Environmental Monitoring by Plant Indicators

(NOTES)

Plants can be effectively used as cheap and naturally-occurring monitoring systems or bioindicators of air, soil and water pollution in an area. Bioindicators are the organisms, which in their presence or absence and in all features of their phenotype or physiology, serve as an index of the environmental status. Both positive and negative aspects of the environment can be monitored through bioindicators. A bioindicator provides quantitative information on the quality of the environment without examining the exact physical or chemical process responsible for the environmental toxicity. A good plant indicator not only indicates the presence of the pollutant in the environment but also it provides information about the amount and intensity of the pollutant-exposure to plants.

Plants, as bioindicators (plant indicators), are used to determine:

1. How various conditions in an environment have changed over time
2. The health of an environment or ecosystem
3. The cumulative effects of different pollutants in the ecosystem
4. How long the pollutant(s) may have been present in the environment

Realizing the need of biological monitoring of the environment, the International Union of Biological Sciences (IUBS) decided in its 21st general assembly meeting held in Ottawa (1982) to initiate worldwide programme for identifying and applying the biological indicators in environmental monitoring, particularly to evaluate the effect of hazardous substances on ecosystems.

The IUBS programme divided the biological systems to be used for environmental monitoring into the following six groups:

<table>
<thead>
<tr>
<th>1. MICROBIOLOGY</th>
<th>5. CELL BIOLOGY AND GENETICS</th>
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<tbody>
<tr>
<td>2. BOTANY</td>
<td>6. COMPARATIVE PHYSIOLOGY AND ECOLOGY</td>
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<td>3. ZOOLOGY</td>
<td>7. HYDROBIOLOGY</td>
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Characteristics of a **good plant indicator** for *environmental monitoring* are given below:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Characteristics</th>
<th>Criteria</th>
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<tbody>
<tr>
<td>(I)</td>
<td>GOOD INDICATOR ABILITY</td>
<td>(1) It should provide <em>measurable response</em>, i.e.</td>
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<td></td>
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<td>➤ It should be <strong>sensitive</strong> to the environmental stress or disturbance but should not experience the mortality.</td>
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<td></td>
<td></td>
<td>➤ It should accumulate pollutants directly from the environment.</td>
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<td>(2) Its response should reflect the response of whole population/community/ecosystem.</td>
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<td></td>
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<td>(3) It should respond in proportion to the <strong>degree of contamination</strong> or degradation.</td>
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<td>(II)</td>
<td>ABUNDANT AND COMMON</td>
<td>(1) It should have <strong>adequate</strong> local population density.</td>
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<td></td>
<td>(2) It should be <strong>relatively stable</strong> despite moderate climatic and environmental changes.</td>
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<td>(III)</td>
<td>WELL STUDIED</td>
<td>(1) Its <strong>ecology</strong> and <strong>life history</strong> should be well understood.</td>
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<td></td>
<td></td>
<td>(2) It should be taxonomically <strong>well documented</strong> and stable.</td>
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<td></td>
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<td>(3) It should be easy to handle and cheap to survey.</td>
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<td>(IV)</td>
<td>ECONOMICALLY/COMMERCIALY IMPORTANT</td>
<td>(1) The species already being harvested for other purposes.</td>
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<td></td>
<td></td>
<td>(2) There should be <strong>public interest</strong> regarding the awareness of the species.</td>
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The type and concentration of a pollutant can be reliably set up by various characteristic damage symptoms produced in the plants; such damage symptoms are pollutant-specific as well as concentration-specific.

For example, changes in **young needles** of *Pinus* indicate the **atmospheric pollution** as given below:

1. **Chlorosis** indicates **SO₂** pollution
2. **Necrosis** indicates **HF** pollution
3. **Bleaching** indicates **NO₂** pollution
4. **Chlorotic mottling** indicates **Cl₂** pollution in the atmosphere.
These characteristic **symptoms of damage** in young **pine needles** appear only when the concentration of the concerned pollutant is as follows:

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Concentration</th>
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<tbody>
<tr>
<td>SO₂</td>
<td>0.3 ppm</td>
</tr>
<tr>
<td>HF</td>
<td>0.07 ppm</td>
</tr>
<tr>
<td>Cl₂</td>
<td>0.0 ppm</td>
</tr>
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</table>

*Certain precautions need to be taken while using plants as pollution indicators.* Such as:

1. **Damage symptoms** in plants should preferably be studied in the **local** or **native** species. **Cultivated** and **introduced** species should be **avoided**.

2. The species, **sensitive** to pollutants, should be first identified in the **local flora** and then used for **pollution monitoring**. **Tolerant** species should be **avoided** in such work.

3. **Damage symptoms** due to a particular **pollutant** should be studied in **different** species **sensitive** to that pollutant so that presence of the pollutant in the area may be cross-checked. For example, **grey necrosis** in *Geranium*, **ivory necrosis** in *Zinnia*, **brown necrosis** in *Chrysanthemum* and **reddish necrosis** in *Azalea* indicates the undoubted presence of SO₂ pollution in the area.

4. Many types of **damage symptoms**, (**viz.** morphological, anatomical, ultra-structural, physiological, biochemical, etc.) should be studied in **one or more sensitive** plant species to ascertain the presence of a particular pollutant in the area.

5. **Samples** should be taken from as many **different** sites in the area as possible.
6. The possibility of damage symptoms in plants, occurring due to some cause other than pollution, (e.g. due to pathogen, environmental condition or nutritional deficiency / excess) should be thoroughly checked and ruled out.

Important characteristics of plant species used in pollution monitoring

The plant species used to monitor pollution in an area should have certain important features, such features:

1. The species should be easy to identify in the field and easy to handle for damage analysis.

2. The species should have a wide range of distribution so that it can be used in different areas.

3. The species should be sensitive to many types of pollutants so that it can be used to monitor different types of pollutants in the area.

4. The species should produce highly specific damage symptoms in response to particular types and concentrations of pollutants.

Pollution parameters regarding plant indicators/monitors

For monitoring the environment, changes in the species composition of vegetation and distribution pattern of populations in the area are studied. Such studies indicate the type and concentration of pollutant(s) concerned as well as the spread of pollution problem in the area. Following may be the pollution parameters for plant indicators:

1. Decrease in the densities of sensitive species and increase in the density of tolerant species.

2. Absence of highly sensitive species

Changes in microbial systems

Microbes are rapid detectors of environmental pollution both in water and soil. Microbes, sensitive to some pollutant get eliminated, while those tolerant to that
particular pollutant *flourish* well. Thus, *elimination* or *abundance* of certain microbe species can indicate the *environmental change*. Thus, *alteration* in microbial communities and *reduction* in species diversity of microbes may be the result of the presence of specific *toxic agents*.

1. **Microbial muds** from *continental* and *intercontinental water bodies* serve as an *ideal pool* for detecting several compounds, including sulphur.

2. Likewise, *petroleum belts* and *sediments* are used to detect *polar lipids* of *Archaebacteria*.

3. *Salmonella typhimurium*, other Bacteria and Fungi (e.g. *Neurospora* and *Aspergillus*) provide excellent device for monitoring the *genetic effects* of physical and chemical agents.

4. Bacteria, like *Escherichia coli* and the bacterial species of *Vibrio, Aeromonas, Pseudomonas, Clostridium*, and *Streptococcus* are used in *assessment* and prediction of changes in marine environment induced by human activities.

5. Cyanobacteria (blue-green Algae) are used as bioindicators of *soil pesticides*. For example: *Nostoc microscopicum* and *Hapalosiphon welwitschii* indicate pollution by pesticides (e.g. the following pesticides: Dithane, Deltan, Aldrex, BHC, Rogor, Phorate, etc.).

6. Various *Algae* are excellent monitors of *water pollution*. For example:
   
   (a) *Ulva* and *Enteromorpha* are used to monitor the *water quality* of estuaries.

   (b) *Cladophora* (*heavy-metal sensitive* alga) and *Stigeoclonium* (*heavy-metal tolerant* alga) get totally perished and flourish, respectively, in polluted environments, thus indicating the *heavy-metal toxicity* in the environment.

   (c) *Chlorella* alga is used to monitor toxic substances in *water bodies*.

7. Some *filamentous* Fungi, Yeasts, Actenomycetes and Bacteria (e.g. the species of *Scolecobasidium, Mortierella, Humicola* and *Verticillium*) are used to monitor oil-spillage pollution because these plants are able to utilize
waste-oil fractions. Algae, like *Dunaliella tertiolecta*, *Skeletonema costatum*, *Criophora carterae*, *Amphidinium cartareae*, *Cyclotella cryptica*, *Pavlova luteri*, etc. are able to use oil fractions. Thus, their presence in water bodies indicates oil-spillage pollution.

**Changes in aquatic plants in freshwater bodies**

1. Decrease in plankton algae and aquatic hydrophytes and spread of *Sphagnum* moss indicate the increased water acidity.

2. Specific changes in the aquatic flora can specify that the pH of the water quite correctly.

3. Eutrophication and water blooms indicate sewage, organic matter and chemical fertilizer pollution of water.

4. Abundance of *Eichhornia* indicates the sewage and heavy metal pollution of water.

5. Increase in *Escherichia coli* and aerobic decomposer bacteria indicate water pollution due to organic sewage.

**Changes in terrestrial plants**

Decrease in the populations of mosses (*Sphagnum*, *Bryum*) and lichens (*Parmelia*) generally indicates the air pollution by SO$_2$, NO$_2$, fluorides and HCl. Poikilohydrous mosses are particularly useful as pollution indicators.

1. Absence of most bryophytes, particularly *Sphagnum* and *Bryum* indicates the atmospheric SO$_2$ pollution of 0.17 ppm concentration or more.

2. Changes in sensitive species of herbs (*Bryum dyffrynense*) and grasses occur much earlier than in shrub and tree populations.

3. Generally, the degree of ‘Crown die-back’ and death of trees is directly related to high level of SO$_2$, NO$_2$, HF and HCl pollution of air.
4. Changes in populations of soil microorganism indicate soil pollution.

5. Increase in ammonifying bacteria shows NH₄ pollution

6. Reduction in nitrate and nitrite bacteria shows NO₃ pollution

7. Decrease in the populations of decomposer bacterial indicates soil acidification and pesticide pollution.

8. Epiphytic lichens and mosses are used to monitor air pollution, because they accumulate heavy metals present in the air.

Changes in physiological and yield parameters

The rates of growth, photosynthesis, respiration, enzyme activities, percentage flowering, yield of fruits and seeds, and percentage of seedling mortality in sensitive species are important characteristics that are very helpful in determining the type and level of pollution in an area because these show highly characteristic and specific changes even before other morphological or vegetational changes appear. For example: Inhibition of photosynthesis and hang-up of activity of enolases in the leaves indicate fluorine damage to plants. Some such symptoms are given below:

In general, the pollution is indicated by:

1. Increased rate of respiration

2. Decreased rate of photosynthesis

3. Stimulation of the catabolic enzymes activity

4. inhibition in the activities of anabolic enzymes

5. Reduced flowering and seed output and

6. Increased seedling mortality
Visible injury symptoms

Leaves of sensitive species generally produce highly specific and characteristic visible injury symptoms in response to pollutants. For such analysis, leaves of same age are collected at the same time of the day and at different localities in the area from plants of a particular sensitive species.

1. Study of such symptoms can reliably indicate the type and level of pollutant(s) present in the environment.

2. Most common symptoms studied are chlorosis, necrosis, discolouration, tip-burn, bleaching, bronzing, stiples and mottles in the leaves.

3. Characteristic colours and patterns of these symptoms in particular plant species indicate the type and level of pollutant present.

4. Ozone damage is depicted by weathered flakes of tobacco leaves and chlorotic flakes of pine needles.

5. Peroxyacetyl nitrate (PAN) damage is depicted by collapse, glazing (coating) and bronzing (browning) of leaf surfaces.

6. Bleaching of perianth and injury to stamens indicate mercury poisoning to plants.

Histological characters

In some plant species, specific pollutants cause highly characteristic damage to cells and tissues. The careful analysis of the type and degree of such cell/tissue damage in the sections of various plant parts is very useful indicator of pollution problem. For example: fluorides cause highly specific injury in the cells and tissues of pine needles.
Ultra-structural analysis

Pollution can also be monitored by the study of specific injury symptoms in the cell organelles, particularly in chloroplasts, mitochondria and cell membranes. For example:

- SO$_2$ pollution causes membrane damage in the moss *Sphagnum*, chloroplast degradation and membrane damage in the mosses *Grimmia pulvinata* and *Hypnum cupressiforme*.

- Pb pollution is indicated by presence of electron-dense vesicles containing lead in the cells of moss *Rhytidiadelphus squarrosus*.

Chemical analysis

Accumulation of characteristic substances in different plant parts can also indicate the type and level of pollution in the environment. For example:

**S/N ratio**

- Sulphur is accumulated in the pollution of SO$_2$ and H$_2$S, while N content is increased in NOx (nitrogen oxide) and NH$_3$ pollution recorded in the leaves and twigs of sensitive plant species.

- As SO$_2$ and NOx are usually present together as air pollutants, sulphur to nitrogen ratio (S/N ratio) is a very useful indicator of their relative proportion in the atmosphere.

**Amino acid content**

- Increase of amino acids (particularly glutamine and asparagine) in the leaves by a factor of 10 than the normal value shows NH$_3$ pollution

- Increase of amino acids by a factor of 2 indicates NO$_2$ or SO$_2$ pollution in the atmosphere.

**Pigment analysis**

The presence of degradation products of certain pigments and absence of others in the leaves damaged by pollution can also indicate pollution. For example,
Absence of degradation products of carotenes and specific zones of chlorophyll in the chromatograms indicates NO₂ pollution.

Presence of degradation products of carotenes with chlorophyll shows SO₂ pollution.

Bark acidity

Industrial SO₂ emissions cause acidification of rainfalls with sulphuric acid. SO₂ is oxidized and hydrated and then returns to earth in the form of acid rains (sulphurous or sulphuric acid rains). This causes acidification and sulphuration of the environment including various components of the forest ecosystem. Sensitive bioindicators of chemical changes in the forest environment include pH of the tree bark, which persists in the ecosystem for exceptionally long periods. Tree-bark acidity is readily affected by air pollution and can be used as a bioindicator.

Air pollution by SO₂ an HF can usually be related with the level of bark acidity. Deciduous trees usually have lower bark acidity than coniferous trees. Dicotyledonous trees are better for such analysis than coniferous trees but Scots pine has been successfully used for bark-acidity analysis.

Metal accumulation

Many plants can absorb and accumulate different metals from their environment. Analysis of plant tissues for identifying the type and level of accumulated metal is very useful in study of metal-pollution problem in the soil, air and water. For example:

1. Willow, birch and poplar accumulate Zn and Cd.

2. Box-elder accumulates boron and tomato accumulates sulphur from the soil.

3. Peat mosses (particularly Sphagnum acutifolium) accumulate Zn, Cd and Pb
4. Carpet-forming mosses like *Hylocomium splendens*, *Pleurozium schreberi* and *Hypnum cupressiforme* accumulate Hg, Ag, Be and other common metal pollutants.

5. Aquatic mosses like *Fontinalis antipyretica*, and *Eurhynchium riparioides*, Algae like *Cladophora*, and vascular plats like *Eichhornia* and *Azolla* are very useful in identification of water pollution by a variety of heavy metals.

6. Several higher plant species indicate heavy-metal pollution because they can safely accumulate heavy metals, and are, thus, able to tolerate heavy-metal pollution. These plants are not only bioindicators but are also scavengers of various heavy metals as given below.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Plant</th>
<th>Metal tolerance</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Anthoxanthum</td>
<td>ZINC</td>
</tr>
<tr>
<td>2</td>
<td>Agrostis</td>
<td>COPPER</td>
</tr>
<tr>
<td>3</td>
<td>Festuca</td>
<td>LEAD</td>
</tr>
<tr>
<td>4</td>
<td>Impatience</td>
<td>CADMIUM</td>
</tr>
</tbody>
</table>

Carnivorous plants (Example: Round-leaf sundew)

**Round-leaf sundew** (a carnivorous plant) is a nitrogen-pollution indicator. It thrives in low-nitrogen environment and, therefore, supplements its nitrogen nutrition by catching insects.
Thus, this plant helps control the local fly and insect populations in the area. As per a Swedish study, the nitrogen, released by industrial processes into the air, spreads into the atmosphere through rain fall. This increases the amount of soil nitrogen. As a result, the sundew plant gets sufficient nitrogen from the soil; hence, it now avoids supplementing its diet with insects. This often leads to an excess of insect individuals. It not only increases the insect population, but also allows the nitrogen-loving hardier grasses and weeds to grow. The sundew plant has not been evolved to compete with weeds and grasses, so it is wiped out from the particular Swedish countryside, leading to an increase in the population of insects and common grasses.

Liverworts and mosses

Liverworts and mosses have been found to be good indicators of environmental conditions.

1. The occurrence of certain aquatic mosses can be used as an indicator of calcium and other nutrient contents in the water.

2. The suitability of liverworts and mosses as bioindicators is mainly due to their simple thalloid or one-cell thick structure, and lack of cuticle or epidermis, resulting in greater absorption and accumulation of nutrients and pollutants directly from the atmosphere.

3. Some Bryophytes grow only in a narrow and specific pH range and, therefore, their presence can be used as an indicator of soil pH.

4. Mielichhoferia elongata and M. mielichhoferia are known as copper mosses because they grow in copper-rich soil. Such species can be used as indicator plants.

Moss bag technique

This technique has been very useful in identifying atmospheric metal pollution. Flat moss bags (10 cm$^2$) of nylon nets are filled with acid-washed clean Sphagnum acutifolium moss and are suspended on poles or tied to trees at specified heights.
The moss bag absorbs various \textbf{metal pollutants} from the air. After specified time interval, the moss bag is again acid washed. The \textit{types} and \textit{amounts} of metals absorbed by the moss are extracted, which indicate the \textbf{metal-pollution status} of the air. These moss bags can be repeatedly used in such metal monitoring work.

Similarly, living \textbf{aquatic moss} plants wrapped in nylon nets are secured in the water body at specified depths. Analysis of the \textit{accumulated metals} and the level of the \textit{decay of moss plants} are used to identify \textbf{water pollution} by \textit{metals}.

\textbf{Lichens}

The \textbf{lichens} are \textit{symbiotic association} of \textbf{alga} and \textbf{fungus} (\textit{alga} resides in \textit{fungus}: Fungus gives shelter, food and minerals, while alga performs photosynthesis). Lichens have been used as \textbf{bioindicator} for \textbf{air pollution} worldwide. Most lichens can only survive in \textit{unpolluted air} and, thus, prove \textbf{good indicator} of \textbf{air pollution}.

1. Lichen thalli can indicate the presence of \textbf{SO}_2 and \textbf{fluorine} in the atmosphere.

2. Even \textbf{dead} thalli of lichens are capable of absorbing \textbf{fluorine} and \textbf{heavy metals} from the atmosphere.
3. Other air pollutants, NOx, O₃, heavy metals, HF, organic pollutants, also caused disappearance of lichens from the cities of industrial areas.

4. In 1866, lichens disappeared from the coal-burning sites at Jardin de Luxembourg near Paris. SO₂, generated from burning coal, damaged the lichens.

5. Lichens are, as follows, differently sensitivity to air pollution. (1) Fruticose lichens: most sensitive (2) Foliose lichens: less sensitive and (3) Crustose lichens: the most resistant one. Thus, (1) Fruticose lichens are the first group to disappear from polluted areas, while (2) Crustose lichens (e.g. Lecanora conizoides) are the most resistance to air pollution.

Lecanora conizoides

Monitoring of environments by aero-allergents

Aero-allergents include air flora and fauna. In fact, air is the medium of transport of flying animals, germs of infectious diseases, plant and animal parts, fungal spores and the related micro-phyto-planktons such as tracheids, cuticles, algal filaments, insect scales and wings, etc. These aero-allergents cause human allergy and plant pathogenicity. Pollen grains cause bio-pollution. They are omnipresent and, thus are good bioindicators in monitoring the air-born allergies.