield. Kinane and Lyngkjaer (2002) also found significant reduction in occurrences of various diseases like net blotch (*Pyrenophora teres*), powdery mildew (*Blumeria graminisf*), and brown rust (*Puccinia recondite*) in barley crop which was intercropped with either of legumes (lupin, pea, and faba beans). Intercropping is also supposed to be an efficient agricultural management practice and sustainable ecological strategy since it has also been reported to overcome the soil-borne plant diseases. Moreover, the complete eradication of pathogen is very difficult in soil-borne diseases; hence substitutive economically best agricultural practice is preferred (Zhu et al. 2000). Maize-soybean intercrop suppressed the incidence of red crown rot in soybean caused by *Cylindrocladium parasiticum*. Scientists found excessive accumulation of five kinds of phenolic acids, particularly cinnamic acid, among plant root exudates of intercropped maize-soybean. Furthermore, the biosynthesis of cinnamic acid was closely associated with row-to-row distance between different intercrops. Similarly, intercropping has been successfully implemented to suppress *Fusarium* wilt in watermelon-rice intercropping system (Hao et al. 2010). Heterogeneous crop cultivation pattern significantly reduced the prevalence of crop specific pests and consequently minimized the extensive application of petrochemical-based pesticides. Intercropping of chickpea with either mustard, wheat, or barley delayed the attack of pod borer and thus enhanced the economic return by reducing the cost of production (Basha et al. 2017). However, further studies should be subjected to elucidate the detailed mechanism of pathogen or pest-host interaction among heterogeneous components of intercrop that determines the occurrence and the severity of diseases or pest levels.

19.7.7 Cover Crops

Growing of cover crops is important to check the growth of weeds and to conserve soil moisture contents. Besides, cover crops may also be used to reduce the outbreak of certain pathogenic fungi and insects. Moreover, the roots of certain cover crops also serve as a source of symbiotic mechanism in which some saprotrophic fungi grow and colonize to help in inhibiting the growth of pathogenic fungi (Harman et al. 2004). Use of grass (*Elymus trachycaulus*) as a cover crop significantly checked the population of Western corn root worm under zero tillage production system. Moreover, use of the said cover crop also enhanced the population of arthropods, beneficial for pollination. Cultivation of rye and crimson clover increased the population of natural predators that eventually reduced flower bugs on cotton under conservation tillage (Tillman et al. 2004). Cultivation of rye as autumn seeded cover crop substantially suppressed the outbreak of leafhopper, aphids, and leaf beetles in soybean (Koch et al. 2012). In the same way, plantation of rye cover crop also suppressed the attack of soybean aphids (Koch et al. 2015).

The growing of wheat, oat, marigold, and forage peanuts as cover crops significantly inhibited the reproduction of sugarcane parasitic nematodes (Berry et al. 2011). The population of pathogenic fungi was markedly reduced when perennial chicory, rye grass, red clover, and white clover were grown in spring wheat and winter barley. Moreover, these cover crops also positively enhanced the activities of the beneficial arbuscular mycorrhizal fungi (Detheridge et al. 2016). The small terminated grain crops and combination of aldicarb reduced the *Meloidogyne incognita* population with no negative effects on cotton yield (Wheeler et al. 2008). The growing of pearl millet, arugula, cowpea, mustard, jack bean, tomato, and sunflower as cover crops was tested against *Meloidogyne* complex under anaerobic soil disinfestation system. Among these, sorghum-Sudan grass, cowpea, and arugula had lowest occurrence of *Meloidogyne*-induced root disease complex (Kokalis-Burelle et al. 2013). In another work, mulatto grass, forage sorghum, and oil radish showed lowest *Rotylenchulus reniformis* nematode densities when grown in cotton as cover crops under greenhouse and field conditions (Asmus et al. 2008). The growing of rye as cover crop increased the incidence of *Fusarium oxysporum*, *F. graminearum*, *Pythium sylvaticum*, and *Pythium torulosum* in corn (Bakker et al. 2016). Winter canola and hairy vetch reduced the incidence of corn root diseases when used as cover crops in combination with fungicidal treatment (Schenck et al. 2017). The rapeseed and cereal reduced the population of soybean cyst nematodes and *Rhizoctonia solani* with uniform crop stand and higher yield (Wen et al. 2017).

19.7.8 Trap Crops

The growing of trap crops is a strategy in which pests are repelled away from the main crop of interest (Ratnadass et al. 2012). There are certain diseases which are spread by the vectors feeding on the infected crops. Likewise, many insect pests attack crop plants of economic importance eventually leading to severe qualitative and quantitative losses. The growing of taro was effective to attract armyworm (*Spodoptera litura*) in tobacco crop. However, it is important to mention that taro plants should be planted 20–30 days before tobacco to efficiently control the attack of armyworm as it was not effective to attract the said pest at seedling stage (Zhou et al. 2010). Soybean and pea were used as trap crops to manage soybean cyst nematode in corn (Chen et al. 2001). The attack of leafhopper was significantly reduced in cotton where okra and castor bean or sunflower were used as trap crops (Hormchan et al. 2009). In another work, soybean planting as trap crop more efficiently reduced boll injury and density of stink bugs in cotton than peanut (Tillman et al. 2015).

19.7.9 Tillage Practices

Different tillage systems have been used in growing of agronomic crops. It has been reported that the tillage practices and methods significantly affect diseases and pest of various agronomic crops. Use of cover crop of grass (*Elymus trachycaulus*) significantly checked the population of Western corn root worm of maize under zero tillage production system. Moreover, use of the said cover crop also enhanced arthropods beneficial for pollination. Cultivation of rye and crimson clover increased the population of natural predators that eventually reduced flower bugs on cotton under conservation tillage (Tillman et al. 2004). Reduced tillage abridged corn rootworm severity on pods with increased population of collembolans, heteropterans, hymenopterans, and acarina in peanut (Cardoza et al. 2015). Cultivation with moldboard or chisel plow increased beneficial arthropods particularly tiger and ground beetles in maize/soybean under legumes and perennial sod or annual cereal grain rotation scheme (Jabbour et al. 2016).

The growing of common bean under no tillage system significantly reduced fusarium wilt incidence and had higher yield, as compared to its conventional cultivation (Toledo-Souza et al. 2012). The cultivation of peanut under maize, soybean, and peanut system increased the population of biocontrol agents (*Trichoderma* and *Gliocladium* spp.) which eventually reduced the soil-borne fungal pathogens under no tillage cultivation system (Gil et al. 2008). The incidence of wheat leaf spot and root diseases was markedly reduced in zero tillage in comparison to conventional tillage (Bailey 1996). Root and stalk rot of sorghum was significantly lower in minimal tillage system, than plow-planted crop (Flett 1996). The cultivation under strip tillage system combined with rye cover crop significantly reduced the population of immature thrips on cotton and peanut. Moreover, it also lowered the incidence of tomato spotted wilt virus in peanut concomitant with higher yield in both crops (Knight et al. 2017). The conservation tillage effectively reduced immature and adult populations of thrips in combination with thiamethoxam seed treatment and cover crop of rolled rye along with higher yield in peanut and cotton. Furthermore, the incidence of tomato spotted wilt virus was also significantly reduced in peanut (Knight et al. 2015). The no-tillage cultivation system significantly reduced severity of fusarium blight with higher pod yield of soybean (Joseph et al. 2016). The eye spot incidence of winter wheat was significantly reduced when it was grown under no tillage combined with mulching having better nutrient use efficiency (Váňová et al. 2011). The tillage with moldboard plow reduced the incidence and severity of wheat fusarium head blight (Dill-Macky and Jones 2000). Tillage practice markedly lowered the infection of seminal roots and crown roots in wheat under winter wheat-barley-winter canola rotation scheme compared to its continuous mono-cultivation (Paulitz et al. 2010).

19.7.10 Fertilizer Application

The doses and application of nutrients may significantly influence infestation of insect pests and diseases. Excessive or reduced application may either increase or decrease incidence of diseases and population of pests depending upon crops and their growth stages. The combined application of nitrogen (N) and silicon significantly reduced attack of leaf folder, dead hearts, and stem borer along with inhibited leaf blight, grain discoloration, and brown spot of low land rice (Malav and Ramani 2015). Application of biochar increased vegetative growth that eventually increased the attack of white backed plant hopper of rice due to changes in jasmonic acid biosynthesis. However, response was found to be cultivar dependent as higher intensity of plant hopper infestation was noted in vigorously growing rice cultivar (Waqas et al. 2018). Application of N, phosphorous (P), or potassium (K) led to significant changes in concentration of soluble sugars, proteins, and silicon. Among these, application of K reduced soluble proteins, free sugars, N, and silicon in the tissues of plants and led to significant reduction of brown plant hopper attack on rice (Rashid et al. 2016a, b). Application of nutrients especially N also influences the feeding habit and oviposition for egg laying. Higher level of N, soluble proteins, and free sugars in plant tissues will increase the egg laying capacity and infestation of brown plant hopper of rice (Rashid et al. 2017a). Higher dose of N, P, or K fertilizers increases vegetative growth and yield of crop plant. However at the same time, higher doses of NPK also increase the development and survival rate of brown plant hopper of rice (Rashid et al. 2017b). The incidence of rice borer was reduced with adequate application of K with improved crop productivity (Sarwar 2012).

It has been reported that some nutrients such as magnesium (Mg) and calcium (Ca) specifically act in a particular pathogen-host interaction and alter their expression symptoms as noted in infection of alfalfa mosaic virus on common bean. In this case, Mg and Ca increased formation of alfalfa mosaic virus lesions in contrast to systemic infections (Tu 1978). Root and foliar application of silicon either as potassium silicate (40 g L^{-1}) or calcium silicate (1.25 k kg^{-1}) significantly reduced the development and severity of brown spot in rice. However, efficacy of foliar application was less than soil treatment (Rezende et al. 2009). Application of silicon (2 mM) reduced anthracnose of sorghum by increasing carbon fixation and antioxidative system due to enhanced free radical scavenging activity (Resende et al. 2012). In the same way, silicon treatment enhanced the activity of defensive enzymes such as PPO and POD against biotic stresses, ultimately leading to inhibition of *Colletotrichum sublineolum*-induced anthracnose of sorghum (Resende et al. 2013). Combined application of NPK and foliar spray of Zn, Cu, and Mn reduced the severity of fusarium head blight with lower levels of mycotoxins in winter rye (Cwalina-Ambroziak et al. 2017). Foliar treatment of B and Cu (20 + 20 mg L^{-1}) reduced fungal disease infestation along with increased number of spikelets, productive tillers, percentage of filled grains, and yield of rice (Liew et al. 2012). Application of P (90 or 120 kg ha^{-1}) significantly suppressed severity and incidence of brown blotch disease of cowpea along with enhanced vegetative growth, leaf area, nodules, pods, and overall yield (Owolade et al. 2006). Likewise, application of Ca (carbonate and silicate) markedly reduced the occurrence of downy mildew, frog eye, and Asian rust in soybean (Nolla et al. 2006). In the same way, optimum application of K or P, in combination with fungicide, reduced the severity of leaf rust with ultimate increase in yield of winter wheat (Sweeney et al. 2000). Application of Zn, Cu, and silicon inhibited rice sheath blight disease and minimized the yield loss (Khaing et al. 2014). Supplemental application of calcium silicate and calcium chloride significantly reduced white mold disease intensity in dry beans (Júnior et al. 2009). Dark spot disease was significantly suppressed with increasing N availability due to enhanced acetic acid emission which acted as antifungal volatile agent in *Brassica napus*. Availability of N also influenced pollen beetles and seed weevils infestation as well as levels of their parasitoids (Veromann et al. 2013).

19.7.11 Biological Control

Use of muscadine fungal strain (*Cotesia flavipes)* was highly effective in controlling stem and moth borers of sugarcane (Suasaard and Charernsom 1996; Suasaard et al. 2001) (Table 19.2). The release of *M. mediator* was effective to manage cotton bollworm larval population in the field conditions (Luo et al. 2014). Wheat aphids were biologically controlled with ladybeetle. However, intensity of control was dependent upon the abundance of lady beetles in the field (Yang et al. 2018). The population of sugarcane borers was significantly controlled with *Trichogramma chilonis* in the farmer's field conditions (Nadeem and Hamed 2011). *Tryporyza incertulas* being parasitoid of rice lepidopterous pests can be used to suppress the population of rice stem borers (Guo et al. 2002). Ootheca, aphids, and stem maggot were efficiently managed with combination of agronomic and biological control measures (Mwanauta et al. 2015). Planting of sesame as nectar crop increased the number of lepidopterous egg and plant hopper egg parasitoids that ultimately checked the population of the said pests of rice (Zhu et al. 2017).

The use of *Bacillus* genus effectively inhibited the incidence of *Exserohilum turcicum*-induced northern leaf blight of maize under greenhouse conditions (Sartori et al. 2017a). Likewise, *Bacillus* spp. also significantly inhibited *Puccinia sorghi*- and *Exserohilum turcicum*-induced common rust and northern leaf blight of maize under field conditions (Sartori et al. 2017b). Seed treatment with *Trichoderma harzianum* was found suitable in reducing *Rhizoctonia solani*-induced tobacco root rot disease in greenhouse conditions (Gveroska and Ziberoski 2011a, b). *Bacillus subtilis* and *Pseudomonas fluorescens* significantly reduced bacterial blight in cotton under greenhouse as well as field conditions (Salaheddin et al. 2010). Soil application and seed treatment with *Trichoderma viride* inhibited the growth of wheat root rot (*Bipolaris sorokiniana*) along with significantly enhanced plant height as well as shoot and root fresh and dry biomass than uninoculated control (Salehpour et al. 2005). *Trichoderma harzianum* and *Macrophomina phaseolina* suppressed root rot and enhanced grain yield of mung bean (Shahid and Khan 2016). Similarly, incidence of charcoal rot (*Macrophomina phaseolina*) was inhibited with combined treatment of *Trichoderma harzianum* and *Sisymbrium irio* leaf powder. Moreover, the same combinational treatment also significantly improved leaf chlorophyll, sugar contents, proteins, and activity of catalase enzyme of mung bean (Javaid et al.

Table 19.2 Effect of biocontrol agents for control of pest and diseases of agronomic crops

Biocontrol agents	Crop pests and diseases	References
	Pests	
Cotesia flavipes	Sugarcane stem borer	Suasaard et al. (2001)
H. armigera, *M. mediator*	Cotton bollworm	Luo et al. (2014)
Trichogramma chilonis	Sugarcane stem borer	Nadeem and Hamed (2011)
Tryporyza incertulas	Rice borer	Guo et al. (2002)
Aenasius bambawalei	Cotton mealybug	Ram and Saini (2010)
	Diseases	
Bacillus spp.	Maize leaf blight	Sartori et al. (2017a)
Bacillus spp.	Maize rust and leaf blight	Sartori et al. (2017b)
Trichoderma harzianum	Tobacco root rot	Gveroska and Ziberoski (2011a, b)
Bacillus subtilis, *Pseudomonas fluorescens*	Cotton bacterial blight	Salaheddin et al. (2010)
Trichoderma viride	Wheat root rot	Salehpour et al. (2005)
Trichoderma harzianum, *Macrophomina phaseolina*	Mung bean root rot	Shahid and Khan (2016)
Trichoderma harzianum and *Sisymbrium irio*	Mung bean charcoal rot	Javaid et al. (2017)
Pseudomonas sp. and *Bacillus* sp.	Sunflower necrosis virus	Srinivasan et al. (2009)
Trichoderma harzianum	Cowpea rust	Arafa et al. (2016)
Trichoderma spp.	Cowpea charcoal rot	Singh et al. (2012)
Trichoderma harzianum	Tobacco rot	Gveroska and Ziberoski (2011a, b)
Trichoderma harzianum	Rice brown spots	Khalili et al. (2012)
Bacillus spp.	Rice bacterial leaf blight	Ahmed et al. (2015)
Trichoderma viride and *Pseudomonas fluorescens*	Groundnut stem rot	Karthikeyan et al. (2006)
Trichoderma viride	Bean anthracnose	Padder and Sharma (2011)
Trichoderma harzianum	Tobacco bacterial wilt	Yuan et al. (2016)

2017). *Pseudomonas* sp. and *Bacillus* sp. competently reduced the incidence of sunflower necrosis virus disease (Table 19.2). Furthermore, these also increased seedling vigor and germination percentage (Srinivasan et al. 2009). The application of *Trichoderma harzianum* substantially reduced rust and positively increased growth and yield of cowpea grown in sandy soil conditions (Arafa et al. 2016). Groundnut stem rot was significantly reduced in response to *Pseudomonas* cf. *monteilii* 9, compared to control (Rakh et al. 2011). Charcoal rot incidence of soybean was effectively inhibited with *Trichoderma* having increased stem length, root elongation, and thousand kernel weight (Khalili et al. 2016). Cowpea charcoal rot was markedly inhibited with *Bacillus firmus*. It also significantly enhanced nodulation with better growth of plants (Singh et al. 2012). Tobacco *Alternaria alternata* disease was significantly checked with *Trichoderma harzianum* biocontrol agent (Gveroska and Ziberoski 2011a, b). Similarly, *Trichoderma harzianum* effectively inhibited rice blast incidence of direct seeded crop under low rain-fed conditions (Singh et al. 2012). Likewise, same biological control agent was also found effective in inhibiting brown spot disease and enhanced the growth of rice plants (Khalili et al. 2012). The plant growth was significantly enhanced with suppression of bacterial leaf blight of rice with rhizobacterial *Bacillus* strains (Ahmed et al. 2015). Similarly, combined application of *Pseudomonas fluorescens* and *Trichoderma* strains controlled rice blast with improved plant growth and yield under greenhouse and field (Subhalakshmi and Devi 2017). Treatment with *Trichoderma viride* and *Pseudomonas fluorescens* enhanced activities of defensive enzymes such as polyphenol oxidase and peroxidase which ultimately inhibited stem rot of groundnut (Karthikeyan et al. 2006). The incidence of CLCV was significantly decreased in response to *Pseudomonas* and *Bacillus* spp. under greenhouse conditions (Ramzan et al. 2016). Application of *Trichoderma viride* resulted in maximum germination percentage and control of bean anthracnose (Padder and Sharma 2011). Combined application of bioorganic fertilizer and *Trichoderma harzianum* was highly effective in controlling tobacco bacterial wilt owing to higher expression of peroxidase, phenylalanine ammonia lyase, and polyphenol oxidase activities (Yuan et al. 2016). *Aenasius bambawalei* parasitoid significantly reduced the incidence of mealybug in cotton (Ram and Saini 2010).

19.7.12 Plant Extracts

The infestation of thrips (*Megalurothrips sjostedti*) on cowpea flowers was inhibited in response to eucalyptus tree bark and *Gmelina arborea* extract application (Table 19.3). Similarly, *Gmelina arborea* and African marigold leaf extract mixture was also as effective as synthetic insecticide treatment. The application of these extracts resulted in increased pod yield due to lower infestation of thrips (Mbonu 2006). Ethyl acetate and methanolic extracts of *Sida acuta* increased the mortality of red cotton bug with dose-dependent concentration (Gadewad and Pardeshi 2018). *Copaifera langsdorffii* bark and leaf extracts significantly reduced larval weight and food intake and led to delayed larval development of *Spodoptera frugiperda* of maize (Samia et al. 2016). *Piper aduncum* leaf extract acted as natural insecticide as it effectively reduced reproduction and survival of soybean stink bug (Piton et al. 2014). The treatment of yard-long beans with tobacco extract showed reduced attack of aphids with increased beans biomass (Bahar et al. 2007). Application of neem seed extract and neem oil showed markedly higher yield with reduced incidence of thrips, jassids, and whitefly of cotton (Rashid et al. 2012). Treatment of sets with Chulai, Absinthe, and Babchi extracts significantly suppressed sugarcane foraging termites (Ahmed et al. 2007). Application of neem, datura, and tobacco extracts significantly suppressed infestation of pink bollworm in non-Bt and Bt cotton. However, efficacy of tobacco extract was much higher, than others

Table 19.3 Effect of natural plant extracts for control of pest and diseases of agronomic crops

Plant extracts	Crop pests and diseases	References
	Pests	
Eucalyptus globulus and *Gmelina arborea*	Cow thrips	Mbonu (2006)
Sida acuta	Red cotton bug	Gadewad and Pardeshi (2018)
Copaifera langsdorffii	Maize *Spodoptera frugiperda*	Samia et al. (2016)
Piper aduncum	Soybean stink bug	Piton et al. (2014)
Nicotiana tabacum	Beans aphids	Bahar et al. (2007)
Azadirachta indica	Cotton thrips, jassids and whitefly	Rashid et al. (2012)
Amaranthus viridis, *Artemisia absinthium, and Psoralea corylifolia*	Sugarcane termites	Ahmed et al. (2007)
Azadirachta indica, *Datura stramonium*, and *Nicotiana tabacum*	Cotton pink bollworm	Rajput et al. (2017)
	Diseases	
Croton heliotropiifolius	Maize weevil	Silva et al. (2013)
Azadirachta indica	Rice *N. lugens*, *N. virescens*, *L. oratorius* and *S. incertulas*	Abdullah et al. (2015)
Azadirachta indica and *Gossypium hirsutum*	Cotton aphids	Pinto et al. (2013)
Allium sativum	Faba beans root rot, wilt, and chocolate spot	Eisa et al. (2006)
Curvularia lunata	Maize leaf spot	Akinbode (2010)
Ziziphus mucronata and *Lippia multiflora*	Groundnut leaf spot disease, necrotic leaf area	Koita et al. (2017)
Garcinia kola, *Aloe vera*, *Zingiber officinale*, and *Azadirachta indica*	Cowpea root rot	Suleiman and Emua (2009)
Vernonia amygdalina and *Maesa lanceolata*	Sorghum smut	Sisay et al. (2012)
Datura stramonium, *Jatropha gossypifolia*, and *Ricinus communis*	Cowpea anthracnose	Falade et al. (2018)
Azadirachta indica	Cotton bacterial blight	Rashid et al. (2016)

(Rajput et al. 2017). The ethanolic extract of *Croton heliotropiifolius* flowers showed contact avoidance of maize weevil (*Sitophilus zeamais*) (Silva et al. 2013). Neem seed extract significantly reduced the insect pests of rice such as *N. lugens*, *N. virescens*, *L. oratorius*, and *S. incertulas* and was found as effective as chlorpyrifos and deltamethrin (Abdullah et al. 2015). The application of *A. indica* bark and *P. guineense* seed extract reduced the severity of pest attack on jute (Okunlola and Ofuya 2013). Similarly, neem oil and oil of cotton seed reduced aphid attack on cotton, but control was less effective than thiamethoxam insecticide (Pinto et al. 2013).

Foliar spray with clove, neem, and quinine extracts completely inhibited leaf rust diseases of wheat with enhanced yield under greenhouse conditions (Shabana et al. 2017). Treatment with moringa plant extract resulted in enhanced germination percentage and controlled seed-borne pathogens of sorghum (El-Dahab et al. 2016). Similarly, garlic extract significantly suppressed incidence of root rot, wilt, and chocolate spot of faba beans under in vitro conditions (Eisa et al. 2006). The extracts of *Curvularia lunata* markedly suppressed maize leaf spot disease in vitro (Akinbode 2010). Similarly, *Ziziphus mucronata* and *Lippia multiflora* aqueous extracts significantly controlled groundnut leaf spot disease and necrotic leaf area and reduced defoliation rate along with higher pod yield under field conditions (Koita et al. 2017). Bitter kola, aloe, ginger, and neem extract inhibited cowpea root rot disease under both in vivo and in vitro environment (Suleiman and Emua 2009). Seed treatment of sorghum with *Vernonia amygdalina* and *Maesa lanceolata* significantly suppressed smut disease under field conditions (Sisay et al. 2012). Application of *Datura stramonium*, *Jatropha gossypiifolia*, and *Ricinus communis* extracts controlled anthracnose infection with increased yield of cowpea under cowpea/maize intercropping scheme in field conditions (Falade et al. 2018). Similarly, application of *Azadirachta indica* controlled bacterial blight disease of cotton with higher yield of Bt cotton under field trial (Rashid et al. 2016).

19.7.13 Ultraviolet Radiation

It has been reported that the intensity of ultraviolet (UV) radiations has increased due to ozone layer depletion. The UV radiations are generally considered detrimental for the crop plants; however they can effectively suppress the activities of pests and growth of various pathogens of agronomic crops (Cheng et al. 2014; Li et al. 2018). Utilization of UV-absorbing films, with the ability to slab near-UV (300–400) light radiation, has been found highly effective to prevent entry of certain pests in the greenhouses (Nakagaki et al. 1984). The coverage of greenhouse with UV-absorbing films appeared to be dark for certain pests. The incidence of various insect pests including thrips, aphids, and whiteflies was reduced where UV-absorbing films were used (Costa et al. 2002; Ohta and Kitamura 2006; Nguyen et al. 2009). So, use of UV-absorbing films/sheets may be an effective way to reduce the population of various pests of agronomic crops. The population and growth rate of *Anticarsia gemmatalis* was markedly reduced when these were forced to eat UV-B (315 nm)-irradiated leaves of soybean. However, UV-B-irradiated soybean leaves had higher concentration of soluble phenols and lower lignin contents (Zavala et al. 2001).

The irradiation with UV-B (280–320 nm) reduced the susceptibility of rice plants to *Pyricularia grisea*-induced blast disease. However, the response was cultivar dependent under glasshouse conditions (Finckh et al. 1995). UV-B treatment significantly reduced wheat stripe rust. Among the three races of *Puccinia striiformis*, CYR-31 was found to be more vulnerable, and CYR-33 was comparatively resistant and survived the UV-B exposure (Cheng et al. 2014). The artificially enhanced UV-B radiation significantly inhibited incidence and severity of *Magnaporthe oryzae*-induced rice blast. Moreover, UV-B-treated rice plants also had higher activities of disease-resistant enzymes such as lipoxygenase, chitinase, phenylalanine ammonia lyase, and β-1,3-glucanase (Li et al. 2018). The increased concentration of UV-A and UV-B (0.15–11.66 MJ m^{-2}) decreased the disease development of soybean rust owing to increased urediniospore mortality. The treated soybean plants also had increased height and leaf area index (Young et al. 201). Exposure of tobacco leaves to UV-B radiation enhanced endogenous production of salicylic acid that eventually enhanced phenylalanine ammonia lyase and signal transduction to activate defense-related protein in the pathogen infection process (Fujibe et al. 2000). So, it is evident that UV radiation can effectively decrease certain diseases of agronomic crops.

19.7.14 Ozone Treatment

The application of 150 ppb O_3 reduced the population of aphids (Telesnicki et al. 2015). In the same way, O_3 treatment reduced the population of aphids in Italian ryegrass (Ueno et al. 2015). The treatment of wheat grains with O_3 at the rate of 5 g/m^3 for 5 h significantly reduced the incidence of grain moth (*Sitotroga cerealella*) (El-Ghaffar et al. 2016).

The spot blotch disease of wheat was markedly reduced in response to ozone (O_3) treatment. The activity of chitinase enzyme and pathogenesis-related protein expression was enhanced, and *Bipolaris sorokiniana*-induced disease incidence was inhibited (Mina et al. 2016). Treatment of sunflower seeds with 0.24 g h^{-1} substantially reduced fungal population of *Fusarium*, *Aspergillus*, *Penicillium*, and *Alternaria* spp., without negatively influencing its physiological potential (Rodrigues et al. 2015). The application of 0.47 g kg^{-1} O_3 to soil completely inhibited *Phytophthora sojae*-induced stem and root rot disease of soybeans. Similarly, 490 μgm^3significantly inhibited the *Pseudomonas glycinea*-induced infection on primary as well as trifoliate soybean leaves (Laurence and Wood 1978).

19.7.15 Plant Growth-Promoting Rhizobacteria

The group of bacteria with beneficial effects on the growth of plants is known as plant growth-promoting rhizobacteria (PGPR). PGPR may also effectively check the dynamics of fungi, bacteria, nematodes, and certain pests with improved growth (Fig. 19.1). PGPR induce systemic acquired resistance in plants against certain disease causing microorganisms and pests (Yadav et al. 2015).

Pseudomonas maltophilia substantially reduced the *Helicoverpa zea* larval stage in corn earworm. The said PGPR strain also reduced the emergence of pupae and ultimately adults from the treated larvae (Bong and Sikorowski 1991). Likewise, *H. armigera* population was reduced in *P. gladioli* PGPR-treated cotton plants due to increased terpenoid and polyphenol contents (Qingwen et al. 1998). Similarly, 526 strain of *P. fluorescens* substantially reduced hornworm population in tobacco (Stock et al. 1990). PGPR *Bacillus amyloliquefaciens* in combination with compost reduced the incidence of pink bollworm, leaf roller, bugs, and aphids with consequent increase in cotton yield. The highest reduction was obtained for aphids with significantly enhanced cotton yield (Alavo et al. 2015).

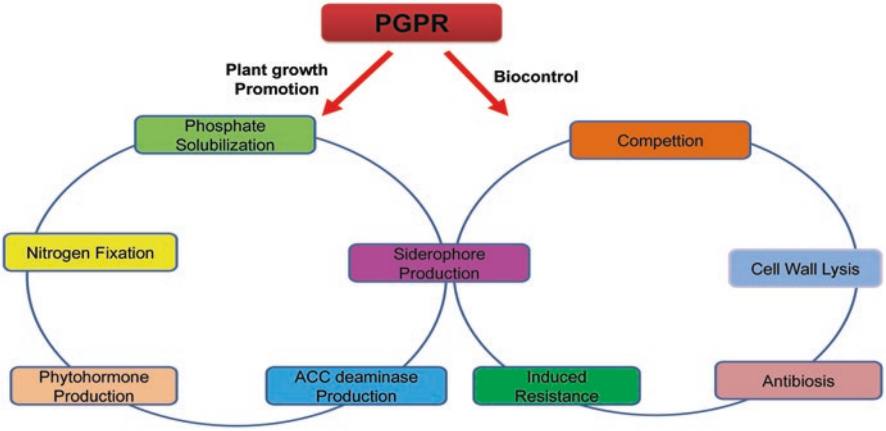

Fig. 19.1 Mode of action of PGPR on growth promotion and biocontrol of various pests and disease of agronomic crops. (Adopted from Shaikh et al. 2016)

Dip and foliar treatment with Pf1 and FP7 strains of *P. fluorescens* showed ISR induction against *Rhizoctonia solani*-induced sheath blight of rice (Vidhyasekaran and Muthamilan 1999). In the same way, PGPR induced ISR against red rot disease of sugarcane. The soil application of *P. fluorescens* exhibited ISR against tobacco necrosis virus (Maurhofer et al. 1994; Maurhofer et al. 1998). *P. fluorescens*-induced ISR inhibited cyst nematode (*Heterodera schachtii*) of sugar beet (Oostendorp and Sikora 1990). Likewise, *B. subtilis* increased protection against *Meloidogyne incognita* and *Meloidogyne arenaria* of cotton crop (Sikora 1988). It has also been reported that combination of PGPR with neem cake and chitin markedly reduced rice root nematode infestation (Swarnakumari and Lakshmanan 1999). *P. fluorescens*-treated rice seeds revealed disease resistance against *X. oryzae* pv. *oryzae* (Vidhyasekaran et al. 2001). The combined treatment with *P. fluorescens* and silica significantly inhibited rice blast incidence (Karpagavalli et al. 2002). Similarly, *P. fluorescens* application found to be effective in inhibiting sorghum root rot disease (Idris et al. 2008). The combined use of *P. fluorescens* with pesticides controlled black gram dry root rot (Siddiqui et al. 1998). The root rot disease incidence of *Vigna mungo* was markedly inhibited in response to *P. fluorescens* treatment (Latha et al. 2000). In the same way, chickpea root rot disease was substantially controlled with *P. fluorescens* application (Ahamad et al. 2000). The incidence of soybean cyst nematode was inhibited in response to *Bacillus* strain with significant increase in plant biomass, early growth, plant height, and yield (Xiang et al. 2017a). Similarly, *Bacillus* strain of PGPR efficiently controlled *Meloidogyne incognita* with improved plant biomass and yield of cotton (Xiang et al. 2017b). Tobacco growth was also substantially enhanced with concomitant protection against blue mold disease (Zhang et al. 2004).

19.7.16 Seaweed/Marine Macroalgae Extracts

At present, natural algal or seaweed extracts are considered more pertinent in agriculture. One of the benefits of these natural extracts is that they control plant infections with increased safety having almost negligible influence on environment. Application of *Sargassum tenerrimum* and *Padina pavonic*a seaweed extracts showed effective insecticidal activity as it reduced the population of *Dysdercus cingulatus* in cotton (Sahayaraj and Kalidas 2011; Sahayaraj and Jeeva 2012). The use of brown algae extract acted as insecticide and reduced *Dysdercus cingulatus* bug population in cotton (Asaraja and Sahayaraj 2013). The combined application of organic fertilizer and seaweed extract reduced the populations of *Bemisia tabaci*, *Liriomyza trifolii*, and *Aphis gossypii* infestation with increased yield and better fiber quality of cotton (Gencsoylu 2016).

The application of extracts of *U. armoricana* reduced the incidence of bean powdery mildew (Jaulneau et al. 2011). Similarly, application of *Sargassum swartzii* and red seaweed extracts efficiently controlled *Rhizoctonia solani*-induced sheath blight disease of rice due to increased accumulation of phytoalexin and phenolic compounds (Raj et al. 2016a, b). Green *Ulva fasciata* extract reduced the severity of anthracnose and enhanced the growth of common bean (Paulert et al. 2009). Seaweed application showed effective reduction of *Fusarium* spp.-, *Macrophomina phaseolina*-, and *Rhizoctonia solani*-induced root rot incidence of sunflower with reduced galls and penetration of the nematodes (Sultana et al. 2011). *Ulva fasciata* and sulfated polysaccharide significantly inhibited anthracnose and improved the growth of common bean (Paulert et al. 2009). Priming of wheat and barley seeds with *Ulva fasciata* extract enhanced the resistance against powdery mildew and improved plant growth (Paulert et al. 2010). Red algae-obtained kappa-/beta-carrageenan markedly suppressed the tobacco mosaic virus in the leaves of Xanthi-nc tobacco (Nagorskaia et al. 2008).

19.7.17 Plant Growth Regulators

The plant growth regulators (PGRs) are natural or synthetic organic compounds, known as biostimulants as well as bioinhibitors which play key roles in plant metabolism. Various growth regulators have been reported to enhance the productivity of plants (Morgan 1979) and improve their resistance against pests and pathogens, when applied exogenously (El-Hai 2015). These compounds (natural or synthetic) have been known to modify crop growth rate during several stages of development (from germination to maturity). Use of pesticides or fungicides is the major and traditional approach for the management of pests or diseases (Dogimont et al. 2010). Several elicitors have been proposed to develop acquired plant resistance. PGRs are also effective in the development of defense mechanism against biotic stresses (Thaler et al. 1999; Boughton et al. 2006; Ryals et al. 1996). War and Sharma (2014) investigated the effect of salicylic acid (SA) and jasmonic acids (JA) to induce resistance in groundnut against *Helicoverpa armigera*. Similarly aphid, a destructive pest of canola crop, is controlled by excessive use of environment-unfriendly insecticides. SA application (50 mg L^{-1}) was found effective in reducing aphid population in the field conditions (Elhamahmy et al. 2016).

JA and SA application reduced the attack of stem borer in sorghum crop and strengthen the defense system against herbivores (Hussain et al. 2014; Thakur et al. 2016). Nickell (1982) observed mixed response regarding metabolic functioning of plants in accordance with disease control in response to PGR applications. It has been observed that some auxins respond positively while GA_3 have the tendency to either decrease or increase the disease inoculum. Moreover, growth regulators (auxins and gibberellins) along with growth retardants (ethrel and PBZ) are used as alternatives to formal fungicide and showed effective control of fungal diseases of agronomic crops (Abdalla 2001; Khalifa 2003; Metwally et al. 2006; El-Hai et al. 2010). El-Hai (2015) found that IBA and GA_3 along with PBZ or ethrel showed effective control against *Alternaria* leaf spot disease. The ethrel and PBZ at 150 mg L^{-1} completely reduced the growth of fungal infection, as compared to fungicide with improved growth and yield of "faba bean."

The application of 100 mg L^{-1} kinetin suppressed the root rot diseases, particularly damping-off incidence in lentil. The treatment also improved the vegetative growth, increased leaf area and photosynthetic pigments, and enhanced yield of lentil (El-Hai et al. 2017). Similarly, the application of methyl jasmonate induced basal resistance in bread wheat against fungal pathogen "*Fusarium culmorum*" causing serious diseases such as root and crown rot.

The use of chlormequat chloride and ethephon at different concentrations, i.e., 750 g L^{-1} and 480 g L^{-1}, was evaluated against *Fusarium* fungi of wheat (Mankeviciene et al. 2008). The application of SA reduced incidence of fusarium head blight of wheat and barley (Makandar et al. 2012; Aldesuquy et al. 2015). Mbazia et al. (2016) also explored the effect of various growth-regulating compounds such as citric acid, oxalic acid, SA, and ascorbic acids with one fungicide on the control of "chocolate spot disease" in faba bean. It was found that application of SA was highly effective in vivo and in vitro and considerably inhibited fungal growth after 6 days of incubation (48%) followed by oxalic acid (39%), ascorbic acid (33%), and citric acid (10%) while the fungicide "carbendazim" provided partial protection of plant. Ali et al. (2013) investigated the effect of brassinosteroids on the resistance development of barley against fusarium disease. Application of brassinosteroids reduced severity of head blight (86%) and reduced grain loss of weight. SA treatment induced resistance against pathogens either biotrophic or hemibiotrophic. The application of SA significantly inhibited the mycelial growth of *Fusarium graminearum* of wheat (Qi et al. 2012).

19.7.18 Coating Materials

Different coating materials have reasonable potential to check the spread of certain pests and diseases of various agronomic crops. Coatings may be applied as seed treatment or as foliar sprays during production phases of the crops. The coatings have high anti-pest and antimicrobial properties that ultimately help to manage the outbreak of pests and diseases in agronomic crops. However, the efficacy of coating material is better against fungal diseases, as compared to insect pests or bacteria (Kong et al. 2010). Chitosan seed treatment effectively controlled pod borer and aphids of soybean. The treatment was also effective to increase the germination potential and growth of soybean seedlings. Application of chitin derivative showed 100% mortality of cotton leafworm larva (Rabea et al. 2005). In the same way, addition of chitosan showed significant control of chiefly moths and aphids of cotton (Badawy and El-Aswad 2012).

Application of chitosan as nanoparticles significantly reduced the incidence of downy mildew in pearl millet by regulating the defensive enzymes and nitric oxide generation. Chitosan treatment also led to higher expression of pathogenesis-related PR-1 and PR-5 proteins under greenhouse conditions (Manjunatha et al. 2008; Siddaiah et al. 2018). Gum arabic coating application significantly controlled *Rhizoctonia solani*-, *Macrophomina phaseolina*-, and *Fusarium* spp.-induced root rot infection with markedly better growth and yield of sunflower (Dawar et al. 2008). Similarly, seed coating with *Prosopis juliflora* extract combined with *Pseudomonas aeruginosa* and *Trichoderma harzianum* significantly enhanced the germination percentage and subsequent vegetative growth with effective control of root rot incidence of mung bean and cowpea (Ikram and Dawar 2013). Combined seed treatment with propiconazole and Genius Coat™ or Disco AG Blue L-237 increased the emergence percentage, tiller number, flowering, and yield exhibiting significantly lower loose smut incidence of barley under field conditions (Zegeye et al. 2017). Treatment with chitosan (low molecular weight) inhibited tobacco mosaic virus-induced necrosis (Davydova et al. 2011). Soil amendment with chitin effectively controlled *Meloidogyne arenaria* of peanut plant (Mian et al. 1982). Similarly, chitin application inhibited the growth of cyst nematodes of soybean crop (Rodriguez-Kabana et al. 1984). Combinational treatment with chemical fertilizer and chitosan significantly controlled rice dirty panicle disease. Moreover, the said treatment also markedly enhanced plant height, leaf greenness, panicle number, dry matter accumulation, and grain yield (Boonreung and Boonlertnirum 2013). Use of Cu-chitosan as nanoparticle significantly increased defense mechanism and reduced the *Curvularia* leaf spot disease of maize. It also improved growth and grain yield in pot experiment (Choudhary et al. 2017).

19.7.19 Biofabricated Nanoparticles

It has been reported that crop pests and diseases are major causes of reduced yield and increased economic losses in the world. Among various crops, wheat, rice, sugarcane, cotton, barley, beans, and groundnut are particularly susceptible to various pests and diseases. Therefore, in order to curb these deleterious ailments, myriad traditional fungicides are being used in the world posing countless harmful effects to sustainable ecosystem. Hence, some alternative approaches like nanoparticles are being developed to combat major pests and diseases of agronomic crops (Mishra et al. 2014).

Nanoparticle-coated halofenozide and tebufenozide checked the population of leafworm (*Spodoptera littoralis*) of Egyptian cotton (Elek et al. 2010). Nanoparticle-coated chitosan showed effective pesticidal activity as it controlled the population of *Aphis gossypii* of soybean under semi-field conditions (Sahab et al. 2015). Nanoparticles of biogenic showed strong larvicidal activity against *Mythimna separata* of rice (Buhroo et al. 2017).

It has been found that use of silver nanoparticles was highly effective to control *Magnaporthe grisea*-induced blast disease of rice (Jo et al. 2009; Rabab and El-Shafey 2013). Similarly, application of biofabricated silver nanoparticles checked the growth of *Bipolaris sorokiniana*-induced spot blotch disease of wheat (Jo et al. 2009; Mishra et al. 2014). Use of silver nanoparticles showed significant nematicidal activity by checking the growth of *Meloidogyne incognita* root-knot nematode of cotton (Abbassy et al. 2017). Silver nanoparticle triggered the phenolic biosynthesis and increased lignifications, which checked the *Sclerotium rolfsii*-induced chickpea collar rot disease under greenhouse conditions (Mishra et al. 2017).

19.7.20 Chemical Control

Different pests and diseases may be controlled with either curative or preventive applications (pesticides or fungicides). The efficiency of curative and preventive schemes depends upon nature of pathogens and chemicals applied (Sarnaik et al. 2006; Anuradha et al. 2015; Fromme et al. 2017).

Legume pests and diseases were significantly inhibited in response to application of dimethoate and mixture of copper oxychloride with subsequent increased growth and yield of plants (Muthomi et al. 2008). Cowpea crop encounters serious insect pest infestation such as pod borers and pod-sucking bugs that can be controlled with various applications of certain insecticides (Dzemo et al. 2010). Similarly, rice spiders were efficiently managed with pyrethroid and lambda-cyhalothrin insecticides under field conditions (Rodrigues et al. 2013). The use of pesticides may be minimized by cultivating genetically modified (GM) crops. Stem borer is the destructive pest of maize crop causing significant economic losses to the grower. Various insecticides in foliar, granular, and seed dresser form were tested under field condition. Attack of stem borer was significantly controlled in response to fipronil (granular) and imidacloprid (seeds treatment) application in maize with increased yield of crop (Iqbal et al. 2017a, b). In the same way, attack of sucking pests (whitefly, thrips, and aphids) was minimized by the application of several pesticides. However, efficacy of acetamiprid, confidor, and jazor was significantly better, than other tested chemicals (Nazir et al. 2017).

It has been reported that curative application of chlorothalonil, flutriafol, cyproconazole + trifloxystrobin, epoxiconazole + pyraclostrobin, cyproconazole + picoxystrobin and cyproconazole + azoxystrobin at 4 and 9 days after inoculation checked rust of Asian soybean. However, efficacy of chlorothalonil was found to be the lowest among all other chemicals (Reis et al. 2016). The application of azoxystrobin, flutriafol (1.0 L ha^{-1}), and pyraclostrobin (0.78 L ha^{-1}) reduced disease pressure and resulted in improved growth and development of grain sorghum (Fromme et al. 2017). The spray of trifloxystrobin and prothioconazole completely prevented grain rot of maize (Kluge et al. 2017). Triadimenol treatment completely checked brown rust of sugarcane. The treatment also lowered down the infection of rust from 36% to 16% in susceptible sugarcane variety (Zvoutete 2006). Chickpea and lentil crops majorly suffer from reduced yield due to fungal pathogens such as *Botrytis*, *Ascochyta*, and *Stemphylium*. These diseases were effectively managed with judicious application of fungicides and bactericides. Similarly, oscalid and fluazinam fungicidal treatment controlled sclerotinia blight of peanut (Woodward et al. 2015). Southern corn leaf blight is considered major disease of maize. Application of Ridomil Gold and mancozeb at 40–60 mg L^{-1} inhibited *Helminthosporium maydis*-induced foliar damage of maize (Sudisha et al. 2010).

19.8 Breeding for Resistance

Breeding for insect pest resistance is not as successful as for the development of resistance against diseases in agronomic crops. The major reason is that pest control is relatively easy to achieve by using pesticides. The major traditional methods used to develop insect pest resistance include pedigree method, mass selection, backcross, single seed descent, and recurrent selections. However, modern biotechnological techniques are more effective to create pest or herbivore resistance in agronomic crops. The expression of “Cry” toxin through genetically modified (GM) plants from *Bacillus thuringiensis* is particularly important. The resistant cultivars have been developed through GM for soybean, corn, and cotton (VanDoorn and deVos 2013). Use of molecular markers such as single nucleotide polymorphisms is of particular significance for marker-assisted selection against insect pests of rice, maize, and wheat (VanDoorn and deVos 2013). Similarly, “gene-for-gene” through R-gene-dependent resistance in which a specific chemical compound is secreted by certain insects on the plants that empowers host plants to start a defense-oriented response is also being used. However, these types of resistance are particularly suitable for sucking insect only. This is very important because sucking insects such as aphids and whiteflies spread various viral diseases in agronomic crops (VanDoorn and deVos 2013). Certain plant volatiles also attract insects for egg laying. It has been reported that herbivore-induced plant volatiles (HIPVs) fascinate natural predatory enemies for the laying of eggs at early stages. So, it could be a suitable measure for the biological control of insect pests in agronomic crops. Similarly, reduction of plant palatability through some breeding tools (modern or orthodox) could also be an option to reduce pest attack.

Naturally, plants are persistently threatened by numerous pathogens or pests. However, disease development in response to those interactions is relatively uncommon. Whether crops are suitable to certain pathogens as a host for disease development generally depends upon a number of biochemical and physiological cascades. It has been reported that resistance can be developed into the agronomic crops against various diseases through a suitable breeding program. Development of natural disease resistance holds an excellent potential to provide sustainable broad range of resistance in agronomic crops. Breeding of crops through quantitative trait locus (QTL) is an imperative tool for the incorporation of host plant resistance. For *Rhizoctonia solani*-induced sheath blight disease of rice, a novel chitinase *gene (LOC_Os11g47510)* cloned through QTL mapping contributing sheath blight disease tolerance "Tetep" rice line to *R. solani* was transformed into "Taipei-309," a japonica rice susceptible to sheath blight disease. The developed transformants were resistant to rice sheath blight. Similarly, *pGRMZM2G174449* known as inducible promoter was developed against sheath blight and banded leaf resistance in maize. Certain genome editing techniques are also available to incorporate resistance against diseases causing agents, posing significant economic losses of agronomic crops. The clustered regularly interspaced short palindromic repeat (CRISPR) is another molecular technique that helps genome-targeted amendment to develop crop with suitable traits (including pest or disease resistance) compared to traditional breeding. Similarly, technology of CRISPR/Cas9 is very advantageous to develop broad-spectrum and durable resistance against viral diseases. In the same way, RNAi (RNA interference) is a promising tool to generate the plants which can protect themselves against viruses, fungi, bacteria, nematodes, herbivorous insects, and parasites.

19.9 Conclusion and Future Prospects

Different pest and diseases of agronomic crops can be effectively controlled. However, the degree of control generally depends upon the used control measure. Several cultural control measures such as cover crops, intercropping, trap crops, tillage practices, and planting time can reduce population of pests or disease severity but are not as effective as chemical applications at commercial scale under field conditions. Similarly, applicability of biocontrol agents, PGPR, and plant extracts is also not commercially viable under field conditions. However, their efficacy may be synergized by combination of other control methods such as integrated use of the said cultural practices with reduced chemical applications. Future research should be focused on developing pest- and disease-tolerant or even pest- and disease-resistant crop varieties through modern biotechnological tools. Molecular breeding and use of QTL mapping should be further explored to incorporate resistant traits benefiting in reducing pest- or disease-induced crop losses to ensure global food security.

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