bacteria to grow on. Water hyacinths grow rapidly, especially in wastewater. Ten water hyacinth plants can generally grow to cover a one acre pond in eight months (Crites and Tchobanoglous, 1998). When left uncontrolled in natural freshwater systems, the water hyacinth can take over natural ecosystems, squeezing out other plant species and clogging the waterways with biomass. Consequently, when it escapes into natural systems, it is considered an invasive species, so it must be carefully handled and contained.

Water hyacinths require persistent average temperatures above 1°C (34°F), and will die in freezing conditions (Crites and Tchobanoglous, 1998). However, if the rhizome tip does not freeze the plant can regenerate. The temperature limitations typically restrict water hyacinth wetlands to Alabama, Arizona, California, Georgia, Florida, Louisiana, Mississippi, and Texas in the United States. **Figure 8.8** is a map of the US indicating states where water hyacinth wetlands may be used, based on climate. Odor and mosquito problems have historically plagued this kind of wetland system, but the aeration can help to resolve these problems.

The need for harvesting depends on several variables, including water quality objectives, the growth rate of the water hyacinths, and the mosquito control strategy. Frequent harvesting is necessary if nutrient removal is an objective. The design of the wetland should accommodate harvesting equipment and plans for disposal or use of the harvested plants. Harvested plants may be composted.

Anoxic: Lacking oxygen.

b. Duckweed

Duckweed wetlands generally consist of ponds 1.5 to 2.4 meters (five to eight feet) deep (Crites and Tchobanoglous, 1998). The water can be even deeper because root-bacteria contact is not a part of this treatment process. Fairly level topography is preferred, otherwise construction costs will increase with additional earth moving and grading. Duckweed does not transfer oxygen to water, creating an **anoxic** wetland system.

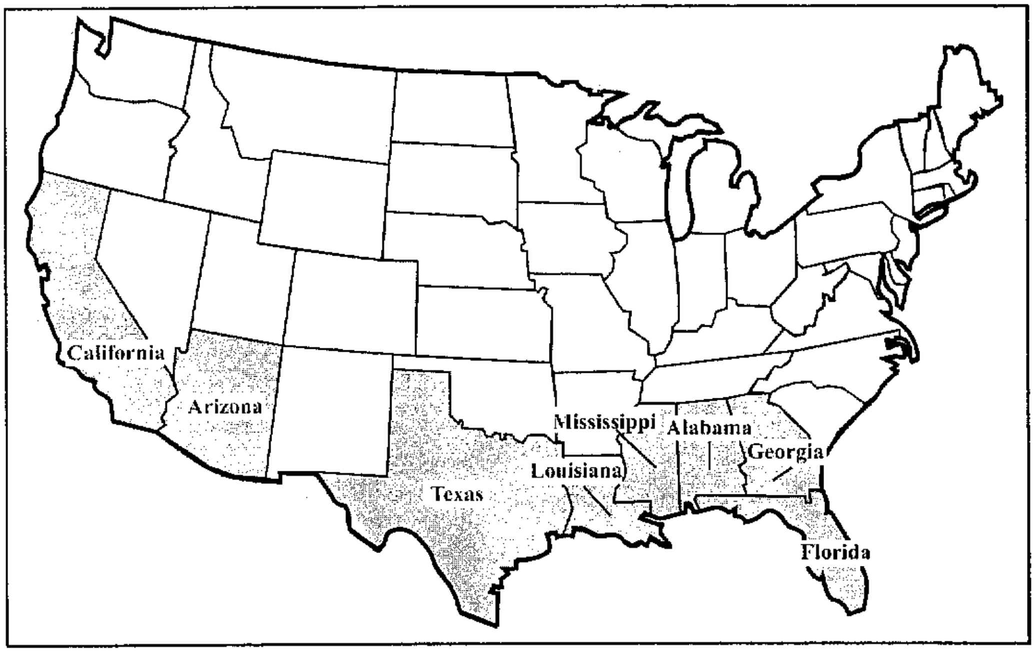


Figure 8.8: US states where water hyacinth wetlands are appropriate (C. White, 2004).

Duckweed is a small freshwater plant with leaves that are one to three millimeters (0.04 to 0.12 inches) in width and roots that are relatively short, less than ten millimeters (0.4 inches) long (Crites and Tchobanoglous, 1998). **Figure 8.9** is a photograph of a duckweed plant. The roots serve as a surface shading system. Duckweed grows even faster than water hyacinth.

Figure 8.9: Duckweed (G. Chandler, 2003).

Duckweed is very sensitive to wind drift. This requires the design of the system to include baffles to keep the plants in the treatment area. Duckweed is slightly more cold-tolerant than water hyacinth; it requires water temperatures of seven °C (45°F) or higher to sustain growth and treatment of the water (Crites and Tchobanoglous, 1998).

Duckweed, like other wetland plants requires some harvesting. Depending on the nutrient content, the duckweed may be harvested and used for animal feed for fish, shrimp, poultry, and cattle.

8.6.4 Comparison of Open Water, Subsurface Flow, and Floating Aquatic Constructed Wetlands

Open water, subsurface flow, and floating aquatic wetlands are three different types of constructed wetlands. In open water and subsurface flow wetlands the vegetation is rooted in soil. In open wetlands the vegetation may be partially or fully submerged in water, while in subsurface flow wetlands there is no standing water. The vegetation floats on the water surface with roots free in the water in floating aquatic wetlands. **Figure 8.10** is a review of the different styles of wetlands.

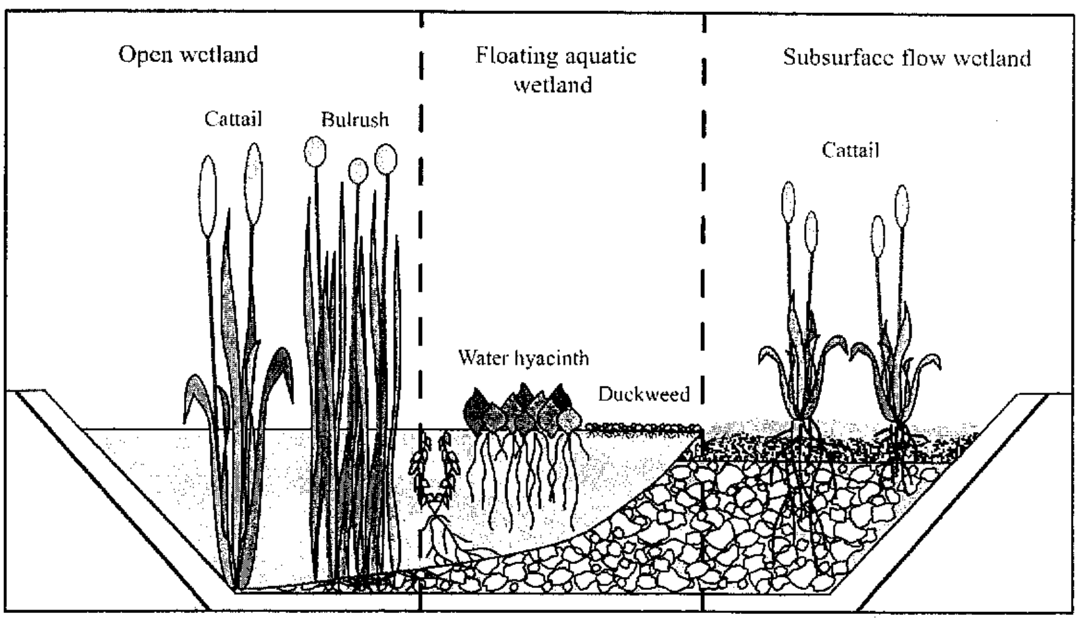


Figure 8.10: Constructed wetland vegetation (United States Environmental Protection Agency, 1993).

Table 8.5 summarizes the removal and transformation mechanisms that take place in open water, subsurface flow, and floating aquatic wetlands. Each wetland operates using different processes. The treatment objectives should dictate which wetland type should be utilized.

Table 8.5: Summary of principal removal and transformation mechanisms in open water, subsurface flow, and floating aquatic constructed wetland systems (Crites and Tchobanoglous, 1998).

Constituent	Open Water System	Subsurface Flow	Floating Aquatics
Biodegradable organics	Bioconversion by aerobic, **facultative**, and **anaerobic** bacteria on plant and debris surfaces of soluble BOD, adsorption, filtration, sedimentation of particulate BOD	Bioconversion by facultative and anaerobic bacteria on plant and debris surfaces	Bioconversion by aerobic, facultative, and anaerobic bacteria on plant and debris surfaces
Suspended solids	Sedimentation, filtration	Filtration, sedimentation	Sedimentation, filtration
Nitrogen	Nitrification-denitrification, plant uptake, volatilization	Nitrification-denitrification, plant uptake, volatilization	Nitrification-denitrification, plant uptake, volatilization
Phosphorus	Sedimentation, plant uptake	Filtration, sedimentation, plant uptake	Sedimentation, plant uptake
Heavy metals	Adsorption of plant and debris surfaces, sedimentation	Adsorption of plant roots and debris surfaces,	Adsorption of plant roots, sedimentation
Trace organics	Volatilization, adsorption, biodegradation	Adsorption, biodegradation	Volatilization, adsorption, biodegradation
Pathogens	Natural decay, predation, UV irradiation, sedimentation, excretion of antibiotics from plant roots	Natural decay, predation, sedimentation, excretion of antibiotics from plant roots	Natural decay, predation, sedimentation

8.6.5 Reciprocating Wetlands

Reciprocating wetlands differ from other wetland systems because they are designed for recurrent filling and draining of adjacent cells. The wetlands are filled with porous material, similar to subsurface flow wetlands. The pores allow for space for water and air during the continuous filling and draining that promotes alternating aerobic and anaerobic conditions. A minimum of two wetland cells are required—one cell drains into the adjacent cell and then the process is reversed. **Figure 8.11** is a diagram of a reciprocating wetland. The drain-fill process manipulates the biological and the physical conditions, transforming carbonaceous nitrogenous and phosphorus compounds. The varying biological and physical conditions support distinct populations of microorganisms that degrade different materials. During the drained time, atmospheric oxygen rapidly aerates exposed surface areas, enhancing the oxidation of ammonia and organic matter and reducing odor. During the fill time, anaerobic conditions prevail, allowing for denitrification and anaerobic bacteria to digest organic compounds. During the aerobic phase, nitrification may convert ammonia to nitrate, which is then converted into dinitrogen gas by denitrification during the anaerobic phase. See Chapter 6 for more information on nitrification-denitrification.

Biodegradable: A material that can be broken down by biological processes.

Facultative: An environment that contains both oxygenated and oxygen-free regions or microorganisms that can live in both oxygenated and oxygen-free environments. When oxygen is not available, these organisms can switch from respiration to fermentation.

Anaerobic: An oxygen-free environment or requiring an oxygen-free environment to survive.

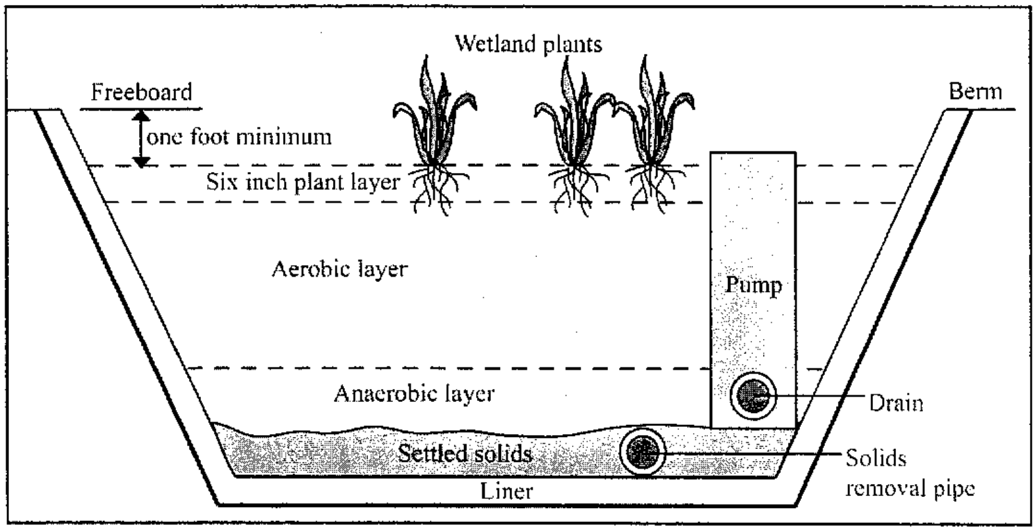


Figure 8.11: Diagram of reciprocating wetland (C. White, 2004).

Fecal coliform: A group of bacteria in the family *Enterobacteriacea* and commonly found in the digestive tracts of all mammals. The presence of fecal coliform in water may indicate fecal contamination and the existence of pathogens.

Reciprocating wetlands can be expensive to construct. Pumps and pipelines are required to control the filling and draining actions. They are also management and maintenance intensive. The design, however, also allows for treatment options that are not available with other wetland design types. **Figure 8.12** is a photograph of a reciprocating wetland.

The reciprocating wetland design was tested in Alabama to treat high strength swine wastewater and the study found the system to be user friendly, relatively cost effective, and efficient with respect to the removal of organic compounds, nitrogen, and **fecal coliform**, and the reduction of odor problems (Behrends et al., 2003). However, it was not efficient in phosphorus removal.

Figure 8.12: Photograph of reciprocating wetland (P. Wright, 1987).

8.7 Summary

Constructed wetlands may be used to treat animal wastewater. Biological, chemical, and physical processes transform and degrade organic matter, destroy pathogens, and transform nutrients. There are four basic types of constructed wetlands—open water, subsurface-flow, floating aquatic, and reciprocating wetlands. Each type of wetland has distinct design, construction, management, and maintenance needs that are influenced by climatic conditions, topographic features, and treatment objectives. Nitrogen removal and odor reductions are two treatment objectives that can be met with successful constructed wetlands. Care must be taken to provide constructed wetlands with appropriate water, solids, and nutrient loading to keep the growing system healthy.

Referenced Materials

Agricultural Research Service. 2004. Photograph of water hyacinth. United States Department of Agriculture.

Baird, C., M. Rice, S. Liehr, D. Rashash, F. Humenik. 2003. Solids separation/constructed wetland system. North Carolina Waste Management Workshop. October 15-18, 2003. Raleigh, North Carolina.

Behrends, L., E. Bailey, W. Ellison, L. Houke, P. Jansen, C. Shea, S. Smith, T. Yost. 2003. Reciprocating constructed wetlands for treating high strength anaerobic lagoon wastewater. Presented at the Ninth International Animal, Agricultural, and Food Processing Wastes Symposium. American Society of Agricultural Engineers. October 12-15, 2003. Raleigh, North Carolina.

Blagden, Jr., T. 2004. Photograph of naturally occurring wetland. Species Descriptions. National Oceanic and Atmospheric Administration, National Marine Fisheries Service. www.nmfs.noaa.gov/habitat/habitatprotection/anadromousfish_descriptions.htm. Last visited 8 September 2004.

Chandler, G. 2003. Photograph of duckweed plant. Arizona State University. Temple, Arizona.

Crites, R. and G. Tchobanoglous. 1998. Small and Decentralized Wastewater Management Systems. McGraw-Hill. Boston, Massachusetts.

Grismer, M. 2004. Photograph of open wetland. University of California at Berkeley. Berkeley, California.

Grismer, M. 2004. Photograph of subsurface flow wetland. University of California at Berkeley. Berkeley, California.

Hunt, P.G., M.E. Poach, A.A. Szogi, G.B. Reddy, K.C. Stone, F.J. Humenik, M.B. Vanotti. 2003. Operational components and design of constructed wetlands used for treatment of swine wastewater. Presented at the Ninth International Animal, Agricultural, and Food Processing Wastes Symposium. American Society of Agricultural Engineers. October 12-15, 2003. Raleigh, North Carolina.

Idaho Completion Project. 2003. Environmental Monitoring Glossary. Bechtel, Idaho. http://cleanup.inel.gov/monitoring/glossary.cfm. Last visited 2 July 2004.

Kowalk, K. and W. Northcott. 2002. Greenhouse scale constructed wetland system for dairy wastewater treatment. Presented at the 2002 American Society of Agricultural Engineers Annual International Meeting. July 28-31, 2002. Chicago, Illinois.

Miner, J.R., F.J. Humenik, M.R. Overcash. 2000. Managing Livestock Wastes to Preserve Environmental Quality. Iowa State University Press. Ames, Iowa.

Poach, M.E., P.G. Hunt, E.J. Sadler, T.A. Matheny, M.H. Johnson, K.C. Stone, F.J. Humenik, J.M. Rice. 2002. Ammonia volatilization from constructed wetlands that treat swine wastewater. Transactions of the American Society of Agricultural Engineerings. Vol. 45(3). P. 619-627. St. Joseph, Michigan.

Prantner, S.R., R.S. Kanwar, J.C. Lorimar, C.H. Pederson. 2001. Soil infiltration and wetland microcosm treatment of liquid swine manure. Applied Engineering in Agriculture. Vol. 17(4). P. 483-488. American Society of Agricultural Engineers. St. Joseph, Michigan.

Regmi, T.P., A.L. Thompson, D.M. Sievers. 2003. Comparative studies of vegetated and non-vegetated submerged-flow wetlands treating primary lagoon effluent. Transactions of the American Society of Agricultural Engineers. Vol. 46(1). P. 17-27. St. Joseph, Michigan.

Rice, M. and F. Humenik. 2003. Solids separation-reciprocating wetland. North Carolina Waste Management Workshop. October 15-18, 2003. Raleigh, North Carolina.

Simeral, K.D. 1998. Using Constructed Wetlands for Removing Contaminants from Livestock Wastewater. Ohio State University School of Natural Resources Fact Sheet A-5-98. http://ohionline.osu.edu/a-fact/0005.html. Last visited 31 March 2004.

Stephenson, M., G. Turner, P. Pope, J. Colt, A. Knight, G. Tchobanoglous. 1980. The use and potential of aquatic species for wastewater treatment, App. A, the environmental requirements of aquatic plants. Publication No. 65, California State Water Resources Control Board. Sacramento, California.

United States Environmental Protection Agency. 1993. Diagram of constructed wetland vegetation. Office of Water. Washington, D.C.

United States Geological Survey. 1998. Diagram of treatment processes in wetlands. US Geological Survey Programs in New York - Constructed Wetlands. http://water.usgs.gov/pubs/fs/FS-032-96/. Last visited 23 November 2004.

White, C. 2004. Diagram of open wetland. Waterkeeper Alliance. Tarrytown, New York.

White, C. 2004. Diagram of subsurface flow wetland. Waterkeeper Alliance. Tarrytown, New York.

White, C. 2004. Diagram of US states where water hyacinth wetlands are appropriate. Waterkeeper Alliance. Tarrytown, New York.

White, C. 2004. Diagram of reciprocating wetland. Waterkeeper Alliance. Tarrytown, New York.

Wood, S.L., E.F. Wheeler, R.D. Berghage. 2000. Removal of dimethyl disulfide and p-cresol from swine facility wastewater using constructed subsurface-flow wetlands. Transactions of the American Society of Agricultural Engineers. Vol. 43(4). P. 973-979. St. Joseph, Michigan.

Wright, P. 1987. Photograph of reciprocating wetland. PRO-DAIRY. Cornell Cooperative Extension. New York State College of Agriculture and Life Sciences. Ithaca, New York.

Chapter 9
Miscellaneous Treatment Technologies

9.1 Introduction

There is no limit to the number of innovative methods available for treating manure. This chapter introduces a few practices that have not been implemented as widely as other technologies, but offer potential for farms looking to manage manure in new ways, as illustrated in **table 9.1.**

9.2 Black Soldier Fly Manure Treatment

Flies are attracted to manure, as evidenced by the swirling, buzzing mass hovering above cowpies in pasture or near manure storage facilities. While flies and other insects are frequently perceived as disease **vectors** or as pests, they can be

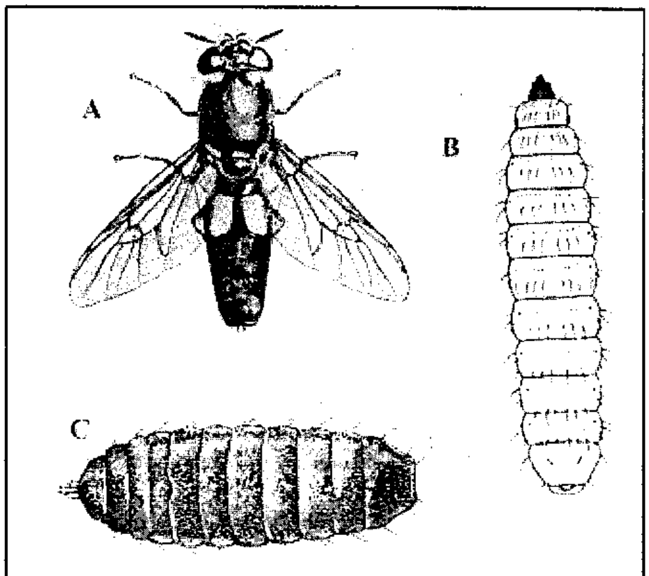
Vector: An agent that transfers a disease or pathogen from one organism to another.

Table 9.1: Potential miscellaneous treatment technologies benefits.

Chapter Number	Chapter Name	Treatment Process	Reduce Nitrogen	Reduce Phosphorus	Reduce Biochemical Oxygen Demand	Stabilize Manure	Reduce Manure Volume	Reduce Pathogens	Reduce Manure Gases	Reduce Odor	Reduce Ammonia Volatilization	Operate at Low Temperatures	Minimal Footprint	Low Energy Requirement	Create Biogas	Create Value-Added Products
9	Miscellaneous Treatment Technologies	Black soldier fly	√	√		√	√	√		√			√	√		√
		Vermicomposting	√	√		√	√	√		√			√	√		√
		Phytoremediation	√	√										√		√

Prepupae: (pl. of prepupa) Insects that are between the larval stage and the adult stage, but must undergo metamorphosis before reaching adulthood.

Larvae: (pl. of larva) Insects that are in the immature, worm-like stage after hatching from the egg.



A, Adult female. B, Larvae. C, Prepupae.

Figure 9.1: Black soldier fly insect life cycle (C.S. Apperson et al., 2004).

Figure 9.2: Adult black soldier fly (B.M. Drees, 1999).

Figure 9.3: Black soldier fly larvae (G. McIlveen Jr., 1999).

managed to digest and stabilize manure. Scientists around the world have studied manure digestion by insects to produce a value-added product, **prepupae,** that may be processed to create a high quality animal feed for both livestock and aquaculture operations. **Figure 9.1** is an illustration of the life cycle for the black soldier fly. This is an appropriate treatment for manure that is collected and stored as a semi-solid, a solid, or that has undergone solids separation. Farms located in warm climates that have existing slatted floors for manure collection are best suited for using this technology.

Like bacteria, insect **larvae** consume manure, assimilating the nutrients. Since the organic material in manure is an excellent larva food source, insects will lay their eggs in manure so the newly hatched bugs will have a readily available buffet of food. Species of flies that have been studied for manure digestion and feedstuff production include house flies (*Musca domestica*), face flies (*Musca autumnalis*), blow flies (usually *Sarcohpaga* spp.), and black soldier flies (*Hermetia illucens*). House flies, face flies, and blow flies are usually considered pests—they have undesirable swarming behavior, infest buildings, and have a high vector potential. Black soldier flies do not exhibit these traits, making this fly species an excellent candidate for manure digestion and feedstock production.

The black soldier fly is a large, wasp-like insect. **Figure 9.2.** is a photograph of a black soldier fly. Their bodies are slender and about 2.5 centimeters (one inch) long (Sheppard, 2004). Black soldier flies are native to the southeastern United States, but are now found globally. They cannot tolerate cold weather, so the use of this insect for manure digestion is restricted to temperate and tropical climates. If both black soldier flies and house flies exist in the same environment, the black soldier flies will out-compete the undesirable house flies, reducing or eliminating the house fly population. The adult black soldier flies live and mate fairly close to their hatching area, so migration away from the farm and into dwellings is not usually a problem. The adult black soldier flies do not feed, but survive on the large reservoir of body fat developed as juveniles in the larval stage. Larvae live in very crowded populations, often covering the manure in a solid layer of writhing bodies. **Figure 9.3** is a photograph of black solider fly larvae.

The insect larvae serve two important roles in the decomposition process. As they eat, they tunnel through the manure, aerating and drying it, and preventing the manure from becoming **anaerobic** and odorous. In approximately two weeks, the larvae can reduce the overall volume of the manure by between 42 and 56 percent (Sheppard, 2004). In the process of digestion, the nutrients are transferred from the manure to the insect bodies. **Table 9.2** lists the nutritional components of black soldier fly prepupae. The high nutritional content makes the prepupae a value-added product as a feedstuff.

Table 9.2: Nutritional components of dried black soldier fly prepupae, on a dry matter basis (Sheppard, 2004).

Nutritional Component	Percent
Crude protein	41 - 42
Ether extract	31 - 35
Ash	14 - 15
Calcium	4.8 - 5.1
Phosphorus	0.60 - 0.63

The black soldier fly prepupae can self-harvest—the mature larvae naturally migrate from the mass of feeding larvae to find a protected pupation site. This behavior presents an easy opportunity to collect the prepupae. A ramp angled at 45 degrees, steep enough to keep the larvae in the manure treatment area but not so steep that the prepupae cannot make the trek, will direct them away from the manure. The ramp leads to a gutter opening into a collection bucket. The prepupae will fall into the gutter and the bucket for removal. **Figure 9.4** is an illustration of a prepupae collection system.

Fresh, aerated manure is required for the black soldier fly larvae to flourish. Old or stockpiled manure will not support larval growth, possibly because large microbial populations compete with the larvae for the nutrients in the manure or cause other environmental conditions that limit fly larvae survival. Since fresh manure is needed, the best design for collection and treatment is a continuous system located beneath the animals. Slatted flooring beneath the animals works well. The manure drops through the slats into a pile, ready for the larvae to begin eating before any competitive bacterial colonies take control. This system not only benefits the insects, but it also saves in the time and expense of handling and transporting manure. Additionally, the prepupae

Anaerobic: An oxygen-free environment or requiring an oxygen-free environment to survive.

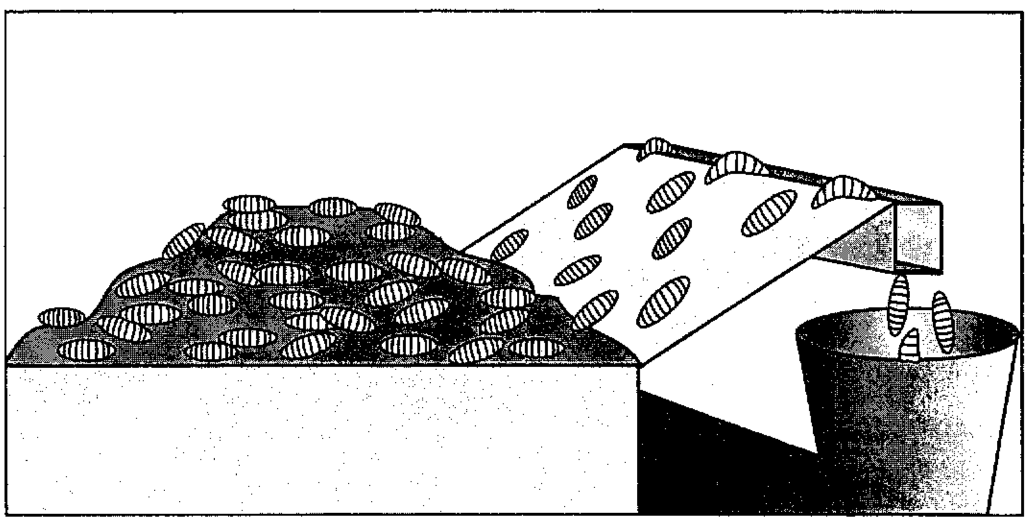


Figure 9.4: Prepupae collection system (C. White, 2004).