Castings: Excrement from earthworms or insects high in plant nutrients.

Soil amendment: Compounds used to build and maintain the physical properties of soil.

Pathogen: A disease-causing organism.

self-harvesting design reduces the labor requirement. **Castings** are the only byproduct requiring removal, but are relatively low in volume and moisture content, making handling easy.

The prepupae require only simple drying and milling to become a high quality feedstuff. The dried feedstuff is a good replacement for soybean or bone meal in rations for swine, chickens, catfish, and tilapia. Prepupae can effectively replace fish meal as a feedstock with a value of up to $500 (US dollars) per ton (Sheppard, 2004). The manure generated from one feeder pig can annually produce 63 kilograms (139 pounds) of prepupae worth more than $12 (US dollars) (Sheppard, 2004). Another prepupae utilization involves the extraction of oleic and linoleic essential fatty acids, which make up over 20 percent of the fat in the prepupae, as well as the extraction of chitin, which has many medical and industrial applications (Sheppard, 2004).

Black soldier fly castings, much like compost, are also a value-added product. They can be used as a **soil amendment** or fertilizer. The larval digestion process reduces **pathogen** levels, making castings a better option than raw manure as a fertilizer for organic vegetable and fruit production. The castings are more valuable and more stable than manure, have fewer odors, and are easier to transport and market.

In summary, the use of black soldier flies as a manure management tool can result in value-added high quality feedstuff and fertilizer, as well as decreased odors and undesirable house fly populations. Black soldier fly utilization requires little additional management, cost, or alteration to existing slatted floor animal housing structures. The decrease of manure volume paired with the transfer of nutrients from manure to insect bodies can reduce potential pollution by 50 to 60 percent or more (Sheppard, 2004).

9.3 VERMICOMPOSTING

Vermicomposting is the use of worms to consume and digest organic matter. Despite its name, vermicomposting is not technically composting—the worms, rather than bacteria, are responsible for decomposing the organic matter. Vermicomposting can successfully treat food and animal wastes and produces a nutrient-rich soil amendment. This is an attractive manure treatment option for semi-solid, solid, or separated manure that is stored seasonally or year-round. Depending on the type of vermicomposting system, this is a technology that requires a relatively small capital investment, but dedicated hands-on management is necessary.

The most common worm used in vermicomposting is the redworm (*Eisenia foetida*), also known as red wigglers or brandling worms. **Figure 9.5** is a photograph of redworms used for vermicomposting. The worms are

Figure 9.5: Vermicomposting worms (New York City Compost Project, 2002).

very sensitive to environmental conditions. The worms require a consistent temperature range between 15 to 20° C (60 to 70°F) to thrive (Appropriate Technology Transfer for Rural Areas, 1999). Cooler temperatures will slow the vermicomposting process and temperatures above 32° C (90°F) may kill the worms (Appropriate Technology Transfer for Rural Areas, 1999). Dangerously high temperatures are easily reached if bacterial decomposition flourishes, as in true composting, a condition that should be avoided in vermicomposting. In order to prevent overheating, manure should be spread in thin layers in warm weather. Thicker layers of manure will keep the worms warm during cold weather. Worms breathe through their skin and must not dry out, so the moisture content has to be carefully monitored and kept between 80 to 90 percent (Appropriate Technology Transfer for Rural Areas, 1999). The pH should be between five and nine for optimal worm health and growth and the soil should be well aerated (Appropriate Technology Transfer for Rural Areas, 1999). Raw slurries are not appropriate for vermicomposting —the slurry must be separated and just the solids fed to the worms. Manures high in ammonia and inorganic salts must be pre-treated because these compounds are toxic to the worms.

To start vermicomposting, bedding material such as shredded paper, wood chips, or other bulky materials is layered with manure. Bulky materials improve **porosity,** keeping the manure **aerobic**. The bedding may also be used to control the moisture content, pH, and temperature. The worms are added, and they eat their way through the bedding and manure. There are four types of vermicomposting systems:

1. Windrow systems,
2. Stacked bins,
3. Batch reactors, and
4. Continuous flow reactors.

Windrows require the smallest amount of capital to begin. However, they are the slowest and most labor-intensive system to operate. Vermicomposting windrows are formed into elongated piles on top of a concrete pad or on the ground. Thin layers of manure and bedding are added at frequent intervals until the windrows reach approximately one meter (three feet) deep (Appropriate Technology Transfer for Rural Areas, 1999). The worms will automatically migrate from the finished vermicompost to the fresh manure so they are always feasting on the top layers of manure and bedding. New windrows may be made directly adjacent to finished vermicompost windrow, inspiring the worms to relocate to the new windrow. The finished vermicompost can then be removed.

Stacked bins or containers require frequent handling and heavy lifting. This system is similar to the stacked bins used to grow mushrooms. Manure is added in the same way as windrow systems. Managing and monitoring the moisture content, temperature, and other conditions inside the bins can be difficult.

Batch reactors are containers that are held off the ground by legs. The reactors are filled with bedding and manure, the worms go to work eating, and then the reactor is completely emptied when the worms are finished. The worms may be screened from the finished vermicompost to be introduced to a new batch of manure and bedding. This "all in, all out" system is a good

Porosity: The degree to which a material is permeated with pores or cavities through which fluids and gases, including air, can move. Porosity is measured by the ratio of the volume of air spaces to the total volume of the material.

Aerobic: An oxygenated environment or requiring an oxygenated environment to survive.

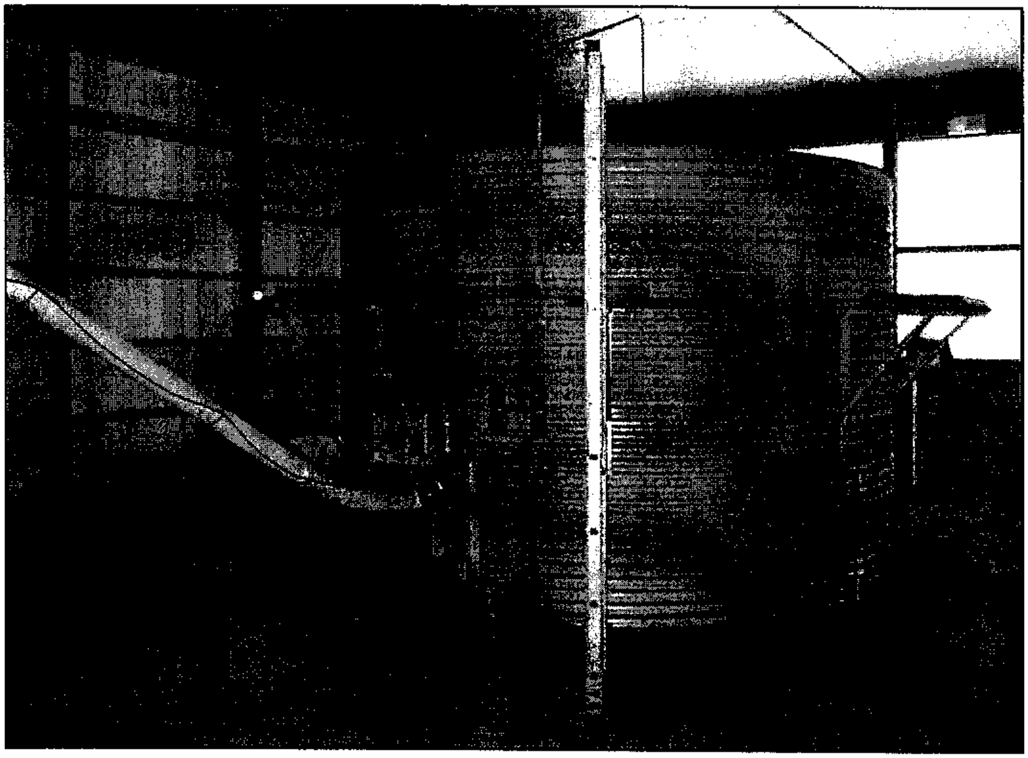

Figure 9.6: Batch reactor (J. Robbins, 2004).

tactic to curtail mite infestations, a potential pest problem. **Figure 9.6** is a photograph of a batch reactor.

Continuous flow reactors are for very intensive vermicomposting systems. They are the most expensive vermicomposting systems. Continuous flow reactors require specialized equipment, worm housing, and skilled management.

Like the black soldier flies, worms produce castings that are nutrient-rich and can be used as a fertilizer or soil amendment. The worms and cocoons are removed from the castings by screening or mechanically separating them. The castings may require additional treatment such as drying or heating prior to use or sale as fertilizer. **Figure 9.7** is a photograph of worm castings.

In addition to the revenue that may be gained from selling the vermicompost, the worms themselves are also a value-added product. About 19.5 kilograms of worms per square meter (four pounds of worms per square foot) can be produced (Appropriate Technology Transfer for Rural Areas, 1999). The worms may be sold as fishing bait,

Figure 9.7: Worm castings (New York City Compost Project, 2002).

processed for supplemental livestock feed for poultry or fish operations, or sold to other vermicomposters. Selling the worms as bait yields a higher market price, but there is a limited market for bait sales.

To summarize, vermicomposting uses worms to digest manure, producing valuable casings which may be sold as a fertilizer or soil amendment. The worms may also be sold as a value-added product. There are four different vermicomposting designs—windrow, stacked bins, batch reactors, and continuous flow reactors.

9.4 Phytoremediation

Phytoremediation is the use of plants to remove pollutants from the environment or to render them harmless. Plant roots form a broad and deep network throughout the soil profile. They take in water, essential nutrients, and other compounds from the soil, including contaminants. The nutrients and contaminants become bound in the plant **biomass.** Phytoremediation is appropriate in situations where there has been a history of nutrient overloading. Phytoremediation can also be used to remediate areas around manure storage facilities. It is an especially attractive treatment technology for farms located near pulp and lumber mills if growing and selling timber for paper production is a treatment objective.

Phytoremediation works through four different mechanisms:

1. Phytoextraction,
2. Hydraulic control,
3. Erosion control, and
4. Phytodegradation.

Phytoextraction is the extraction of contaminants, including nutrients, from soil by plant roots. The contaminants travel from the soil to the leaf and stem biomass by entering the roots and traveling through the **xylem. Figure 9.8** illustrates the

Biomass: The total dry mass of an individual or population.

Xylem: The vascular tissue in plants that transports water and minerals from the roots to the leaves and other parts of the plant.

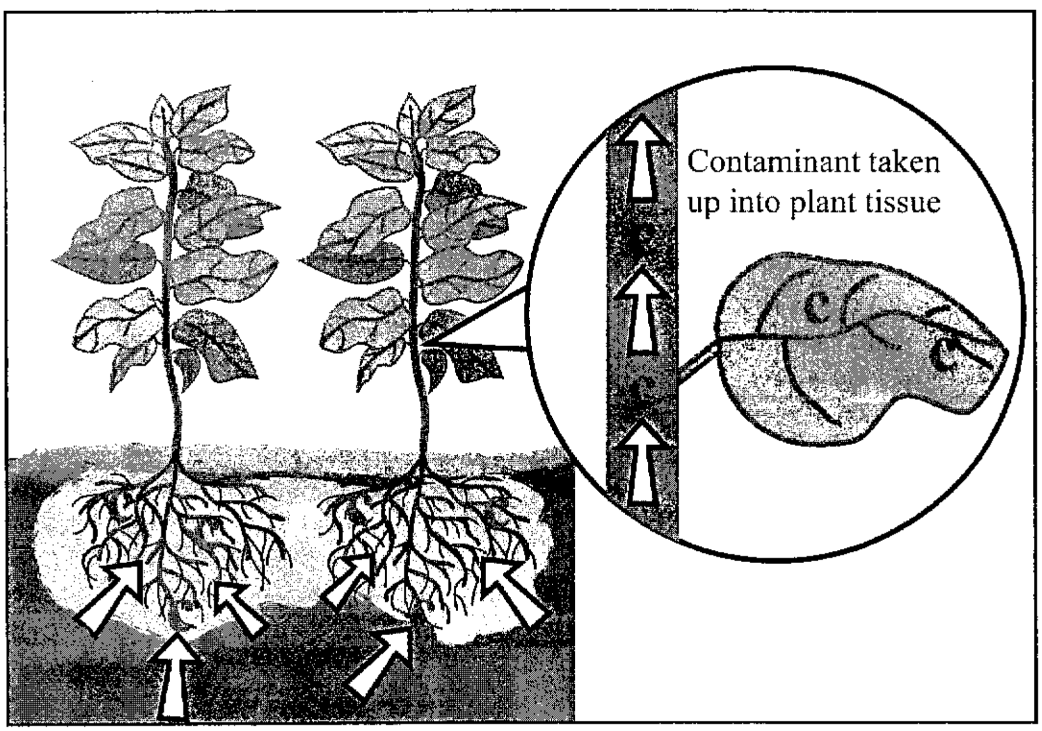

Figure 9.8: Phytoextraction (C. White, 2004).

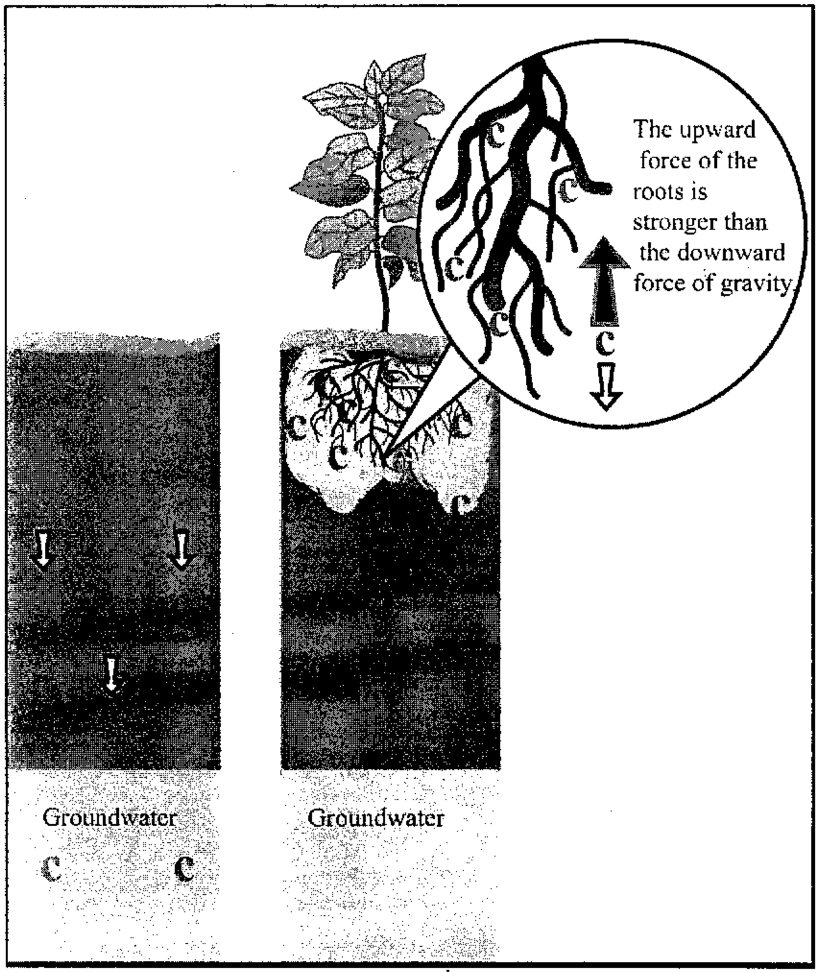

Figure 9.9: Hydraulic control (C. White, 2004).

phytoextraction process. The contaminants are later removed from the ecosystem when the plant is harvested. Plant biomass that contains extracted essential nutrients may be used as feed for animals. Biomass containing extracted metals, toxins, radioactive compounds, and other pollutants must be disposed of in a way that will remove the threat of contamination to the environment. Biomass may be landfilled or incinerated in an appropriate disposal facility.

Hydraulic control is the regulation of water-soluble contaminant movement by plant root water uptake. The soluble pollutants are drawn upward through the soil profile by the thirsty roots. The upward pull on the water by the plant system counteracts the downward gravitational movement of water infiltration. The upper layers of the soil profile then contain the contaminants, which may be taken in by the plant, transferred to the atmosphere by evaporation, or retained in the soil. **Figure 9.9** is a graphic of hydraulic control. Hydraulic control is effective in controlling groundwater pollutants, such as nitrate. It is important to note that hydraulic control is dependant on the growth stage of the plant and the weather conditions—for instance, during the cold winter months many plants do not grow and do not take up much soil water.

Erosion control involves the use of plants to control both soil movement from a site and contamination. The roots of plants hold soil in place, preventing the movement of the soil by water or wind. Since the soil is held in place, any contaminant that is bound to the soil is held in place as well. This method of phytoremediation is an economical way of restricting contaminants to their original location. **Figure 9.10** illustrates erosion control phytoremediation.

Phytodegradation is the transformation or breakdown of contaminants in the soil by plants. This can occur in one of two ways; it may occur in the plant after the contaminant is absorbed or in the soil by the action of enzymes that the plant roots have released. Phytodegradation is most often used to remediate areas affected by organic compounds such as pesticides. **Figure 9.11** illustrates phytodegradation phytoremediation.

Phytoremediation has been utilized all over the world to mitigate a variety of environmental contaminants such as excess nitrogen and phosphorus as well as heavy metals and other pollutants. Both the nature of the contaminants and the physical environment guide the choice of plant species used for phytoremediation. Some plants are better suited for certain climatic and geological conditions. Root depth and horizontal reach, growth rates, and water consumption rates are characteristics to consider. Trees are often the plant of choice due to their capacity to utilize huge quantities of water and effectively capture large amounts of dissolved nutrients. Trees also offer other advantages—they are harvested infrequently, requiring lower labor requirements than plants that need frequent harvesting. Many trees have deep root systems, penetrating the soil profile to extract pollutants. Trees also provide wildlife habitat and are aesthetically pleasing. Additionally, trees may be grown on land that is too steep, rocky, or otherwise unsuitable for other agricultural crops. However, manure applied to steep and rocky land must be carefully managed to prevent runoff. Harvested trees are a value-added product that can be used as lumber or paper pulp.

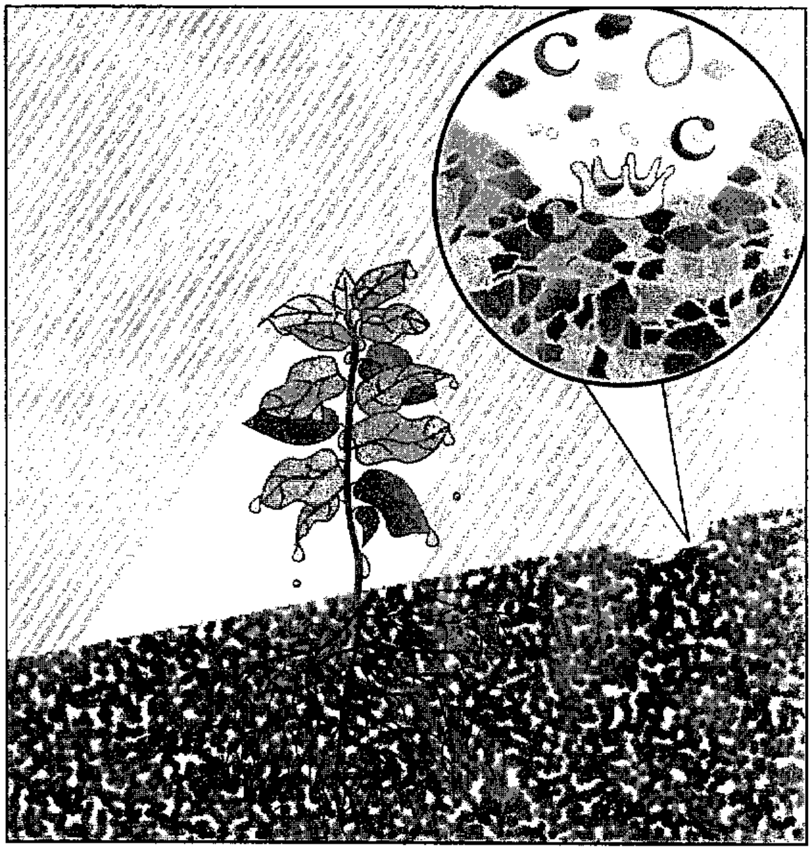

Figure 9.10: Erosion control (C. White, 2004).

Hybrid poplar trees are one of the more common plant species used for

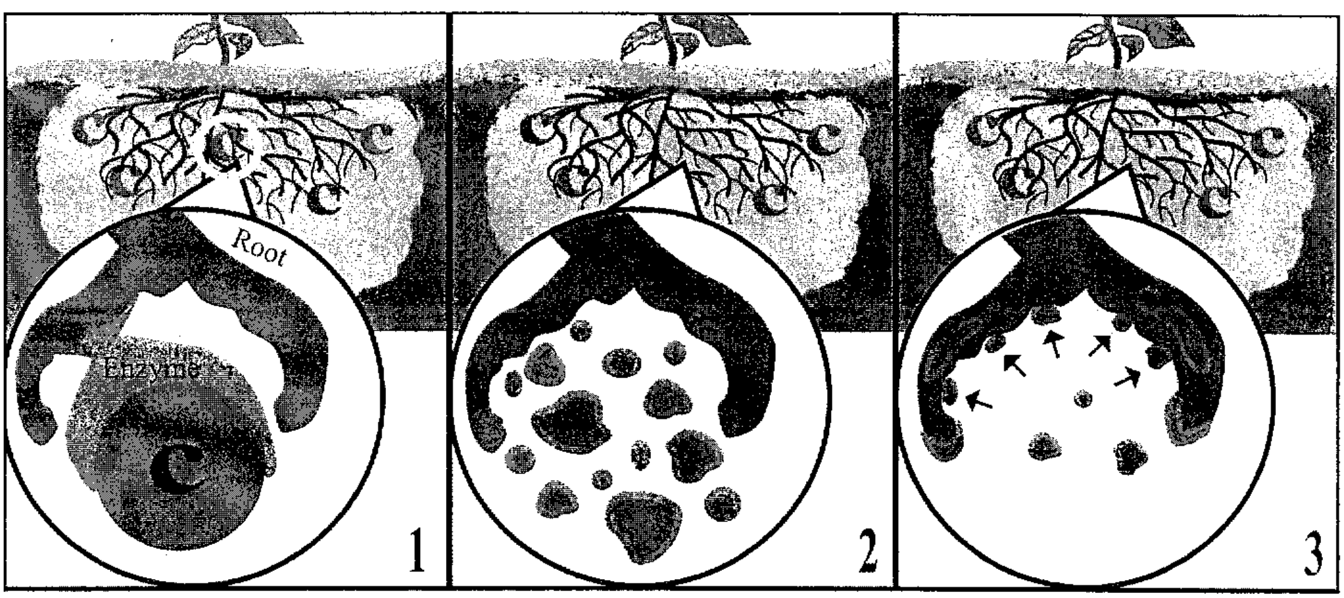

Figure 9.11: Phytodegradation (C. White, 2004).

Lagoon: A shallow pond where sunlight, oxygen, and bacteria degrade and transform compounds in manure.

phytoremediation and have been used to clean up abandoned **lagoon** and earthen manure storage areas. Their popularity arises from their rapid growth rate and high water consumption rate. Poplar plantations will extract more water and nitrogen from an area than a conventional crop such as corn or fescue and other grasses harvested for hay. Young poplars can consume 95 liters (25 gallons) of water a day (Schmiedeskamp, 1997) and consumption will double for a mature tree (US Environmental Protection Agency, 2000). Nitrogen extraction rates of more than 454 kilograms (1,000 pounds) per acre per year have been observed (Miner et al., 2000). Rapid-growing hybrid poplar trees can reach harvesting size in five to seven years (Miner et al., 2000). The wood fiber can be sold for the manufacture of paper. A poplar plantation is easy to start by placing poplar switches in a hole, allowing roots to grow and develop into a tree. Alternatively, saplings can be planted in rows approximately three meters (ten feet) apart, with the spacing between trees as close as 0.3 or 0.6 meters (one or two feet) (Miner et al., 2000). The trees can be harvested at any time by cutting just above ground level.

In summary, phytoremediation is the use of plants to reduce or eliminate contaminants from the environment. Phytoremediation works by four mechanisms-phytoextraction, hydraulic control, erosion control, and phytodegradation. The use of tree plantations as a manure management tool offers a flexible management regimen, may use land otherwise unsuitable for agricultural processes, provide wildlife habitat, and can be relatively inexpensive. Hybrid poplar trees are popular plants for phytoremediation. Mature poplars may be harvested for paper production as a value-added product.

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