Chapter 5

Environmental and Nutritionary Role In Disease Development

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Introduction:

Pathogens in the field come into contact with a number of environmental factors. A favorable environment is necessary for nearly all plants' increased growth, development, and subsequent production. Many biotic and abiotic factors have an impact on the frequency of different disease severity levels and the intensity of plant infections (Garcia, 2016). In a crop disease, the host and the pathogen interact dynamically and have a close relationship with the environment. This contact causes the host to undergo morphological and physiological changes.

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Crop illnesses are more likely to occur as climatic conditions change, and this is the case for 44% of diseases. It happens as a result of a three-way interaction between the virulent virus, the susceptible host, and the favorable climate (Anderson *et al*., 2004). Crop diseases cause about 10% of the world's food output to be lost, endangering the security of the world's food supply (Strange and Scott, 2005).

Individual factors:

Temperature:

Temperature is one of the major factors that influences the beginning and development of many diseases. When temperatures are somewhat higher than when they are for fungal diseases, bacterial infections are more severe, and when temperatures are slightly lower, most fungal diseases are more severe. Temperature, however, becomes more unstable when it deviates from the optimal level. Climate change-induced temperature stress has a direct effect on plant growth and development as well as the severity of disease (Colhoun, 1973). When plants that are susceptible to them are planted in an area, many infections can result in diseases because they can endure a wide variety of environmental fluctuations.

The lowest temperature, at which onions may germinate, 10–12 ° C, is when onion smut caused by *Urocystis cepule* is most prevalent. Temperature also has a direct impact on spore germination, inoculum generation, and hyphal development in plants (Huber and Gillespie, 1992). Temperature affects how sickness symptoms manifest themselves. Symptoms of the Yellow Dwarf Virus (YDV) in barley create significant symptoms at 16°C, although symptoms are hidden at 32°C, aster yellows on barley, for example, are visible and noticeable at 32°C at 16°C (Gill and Westdal, 1966). The interplay between the pathogen, vector, and host plant in a tripartite system has a significant effect on disease progression, especially for viruses (Whitfield *et al*., 2015).

Pentalonia nigronervosa, the aphid that disseminates the virus that causes banana bunchy tops, can grow more rapidly at 25°C, which is a temperature that is conducive to bunchy top growth. *Fusarium nivale* mostly causes pre-emergence and post-emergence deaths of cereal crop seedlings in low temperatures, but high temperatures result in a large number of seedlings bearing leis and little pre-emergence death (Millar and Colhoun, 1969). Certain host species grow more susceptible to illnesses as temperatures increase above the point at which other species can contract the virus. For instance, cherries grow galls at 37°C for 4 days after inoculation, whereas Agrobacterium tumefaciens does not on herbaceous hosts at 31°C (Deep and Hussin, 1965). (Tables 1 and 2).

Moisture:

The bulk of plant diseases are more likely to occur in environments where the soil often lacks water. Certain plant diseases, however, are more severe in wet soils than they are in dry soils, and vice versa. For instance, cabbage club root (*Plasmodiophora brassicae*) (which is more dangerous in moist environments). Dry soil can exacerbate the severity of several diseases, such as *Streptomyces* scabies in potatoes, *Uromyces agropyrion* in wheat, *Fusarium* in cereals, *Pyricularia oryzae* in rice, and *Sclerotium* in onions. In moist soil at intermediate levels, some pathogens engage in active behavior. For example, pea foot rot may result from moderate soil moisture (caused by *Fusarium solani*). Due to poor chlamydospore germination in dry soil and poor germination growth in wet soil, this is the case (Cook and Flentje, 1967).

The host becomes vulnerable because of increased water stress, decreased photosynthesis (which restricts the production of phytoalexins), and a decline in plant growth without a corresponding decline in pathogen multiplication [Boyer, 1995]. Pathogens then attack and spread within the host plant. The temperature and moisture of the soil have an impact on how serious plant diseases are. In opposed to the majority of above ground diseases (leaf rust, powdery mildew, leaf spots, etc.), some fungal pathogens, like *Phytophthora infestans*, *Pythium debaryanum*, and downy mildew fungi, are less evident at lower moisture contents [Agrios, 2005]. For illnesses that reside in soil, soil moisture becomes more crucial than air humidity. According to Islam and Toyota (2004), low soil moisture content lessens tomato *Ralstonia solanacearum* infection.

Humidity:

According to Damiri (2011), humidity changes the spore germination and dispersion processes, which accelerates the disease's progression. When it rains and is humid outside, the diseases enter aerial plant tissues. High atmospheric humidity (>85%) encourages the spread of diseases and infections. The majority of fungal infections depend on leaf wetness, or how long a leaf has water on its surface, for the development of disease. For example, *Pyricularia oryzae* for rice blast and *Puccinia striformis* for striped rust of wheat both require at least 5 hours for a disease to thrive and infect (Magarey *et al*., 2005). High humidity can sometimes impair a product's marketability but not necessarily the production of crops. The amount of mycotoxins produced by *Fusarium graminearum*, especially deoxynivalenol, in wheat when there is a lot of humidity reduces the possibility that the grains will be sold (Beyer *et al*., 2005). High atmospheric humidity affects an apple's vulnerability to invasion by *Botrytis cinerea* and *Penicillium expansum* during development by modifying the lenticels (Colhoun, 1962). Humidity commonly interacts with temperature, light, and moisture in ascomycetes to release ascospores.

Table 5.1: Optimum temperature for disease development of different crops

S.N.	**Crop Disease**	**Pathogen Optimum**	**temperature (°C)**
1.	Cyst nematode of potato	*Globodera pallida*	15
2.	Early blight of potato	*Alternaria solani*	28-30
3.	Late blight of potato	*Phytophthora infestans*	12-20
4.	Bacterial leaf blight of rice	*Xanthomonas oryzae*	27
5.	False smut of rice	*Ustilaginoidea virens*	20
6.	Papaya ring spot	*Papaya Ring Spot Virus (PRSV)*	26-31
7.	Black rust of wheat	*Puccinia graminis*	25-30
8.	Stripped rust of wheat	*Puccinia striformis*	18-30

9.	Loose smut of wheat	*Ustilago nuda var, tritici*	16-22
10.	Bunchy top of banana	*Banana Bunchy Top Virus (BBTV)*	25
11.	Brown spot of rice	*Helminthosporium oryzae*	28-30
12.	Sheath blight of rice	*Rhizoctonia solani*	28-32
13.	Damping off	*Pythium, Phytophthora, Rhizoctonia, Fusarium, Sclerotia*	< 24
14.	Club root of cabbage	*Plasmodiophora brassicae*	18-25
15.	Leaf spot of cole crops	*Alternaria brassicicola*	28
16.	Downy mildew of cole crops	*Peronospora parasitica*	12-27
17.	Downy mildew/crazy top of maize	*Peronosclerospora sorghiis*	21-33

Table 5.2: Effects of elevated temperature on host pathogen interaction.

Disease and host	Pathogen	Change in temperature	Change in severity
Late blight of potato	*Phytophthora infestans*	Elevated temperature	Increase
Anthracnose of citrus	*Colletotrichum acutatum*	Elevated temperature	Increase
Bunt of wheat	*Tilletia controversa*	Elevated temperature	Increase
Striped rust of wheat	*Puccinia striiformis*	Higher temperature	Increase
Root knot of coffee	*Meloidogyne incognita*	Elevated temperature	Increase

Light and photoperiod:

Light is the most important environmental factor for circadian regulation, claim (Dunlap *et al*., 2004). Several studies have shown that certain oomycetes and other fungi immediately respond to light by producing spores, and that the fungal pathogen's virulence is closely tied to its circadian rhythm. Continuous light revealed the juvenile sporangia of *Plasmopara viticola*, the organism that causes downy mildew on grapevines, and these sporangia had no effect on the development of the mycelium or the production of sporangia (Rumbolz *et al*., 2002). In *Phytophthora infestans*, light regulates both sexual and asexual spore formation. The spontaneous germination of *Uromyces phaseoli* uredospores can occur in either light or darkness (Snow, 1964), but *Puccinia gramini* uredospores prefer darkness (Burrage, 1970). *Puccinia graminis* prefers low light levels to cause rust disease, whereas *Septoria tritici* on wheat prefers high light levels (8000 lux). *P. graminis*, however, demonstrated less success in nighttime stomatal penetration of wheat leaves. *P. striiformis* is not harmful to barley plants with photoperiods longer than 12 hours, while the disease is more harmful to plants with shorter photoperiods (Bever, 1934). Low light intensity and a brief photoperiod favour tomato *Fusarium* wilt (Foster and Walker, 1947). The duration of the day and the amount of light exposure both before and after the inoculation of the inoculum, affect how severe the disease develops.

Soil pH:

The pH of the soil is a key component that controls the severity of plant disease caused by pathogens in the soil. The common crucifer club root can be managed by liming in acidic soil. *Plasmodiophora brassicae* spores can survive and do not germinate in alkaline soil. Soil pH is crucial for the successful growth of illnesses along with the previously mentioned factors. At pH 5.2, *Streptomyces scabies* is more apparent, but at pH 8.5, the severity of scab lesions lessens (Lawrence *et al.*, 1990). *Fusarium* wilt of flax is virtually eliminated at neutral soil pH, or 7. Disease incidence is higher (Agrios, 2005), despite the fact that pathogens grow in their optimal pH conditions. Acidic soil is more typical of club root of cabbage than alkaline soil. An alkaline soil must have a high crop load (105–107 spores/gram of soil), a high moisture content (70%) and a high temperature (23°C) for disease to exist (Colhoun, 1953).

In response to particular soil-borne diseases, a number of saprophytic organisms live in soil display hostile behaviour. The availability of soil nutrients, plant vigour, and growth can all be impacted by soil reactivity, which alters the microclimate inside a crop and unintentionally affects the emergence of disease and infection (Colhoun, 1973).

Soil nutrients:

A disease's susceptibility to potassium, phosphorus, and nitrogen can occasionally be increased or decreased. Via altering the soil environment, nutrients' effects on disease development can be influenced by the pathogen, the host's rate of growth, the plant's vigour, the effects on cell walls and tissue, and more. The vulnerability of plant roots to the pathogen changes as plant nutrients change. The *Chrysanthemum* root rot in this case was brought on by *Phoma chrysanthemicola*. According to Peerally and Colhoun (1969), high quantities of phosphate and nitrogen can prevent this root rot. Microelements also have an impact on disease development, while being less significant than main elements. Deficiency disorders include the following: Whiptail of cauliflower and internal browning of tomatoes are caused by a Mo deficiency; khaira disease of rice and marsh spot of peas are caused by a Mn deficiency; blossom end rot of cauliflower and internal browning of tomatoes are caused by a Ca deficiency. Small aspects enable pathogens be somewhat ineffectual on host plants. Potatoes are reportedly resistant to *Alternaria solani* and *Phytophthora infestans* in environments with high levels of nickel and cobalt (Isaeva, 1969).

Influence of Plant Nutrition on the Development of Disease:

A man-made ecosystem is agriculture. Any kind of plant productivity losses in this system depend on how the plants interact with the various biotic and abiotic elements that make up the ecological niche. One of the main things that leads to significant output losses is plant disease. Plan illness is a dynamic condition that develops because of the interaction between the host and the pathogen during a period of time when the environment is conducive to the beginning and spread of the disease. Disease development is influenced by the host factors such as genetic make-up, age, nutritional state, and population composition (Huber and Graham, 1999). In general, host nutrition denotes an organism's nutritional state. The state of a plant's nutrients determines how healthy it is. The rate of plant growth and the degree to which they are prepared to fend off pathogenic attack are both influenced by nutrients. The soil, which is replenished by organic matter and minerals, provides nutrients to host plants. For plants to develop and thrive properly, they need a diet that is balanced. The agro-ecosystem incorporates both inorganic and organic fertilizer has to feed the plants with sustenance. When compared to young, aggressively growing plants, foliar infections like *Alternaria* spp. and *Helminthosporium* spp. severely harm old, senescent plants. Poor nutritional state results in slower developing plants, which are more vulnerable to attack by weak parasites. Conversely, good nutritional condition results in development of young, succulent growth, longer vegetative period, and delayed maturation.

Nutrients that plants need:

Macronutrients: The primary elements that plants need in high concentrations (g/kg dry matter) are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, and Sulphur.

Micronutrients: They are needed in very small amounts (500 mg/kg dry matter), and include iron, zinc, manganese, copper, boron, molybdenum, and silicon among others.

Table 5.3: Role of various elements in the plants:

Macronutrients	**Physiological function**
Nitrogen	Constituent of proteins, amino acids, enzymes, hormones, chlorophyll
Phosphorus	Constituent of phospholipids, nucleic acids, ATP
Potassium	Catalyst in nitrate reduction photosynthesis and cambium activity
Calcium	Constituent of middle lamella, activator of enzymes
Magnesium	Part of chlorophyll, structural integrity of cell components
Sulphur	Component of amino acids
Silicon	Cell wall component
Micronutrients	
Boron	Increase mobility of sugars ,essential for cell division, protein synthesis
Iron	Constituent of cytochrome, haemetin enzymes
Zinc	Constituent of enzymes, DNA polymerase
Copper	Constituent of Plastocyanin, oxidation reduction reactions
Molybdenum	Essential for nitrogen fixation process

These components are included in a variety of fertilizer’s and organic materials that are added to the soil. They affect the plant's growth, but as green plants are known to host numerous microbial parasites and pathogens, the plant's nutrient status directly affects these microbes.

Factors affecting the severity of a disease

1. The kind and quantity of fertilizer's have a deterministic impact on the emergence of plant diseases.
2. The impact of organic additions.
3. Mineral concentration in sensitive and resistant cultivars.
4. Correlating factors affecting the availability of minerals.

What impact do nutrients have on a plant's defense?

Via the metabolism and growth of the host, plant nutrition affects the development of the disease. A plant's nutritional state has an impact on disease development by either enabling disease escape or by improving the plant's physiological resistance. By compensation, it increases the plant tissues' tolerance to disease or pathogenic damage.

Many potash and phosphate fertilizer's are known to lessen the severity of illness by increasing host resistance or speeding up the maturity of crop plants, which in turn lessens pathogen virulence.

Use of fertilizer's has an impact on the development of plant infections and diseases

1. Higher nitrogen applications not only promote vigorous plant growth but also render plants more vulnerable to diseases like powdery mildew and rust fungus. Low nitrogen fertility, on the other hand, promotes infection by diseases such *Alternaria*, *Fusarium*, *Pseudomonas*, *Sclerotium*, and *Pythium* by stressing out plant growth and speeding up senescence. The development of diseases is also influenced by the kind of nitrogen fertilisers employed (nitrate or ammonium). Use of ammonium fertilisers makes diseases brought on by *Fusarium* spp.,

Plasmodiophora brassicae, and *Sclerotium rolfsii* more severe. According to reports, *Gaumenomyces graminis*, *Phymatotrichum*, and *Streptomyces scabies* prefer the nitrate nitrogen for infection. The different nitrogen forms may have an impact on microbial activity and soil pH, which in turn may affect disease/pathogens.

2. It is known that fertilisers high in phosphorus and potash might hasten plant maturation or increase host resistance, hence reducing the severity of disease. Avoid getting infected by a virus that favours younger tissue. While it worsens *Cucumber Mosaic Virus* on spinach and wheat glume blotch, phosphorus lessens the severity of take "all illness" of barley and potato scab.

3. Potassium changes how susceptible potatoes and cabbage are to scab and club root, respectively. While kernel weight and grain yield were negatively connected, *Septoria* glume blotch severity was positively correlated with phosphorus rate. Potassium intake was increased, which mitigated the negative effects of applied phosphorus. Potassium lessens the severity of rice blast and Root knot, but increases the severity of tomato early blight, tomato stalk rot, and wheat stem rust.

4. Application of calcium fertilizer's lowers root and stem disease brought on by *Rhizoctonia*, *Sclerotium*, *Botrytis*, *Fusarium*, *Erwinia*, and other pathogens by hardening the plant cell wall and making it impermeable to pathogens. Its excessive use increases potato common scab and tobacco back sink.

5. As long as Ca levels are adequate, magnesium may lessen sensitivity to infections that created macerating enzymes (Csinos and Bell, 1989). The use of magnesium fertilizer's reduces potato late blight and apple scab.

6. The Shikimate pathway must be activated in order for there to be a sufficient supply of certain micronutrients, such as manganese (Mn), which results in active

defensive mechanisms against various infections. Mn is necessary for the function of glycoproteins (lectin) that are linked to sweet potato resistance to *Ceratocystis fimbriota* (black rot) and potato resistance to *Phytophthora infestans* (late blight) (Garas and Kuc, 1981; Singh *et al.*, 2022).

7. Silicon strengthens cell walls and acts as a physical barrier to prevent *Pyricularia grisea* (rice blast) and *Erysiphe* spp. from penetrating those (mildews).

8. Fertilizers containing iron, which are known to lessen tree and mango *Verticillium* wilt.

9. Rice blast disease, brown spot, and cucumber powdery mildew are reduced by applying silicon to the soil or as a foliar spray.

When certain essential nutrients are lacking, the introduction of micronutrients may make up for it, changing the host's reaction.

Table 5.4: Effect of nutrient deficiency on the plant

Element	**Deficiency symptoms**
Nitrogen	Pale-yellow chlorosis near the tip of leaf blade advances towards base in V shape pattern. Plants generally stunted less flowers with shriveled grains. e.g. Yellow berry of Wheat - Characterized by hard or flinty grains, partially or entirely starchy
Phosphorus	Plant develop poor root system, stunted, older leaves develop dark blue green coloration from tip backward. Spindly growth, reddish internodes and formation of anthocyanin. Purple coloring on underside of leaves. Reduced flower, seed and fruit

	production. Susceptible to cold injury. Poor quality fruit and seeds.
Potassium	Chlorosis from leaf margin, scorching and browning of tips and margins of Potato, wheat, oat, barley and maize. eg. Potash hunger of Potato; characterized by change in color during July from normal green to bronze, wilting and drooping of leaflets, premature death.
Calcium	Younger leaves retarded, short, distorted and torn. In cereals, upper internodes become very small, rosette leaves, Weak stems and limited root development. e.g.- Blossom end rot of Tomato, Apple bitter pit.
Magnesium	Interveinal chlorosis, development of purple lesion within chlorotic tissue. e.g. Sand drown of Tobacco-Characterized by chlorosis on tips, advances towards base, reduces growth and commercial value.
Iron	Pale yellow interveinal chlorosis on younger leaves, brown lesion or pale red streaks in sorghum and maize
Zinc	In second or third fully mature young leaves, white yellow chlorosis between green mid vein and margins. Rosette appearance, stunted plant growth. e.g.- White bud in maize and sorghum, khaira disease of rice

Effects of overeating:

There is an optimal concentration of foodstuff needed for each crop. Excess fertilizer application causes the plants to grow more vegetative, have deeper green than usual, become more succulent, and have their reproductive processes stifled. Structures become deformed because of the excessive accumulation of plastic materials. For instance, abnormal proliferation, pistillody, and phyllody (Rose kings).

By promoting vegetative growth, excessive nitrogen application delays maturity, weakens the straw, lodges the grains, degrades quality, and reduces resistance. An excessive amount of phosphorus causes soluble salt to grow, which can dry up roots by removing water from them. Consequently, for plants to grow properly, a balanced dose of organic or inorganic fertilizer's is required.

A plant's nutritional state affects whether it is resistant to a disease or susceptible to it. The dynamic interaction between a plant's nutritional status and plant pathogens, the environment, and other organisms in the environment means that nutrient management may always affect how severe most diseases are. Understanding the connection between plant nutrition and disease development will be crucial in determining the future of disease management in agricultural production systems, both intensive and integrated.

Interaction of multiple environmental factors:

A number of factors influences the development of disease, even though the impacts of each individual ingredient are given top importance in the research on how those elements interact to generate crop disorders. Turnip growth can be significantly slowed down when *Turnip Mosaic Virus* (TuMV) infection, heat, and drought all coexist (Prasch and Sonnewald, 2013). When high levels of humidity and warm temperatures are present at the same time, the majority of fungal pathogens can result in serious illnesses (Clarkson *et al*., 2014). When the circumstances of acidic soil, 70-80% soil moisture, and 18-25°C soil temperature are present, *Plasmodiophora brassicae* generates more club roots in cabbage. *Botrytis cineria* creates prominent grey-brown lesions on grapes at a temperature of 20–25 °C and a relative humidity of 100 %; infection levels drop when environmental conditions are less favourable (Ciliberti *et al*., 2015).

Table 5.5: Effects of elevated CO_2 concentration on interaction between host and pathogen

Disease and host	**Pathogen**	**Climate change**	**Change in severity**
Stripe rust of wheat	*Puccinia striiformis*	ElevatedCO_2	Decrease
Crown rot of wheat	*Fusarium pseudograminearum*	ElevatedCO_2	Increase
Smut of barley	*Ustilago hordei*	ElevatedCO_2	Increase
Powdery mildew of barley	*Blumeria graminis*	ElevatedCO_2	Decrease
Barley yellow dwarf	*Yellow Dwarf Virus*	ElevatedCO_2	Decrease

Several experts have highlighted the significance of the interactions between various environmental factors and disease, although more research that is extensive would be helpful for many disorders. During the study of late-onset potato blight brought on by *Phytophthora infestans*, the minimum, ideal, and maximum temperatures, the duration of leaf wetness, and the concentration of inoculum were all reliant on the other two factors, occasionally on one and commonly on a balance of both.

Environmental affects PAMP-triggered immunity (PTI)

PTI, or pathogen-associated molecular pattern-triggered immunity, tries to halt the spread of bacteria that are not harmful. Virulent bacteria infect plants by causing the apoplast of leaves to become wet (Xin *et al*., 2016). Since they produce PAMP-triggered immunity, non-pathogenic bacteria like *Pseudomonas* flourish in humid settings. Bean, *Arabidopsis*, and tobacco plants are just a few examples of the plants that serve as hosts for these PTI-causing bacteria [Sharma and Verma, 2019]. Pattern recognition receptors found in plant plasma membranes recognise conserved chemicals from bacteria or pathogens (PAMP or MAMP) using the PTI method (PRR). PTI activation enables the stomata to close more quickly when MAMP is recognised by stomatal guard cells, demonstrating the existence of a plant defence mechanism against microorganisms in the leaf apoplast (Panchal and Melotto, 2017). High ambient humidity inhibits PTI-induced stomatal closure in bean and *Arabidopsis* plants. Similar to how it can influence PTI signals, temperature can do so both shortly and permanently (Reddy *et al*., 2019).

Environmental impacts on Effector-Triggered Immunity (ETI):

A pathogen defense method called effector-triggered immunity (ETI) manages genetic resistance. Two examples of plant resistance(R) proteins that are employed to locate the virulent pathogen inside the plant host are the leucine rich repeat (LRR) and the nucleotide-binding domain (Jones *et al*., 2016). The hypersensitive (HR) response, a type of programmed cell death, is similar to this identification. ETI is constantly activated and causes cell death because of rising temperature.

Preventing disease:

The environmental factors mentioned above have an impact on illness management strategies. The amount of fungicide left behind in foliage is influenced by changes in temperature, precipitation, and light, which can also alter how rapidly some treatments break down. Agricultural cultivars acquired through both GE and traditional methods may experience physiological and chemical changes that alter the resistance mechanisms (Raquel, 2005). Biological disease control systems do not typically result from environmental factors. It is possible to make soil bacteria inert by changing the temperature, moisture content, and nitrogen concentration of the soil. Diseases in soils with an acidic pH can be treated with lime, whereas diseases in soils with an alkaline pH can be treated with gypsum. Many physiological alterations may increase a person's resistance to a variety of diseases. Regulations for the prevention, management, and eradication of agricultural diseases are being put into place in a number of countries. Phytosanitary regulations are put in place to get rid of and stop illnesses that harm plants. Systems of quarantine, which control the spread of diseases from a contaminated area to a new one, directly restrict and delay the introduction of pathogens.

Conclusion:

In order to lessen crop illnesses, it is vital to assess present management strategies and create alternatives to deal with the issues brought on by environmental change. Current host-pathogen interactions suggest that relevant research on the influences of the environment on agricultural diseases should be done. Qualitative and quantitative assessments of diseases are needed to ascertain the prevalence and spread of infections and their effects on crops. Making policy decisions and working with national and international organisations are crucial for reducing the threat that illnesses represent.

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