AN INTEGRATED FARM FOR THE UNIVERSITY OF GEORGIA COSTA RICA CAMPUS

by

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(Under the Direction of Alfred Vick)

ABSTRACT

The University of Georgia has committed to the creation of a sustainable facility for its Costa Rica Campus. A major part of their strategy is the development of an integrated farm. This thesis proposes a design solution which answers the following question: What is the optimal environmentally and culturally sensitive integrated farm system for the UGA Costa Rica Campus? The resultant response is a design that links crop, dairy, poultry and swine production with a biodigestor for waste management, production of fertilizer and creation of methane gas. The system is designed to provide a high level of productivity while eliminating many of the problems that plague other agricultural production systems. An illustrative master plan and narrative specifies the system infrastructure, management strategies and the arrangement of biotic and abiotic components.

INDEX WORDS: integrated farm, integrated farming, sustainable agriculture, UGA Costa Rica Campus, environmental design, Landscape Architecture.

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CHAPTER 1

INTRODUCTION

Costa Rica, a country applauded for its stunning natural beauty and widely publicized conservation efforts, seems a tropical paradise. The tiny Central American country is estimated to contain five percent of the world's biodiversity while taking up only 0.01 percent of its landmass. The verdure there is stunning; expansive parks protect species like the jaguar and the resplendent quetzal in their towering trees. Outside the protected areas, banana plantations carpet the landscape of the lowlands as far as the eye can see, and in the highlands, bucolic scenes of grazing cattle delight visitors. To the unknowing, everything seems pristine, but looking through the veneer of lush vegetation a myriad of environmental problems contributed to agriculture are apparent. In fact, the need to protect against widespread environmental degradation in Costa Rica has been the motivation for the country's conservation efforts which guard the forests and shores where more than a million tourists visit each year. Fully one third of Costa Rica's forest cover was lost from 1950 to 1985. By 1998, almost 28 percent of the country was maintained under some form of protection (Beletsky 1998), the highest percentage in the world, yet less than 5 percent of the areas outside the reserves remained forested. In the same year the rate of cutting continued at a pace of 3.9 percent, totaling some 160,000 acres (Beletsky 1998). In recent years, though, this trend has begun to reverse. In 2005 the rate of deforestation slowed to 0.09% and the forest cover was recovering at a rate of 0.66% meaning the net increase in forest cover was 0.57% (FONAFIFO 2007).

This is due in part to reforestation efforts and the development of timber plantations. Widespread deforestation, driven primarily by agricultural practices has lead to a loss of biodiversity, widespread erosion, flooding, local climate change due to hydrologic cycle disruption and other problems. Forests have been replaced with plantations and pasture, which in total now cover approximately 58 percent of Costa Rica's land area (Haggett 2002). Compounding the ills of deforestation is a long list of environmental problems attributed to agriculture, namely: the use of enormous amounts of nonrenewable fossil fuels; the use of dangerous pesticides that have been linked to numerous health concerns for both humans and the environment; soil degradation caused by erosion, and nutrient leaching which simultaneously pollutes waterways and reduces soil fertility (Griffith 2000 p 394), and thereby diminishing the land's capacity for productivity.

Concerns over these problems have spurred an interest in developing improved agricultural practices. EARTH University in Guácimo de Limón, Costa Rica, is experimenting with one such agricultural system known as an integrated farm which offers promise for ameliorating many of these harmful effects. EARTH's integrated farm successfully integrates the production of pork, beef, dairy, crops, and poultry with aquaculture (the production of fish and aquatic plants) and wastewater treatment. The wastewater treatment component in this system is notable because it employs an anaerobic biodigestor and aerobic purification lagoons. The byproduct of biodigestion is liquid fertilizer and methane gas, both of which replace fossil fuels with renewable resources produced on-farm. The system is organic, requires minimal amounts of fossil fuel inputs, and reduces nutrient and soil loss, all of which have the potential to contribute to the long term economic and environmental viability of the technology. The positive results shown by this methodology have spurred its adoption in several sites around Costa Rica where it has also proven to be effective. The United Nations Food and Agriculture Organization and Heifer International have also seen success with similar systems in other parts of the moist tropics including Vietnam, Africa and South America, further proving the adaptability and efficacy of the system (Heifer International, Preston 1995 and Rodriguez 1996, Yoshiro 1999, Mukherjee 1992, Little and Edwards 2003).

The University of Georgia owns and operates a 153 acre educational facility near Monteverde, Costa Rica comprised of a research center, residential campus, working farm and The Ecolodge San Luis which is comprised of 12 rooms where guests experience nature-based tourism. Collectively these are known as “UGA Costa Rica”. The campus sits amidst an incredibly diverse and unique tropical ecosystem home to thousands of species of plants and animals, many of which are endemic and threatened by the encroachment of human activity in the area. Understanding the potential negative impacts a facility of this sort might contribute, the administration of the UGA Costa Rica Campus has committed to mitigate these as articulated in the following objectives. The UGA Costa Rica Campus will provide educational facilities and opportunities that:

- serve as a model for sustainability, educational tourism, conservation, and stewardship;

- maintain the architectural vernacular, cultural, and aesthetic qualities of the community;
- encourage interaction and integration with the people of the San Luis Valley via outreach, employment, and partnerships;
- minimize environmental impact; and provide comfort, convenience, and security for our students and other campus visitors (UGA Costa Rica [Internet]).

Fulfillment of this commitment is best demonstrated by the campus earning a rating of three out of five “leaves/levels” from the Costa Rican Tourism Institute’s Sustainable Tourism Certification (CST) program for its exemplary natural, cultural and social resource management. Some of the many reasons that the campus was bestowed this prestigious honor are: guests can participate in a carbon offset and reforestation program by planting trees; sixty percent of the campus is voluntarily protected as part of Costa Rica’s network of private reserves; and, the campus operates a working farm to provide for a portion of its food needs. Continuing to improve the operation is an ongoing process, and in light of the successes and positive attributes of the integrated farm system pioneered on the EARTH University campus, the development of a similar system is desired at the UGA Costa Rica Campus.

The integrated farm will make the best use of the Campus’ current facilities and employee skill base and stands to ameliorate a number of financial and environment concerns. In Costa Rica, food prices are exceptionally high and, along with high costs of transportation, represent a large portion of the UGA

Campus' operational budget. Thus, increasing on-farm food production could mean substantial monetary savings, as locally produced goods are less expensive, better for the environment and eliminate the need for long distance transportation. Integrated farms employ environmentally sensitive production techniques which lessen the impacts of agriculture in a number of ways. These will be discussed in detail in chapter four. In addition to the tangible benefits of the integrated farm, the project will create new educational programs, support opportunities for field research and internships, and provide community outreach to local farmers. These secondary products will provide an expanded set of campus offerings to enhance the long-term viability of the campus.

While the integrated farm system proposed for the UGA Costa Rica Campus is based on the model at EARTH University, the specific needs, climate, and considerations of the UGA Costa Rica Campus require an appropriate design response which addresses these differences. This thesis presents a potential design solution which answers the following question: What is the optimal environmentally and culturally sensitive integrated farm system for the UGA Costa Rica Campus? The design will be represented by an illustrative master plan, details, diagrams and a narrative of the flows and processes of the integrated farm system.

Chapter 2 defines integrated farming and discusses the theory and previous work that has lead to the development of the system. Following the discussion of the theory and history of the integrated farm concept, chapter 3 will present a case study of the integrated farm at EARTH University in Guácimo, Costa Rica. Chapter 4 provides an inventory and analysis of the UGA Costa Rica site. Chapter 5 details the design. Specifications will be represented both graphically and in narrative form. Interwoven into the narrative are the justifications for design decisions and comments on the function, ecology and management of the system. Chapter 6 concludes the thesis through self evaluation, reflections and by defining areas for further research.

CHAPTER 2

THEORY AND CONCEPT OF THE INTEGRATED FARM SYSTEM

> “. . .we must begin learning to apply ecological principles to the design of our food production systems now—we are rapidly approaching or are already at the peak of planetary oil production, and the world of energy descent is upon us. This sea change in our culture will require that we learn to live within our energetic means and begin to rebuild ecosystems that support human and humane lives without diminishing the ability of the ecosystem to support our children and grandchildren.” David Jacke

Integrated farming, or integrated agriculture, refers to an agricultural system and methodology in which aquaculture, livestock and crop production is linked so that byproducts from one element are used to drive another. Integrated farms are comprised of multiple interconnected cyclic production pathways, as opposed to many industrial systems which exhibit linear flows of resources resulting in waste. A well-documented example of an integrated farm system that is widely used in Vietnam combines the production of poultry, swine, grain and aquaculture (Heifer International, Preston 1995 and Rodriguez 1996). In this system, chickens and pigs are raised adjacent to or over tilapia ponds. Their manure falls into the water where the nutrients stimulate the growth of plankton, aquatic plants and benthic organisms which the tilapia feed upon. Additionally, the aquatic plants are fed directly to the livestock or are composted for application to crops. After the tilapia are harvested, the ponds are drained and dredged of the silt and nutrients that have collected at the bottom for later application to the fields. To complete the cycle, grains and grasses from the fields are fed to the poultry. In this closed-loop system, the only appreciable losses are from products sold off farm. The Vietnamese method is but one of many possible variations of the integrated farm concept. Many other permutations exist which are adapted to the environment and culture where they are located ((Heifer International [Internet], Preston 1995 and Rodriguez 1996, Yoshiro 1999, Mukherjee 1992, Little and Edwards 2003). A detailed case study of the integrated farm at EARTH University in Guacimo, Costa Rica is provided in chapter 3.

For the purposes of this work, the above definition of integrated farming will be expounded upon to describe agricultural ecosystems that over the long term will:

- satisfy human food and fiber needs
- enhance environmental quality and the natural resource base, upon which the agricultural economy depends
- make the most efficient use of nonrenewable resources and on-farm resources and make use of, where appropriate, natural biological cycles and controls
- sustain the economic viability of farm operations

- enhance the quality of life for farmers and society as a whole (based on the 1990 Farm Bill definition of sustainable agriculture).

Integrated farms are generally small, highly diverse operations, as opposed to larger industrialized systems characterized by monocultures. The diversity helps insulate the operation from catastrophic loss if a single component fails and provides the basis for integration. Integrated farms are mostly self-sufficient, deriving a majority of their resources from within the established system. A high level of productivity is made possible by intensive land use and by resource conservation within the system. Residues and byproducts from one process are fed to others in a regenerative cycle. This is facilitated by the proper arrangement of linked elements achieved by a whole-system approach to design and management. The system is organic and relies on the ecology of the site to inform the design and capabilities. Soil is conserved and generated through a variety of management techniques and physical devices.

Each of these properties represents improvements to the practices of industrial agriculture and, when used together, result in a system that has a the capability of reducing the environmental impact of agriculture. Collectively these criteria also form the conceptual basis for the development of novel systems adapted to individual site-specific conditions. As such, they will act as the principles that will guide the design of the integrated farm proposed for the UGA Costa Rica Campus.

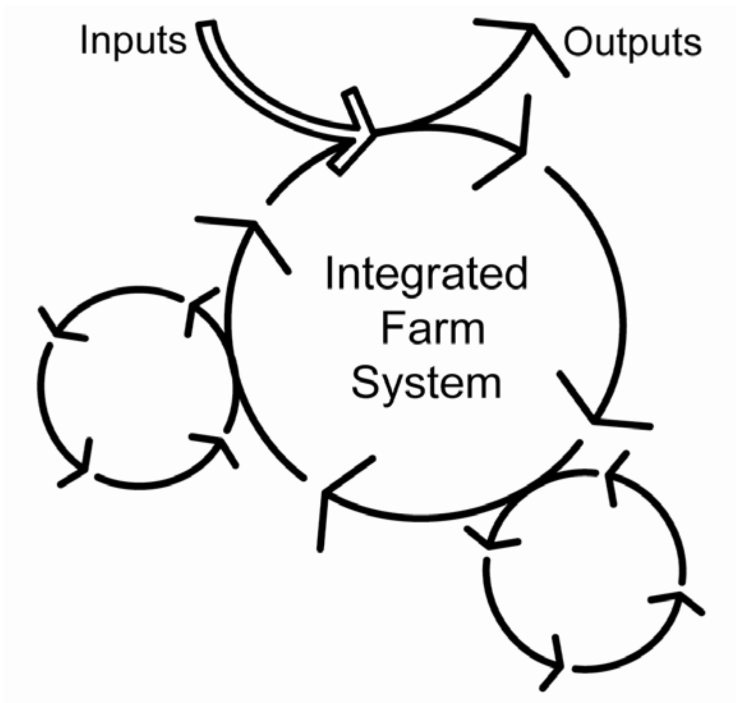


Figure1. Diagram of the concept of the integrated farm system. The circles represent the interlinked cycles that together make up the system.

Historical Context of the Integrated Farm Methodology

In the West, integrated farming has developed from a number of agricultural movements, beginning with scientific agriculture dating from the late 1700's and early 1800's in England. Scientific agriculture was the earliest examination of the science behind the production of food and fiber (Leigh 2004). During this time, a great increase in productivity was realized, as improved plant and animal breeds increased yields, crop rotations were implemented and mechanization reduced labor. This movement continues today through the scientific research that has been ongoing since its inception. Permanent agriculture was the next major advancement to shape the agricultural practices employed in the integrated farm method. This evolved from scientific agriculture in the first half of the 20th century and is characterized by a new understanding of soil fertility made possible by advancements in chemistry.

The proponents of permanent agriculture, most notably Franklin Hiram (FH) King (1911) and Cyril Hopkins (1910), rejected common notions of the time that, contrary to observation, soil fertility would be maintained forever without replenishment and that manure applied to fields acted to offset the *toxic excreta* of plant roots (Paull 2006). By this time croplands in the United States were already depleted and crop production was in decline. King and Hopkins worked to understand the mechanisms behind this phenomenon and to offer solutions. King published his famed book after visiting the Orient where he studied how masses of people had been provided for on the same land for centuries without decreasing the lands' productivity. In it he describes an intensive system of farming that provided for millions with no petroleum fuel inputs. Fertility was maintained by the addition of river sediments, composts and organic material particularly night soil (human excrement). The system did have drawbacks, though. A large portion of the landscape was used for the purposes of feeding the population to the detriment of the environment and it was highly dependent on human labor, a fact used to undermine the book's applicability to the United States where rapid industrialization and the advent of the tractor was actively reducing the need for farm labor. Hopkins takes a more scientific approach, quantifying how the addition of these materials contributes to soil and thus crop health. Together what these researchers provided was an understanding that soil is the basis for crop production and must be cultivated to sustain production.

The catastrophe of the Dust Bowl in the 1930's in the US lead to another key improvement in agricultural practices. Faced with widespread cropland degradation the Natural Resources Conservation Service, formerly the Soil Conservation Service, championed the use of physical controls to stop erosion and degradation of topsoil. These included contour plowing, strip cropping and terracing which together have significantly reduced soil erosion and sedimentation of rivers as well as aiding in the reestablishment of millions of trees across the world (Environmental Defense Fund). It was in the years following the Dust Bowl that soil began being valued as a natural resource that must be preserved.

Following World War II the most detrimental forms of agriculture arose. . It was in this period, called the Green Revolution, when the use of chemical fertilizers and toxic pesticides proliferated. The ills of industrialized agriculture were recognized and identified early on in the writings of Rachel Carson and Aldo Leopold, but these researchers' warnings were not heeded. These farming methods are still in place today and have had a serious and arguably irreparable effect on the environment. Nevertheless, since the inception of the Green Revolution, a counterculture has been steadily building.

Part of this response is the organic agriculture movement which seeks to produce foods without the use of fertilizers and harmful pesticides. This is more of a commitment than a well-defined methodology, although the Center for Agroecology & Sustainable Food Systems at the University of California, Santa Cruz, through years of research, education, and public service dedicated to increasing ecological sustainability and social justice in the food and agriculture system, has contributed much to codifying the many disparate techniques involved in growing foods organically.

Another highly influential movement is that of Permaculture, a holistic framework for the creation of sustainable human settlements based on ecological principles and permanent systems of agriculture. It was introduced in the mid-1970's and is continuing to gain strength worldwide. The term "Permaculture", derived by combining the words permanent, agriculture and culture, was coined in the mid-1970s by Bill Mollison and David Holmgren to describe cultural agro-ecosystems of perennial or self-perpetuating plant and animal species useful to man. It envisions a permanent human culture supported by a sustainable system of agriculture. Since its introduction, the term has evolved to mean "Consciously designed landscapes which mimic the patterns and relationships found in nature, while yielding an abundance of food, fiber and energy for the provision of local needs" (Holmgren 2002 p xix). The definition has further expanded to include not only the development of agricultural systems, but the holistic design of cultural systems of which agriculture is a part (Mollison 1988). In addition, the word refers to the social movement and techniques/technology used for implementing the vision of a permanent culture. The system works on the basic tenet that well designed intensive agricultural systems associated with settlements reduce environmental impacts by decreasing the amount of land dedicated to these cultural ecosystems. More land in its natural ecological state contributes to overall ecosystem health. Permaculture provides a holistic framework for the design of these systems based on twelve ecological principles provided by Holmgren in *Permaculture: Principles and Pathways beyond Sustainability* and three ethical imperatives from Mollison's *Permaculture: A Designer's Manual* (1988). Together these form an ethos which mandates: 1) care of the earth; 2) care of people; and, 3) fair share (set limits to consumption and reproduction and redistribute surplus). This is the single most important contribution of Permaculture, as none of the other movements provide a moral obligation for ecologically compatible design. The Permaculture process requires that each principle be considered when making design decisions resulting in a cultural ecosystem that functions more like that of a natural ecosystem and is thus more compatible with its surrounding environment.

Masanobu Fukuoka (1985), the Japanese author, scientist and farmer contributed the *natural farming* ideology in which the natural tendencies of species are used to make agriculture effortless yet abundant. The farming system developed by Fukuoka is a small-scale intercrop system for grain production that does not require weeding or tilling. Nor does it require fertilizer or pesticide application. Fukuoka looked at the natural properties of each crop (i.e. life cycle nutrient requirements, reaction to competition/cooperation, growth form and habit) and then designed his system to provide the conditions needed for the crops to thrive. For example, he seeded rice by encasing the seeds in small balls of clay and distributing them in the fields in the winter. The clay protects the seeds until they germinate in clumps the spring. The traditional method would have him raise seedlings in a nursery and then transplant each one separately by hand. His method saved considerable labor and the clumps of plants were stronger and had higher yields than the transplanted crop. During the winter when many fields were traditionally left fallow, Fukuoka planted winter rye and clover which produced a valuable crop in the lean times of winter. The clover replenished the nitrogen depleted by the grain harvest and helped to stabilize the soil. These practices resulted in a system with yields equal to or greater than the industrial systems in place in Japan by that time – with much less effort and input. While this specific system may have limited applicability outside of Japan, the governing philosophy of natural farming has been successfully used around the world. For example, in India a similar system is known as “Rishi Kheti” (agriculture of the sages) (Aggarwal [Internet]).

The Green Revolution has quickly spread into developing nations since the 1970’s. Yet, in Asia, small farms with production models closely resembling integrated farming are traditional practice and are still found in abundance. There are numerous examples, many of which are documented by the multitude of United Nations Food and Agriculture Organization publications on the subject (Mukherjee 1992,. Little 2003, Jian 1985) Most notably is the Vietnamese system described earlier (Heifer International, Preston 1995 and Rodriguez 1996) and a Japanese rice production system in which animal manures are used to fertilize rice paddies which, in addition to rice, produce fish, ducks and the aquatic plants azolla and duckweed which are fed to cows and pigs to close the nutrient loop (Yoshiro 1999). Governments, with the help of aide organizations, particularly in China, India and Vietnam are working to further integrate these farm systems to build their efficiency and productivity mainly through the construction of aquaculture and biodigestion units.

This historical summary is by no means complete, but it provides a look at the major advancements in thought which form the framework on which the overall movement of sustainable agriculture is built and that have brought about the development of the integrated farm methodology. Integrated agriculture is a holistic agricultural production paradigm derived from a synthesis of these lines of thought.

<u>Applicability</u>

Integrated farms, being highly adaptable to site-specific conditions, are applicable with modifications to much of the moist tropics due to the region's characteristic warm temperatures and high rainfall. Another attribute that allows the technology to be transferred easily is the ubiquitous use of the same domesticated plants and animals across the region. Cows, pigs and poultry are all commonly raised in the tropics. Costa Rica is an especially prime place to implement this system since the only components of the EARTH University system that are not in widespread use are the biodigestor and aquaculture, although in recent years the technology has begun to spread, as publicity of the EARTH University system increases and large industrial tilapia operations are developing. In the region, a large percentage of the population, thirteen percent in Costa Rica (CIA World Factbook [Internet]), is currently working in agriculture. Thus, the culture and lifestyle of the people is compatible with this technology. Costa Ricans are relatively well educated by comparison to the people of other

Central American countries and have proven to be highly adaptable in their use of different agricultural methods in response to market and systemic changes. This is evident in their introduction and use of new grasses for animal forage after infestations of spittle bugs destroyed the traditionally-used species, and in the farmers' rapid adoption of organic methods of coffee cultivation in response to rising market prices for organic beans (Griffith, Peck and Stuckey 2000). Furthermore, the techniques and management strategies needed for the integrated farm systems' operation are already used or are only a slight departure from normal, making this technology easily implemented.

Considering the unique and somewhat extreme microclimate of the site, which is described in detail in chapter four, the design for the UGA Costa Rica Campus described in this thesis will apply to the specific site and to very limited areas of similar temperature, rainfall and elevation. However, it is the author's hope that some of the design considerations may be gleaned from this work and be used to inform the development of others.

The following chapter will provide a detailed description and evaluation of the integrated farm of EARTH University, located in Guácimo, Costa Rica.

CHAPTER3

CASE STUDY

EARTH University in Costa Rica was visited in order to better understand the structure and function of the integrated farm system there and to determine the applicability of this system to the UGA Costa Rica Campus. For integrated farms the functional linkages between components are determined by their physical arrangement and interactions, thus an understanding of these relationships is key to understanding the function of the system. The following case study details the pathways that make up the system and how these are facilitated by their configuration. It will start with a diagrammatic look at the system's processes and connections (Figure 2) and then describe them in more detail later.

The Integrated Farm at EARTH University

Earth University has developed an integrated farming system suited to the Caribbean lowlands of Costa Rica. The farm provides both food and biogas for the campus while serving as a teaching tool and laboratory. The campus is located in Las Mercedes de Guácimo, Provincia de Limón, Costa Rica (10°11' to 10°15' North 83°40' to 83°55' West) at an elevation of 59 meters (194 feet) above sea level. The average annual precipitation is 2360.3mm (92.93 inches). The average temperature is 25.6°C (78.6°F) with a maximum of 32.17°C (89.9°F) and minimum of 21.48°C (70.7°F) recorded in 1998 (Del Jesus 1999 p 46). Based on the above characteristics, the site is classified as 'bosque muy húmedo

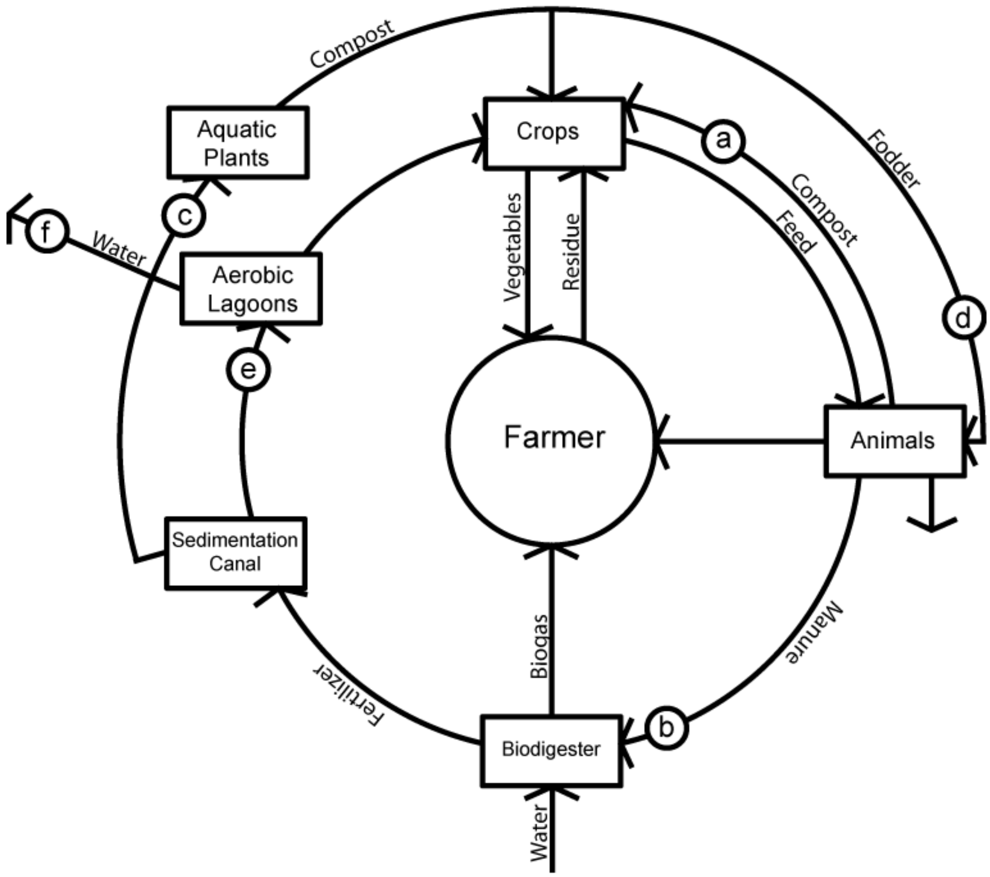


Figure 2. Functional connection diagram of the EARTH University integrated farm.

premontano transición a basal' (superhumid moist tropical forest) in the Holdrige life zone system (Holridge 1982).

A thorough description of the farm is provided by Santos (2005). The major components of the system are pigs, cows, tilapia, aquatic plants, protein banks, a biodigestor and aerobic wastewater treatment lagoons.

Because the system is cyclic, it has no true starting point. For the sake of discussion the description will begin with the process by which manure is converted from waste into biofuel and fertilizer. Manure from the pigs and cows collects on the floor of the animal enclosures. The manure and water slurry is washed twice daily into drainage canals where it is directed to a sieve that separates the solids. This solid material is composted and returned as an amendment to the pastures and vegetable garden (a). The liquid fraction of the slurry enters an anaerobic biodigester where the action of microbes converts the manure into biogas and a rich liquid fertilizer (b). The effluent (fertilizer) then flows out of the biodigester into a sedimentation canal. Aquatic plants grown for animal fodder are produced in the sedimentation canal. The aquatic plants remove the nutrients from the water and store them in their biomass until they are fed to the cattle and swine closing the nutrient loop (c). Solids from the effluents settle in bottom of the canal and are periodically used to fertilize stands of high protein fodder plants for the livestock known as cut feed or protein banks (d). The water leaving the sedimentation canal then enters a series of two aerobic lagoons where aquatic plants further treat the effluent (e). Upon exiting the lagoons, the water is now safe to enter the environment, having had the nutrients it contained returned to the cycle of production (f). Compost made from the organic residues from all of the previous processes is used in the station gardens to grow vegetables.

Biodigestion

A major concern in animal production is the proper handling and treatment of manure. Manure, when improperly handled can cause health risks by spreading disease and by leaching nutrients which enter waterways causing a reduction in water quality. On the integrated farm at EARTH University, biodigestion technology is used to turn manure into a resource.

Biodigestion is the decomposition of organic material in the absence of oxygen by the action of anaerobic bacteria. This process occurs naturally in wetlands, producing biogas, also known as “marsh gas" or "swamp gas." Biogas is comprised of approximately 40% water vapor, 0.01% sulfuric acid and 60% methane (Lansing, Botero and Martin 2008). It burns cleanly and readily making it suitable for a number of uses including heating, lighting and the production of electricity. On the integrated farm, the biodigestion process is harnessed within a biodigester to create methane, to treat animal manures and to produce fertilizer by concentrating the nutrients found in manure. There are many types of biodigesters ranging from the very small and inexpensive systems outlined in this work to multimillion dollar industrial-scale systems that process the waste created in feed lots by hundreds of animals. These large systems often fuel generators which supply electricity for the farm operation and surrounding community.

Biogas is a promising alternative to the bottled propane gas and wood currently used as cooking fuel in rural areas of Costa Rica. Propane gas is most commonly used and is regarded as an improvement over fuel wood because it is cleaner, requires less labor and does not contribute to deforestation. The downside is that propane gas is expensive, is not always available locally, and is made from non-renewable fossil fuels. The use of biogas is a viable alternative to both propane and fuel wood as it is clean, requires little effort to produce, is inexpensive, and is carbon neutral. The appropriate use of biodigesters can also contribute a number of related socio-economic benefits by improving the quality of life for women and children in areas where firewood is still used since the using biogas reduces the amount of labor involved in cooking as no firewood has to be collected and it saves them from inhaling wood smoke which has been linked to numerous serious health issues (Preston and Rodríguez 2002).

In addition providing clean fuels, biodigesters produce an effluent that is a source of fertilizer for fish ponds and crops. EARTH University studies of effluent from the treatment of combined pig and cow manure yielded the equivalent of 45 kilograms of chemical nitrogen fertilizer per 240 liters of the effluent (Vidal 2009). This is of enormous value to farmers. Evidence from informal experiments performed by USAID to test the value of the effluent from biodigesters fueled with goat manure in Brazil showed a positive benefit from the use of this resource. Plots treated with the effluent yielded higher amounts of forage than those that were unfertilized as well as those treated with undigested manure (USAID [Internet]). Similar findings were obtained in Asia where cassava foliage treated with biodigester effluent yielded significantly higher amounts of biomass and protein content than cassava grown with untreated manure alone (Preston and Rodríguez 2002).

The processing of manure in a biodigester reduces the biological oxygen demand (BOD) by 80% compared to undigested manure (Lansing, Botero, and Martin 2008). BOD is a way to judge the quality of wastewater. The lower BOD the wastewater has the less polluting it is. BOD is a measure of the amount of oxygen that will be consumed by bacteria during the process of decomposition of organic matter in an aqueous environment. Wastewater with a high BOD, when introduced to a waterway, will spur the growth of aerobic bacteria as the waste is decomposed. This has the effect of removing oxygen from the waterway thereby creating a toxic environment for other organisms. The bacteria in polluted waterways themselves can be toxic and can block the sunlight needed by aquatic plants. The biodigester prevents this negative impact on waterways by using the oxygen-depleting effects of the wastewater to its advantage to create the anaerobic conditions necessary for biodigestion. Inside the contained environment of the biodigestor, the process of decomposition is performed by anaerobic bacteria that convert the organic material into methane, which is lost from the aquatic system, and stable compounds such as organic acids and alcohols. With a portion of the carbonaceous material removed and a majority of the other components reduced to stable forms, the BOD of the effluent is lowered, allowing it to be treated further in sedimentation canals without creating a polluted environment. Nevertheless, the effluent does contain a concentrated amount of nutrients which could pose problems if discharged untreated into waterways containing other organic material on which the bacteria could feed.

The biodigestion process also reduces pathogens and parasites. As waste is processed in a biodigester, it is sterilized by methane-producing bacteria and the high-methane environment; over 90% of protozoa, cysts and disease-causing bacteria, such as *E. Coli*, are killed (Appropriate Infrastructure Development Group[Internet]). In Brazil, biodigestion was implemented as a way

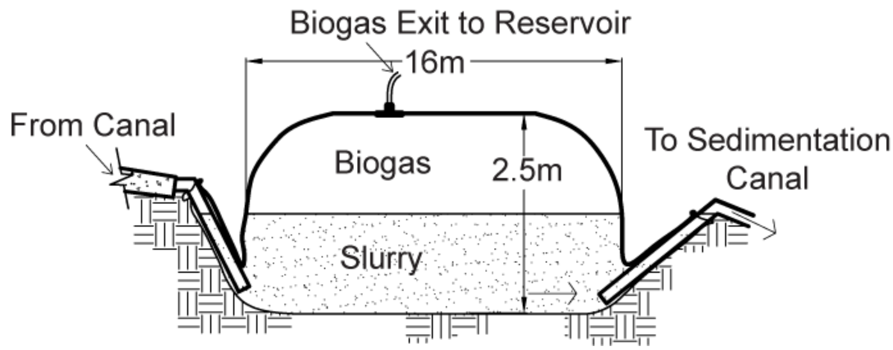


Figure 3. Biodigester diagram. Not to scale.

to increase hygiene and had the effect of increasing goat yields (USAID [Internet]).

The type of biodigester used at EARTH is called a plug flow tubular polyethylene biodigester (Figure 3). Due to its elongated shape, in Spanish speaking countries it is known as a “salchicha,” the word for sausage. Refer to Brown (2004) and Rodríguez and Preston (2004) for a complete description of the construction and installation of this technology. EARTH uses two large biodigesters, each 16 meters in length and 2.5 meters diameter. The biodigesters are made from two layers of heavy gauged tubular UV stabilized polyethylene plastic. The tubes are sealed at each end with an airlock created by the configuration of the slurry inlet and outlet pipes which allow the entry and exit of the manure and water slurry mixture without the introduction of air.

Each day, slurry from the barn containing the milk cows and the swine production facility is added to the digester. The optimum composition of the slurry is one part manure to four parts water. This volume will vary according to the amount and size of the animals actually in production at any given time. To ensure the correct slurry ratio the amount of time the wash down hose is used is regulated. The hose has a constant rate of flow and, knowing this rate, one can calculate the maximum number of minutes the hose should be used to deliver the appropriate amount of water. It is better to use too little water than too much. Excessive water will dilute the mixture resulting in the residue not spending sufficient time in the digester to be completely processed before it is discharged.

The slurry flows to the biodigester by gravity in concrete canals. Before the slurry can enter the biodigester the fibrous solids must be strained from the mixture. If the large particles were allowed to enter they would form a cap at the top of the water causing the production of biogas to slow. The material removed from the slurry is either composted or made into bokashi for use as a soil amendment. The production of bokashi will be discussed later.

Once inside the biodigestor, the slurry remains for at least 22 days and as long as 50 days to ensure complete digestion. This period is known as the retention time. EARTH University recommends a retention time of 22 days minimum for their location in the warm Caribbean lowlands of the eastern part of Costa Rica and a longer period in cooler regions (Santos and Valladares 2005).

As the fresh slurry is added, it displaces an equivalent amount of processed material. This method of biodigestion is known as plug flow because the new material theoretically travels through the biodigester as a unit or plug, though in reality the plug mixes within the unit and may be treated for more or less time. The plug flow biodigester is well suited to farm systems where new material (manure) is created and treated daily, thereby reducing the amount of material that is stockpiled. This is in contrast to batch-type digesters in which all of the material to be processed is added at the start of a discrete digestion period which runs without the addition of new material.

Biogas is produced constantly and therefore must be stored for later use. It is collected in a reservoir bag of the same material and size as one of the biodigestors. From the reservoir, it is compressed and stored in tanks for use in cooking in the campus kitchen. Before it can be stored, it must be chemically treated to remove the water and sulfuric acid. This is accomplished with a simple device made by placing steel wool or iron filings into the pipe that the gas travels through. The sulfuric acid reacts with the metal becoming trapped as iron sulfate. The iron material is replaced periodically as it becomes corroded.

The biogas is also used at the farm to cook the food scraps from the dining facility that are fed to the pigs thereby killing any bacteria in the food that may be harmful to the animals. The gas is also used to warm the piglets in a brood box. This is a concrete box mounted with a harrow disk at the top under which a flame burns. Because the gas is lighter than air, it rises within the piping. For this reason the system works best if the gas is burned at a higher elevation than the reservoir. To overcome the need to have the point of use higher than the reservoir, the bag can be pressurized with elastic bands. This will allow the gas to be used even when it is partially deflated.

Table 1. Aquatic plants for animal fodder.

English Common Name	Scientific Name	Spanish Common Name
Water Spinich	*Ipomoea aquatica*	Espinaca Aquatica
Water Hyacinth	*Eichhomia crassipes*	Lirio aquatico
Azolla	*Azolla spp.*	Azolla
Water Lettuce	*Pistia stratiotes*	Lechuguilla
Salvinia	*Salvinia natans*	
Lesser Duckweed	*Lemna minor*	

Soaps, chemicals (e.g. chlorine in treated water) and antibiotics will kill the microbes in the biodigester. To prevent these from entering the biodigester (e.g. when the animal pens need to be disinfected or treated to prevent the spread of disease) a bypass pipe is used to route the slurry around to the aerobic treatment lagoons.

As new slurry is added each day, an equivalent portion exits. This concentrated effluent is rich in nutrients having had a large portion of its carbon removed by the filtration process and through biodigestion which converted it to methane. In this system, the liquid fertilizer effluent is channeled into an aerobic sedimentation canal or applied to crops or pastures.

<u>Sedimentation Canals</u>

The sedimentation canal is used to further treat the effluent from the biodigester and to grow high protein aquatic plants for animal fodder. As the plants grow they absorb the nutrients from the fertilizer holding them in a stable form in their biomass which allows them to be recycled and retained in the system. These plants (Table 1) are frequently removed, leaving a portion in the canal to multiply, and either composted or preferably fed directly to the livestock. The important species are water hyacinth (*Eichhomia crassipes),* water spinach *(Ipomoea aquatic*), Azolla (*Azolla spp*.), Water Lettuce (*Pistia stratiotes*), Salvinia (*Salvinia natans*) and Lesser Duckweed (*Lemna minor*). See Mendoza and Sánchez (2006) for a synopsis of these plants' nutritional values and potential usages. Azolla is notable due to its ability to fix atmospheric nitrogen. All of these plants provide high percentages of protein and can represent a significant source of nutrition replacing concentrated animal feed in the livestock diet. Figures 4: (a),

(b) and (c) provide technical specifications for the canals' construction. Water leaving the canals at EARTH University has been determined to have a BOD of less than ten percent of its original content (Santos and Valladares 2005).

The sedimentation canals are constructed of four inch thick reinforced cement and are 24" deep by 22" wide at the top and 12" wide at the bottom. The length varies based on the volume of effluent to be treated. At EARTH there are approximately 8 canals connected in series to accommodate a 10-day retention time. Sediment collects in the bottom of the canals and is removed for application to fertilize the "protein banks". Protein banks are plants grown for animal forage. These will be discussed in detail later. After leaving the sedimentation canal, the effluent is directed into a series of aerobic lagoons for further treatment.

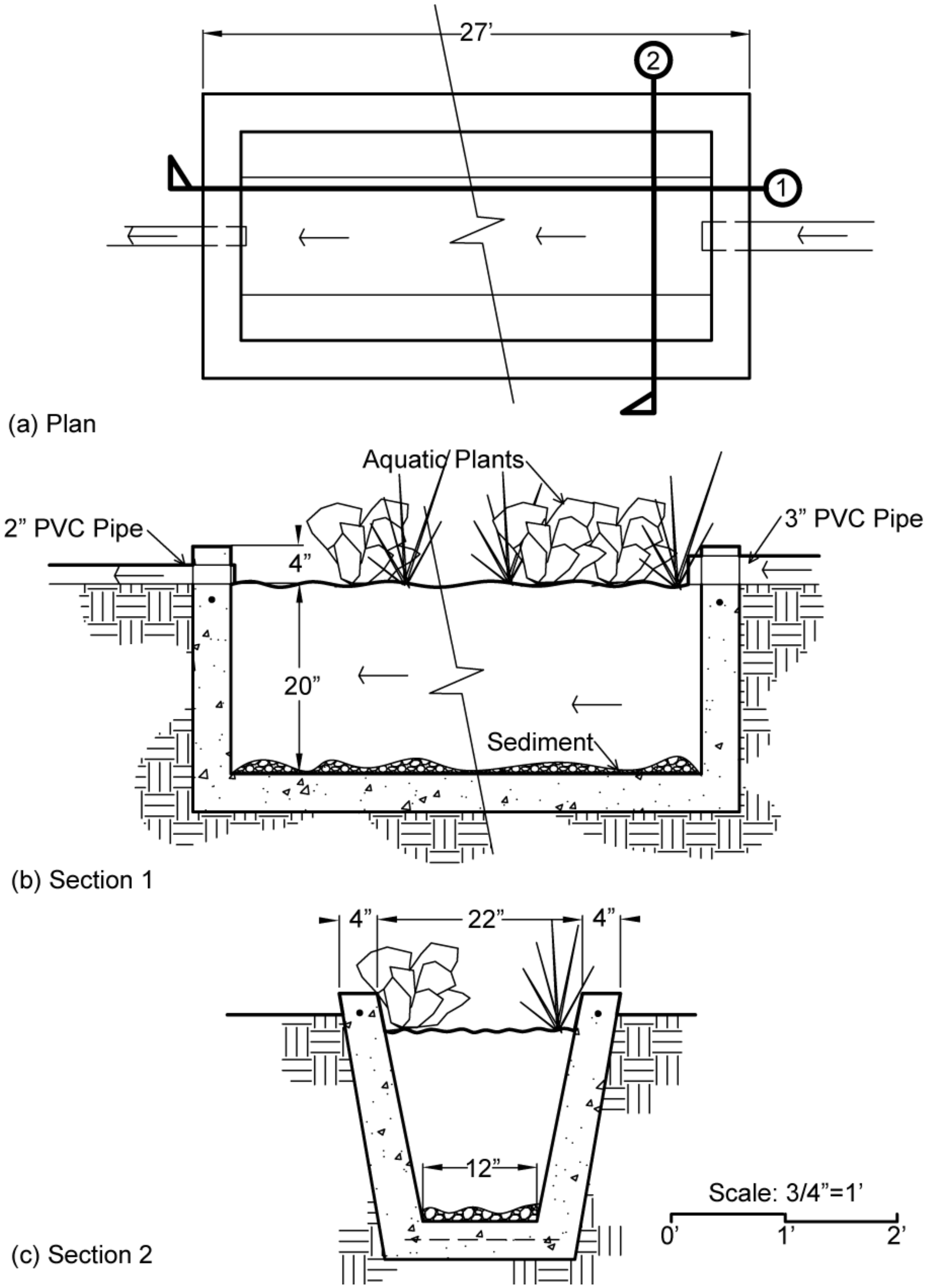


Figure 4: (a),(b), (c). Sedimentation Canal at EARTH University.

Purification Lagoons

There are five, free-water, surface purification lagoons at EARTH which function aerobically. They are unlined basins five feet deep designed with a retention time of 20 days each and are connected in a series. As in the sedimentation canals, aquatic plants are grown in these lagoons to help treat the water and for use as animal feed. Tilapia are grown in the first two lagoons using the later lagoons to further treat the water from this activity.

EM

EM (Effective Microorganisms) is a manufactured product first developed in Japan 25 years ago by Dr. Teruo Higa professor of horticulture at the University of the Ryukyus in Okinawa, Japan. A number of companies now market similar products under the names “beneficial microbes,” efficient microbes,” and “compound microorganisms.” EM is a cultured mixture of microorganisms including lactic acid bacteria, yeasts, acetic acid bacteria, phototrophic purple non-sulphor bacteria, non-pathogenic actinomycetic bacteria (ray fungi) and other fungi specially bred and selected for their vigor. Each of the organisms in EM is benign or beneficial to humans and each has specific uses applicable to the integrated farm. For example, at EARTH EM is used to inoculate compost piles to increase the speed and efficiency in which they mature, as a disinfectant, as an inoculum for the production of bokashi and for reducing odors (Shintani and Yepez 2000). EM works because it contains a variety of organisms each of which has a specific niche in which it thrives. When applied, the microbes in the mixture, which are suited to the particular environment where they are being used, proliferate - often driving out pathogenic or otherwise harmful microbes. For example, in the production of compost, the anaerobic bacteria are inactive while the ray fungi multiply rapidly, quickly breaking down the organic material. EM is sprayed daily on the floors of the barn and swine facility to reduce odors.

Bokashi

Bokashi refers to the product of a process by which organic material is stabilized, primarily by the action lactic acid bacteria, by converting carbonaceous material into organic acids beginning the process of biodegradation. This process is similar to pickling food. It is used to treat the solid residues which are strained from the manure slurry before it enters the biodigester and placed in a pile. These solids are comprised of fibrous material that drains easily, does not attract flies and tends not to have a typical manure odor. An 8% solution of EM activated by the addition of molasses is applied to the pile on a weekly basis. The pile should be mixed thoroughly each week, as the EM is applied, to ensure even distribution of the inoculant. The process is complete after a number of weeks when the material has reached a dry crumbly consistency. It can then be applied to the fields and garden as an amendment where it will rapidly degrade into the soil. During the bokashi process the material should be stored in the compost area and remain dry except for the EM inoculation. Instead of composting, the bokashi process is used to treat this material because composting would be very slow due to the material's low nitrogen to carbon ratio.

Protein Banks

Protein banks or cut feeds are plants grown for fodders and forage. They are used to improve animal production by replacing purchased protein concentrate feeds. Cut feed is a term to describe a number of high biomass yielding plants which are also higher in protein than pasture grasses. They are large plants that are cut with a machete and carried to the cattle and swine. On flatter ground and larger farms this process can be mechanized. At EARTH University, King Grass (*Pennisetum hybridum*), Elephant Grass (*Pennisetum purpureum*), Imperial Grass (*Axonopus scoparius*) and Sugar Cane (*Saccharum officinarum*) are grown. Sugar cane is processed into molasses which is given to the cattle as feed supplement and its leafy tops are good cattle fodder. Before cut feeds are fed to the animals they are finely shredded by a machine to increase their palatability. Some non-grass cut feeds used are White Mulberry (*Morus alba*), Cratylia (*Cratylia argentia*) and Wax Mallow (*Malvavisco arboreus*). These are all shrubs from which leaves are harvested for fodder. Mendoza and Sánchez (2006) provide a summary of the cultivation and use of many of these plants and Table 2 provides a more complete list of these forages.

In areas that experience prolonged dry periods, these plants offer a way to sustain livestock during dry periods because, unlike pasture grasses, they remain productive during drought or can be grown during the wet season and harvested as needed in the dry period.

Figure 5. Elephant Grass (*Pennisetum purpureum*) growing at Terra Viva near Santa Elena de Puntarenas, Costa Rica.

They make land use more efficient because they allow greater productivity from a given area of land; 0.25ac (0.1 hectare) of cut feed can supply all the dry matter and nearly all the protein for a producing dairy cow (CATIE 1983). In contrast, about 1.24ac (0.5 hectares) per cow is required of typical upland pasture (Griffith, Peck and Stuckey 2000). The additional labor needed to process the cut feed is an oft cited drawback of the system; but its widespread and increasing use is evidence of its usefulness to the farmer. Another benefit cut feed provides to the farm is a reduction in erosion because the cattle generally do not graze in the protein banks which can be planted on steep marginal hillsides. However, some farmers allow cattle to graze the protein banks directly to reduce labor inputs.

Table 2. Cut feed/protein banks. Key: Porcine=P, Bovine=B

English Common Name	Scientific Name	Spanish Common Name	Habit
Elephant Grass	*Pennisefum purpureum*	Elefante	B, grass
Imperial Grass	*Axonopus scoparius*	Imperial	B, grass
King Grass	*Pennisetum hybridum*	King Grass	B, grass
White Mulberry	*Morus alba*	Morera	BP, shrub
Sugar Cane	*Saccharum officinarum*	Canya de Azucar	BP, grass
Trichanthera	*Trichanthera gigantea*	Nacedero	BP, shrub
Ramie	*Boehmeria nivea*	Ramio	BP, shrub
Wax Mallow	*Malvavisco arboreus*	Amapalo	BP, shrub
Cratylia	*Cratylia argentea*	Cratylia	BP, legume shrub
Coral tree	*Erythrina poeppigiana*	Poró	BP, legume tree

Their height also allows them to function as windbreaks when planted as contour strips for erosion control.

Beef and Dairy Production

The cattle at EARTH are milked twice per day. They are to be held in the milking parlor for a total of 6 hours per day divided between the two milkings so that they may be given cut feed, minerals and any supplements that might be needed. This also allows manure to be harvested for conversion to biogas and fertilizer in the biodigester. They are allowed to graze for 18 hours per day. They are dual-purpose cattle raised for both meat and dairy.

Swine Production

Swine are raised from start to finish in a partial confinement system. Piglets are weaned after three weeks. For the next two months, in the early development phase, they are allowed free range in an outdoor corral. The final stage is the fattening which takes from four to six weeks. This is done in a swine fattening facility. The enclosures contain a "pool" in which the pigs can wallow which reduces stress on the animals (Figures 6 and 7). These pools are filled with rain let in through a gap in the roofing material. They are drained daily by the use of a rotating 3" PVC elbow set into the drainage canal which delivers the slurry to a separator and then to the biodigestor. It remains questionable as to how the correct amount of water is metered to ensure the correct slurry ratio since the rainwater flows freely into the pens and then into the digester. Mendoza and Sánchez (2006) describe a method by which the facilities inexpensive and durable ferrocement walls are made from materials commonly available on farms. The walls are from 4" of concrete applied in layers over a lathe of welded steel reinforcing mesh and feed sacks. They are 36" tall. The pens are sufficiently large, 12'x9', to reduce animal aggression. In both the early development and fattening phases the pigs are fed aquatic plants, supplements, bagasse, kitchen scraps, grain and cut feeds. The use of concentrated feed is minimal. The animals are harvested at 85kg.

Figure 6. Swine fattening facility at EARTH University. In the foreground is the pool, in the background are ferrocement walls and the cistern.

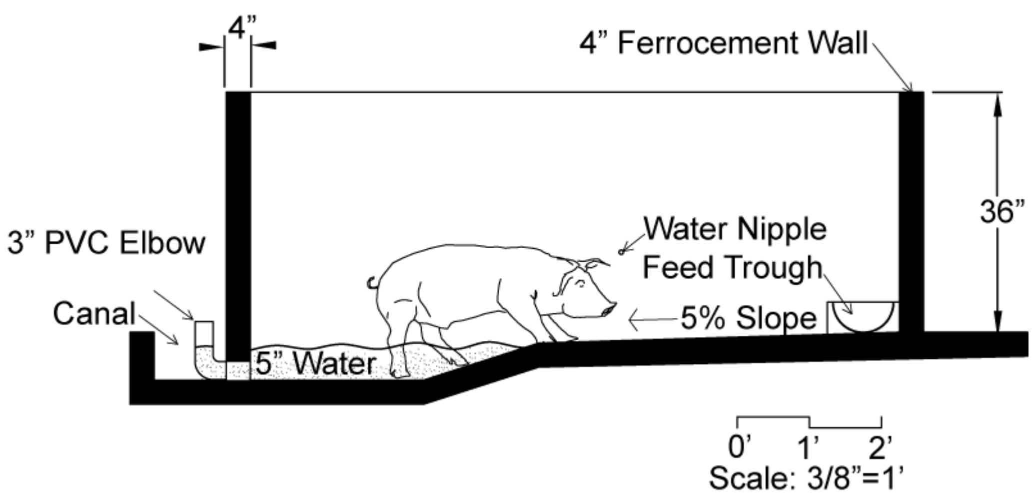


Figure 7. EARTH University pig pen featuring pool and drainage system.

This system requires four months for maturity instead of the standard three month period of industrially produced pork raised entirely on concentrate (Diaz and Vega 2000). EARTH's more natural system with its the free range period creates more healthy and disease resistant animals that fetch premium prices (Vidal 2009).

In contrast to many systems in Asia which produce mainly poultry, fish and grain for direct human consumption (Fukuoka 1985), the system at EARTH is designed to yield beef, pork and dairy. As a result, the system contains a number of crops that are grown to feed the animals including corn, soy, and sugarcane. Soy is grown not for human consumption but to fatten the livestock. This represents a loss of efficiency in the system, but one that is made up economically as the market price for these products is high.

The integrated farm at EARTH University is a diverse and mostly self-sufficient system that utilizes improved methods of production to reduce the environmental impact of farming. This is achieved by what is known in the business world as vertical integration. That is to say, the many processes required to produce a product are combined under one system of management to increase efficiency and reduce costs. Also, by retaining nutrients and returning them to the system, a cyclical flow is created, conserving the resources which otherwise would be lost and need to be replaced to sustain yields. This is the case in highly linear conventional production which purchases feed from outside sources and is then unable to recover the nutrients in the resulting manure.

Having articulated the structure and function of the integrated farm at EARTH University, the next step in the design process is to detail an inventory and analysis of the UGA Costa Rica Campus in preparation for creating a novel site-specific design.

CHAPTER 4

INVENTORY AND ANLYSIS

The UGA Costa Rica Campus and Its Surroundings

The UGA Costa Rica Campus sits in the San Luis valley on the leeward side of the Tilarán Mountain Range at an average elevation of 1270 meters above sea level. Adjacent is the world famous Monteverde Cloud Forest Reserve – renowned for its spectacular beauty, unique ecology and high biodiversity. Eight kilometers uphill lays the bustling tourist town of Santa Elena. Each year thousands of tourists flock to this Mecca before venturing into the magical cloud forest with its dripping carpet of mosses and ferns in search of a glimpse of the resplendent quetzal, tapir or golden toad. San Luis, down in the valley, is a community of 375 or so people struggling to maintain a traditional way of life in the face of a rapidly change brought on by tourism. Until recently, when a new road was completed, San Luis was effectively isolated from the activity of its neighbors. This kept the Valley rural and agrarian in character and pace. Small farms dot the landscape, and the families that work them, still tight knit, bonded to one another by tradition and necessity. It is within this fabric that UGA Costa Rica is woven.

The campus is intentionally designed and managed to be harmoniously integrated with its cultural and natural surroundings. Culturally, the campus strives to work to be a positive force within the community. It is the Valley's single largest employer with a permanent staff of around thirty people, the majority of whom are from the local area. The campus encourages interaction between employees, guests and the community through parties, tutoring, workshops, and an internet café open to the public. Students have the opportunity to participate in homestays where they live as part of a local household, further linking the campus activities to the community. The architecture is derived from the local vernacular style and the entire campus is seated in a working farm. Traditional food is served in the dining hall and tours of local farms allow visitors to experience life in rural Costa Rica. Environmentally, the ecology and natural history of the site is interpreted for guests by a staff of trained naturalists. Researchers are hosted onsite. Both guests and researchers alike learn from the protected forest, which makes up sixty percent of the property, or they can travel to the adjacent reserves using the campus as a home base. A true sense of place is actively fostered for visitors, creating an experience for guests which is authentic and far more rewarding than those readily available elsewhere in the country.

To better understand the physical and cultural environment as it exists today it is important to look to the history of the site for clues about the forces that have shaped its present form. In this case, the known history of the area and campus is relatively short. The discovery of stone tools suggests that the valley was once home to an indigenous population possibly in permanent or semi permanent settlements, though none were present in the early part of the 20th century when the first European settlers arrived. Most of the older families in San Luis valley display *metates* and *manos* (a type of flat mortar and pestle carved from volcanic rock used for grinding grain) recovered from their land and the earliest settlers recall that parts of the forest were secondary growth when they arrived indicating that the land had been cultivated and abandoned relatively recently (Griffith, Peck, Stuckey 2000).

Refer to Griffith, Peck and Stuckey (2000) for a thorough account of the agricultural practices and culture of the area, both past and present. The known history begins when the first Western settlers arrived in the 1920’s. They immediately created clearings in the forest for home sites and food plots. With external trade difficult due to the remote location and poor roads, these early inhabitants were relegated to subsistence farming. This remained the case until the 1950’s when a group of Quakers from the United States settled in the area three kilometers uphill from the San Luis valley and named it Monteverde. Monteverde’s high elevation and frequent cloud cover create a cool climate that is well suited to dairy farming. Realizing the potential for the production of cheese, a high value product stable enough to be transported over long distances, the Quaker settlers opened the Monteverde Cheese Factory. In doing this, they overcame one of the difficulties of their isolation by producing a revenue generating product. Soon the demand for milk to feed the factory rose and they began to buy from local farmers including those in San Luis. This had two transformative effects. It spurred further clearing of forests for cow pasture and it gave the farmers the money they needed to improve their quality of life (Chornook and Guindon 2008). Coffee was the next product to prove important to the development of the area. It is so prevalent and well suited to the climate that naturalized plants can be found along many of the trails, the seeds deposited there by birds. It was first planted in the 1970's but not in great abundance until the formation of the Cooperativa Santa Elena in 1989. The processing of coffee is time consuming and labor intensive when done by hand, but when the Cooperativa built a mechanized processing facility in lower San Luis it allowed families to plant and harvest much more since they were no longer limited by the amount that they could process by hand. Thus the valley changed again as cattle pasture was converted to coffee orchards and more trees were felled to make room for the crop. Today, most farms have at least a small stand of coffee and the orchards are being increased in size and number. Even the campus had a small plot until recently when it was replaced with vegetable crops. The San Luis valley, and indeed much of the mountainous area outside the reserves, follows a general land use pattern where any land with a slope of thirty percent or less has been cleared for pasture or crops. In many areas, even much of the steeper land, too steep for cultivation, is cleared for use as cattle pasture. Thus the landscape is a patchwork of fence rows, pasture, farm houses and remnant forest.

In 2001 the University of Georgia acquired the Ecolodge San Luis and Research Station. Since 2001, the site has been developed into a fully equipped educational facility retaining its agricultural and Ecolodge activities. The property has had a similar history to that of the San Luis valley – early indigenous inhabitation, homesteading and subsequent deforestation for agriculture sometime between the 1920's and 1950's. Thirty percent of the property is used for agriculture mainly producing beef, pork, fruit and vegetables. Eighteen

Figure 8. Altos de San Luis Valley. Notice the deforested and steeply sloped hill sides. The UGA Costa Rica Campus lies just over the rise in the center of the photo. In the background are clouds that are dissipating as they travel westward towards lower elevations.

percent of the land, 20.58ac, is cleared of trees. These areas are where the primary agricultural production occurs.

Sixty percent of the total 153 acres (62 hectares) is protected primary and secondary forest registered with Costa Rica's National Network of Private Reserves (Red de Reservas Privadas [Internet]). A network of trails two and a half miles long leads visitors among the steep valleys, ridges, agricultural fields, and orchards characteristic of the site. The remaining ten percent is comprised of the campus and living space, including facilities for academic instruction, research, food service, residences, recreation, and

Figure 9. UGA Costa Rica master plan. Courtesy of Gregg Coyle.

Figure 10. Master Plan of the UGA Costa Rica Campus. Courtesy of Gregg

Figure 11. Costa Rica regonal context map (Google Maps).

Figure 12. Costa Rica country map (Google Maps).

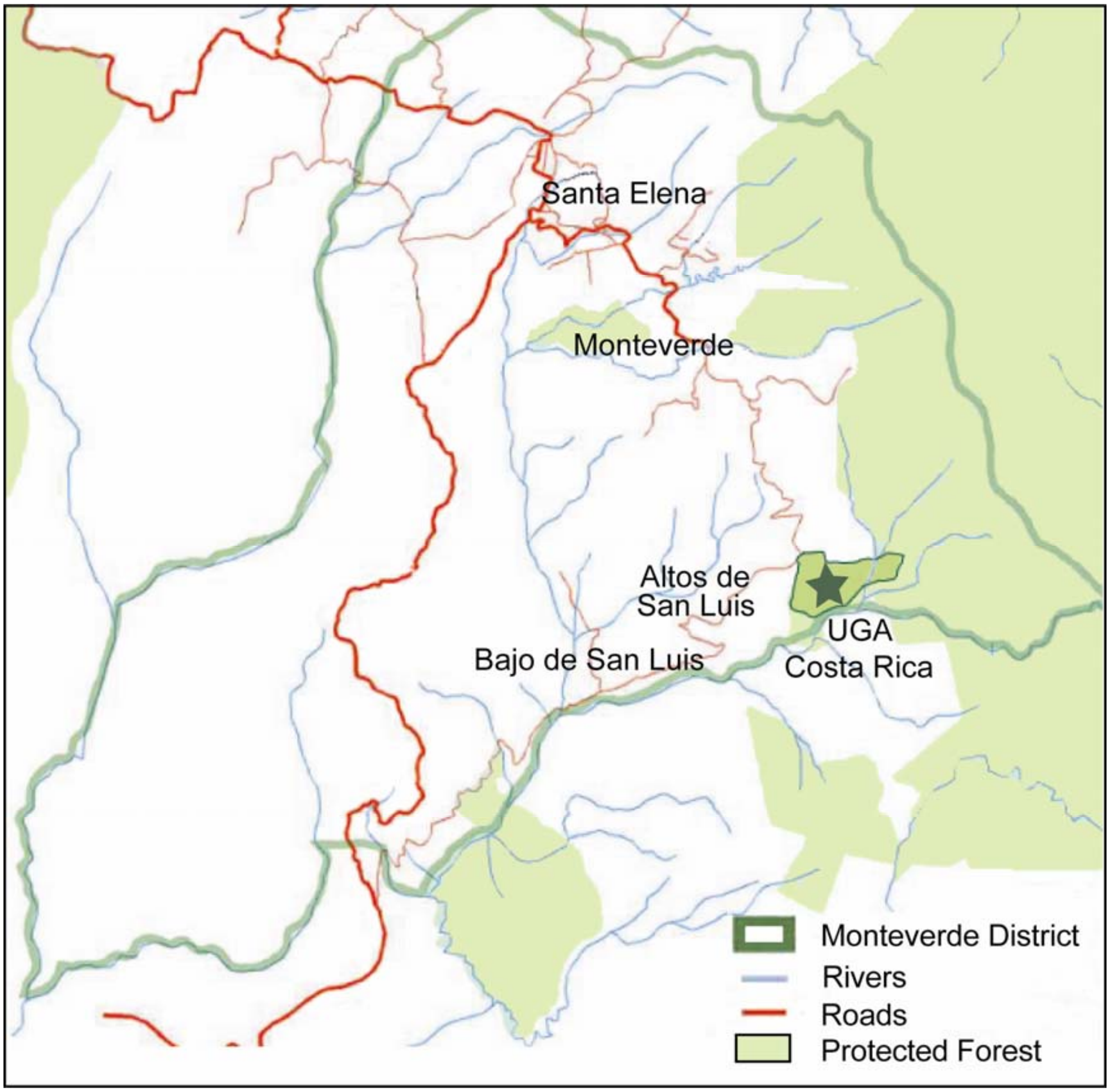


Figure 13. Protected areas adjacent to the UGA Costa Rica Campus. Map courtesy of the Monteverde Institute.

maintenance/housekeeping. The development of the integrated farm is limited to the extant agricultural area with small additions in the campus area for small cooking herb and garden plots.

UGA Costa Rica Campus Inventory and Analysis

For clarity, the inventory and analysis section is formatted so that the inventory is presented along with the appropriate analysis.

Weather

The climate of Alto San Luis de Monteverde Costa Rica, 84°46'W Longitude 10°15' Latitude, is classified under the Holdridge Life Zone System as tropical premontane wet forest. The temperature ranges from 59° to 77° Fahrenheit (15 to 22° Celsius) which feels much like a temperate spring year-round.

Total average rainfall is estimated to be 3420mm or almost 8 feet. A majority of rainfall events occur in the afternoon between 3pm and 5pm as the humidity level of the air increases due to the respiration of the forest in the heat of the day (Clarke 2000). The weather is categorized into three seasons based on rainfall amounts received in each: 'wet' occurring May through October, 'transitional' November through January and 'dry' February through April (Clarke 2000). Most of the 'dry' season receives consistent precipitation events but there are years where infrequent rains necessitate the use of irrigation on fragile vegetable crops like lettuce (Leiton 2009). The weather patterns are governed mainly by the migration of the Intertropical Convergence Zone (ITCZ). Warm moisture laden air from north and south of the equator converge at roughly the latitude of the sun as it moves between the Tropics of Cancer and Capricorn and create a mass of air moving toward the east. From May to October the ITCZ migrates over Costa Rica bringing intense convective precipitation events.

Rainfall is heaviest in June and from September to October. There is a slight ease in the rainy season for a period of two weeks in July known as the ‘little summer” or “veranillo”. In the transitional and dry seasons the ITCZ is located south of Costa Rica. During this time moisture is brought to the region via Northeasterly trade winds from the Caribbean Sea (Clarke et al. 2000). Also during this time strong damaging winds are experienced. They are a major factor in the design of buildings and placement of crops, as both must be protected from their effects. Crops are protected by windbreaks and by being planted in sheltering “milpas” which are small clearings in the forest. Buildings are enclosed on the windward side (East and North) and are often sheltered with trees as well.

In comparison to Monteverde and Bajo (Lower) San Luis, Altos (Upper) de San Luis where the campus is located experiences a unique microclimate created by its elevation (1075m-1375m) and position on the leeward (Western) side of the Tilarán Mountain range. Warm moist air moving from the Northwest across the Caribbean lowlands is lifted up on the windward slope of the mountains where it experiences a phenomenon known as adiabatic cooling. As the air rises, it expands due to lower atmospheric pressure at increased elevation. The expanding air pushes against the surrounding atmosphere. In doing so it loses heat. Cooler air conveys less water, thus the relative humidity increases to one hundred percent in the air mass as it cools. The result is that the moisture in the air condenses to form clouds and precipitation. Areas that lie in the zone of condensation are bathed in moisture for a vast majority of the year and are known as cloud forests. The Monteverde Cloud Forest Reserve, located just 4 kilometers from the campus is the most famous, studied and visited in the world. The campus is situated in the transition zone below the cloud forest, where the air has lost a portion of its moisture through precipitation. At this elevation, condensation is possible but not constant. Here the clouds dissipate overhead as the drier and denser air begins its downward descent toward the Pacific. The dissipation is a result of the adiabatic heating of the air as it is recompressed and heated at lower elevation. The warm air is able to carry more water than is present, causing the clouds to evaporate. Rainfall in Altos de San Luis is plentiful but slightly less than that of Monteverde 100m higher. At the lower elevations of Bajo de San Luis and beyond there is a noticeable decrease in rainfall due to the rainshadow effect.

What this means for the integrated farm design is that many species of fruit and otherwise useful trees do not perform well in the high moisture conditions of Altos de San Luis. Their growth is stunted and yields are low. For example, mangos and cultivated avocados do not yield appreciably enough to warrant their planting here. Yet, Bajo de San Luis, situated at least 100m lower in elevation, experiences a much drier and less windy climate and is thus more suited to fruit tree culture. Trade for these products is common on the campus. The lower temperatures do have an advantage in that the climate is conducive to dairy farming, allowing high yielding Jersey and Holstein milk cows to be raised, a practice that is not possible at lower elevations.

Solar Pattern

At 10°N latitude, Costa Rica receives two periods of maximum solar radiation each year as the sun reaches its zenith overhead. This occurs once in May as the sun moves northward towards the Tropic of Cancer in northern Mexico and again in August as it is travels southward toward the Tropic of Capricorn (Janzen 1983). The periods of highest solar radiation correspond to the more rainy times of year. During this period, from May to October which corresponds roughly to the North American summer, know in Costa Rica as winter, much of the solar radiation is attenuated by the constant cloud cover associated with heavy rains (Janzen 1983). This is also the when the coolest temperatures are experienced. This means that the time of the year when planting is most ideal, that is in November through January when the rains are light; the solar radiation is at its lowest. Yet, crops planted in this period grow at twice the rate of those planted in winter (Otoniel 2009).

Soils

Soil survey and soil test data is lacking for the site. General soil surveys and research conducted in Monteverde indicate that the soils of the site are Andepts (also known as Andisols). Andept soils were formed on volcanic ash deposits. These ash-derived soils are found at elevations higher than 600 m, on mountainous relief with slopes of 30-80%, with model profiles occurring at elevations between 1000 and 1800 m. These Andepts have a fairly uniform morphology, and the amorphous materials have become strongly stabilized with the soil organic matter to give the dark color, loamy texture, granular-fluffy structure, friable-smeary (thixotropic) consistence, acid reaction, low bulk density, high porosity and water retention, and high cation exchange capacity. Andepts are relatively freely drained. They are rich in either glass or allophones, such as amorphous clays. Found in any latitude, these soils are restricted to areas in or near mountains with active volcanoes (Martini 1985).

Unlike in warmer areas of the tropics, topsoil here is quite deep owing to a high rate of productivity and low rate of decomposition. The undisturbed areas of primary forest depths of topsoil can be more than six feet. In the agricultural lands the topsoil is still generally quite deep, reaching depths of several feet in most places even after years of grazing and cultivation. In the pasture adjacent and to the west of the main campus the soil has been degraded by intense grazing and must be rehabilitated.

Being highly friable, the soils are quite erodible when not held in place by vegetation. It is of the utmost importance to protect them through physical control methods and proper management techniques. These will be discussed in detail later. Similar sites in Costa Rica show a high content of organic matter ranging from 19-47%. This high organic content contributes large amounts of free hydrogen ions to the soil which bind to cation exchange sites having the effect of reducing the effective cation exchange capacity. The hydrogen ions also lower the soil pH to a range from 5.4 to 3 (Clarke, Lawton and Butler 2000). Both low pH and cation exchange capacity reduce productivity. Farmers in the area frequently apply lime by hand to counter these effects. Results of soil tests will determine the application rates for this amendment if needed.

Farmer's experience in Monteverde shows that the soil is only productive for five years or so after clearing the forest. After five years the soil nutrients have been depleted such that vegetable production is not possible without amendment. In this condition the land is used for pasture (Chornook and Guindon 2008). It is the intent of this design to begin the process of regenerating the soil and its productive potential.

Vegetation

Refer to Haber (2000) for an in-depth look at the vegetation of the Monteverde area including a list of the dominant forest tree species. The campus is classified as tropical premontane wet forest (bosque muy humedo-Premontano). Although the weather patterns are anthropologically broken into dry, wet and transitional seasons, because precipitation occurs year round and is never truly dry, the forest is classified as aseasonal. The vegetation is an evergreen forest with large numbers of epiphytes in moderate diversity. Tree heights are normally between 65-130 feet (20-40m) but can be as tall as 150 feet in sheltered valleys (Haber 2000). The understory in undisturbed areas is open. In openings and along trails and roads a thick shrub and herb layer forms if not cleared. The high rain amounts favor the growth of epiphytes which cover the topsides of most trees. This contributes significantly to the amount of biomass per unit of area.

Hydrology

The Monteverde area is highly active hydrologically due to high amounts of rainfall and because it is constantly saturated. Two permanent rivers rivers flow through the site, the Rio Alondra and the Rio Bruja. These rivers are

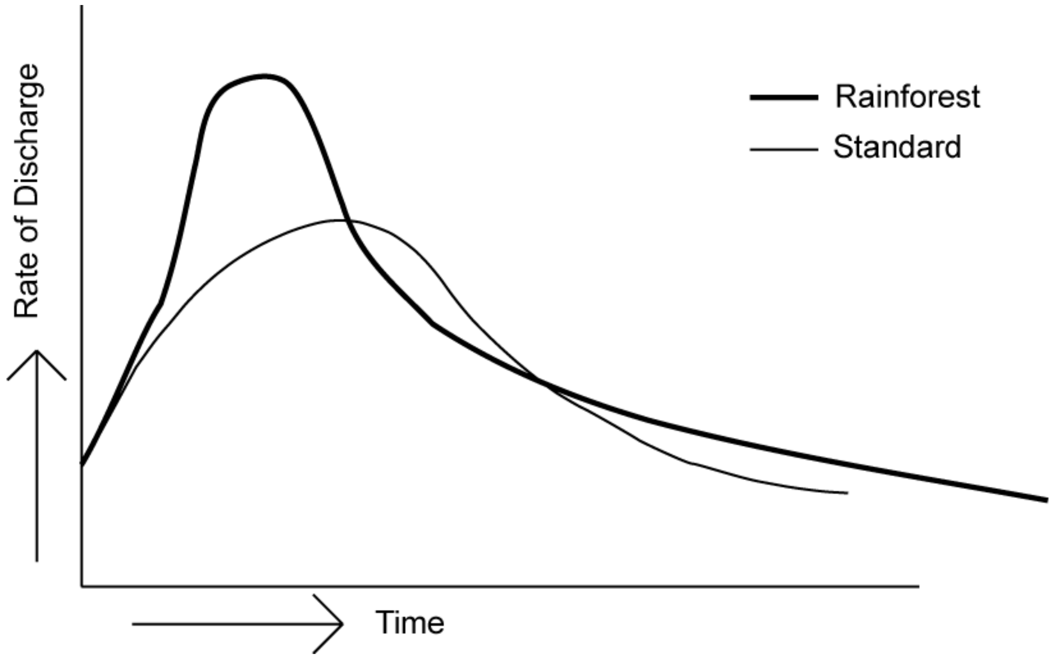


Figure14. Hydrograph showing the characterisitc short peak and long recession limb of rain events in moist tropical environments. (Clark, Lawtona dn Butler 2000).

characterized by clear fast flowing water. Neither is bridged. During and after heavy rains the road across is impassable due to the ferocity of the water which regularly moves large boulder downstream. They are a source of non-potable water for the farm and have the potential to supply the inertia needed for the production of micro-hydroelectric power. The Rio Alondra forms the Southwest boundary of the property.

Several springs arise on the property one of which flows year round and provides a portion of the water for the campus. Two small ponds are located on the property, one on each side of the road just past the cabina access road. The northern lagoon retains water year round and other is seasonally dry. They are located in open pasture in slight depressions in a saddle.

An interesting characteristic of the cloud forest is that due to the high number of epiphytes and high leaf surface area a large portion of hydrologic inputs are intercepted and never make it to the ground. Clark (1998) calculated this number to be as high as 38% for the leeward cloud forest of Monteverde. With the full amount of precipitation falling on pastures and deforested areas of the area this represents a major alteration of the hydrologic cycle and makes it especially important to minimize runoff from the site.

Another noteworthy property is that the high amounts of organic matter in the soil retain large volumes of water having the effect of lengthening the hydrological time of rise and extending the recession limb following rain events (Clarke, Lawton and Butler 2000).

<u>Elevation</u>

The property spans an elevation from 3,520 to 4,511 feet (1075m-1375m) above sea level. The influence of the elevation on the site is described above as it pertains to climate, temperature and weather.

<u>Aspect</u>

Due to the hilly terrain all aspects are represented on the property. The proposed site faces the ideal West-North West exposure. This orientation is ideal since it will allow the much needed afternoon sun access to the site for solar heating and better plant growth.

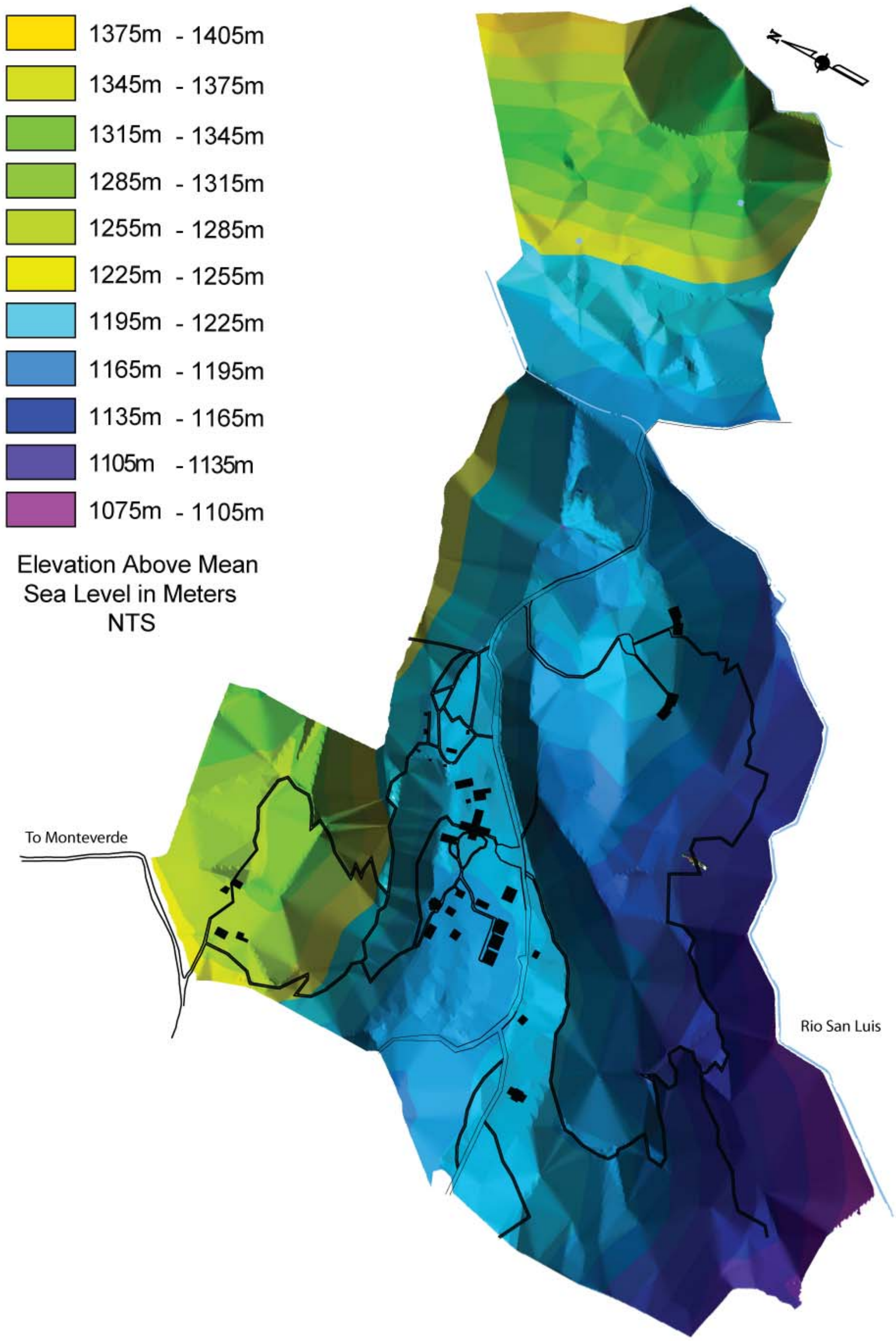


Figure 15. Elevation.

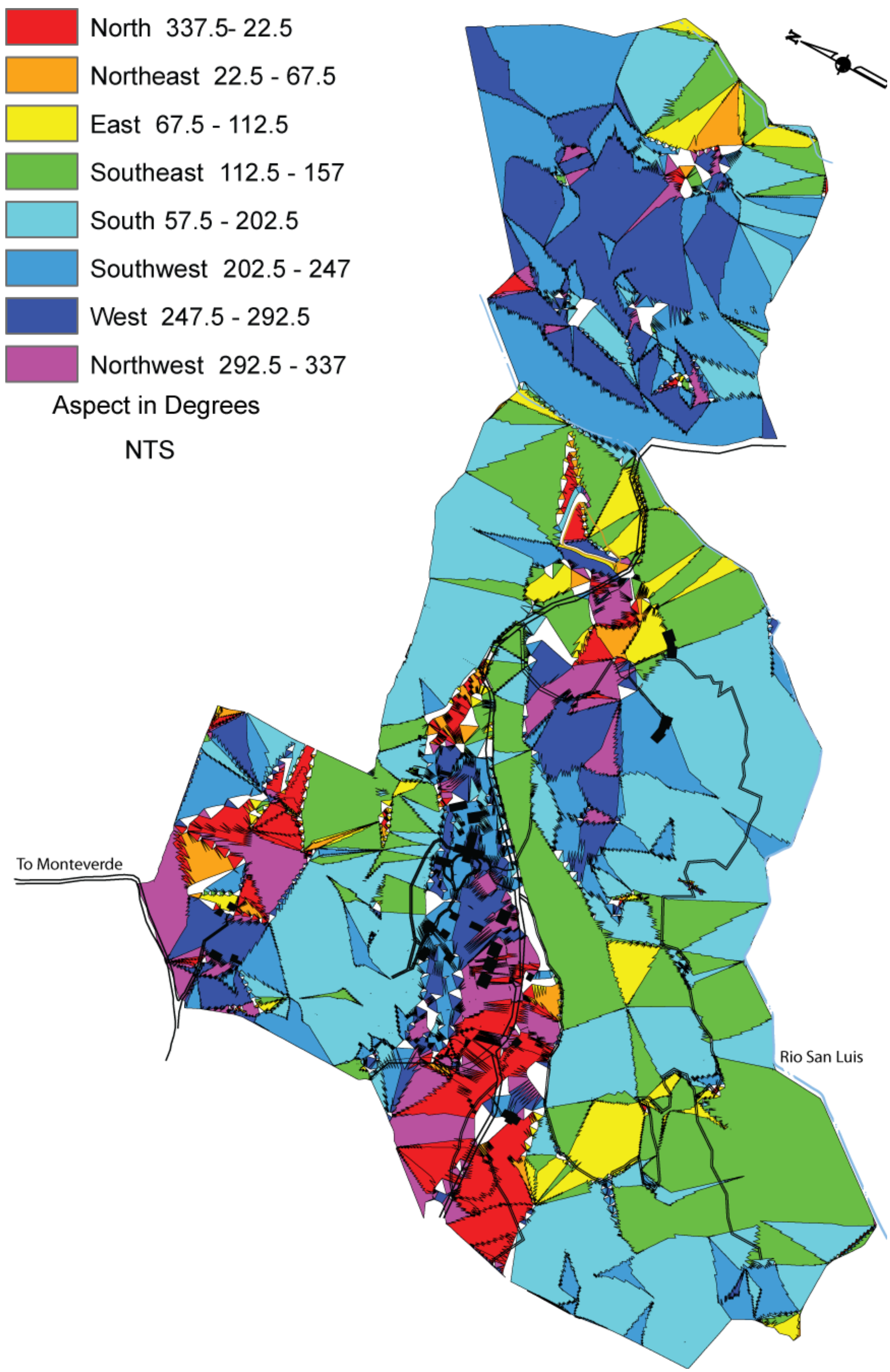


Figure 16. Aspect.

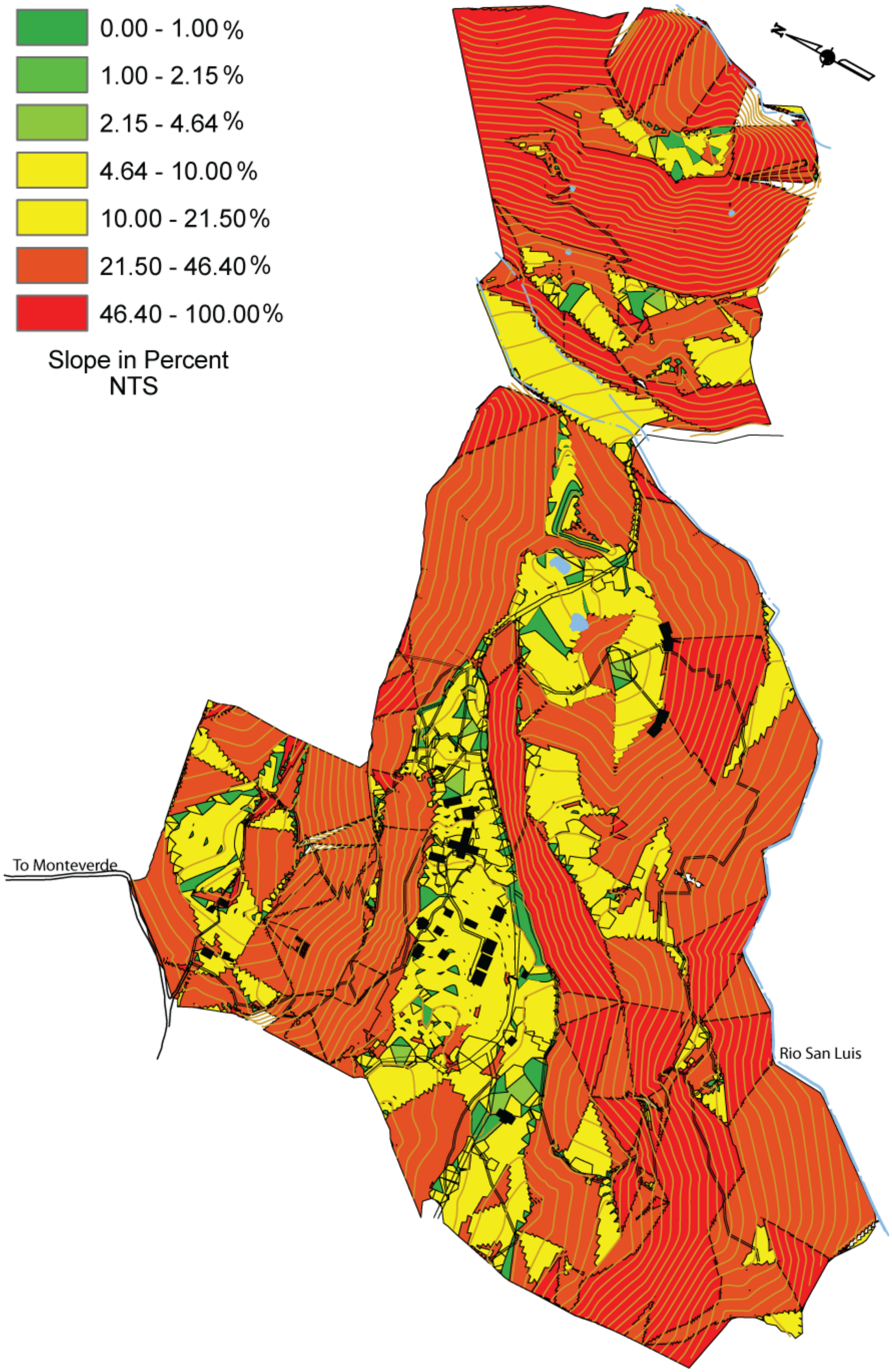


Figure 17. Slope.

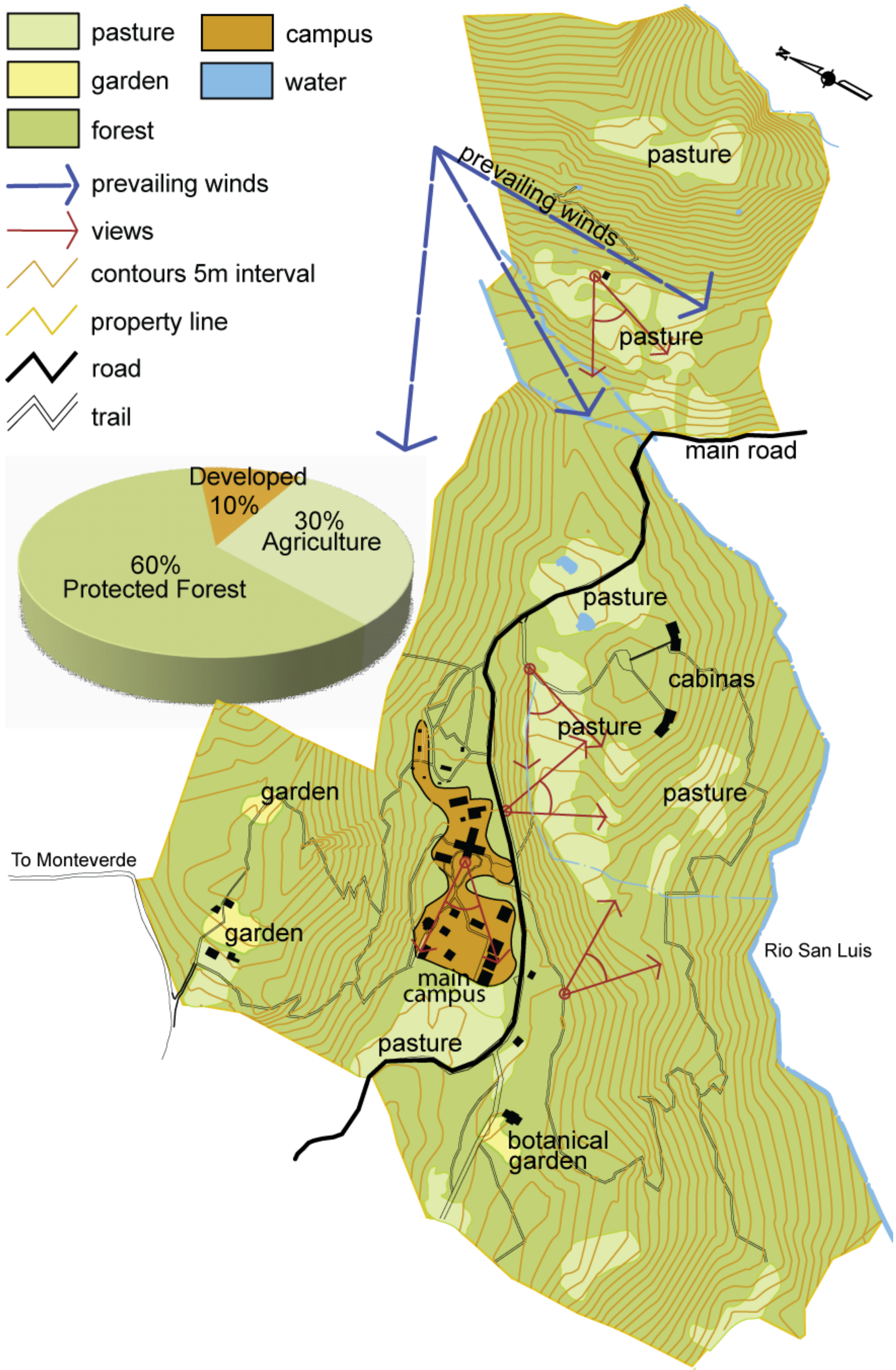


Figure 18. Composite inventory.

Slope

The site is characterized by steep topography; over half of the land has a slope of greater than 20%. In the hills of Costa Rica the interpretation of suitability of slope for agricultural use is relative. Almost all unprotected land having a slope of 10% or less has been deforested and even slopes of 50% are cleared for pasture. Structures are almost always situated on flat areas because of the instability of the footings due to the unusually deep topsoil. Structures built on steep terrain are at risk of sliding due to the large amounts of rainfall and seismic activity. The main campus portion of the property is located on a relatively flat bench between steep embankments to the North and South. The steep topography limits the use of most types of farm machinery, especially the tractor. Therefore all work must be done by hand from mowing to preparing the soil for planting.

Summary of Analysis

The campus is located in a unique and somewhat harsh environment for agriculture due to its position in a zone of transition between cloud forest and rain forest, its prevalence of high winds, lack of direct sunlight due to the consistent cloud cover, and steep topography. The cool temperatures are a positive attribute in that manual labor is much easier in this climate, and they are ideal for dairy production. With the use of irrigation in the dry months from February through April constant productivity is possible year round despite the sunlight being attenuated by the clouds.

Site Selection

Site selection was straightforward due to a number of limiting conditions. The main factors considered in determining the placement of the integrated farm complex are the topography, forest clearings/pasture and accessibility. The areas with suitable topography are indicated in yellow in Figure 17. Suitability is further limited to current clearings as the campus has committed to retain all of its current forest cover. With these factors in mind, the site proposed is located on the western side of the road to the cabinas in the only remaining clearing of sufficient size with appropriate access. The site was chosen for its proximity to the improved road, its flat topography and because it is sheltered from the winds and rain by forest to the north and east. This areas sits at the top of a small saddle. Positioned here water flows down and away from the site instead of though it as it does in areas lower down in the clearing. There are concerns over the possibility of noise and odor emanating from the site. This integrated farm with its biodigestor and manure treatment system should not create odors as manure is not allowed to collect and rot. Instead it is washed from the animal enclosures and treated almost as soon as it is produced. The cabinas are upwind from the facility making the likelihood of odors reaching the rooms unlikely. Furthermore, the site is located at a distance of 350 feet of dense secondary forest growth from the Ecolodge cabinas, a sufficient distance to mitigate any odors or sound that might occur. Refer to the Map of the Agricultural Areas of the UGA Costa Rica Campus (Figure 19) which indicates its location on the property.

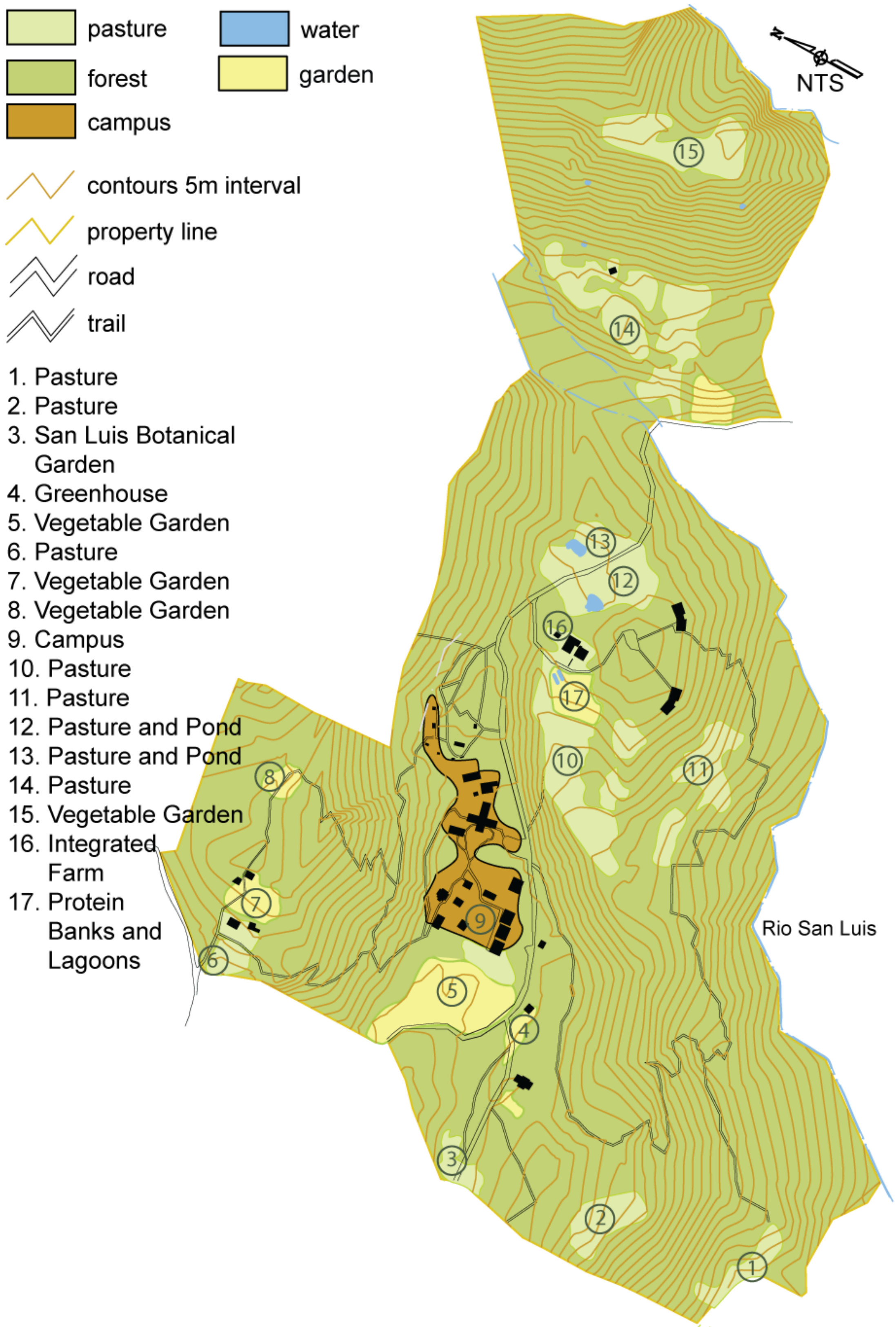


Figure19. Integrated farm agricultural areas map.

CHAPTER 5

THE DESIGN

The following chapter describes the integrated farm design proposed for the UGA Costa Rica Campus. The design was derived from the EARTH University model, but has been modified to suit the environment and needs of the campus. Primarily, the system has been scaled down to accommodate a lower number of animals, the production of vegetables is increased and erosion control and soil building are emphasized. This thesis is mainly concerned with the physical arrangement of the system infrastructure and will only specify managerial and operational matters if they are of vital importance to the function of the system.

Program

The primary purpose of the integrated farm is to produce dairy, pork and vegetables for the UGA Costa Rica Campus therefore the program is defined by the needs of campus and the capabilities of the land to meet these requirements. Based on assessments made by the management and farm operators at the campus an estimated carrying capacity of the pastures for dairy cattle is 15 and the capacity for pork production is 12 (CATIE 1983 and Leitón 2009). Vegetable requirements are high for the campus and production could be increased many times, but land flat enough to be suitable for this is limited to only a few acres. This area then sets the program for vegetable to include all land suitable for this. All of these figures have been determined assuming that two fulltime workers will

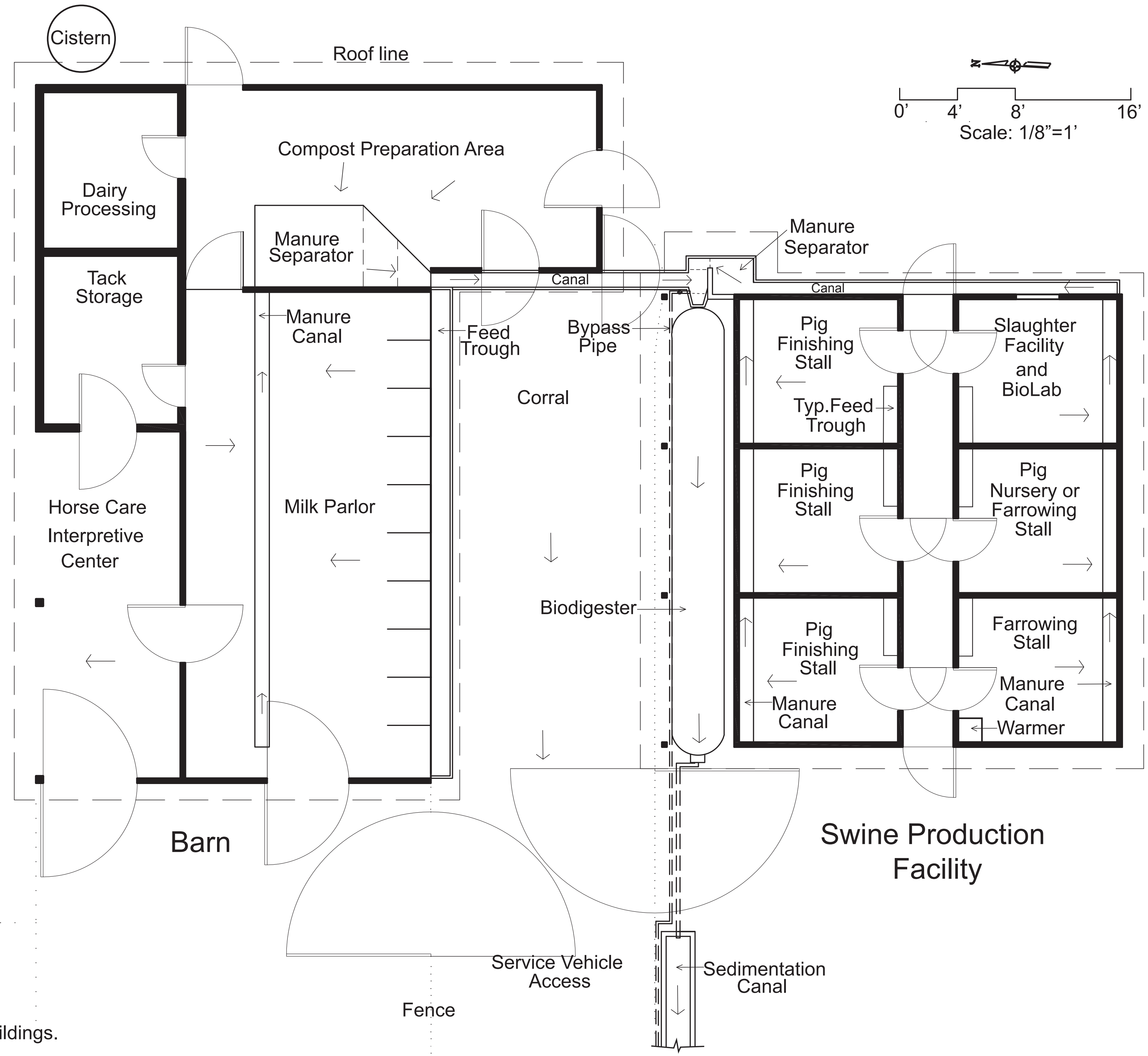


Figure 20. Plan. Integrated farm buildings.

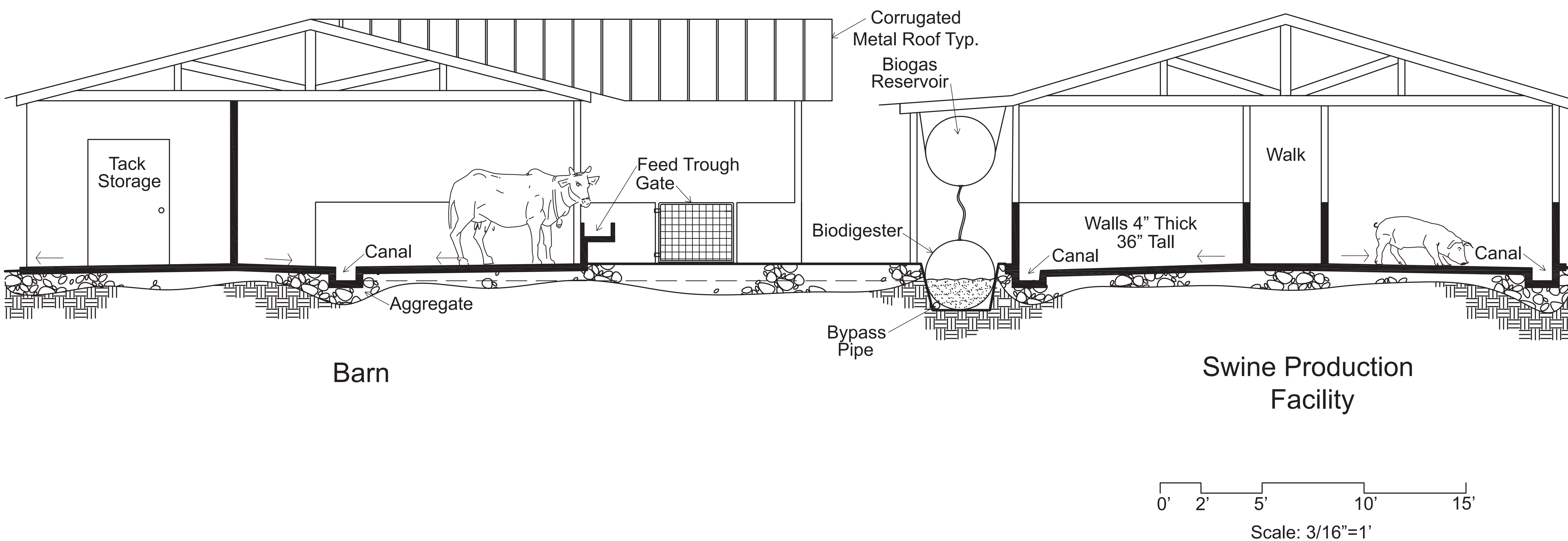


Figure 21. Section. Integrated Farm Buildings.

Figure 22. Proposed Master Plan of the Integrated Farm at the UGA Costra Rica Campus.

be dedicated solely to the operation and management of the integrated farm system.

In the integrated farm system a swine production facility is used to contain the animals and their manure for treatment. A barn is needed for milking and the collection of manure. These facilities form the heart of the integrated farm. These buildings are positioned in close proximity to one another for efficiency of movement of workers, animals and materials.

Barn

The barn is comprised of a milking parlor, drainage canals, manure separator, compost and bokashi production area, milk and cheese processing facility, horse care area and tack/general storage room totaling 1540 square feet. The floor is to be concrete sloped for drainage as indicated in Figures 20 and 21. Slopes of the milk parlor and compost production shall be between three and five percent to aid in the movement of the manure. The roof is to be galvanized tin and fitted with gutters to direct rainfall to the cistern. Part of the roof should be of translucent fiberglass to allow natural light to enter. The walls are to be constructed in the same manner as displayed at EARTH University and as described by Mendoza and Sánchez (2006). They are to be solid and extend to the roof for the dairy processing facility. In the tack room the walls are to be 36” tall cement with the remainder extended to the roof with framed hardwood. The walls on all sides of the compost processing area are to be made of 36” tall ferrocement with no framing. The remaining partitions between the milk parlor and horse care area are to be made of durable wood posts a framing.

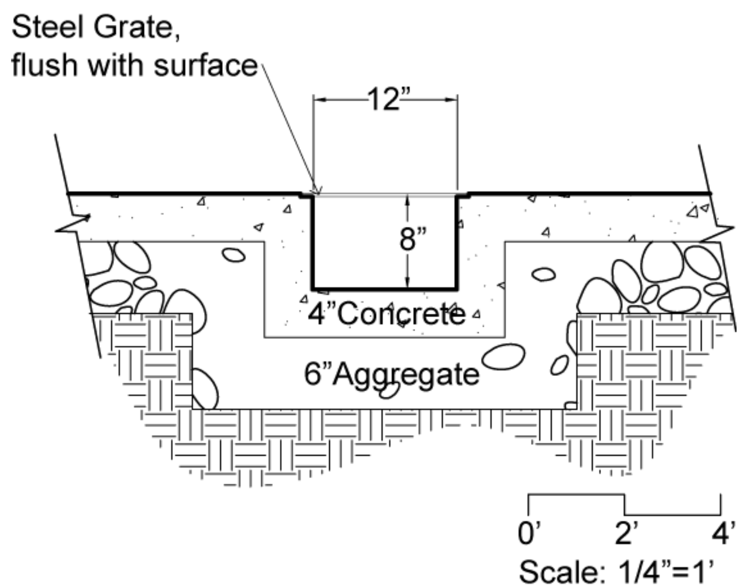


Figure 23. Drainage canal, typical.

All drainage canals are to be 12” wide and 8”deep and should slope toward the manure separator at an inclination of 4 percent (Figure 23). It is to be covered in a recessed metal grate suitable for cattle to walk on and to easily allow the slurry to enter unimpeded.

The feed trough is to be made of ferrocement 16” wide and 8” deep to receive the cut feed which can loaded from the front outdoor corral. It should slope towards the manure separator at 2% and be fitted with a metal strainer over the outlet to keep large material out of the biodigester. The roof overhang should be 18” past the outer edge of the trough to prevent rain from entering.

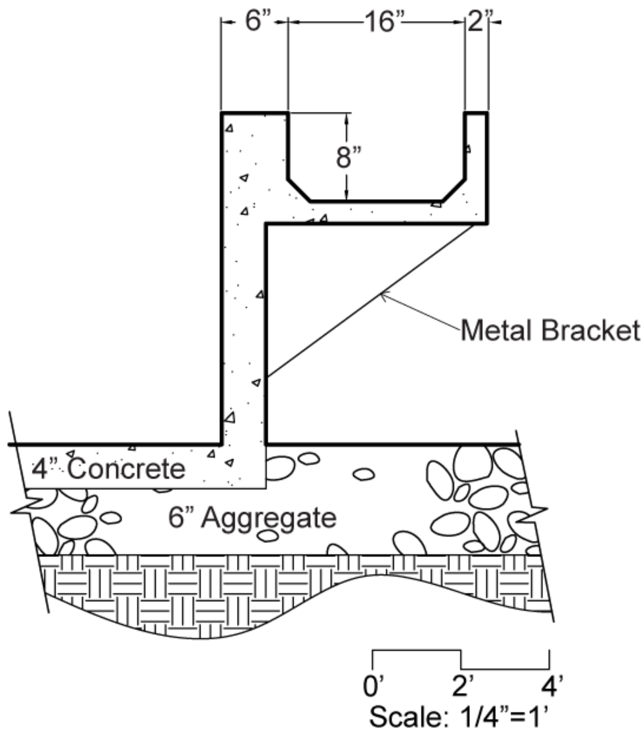
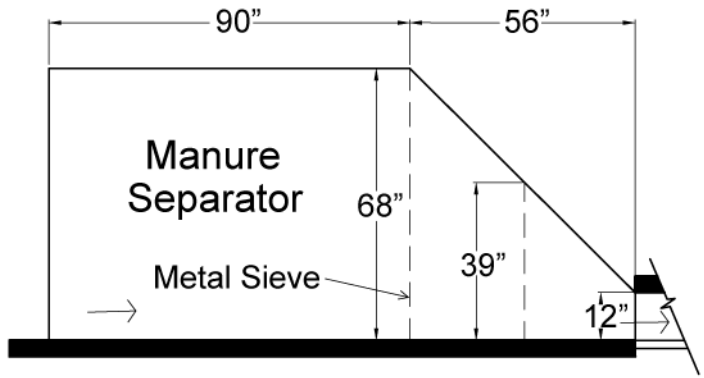


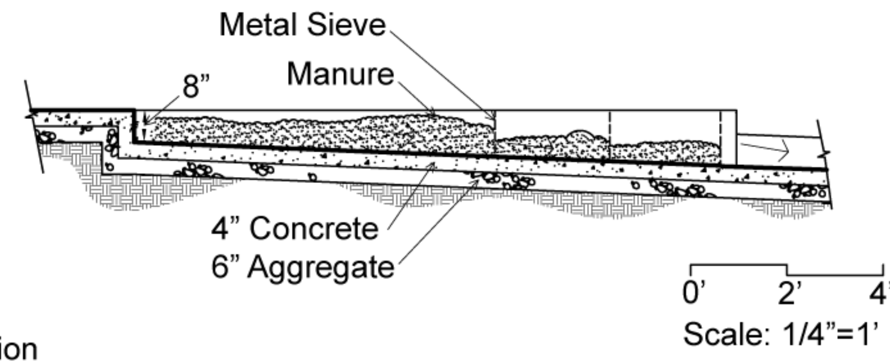
Figure 24. Cattle feed trough.

The roof overhang shall be 18” around the rest of the building for the same reason.

The manure separator (Figure 25 (a) and (b))is to be of cast concrete and recessed into the floor as are the canals. It is 8”deep, 5’ wide and 7.5’ long and has a slope of 4% toward the biodigster. It shall be fitted with metal sieves of decreasing size from 1/4” to 1/8”. The slurry should be removed from the sieve each morning after having been left to drain overnight. The residue should then be moved to the compost production area for bokashi treatment or for the production of compost. The floor of the compost production area should slope toward the manure separator.



(b) Plan



(a) Section

Figure 25: (a) Plan and (b) Section. Manure Separator.

Dairy Production

Don Otoniel Leiton a longtime farmer in the San Luis valley and resident dairy farmer for the UGA Costa Rica Campus estimates that the carrying capacity of the pastures to be fifteen head. This number is also equal to the number calculated using the data gathered by CATIE (1983) which estimated the pasture requirement per animal to be 1.24 acres. Dairy production requires a relatively low amount of labor input compared to fruit and vegetable farming because the cows do a majority of the work as they graze and convert bulk plant material into proteins usable by man. Most of the labor input is in moving the animals from paddock to paddock and in milking. It was indicated by Don Otoniel that he or other farm labor would have no problem managing and milking 15 cattle. Considering the high value of dairy products in both monetary terms and in the protein they provide in the diet, the production of this commodity is the preferred form of agriculture on the farm and indeed in the Monteverde area as well. Being the backbone of the agriculture and thus the food culture of the San Luis Valley, dairy is an important part of the diet served on the campus. Therefore demand is high for dairy products on the campus. Data does not exist for the milk volumes produced per day, only the weight of processed "homestead" cheese. Based on calculations made by the author the daily production of cheese for 15 heifers is approximately 11.42 pounds. A portion of the milk will be made into other products or consumed fresh. This volume would adequately provide for the needs of the during peak visitation periods. In the off season when the productivity may exceed demand any surplus can be traded locally for produce not supplied by the farm. Therefore, because dairy is a high-value low-labor-input agricultural practice it is recommended that the herd be increased to the maximum carrying capacity of the farm (exclusice of the areas designated for vegetable production the other primary function of the farm).

The cattle will not be raised for meat as dairy is a much more valuable commodity than beef in Costa Rica. Dairy farming in San Luis and the greater Monteverde area can be thought of as not only the production of milk, but as the management of pasture and food stocks as these two are wholly interdependent. The most common and effective method for raising cattle in San Luis is by intensive rotational grazing. This system will be augmented with the addition of cut feeds in the animals' diet. In the intensive grazing system cows are moved to a new paddock, the size of which depends on the herd size and length of graze time and pasture composition, as necessary to properly graze the pasture grass (Griffith, Peck and Stuckey 2000). The primary pasture grasses are Kikuyu (*Pennisetum clandestinum*) and East African Star Grass (*Cynodon nuemfuensis and C. plectistachyus*). Proper grazing is necessary to maintain the pasture at its peak level of productivity, palatability and nutrition. Grazing can be thought of a mowing and is absolutely necessary for the upkeep of the pasture.

Intensive grazing places a large number of animals is a small area. This forces them to uniformly consume the grasses as well as the weeds which might otherwise outcompete the grasses. Improperly grazed grasses become too tall for cows to move through, are reduced in nutrition and have to be manually cut with a machete or treated with herbicides to return them to productivity which is costly and labor intensive. The size of the herd, graze period and paddock size are all variables that are managed to achieve uniform grazing of the forage.

The intensive rotational grazing system is an improvement over the range style of production where cattle are allowed to graze freely in large fields. Two main problems occur in ranged pastures. Grazing of the grass becomes uneven as the cattle differentially consume different portions and cattle tend to congregate in certain areas which causes the undesirable buildup of manure in these areas and erosion as the soil becomes denude of grasses due to the churning action of hooves. In the intensive rotational system this is alleviated by the fact that the cattle are moved frequently giving the fields time to recover between grazing and manure is evenly distributed throughout the fields where it is needed.

The milk cows will be moved from the paddocks to the milk parlor two times per day for milking. They are to be held in the parlor for a total of 6 hours per day divided between the two milkings so that they may be given cut feed, minerals and any supplements that might be needed. This also allows manure to be harvested for conversion to biogas and fertilizer in the biodigester.

Local farmers commonly apply chemical fertilizers, nitrogen in particular, to pastures as a way to increase yields. Griffith, Peck and Stucky (2000) conclude that this is a sustainable practice due to the perceived necessity of this input to sustain yields. It is the intent of the integrated farm system to reduce or preferably eliminate the need for these types of inputs, therefore investigations aimed at the development of this capacity is needed. One way to add nitrogen to the soil is the use of non-grass forages, especially legumes, in the pastures. This has the potential to increase productivity when compared to grass alone. Table 3 provides a list of crops that merit investigation in trials to determine their efficacy in this service.

<u>Protein Banks</u>

The protein bank plants grown at EARTH (Table 1) will also be used as animal feed at the UGA Costa Rica Campus. They are to be planted on contour in plots

Table 3 . Crops to investigate for use in mixed pastures.

English Common Name	Scientific Name	Spanish Common Name
Peanut Grass	Arachis pintoi	Maní forrajero
White Clover	Trifolium repens,	Trébol
Burchell's Clover	Trifolium burchellianum	
Kenya White Clover	Trifolium semipilosum	
Creeping vigna	Vigna parkeri	
Oats	*Avena sativa*	Avena
Rape	*Brassica napus*	
Turnips	*Brassica rapa L.*	Nabo
Buckwheat	*Fagopyrum esculentum*	Alforfón
sunn hemp	*Crotalaria juncea L.*	Cascabel

and as the stabilizing plants in the on contour swales. In this arrangement they also function as windbreaks. Cut feeds are to be planted in the upper portion of the main pasture across the road from the farm buildings. They are also to be planted on the steeper slopes of pasture number 14. The total area allotted to the planting of the protein banks is 2.82 acres.

Milk Parlor

The milk parlor serves multiple functions. It is used for milking and as the space in which the cattle are given cut feed. During this time manure collects on the floor where it can then be mixed with water during cleaning for processing in the biodigester. The space has been designed with ten catches which have access to the feed trough, though more animals can be contained or rotated through if

Figure 26. Protein bank . A newly planted protein bank of White Mulberry (Morus alba) created at on contour to reduce erosion at Rancho Margot, La Fortuna, Costa Rica.

the herd is larger. The cut feed is shredded and placed into the trough from the outside between the two buildings.

Dairy Products Production and Storage Area

Milk will be processed into a variety of products including butter, yogurt, natilla (a cultured heavy cream that is similar to sour cream in consistency but lacking the sour flavor), the typical Costa Rica farm style cheese which does not require heating of the milk and artisanal cheeses which require elevated temperature for their production.

The dairy production facility will need counter space, refrigeration, stainless steel bins in which to make the cheese, a sink, a hot water heater or stove and potable water. The floor should be well drained. Whey from the process is rich food for the swine and should be fed to them. Natural gas refrigerators are available and pose an ideal use for the biogas produced in the biodigester. The biogas can also be used to heat the milk in the process of making artisanal cheeses. The room should be fully enclosed and contain windows on both external sides for ventilation as needed. The floor and walls should be tiled for sanitation.

Cistern

A 1300 gallon cistern will retain water falling on the roof of the barn. This water is not potable and will only be used for farm operations, mainly to wash the manure from the floors of the stalls. The pipes and hose should be clearly painted purple to denote that the water is non-potable. The almost daily rains will allow the reservoir to remain full continuously even in the dry season. The outlet of the cistern shall be at the bottom and should be at least 4 feet above grade. This ensures that the water does not stagnate and requires no pump.

Horses

Horses have traditionally been used in Costa Rica for work and show. Today their use as work animals is declining as many farmers now have vehicles instead although horseback riding tours are popular and show horses are still seen in festivals and parades. On the campus horses have traditionally been utilized for transporting supplies and for tours. Disease and old age has reduced their numbers from six to two. The minimum number need to economically offer tours is six because lead and follow guides are needed for rider safety. With only two horses tours can no longer be offered. The campus now has a utility truck as well as a four-wheeled all terrain vehicle with trailer which is used in place of the horse for hauling and transportation. Thus the two remaining horses are no longer used and offer no benefits to the farm. One of two courses of actions should be taken, either purchase four or five more to be able to offer tours again or preferably sell the remaining two. The later is the recommended option because outside tour providers are already offering comparable services at competitive rates nearby. This provides work and income for the community and frees the campus from the liability and expense of maintaining the animals. The large land area required for pasturing the animals would be better used for food production instead. The barn has been designed with space for horse care and tack and feed storage with the assumption that more horses will be acquired. If this is not the case the area can be used for general storage, cut feed and hay storage, the production of compost, vermiculture or as teaching space.

Pork Production

The pork production facility is comprised of five pig enclosures, four will house pigs in the fattening stage, three per pen, one will house gestating, lactating or brooding sows. The sixth room will be used for slaughter. It is to be enclosed and tiled to ease sanitation. The walls are to be made with the typical ferrocement 36” supporting metal uprights as seen at EARTH University. The total floor area is 840 square feet. Due to the low temperatures and high rainfall

Table 4. Alternative pig forages.

English Common Name	Scientific Name	Spanish Common Name
purple/winged yam	*Dioscorea alata*	Ñame blanco
Yam, Cinnamon	*Dioscorea batatas Decne.*	Ñame de canela
Yam, Wild	*Dioscorea spp.*	Ñame
Air Potato	*Dioscorea bulbifera L.*	Ñame
Guava	*Psidium guajava L.*	Guayaba
Avocado	*Persea americana Mill., Persea spp.*	Aguacate
Wild avacado	*Persea sp.*	aguacatillo
Cas / C.R. Guava	*Psidium friedrichsthalianum (O. Berg)*	Cas / Cas ácido
Cassava / Manioc	*Manihot esculenta Crantz*	Yuca
Chaya / Chicasquil	*Cnidoscolus aconitifolius (Mill.)*	Chicasquil
Chaya / Chicasquil	*Cnidoscolus chayamansa McVaught*	Chicasquil
Chayote	*Sechium edule (Jacq.) Sw.*	Chayote
Chinese Broccoli	*Brassica spp.*	Brócoli de China
Dasheen, Taro	*Colocasia esculenta*	Nyampi, Chomol,
Mustard, brown	*Brassica juncea (L.) Czerniak.*	Mostaza
Naranjilla	*Solanum quitoense Lam.*	Naranjilla de montaña
Plantain	*Musa spp.*	Plátano
Purslane	*Portulaca oloracea L.*	Verdolaga
Sapote	*Pouteria sapota (Jacq.)*	Zapote colorado
Sugar Cane	*Saccarum officinarum L.*	Caña de azúcar
Yautia, Malanga	*Xanthosoma spp.*	Tiquisque / Yautia
Malanga, Purple Stem Taro	*Xanthosma violaceum Schott.Oesterr.*	Malanga
Sweet Potato	*Ipomea batatas*	Camote

amounts in San Luis, the enclosures will not include the pools as described in the EARTH systems and the roof will not drain rain water into the pens. The drainage canals will be built to the same specifications as those in the barn. The solids filter is positioned just before the opening to the biodigestor within a short distance to the compost area to make moving the material easier.

The pigs are to be fed with a minimum of concentrated feed used only as needed to supplement lean times of production of feed on the farm. Swine forage crops are the same as those grown at EARTH (Tables 1 and 2.). In addition, they are to be fed kitchen scraps and leftovers from the kitchen, cut feeds, aquatic plants and they are to be allowed to forage in the mixed grass and legume pastures. A number of other crops can be used for forage. Investigation is warranted into which species will perform well in San Luis. These are be planted in pasture on which the pigs will graze or are taken to the pigs like cut feed. These plants are listed in table 4.

The vehicular access area and corral area between the buildings will be paved with the locally available volcanically derived aggregate which is soft enough to be crushed by the weight of vehicles forming a somewhat pervious surface free from mud. This armament will help to reduce the amount of mud that enters the barns and biodigester on the animal's hooves and reduce erosion.

Poultry Production

A flock of 25 chickens will be raised in a large run containing a chicken coop. These birds will be layers and will provide eggs only. They will not be raised for meat because relatively inexpensive chicken is available locally. The coop will

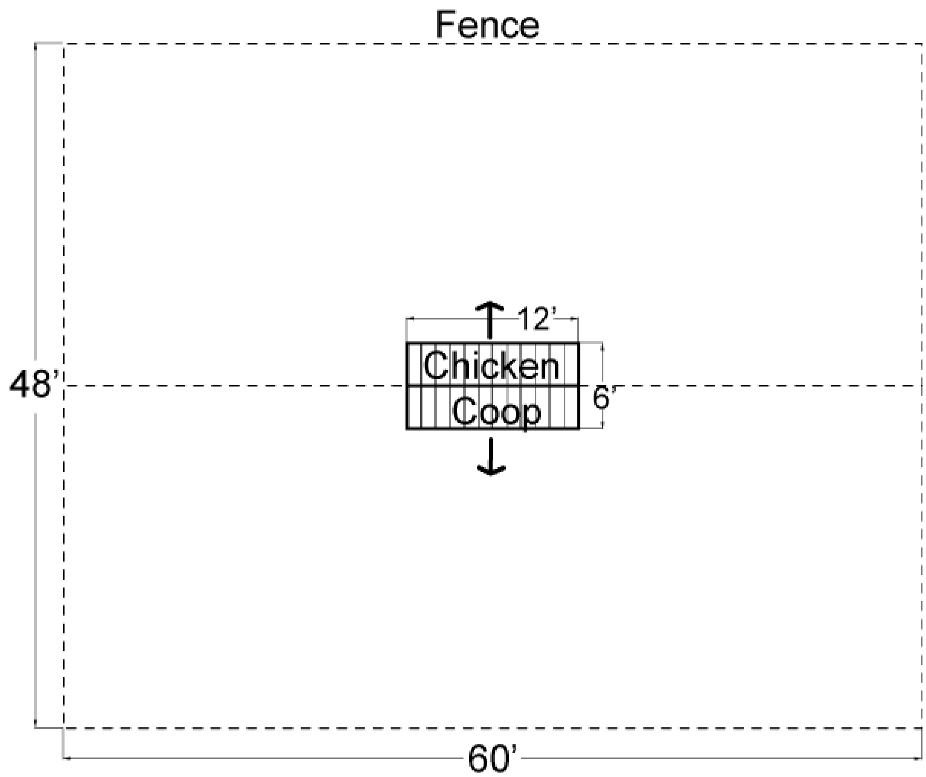


Figure 27. Diagram of poultry coop and associated runs.

sit between two runs which can be used alternatively. This concept is illustrated in Figure 27. To manage the grasses cows can be admitted periodically to graze them down. By allowing the birds access to pasture they can gain a fair portion of their feed requirements from insects and plant material. Their food requirements should be supplemented with kitchen scraps, bananas, and guava fruits. Bedding for the roosts should be changed often and added to the compost to make use of its high nitrogen content.

<u>Vegetable Production</u>

Fresh vegetables are a major component of the Costa Rican diet and are served with every meal at the campus. A large portion of these products are purchased from outside sources. Yet, a relatively small portion, just over one acre, of the agricultural lands is dedicated to vegetable production. Vegetables are currently being grown in gardens number seven and eight and in the food crops demonstration area of the on-site San Luis Botanical Garden. Considering the high cost of these products, the vegetable garden has been expanded considerably to meet the needs of the campus. The new garden area is to be located in pasture number five which is adjacent and to the west of the main campus. The area of this space is 2.58 acres, bringing the total area dedicated to vegetable production to 3.65 acres. This area was chosen for vegetable production because of its close proximity to the campus and because of its relative flatness. This area is also highly visible which will help to bring attention to food production activities and encourage interaction with the garden by guests. Winds tend to travel from the east down the valley that this area occupies, therefore the establishment of windbreaks at the eastern edge of the garden will be necessary. Bamboo is a dense formed plant that has many uses on the farm and will serve this purpose well.

The day to day managerial and operational considerations of the vegetable production will be left to the discretion farm management staff but, several modifications to the current practices are necessary to augment the work already being done. These improvements including the use of swales, cover crops, intercropping and the application of composts are described below in the soil section. Table 5 contains a list of vegetables grown in San Luis.

<u>Soil Management</u>

Foremost, soil must be protected, nourished and developed. Because the site receives high rainfall amounts nutrients are quickly leached from the soil following deforestation (Griffith, Peck, Stuckey 2000). Soil nutrients must be replenished and retained by the addition of organic material including bokashi, compost, cut plant material collected during site maintenance and worm castings. Intercropping and the use of both nitrogen fixing and non-nitrogen fixing cover crops is vital to replenish these nutrients. The garden area has been increased to allow parts of the growing area to be planted intermittently with cover crops in rotation for this purpose. The benefits of cover crops include reducing erosion, improving soil structure, providing nitrogen, exclusion of weed species, and increasing soil organic matter (soil building). Research into the suitability of cover crop species is lacking in the area. Therefore, trials to determine which species are suited to the area should be undertaken.

White clover (*Trifolium repens*) has naturalized in the area and should be a priority for investigation. Other species of interest are sunn hemp (*Crotalaria juncea L.*), hairy vetch, buckwheat and other leguminous plants. See Table3 for a complete list. As mentioned in the cattle section, the establishment of mixed pastures will be beneficial to animal production and in maintaining the soil fertility. Many of the cover crop species are also fine animal forage and can be used in mixed pastures.

Table 5. Food crops of Altos de San Luis.

English Common Name	Scientific Name	Spanish Common Name
Arracache	*Arracacia xanthorribiza*	Arracache
Basil, Sweet	*Ocimum basilicum*	Albahaca
Beets	*Beta vulgaris*	Ramalacha
Cabbage	*Brassica oleracea*	Repollo
Carrots	*Daucus carota subsp. Sativus*	Zanahoria
Cassava / Manioc	*Manihot esculenta*	Yuca
Cassava / Manioc	*Manihot esculenta*	Yuca
Cauliflower	*Brassica oleracea*	Coliflor
Chayote	*Sechium edule*	Chayote
Dasheen, Taro	*Colocasia esculenta*	nyampi, chomol, malanga
Golden Apple	*Spondias dulcis*	Juplón
Grapefruit	*Citrus paradisi*	Toronja
Lemon	*Citrus limon*	Limón ácido
Lettuce	*Lactuca spp.*	Letchuga
Lime, Key	*Citrus aurantifolia*	Limón Criollo
Loquot	*Eriobotrya japonica*	Nispero
Malanga	*Xanthosma violaceum*	Malanga
Onion	*Allium cepa*	Cebolla

Table 5. Food crops of Altos de San Luis continued.

English Common Name	Scientific Name	Spanish Common Name
Orange	*Citrus sinensis*	Naranja dulce
Papaya	*Carica papaya*	Papaya
Passion flower, Fruit	*Passiflora spp.*	Maracuyá, Granadilla
Pepper, Cayenne	*Capsicum frutescens*	Tabasco
Pepper, Hot / Sweet	*Capsicum annuum*	Chile picante / dulce
Pineapple	*Ananas comosus*	Piña
Pineapple	*Ananas comosus*	Pinya
Plantain	*Musa spp.*	Plátano
Potato	*Solanum tuberosum*	papas
Purplestem Taro	*Xanthosoma violaceum*	Tiquisque / Yautia
Squash, Pumpkin	*Cucurbita moschata*	Ayote, Calabasa
Sugar Cane	*Saccarum officinarum*	Caña de azúcar
Sugar Cane	*Saccharum officinarum*	Caña de Azucar
Sweet Potato	*Ipomea batatas*	Camote
Water Apple	*Syzygium malaccense*	Manzana de Agua
Yauta, Tiquisque	*Xanthosoma sagittifolium*	Tiquisque / Yautia

All planting is to be on contour to reduce erosion. Strips of perennial plants are to be planted on the downhill berm of contour swales at five meter contour intervals to stabilize the soil, reduce erosion and to mine nutrients at depth in the soil with their deep and well established roots (Figure 28). Plants suitable for this purpose are peppers, pigeon pea, moringa, banana and related species, white mulberry, katouk, tiquisque, malanga, lemon grass, citronella grass, vetiver grass, ginger, cratylia, turmeric, chaya and yucca. These plantings will also serve as windbreaks which in Monteverde have shown to increase yields by reducing mechanical damage to crops (Griffith, Peck, Stuckey 2000). Soil is to be exposed for the minimum amount of time possible and bare soil should avoided during the rainy season as a substantial amount of soil can be lost in a single rain event.

Perennial Agriculture

Annual crop production is labor and energy intensive. Alternatively, the use of perennial food crops can greatly reduce inputs and is more suited to the natural tendencies of the site which is to produce forest. The difficulty in tree crop production in Altos de San Luis has been noted, but there are a few species that do perform well, guava, Inga spp., guitite and the non-domesticated avocado. These are found in abundance in the secondary forest. None of these are important human food sources, but can form a large part of the swine diet. A

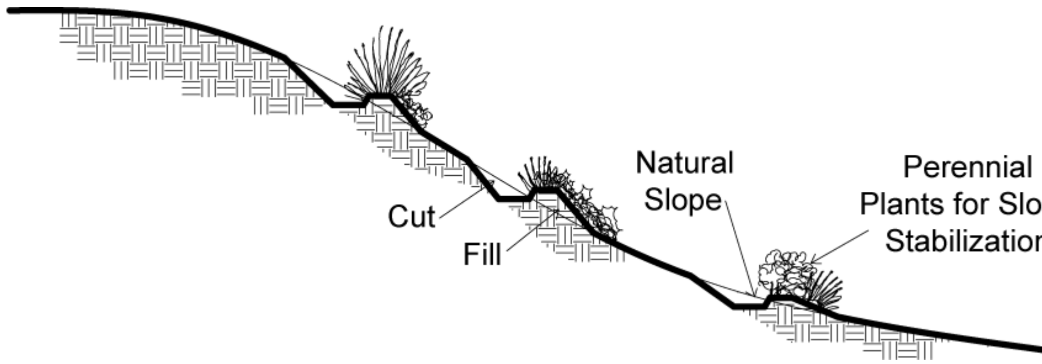


Figure 28. Garden section showing on contour swales and plantings.

concerted effort should be made collect these naturally occurring fruits for the pigs and to allow the pigs to forage these resources as they become available. This will require the use of movable fences to contain the swine as they forage. T-posts with thin gauged wire work well for this purpose.

Other perennial crops including bananas, quadrados and plantains are important food sources and should see increased production on campus. A number of perennial crops are available that should be trialed on the campus for suitability. These are primarily leafy greens and can replace a large portion of the less nutritious lettuces that are served daily. Others are root crops that can be eaten by humans and livestock alike. These are listed in table 6. The following are some of the plants with the most potential in San Luis.

Katouk (*Sauropus androgynus*) is a leafy green from Borneo that is highly prolific and tastes faintly of peanuts, though it is not a legume. It spreads by rhizomes in loose soil and is easily propagated by seed or cuttings. The tender

Table 6. Crops of to be tested for suitability in Altos de San Luis.
Key: Human=H, Bovine=B, Porcine=P.

English Common Name	Scientific Name	Spanish Common Name	Habit
American Ground Nut	*Apios americana*		HPB, vine
Katouk	*Sauropus androgynus*	Katuk	H, shrub
Sunchoke	*Helianthus tuberosus*		HP, tuber
Chaya, Tree Spinich	*Cnidoscolus aconitifolius*	chaya	HPB, shrub
Jicama,yam bean	*Pachyrhizus erosus*	Jicama	HP, vine
Oca, New Zeland Yam	*Oxalis tuberosa*	Oca	HP, tuber
Ulluco	*Ullucus tuberosus*	Ulluca, Papa lisa	HP, tuber
Mashua	*Tropaeolum tuberosum*	Mashua	HP, tuber
New Zealand Spinach	*Tetragonia tetragoniodes*	Espinaca Nueve Zelandia	HP, vegetable
Garden egg, Jiló	*Solanum gilo*	Jiló (Portugese)	H, vegetable
Chipilín	*Crotalaria longirostrata*	chepil, chepilin	H, herbaceous
Loroco	*Fernaldia pandurata*	Loroco	H, vine
Purselane	*Portulaca oleracea*	Verdolaga	H, vegetable
Boc Choi	*Brassica rapa*	Espinaca china	H, vegetable
Malabar Spinach	*Basella alba, B. ruba*		HP, vegetable
Moringa, Drumstick Tree	*Moringa oleifera*	Moringa	HPB, Small tree
Arrowroot, Indian Shot	*Canna edulis*	Achira	HP, herbaceous, 3'
Wild Avocado	*Persea spp.*	Aguacatillo	HP, tree

new leaves are edible raw, while older leaves are best served as part of a cooked dish.

Chaya or Tree Spinich (*Cnidoscolus aconitifolius*) is a leafy green from Mexico. It is closely related to yucca/manioc though it does not produce an edible tuber. It can be seen in parts of San Jose growing as an ornamental. The leaves are edible by both humans and pigs, but for human consumption they must first be boiled to rid them of cyanic acid. It produces no viable seed but is readily spread by cuttings of its fleshy branches.

Moringa of the Drumstick Tree is a native to India and has been hailed as a miracle food by relief workers in Africa due to its unusually high nutrient content and resistance to both drought and heavy rains. All parts of the tree are useful, though it is not recommended that the root be consumed. The young seed pods resemble drum sticks giving the tree its name. They are spicy in flavor when eaten raw and mild when added to cooked dishes. The leaves can be added to salad, cooked or dried and powdered to make tea or simply sprinkled on dishes to impart their somewhat spicy seasoning. The leaves are also highly recommended forage for livestock. To use them as forage they are planted tightly and allowed to reach a few feet in height before allowing them to be grazed. After the crop is grazed down they are allowed to regenerate for another iteration. The tree grows tall and spindly without being pruned, but responds well to being coppiced. When treated this way moringa will put out a number of new branches and increases its leaf production many fold. Often this is done at waist height to make the harvest of the leaves easiest. The flowers are edible and make great garnish.

Though they are not perennials, a number of Asian greens in the Brassica family are ideally suited to the climate of San Luis and should be included in the garden. These include Boc Choi (*Brassica rapa)*, Yukina Savoy (*Brassica juncea*) and Mizuno (*Brassica rapa* (Japonica group)) among many others. These are readily available from organic seed companies in the US.

Biodigestion

UGA Costa Rica wishes for this project to be a model for the development of others like it throughout the area. With this in mind the design must represent appropriate technology. The plug flow polyethylene type biodigester is recommended for implementation as it meets this criterion due to iits low cost, reliability and ease of use. Biodigesters of this type are already being utilized in the area and are familiar to farmers. The materials are available locally and construction, installation and repair are simple and rapid. With a cost of less than four hundred dollars – or about the cost of bottled gas for two years for a family (Rural Costa Rica [Internet]) the biodigester pays for itself quickly. The biodigesters are known to last at least five years and then only the bag must be replaced (Rodriguez 2004). Thus over the lifetime of the unit a farmer can expect considerable savings in labor and money.

The biodigester (Figure 29 and 30: (a) and (b)) at the UGA Costa Rica campus will be of the “salchicha” type demonstrated at EARTH University, though it will be considerably lower in volume to accommodate the smaller

Figure 29. Salchicha biodigester at Terra Viva, Santa Elana de Monteverde, Costa Rica.

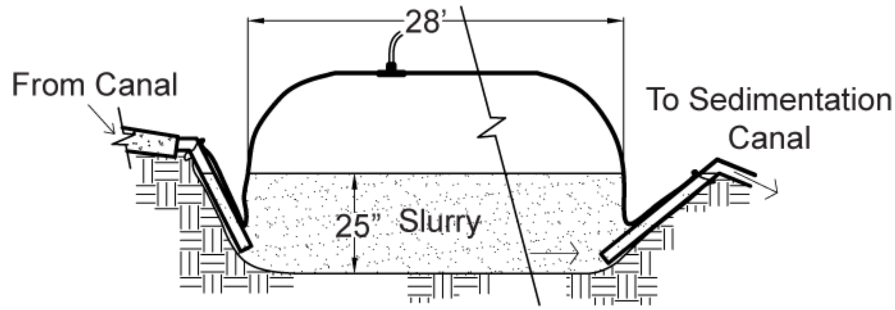
animal population at the campus. It will be 50” in diameter, 28’ long and will have a volume of 191 cubic feet (5.41 cubic meters) which is equal 1,428 gallons. The total slurry produced daily is approximately 43 gallons (162.5L) when calculated for 15 cows and 12 pigs. The biodigester is designed to retain and digest the slurry for 33 days. This size was calculated using the methodology provided by Santos and Valladares (2004). After 33 days the processed effluent is displaced by fresh slurry input and discharged into the sedimentation canal. EARTH University recommends a retention time of 22 days minimum for their location in the warm Caribbean lowlands of the Eastern part of Costa Rica (Vidal 2009), but the lower temperatures experienced in San Luis dictate a longer retention time to fully digest the material. The literature cites the appropriate temperature for mesophilic biodigestion to occur at is 95°F (35°C) (Appropriate Infrastructure Development Group [Internet]). The temperatures in San Luis are well below this at an average of 65°F (18°C), yet in nearby Santa Elena at a higher elevation and cooler temperature than San Luis, biodigesters have proven to effectively produce gas despite the less than ideal temperatures. At Rancho Margot on the shore of Lake Arenal at an elevation of 1800 feet (548m) a large “salchicha” biodigester also functioned effectively despite low temperatures. There is a high degree of uncertainty in estimates of gas production, but based on reported productivity from Rancho Margot and Santa Elena there should sufficient fuel for from six to eight hours of flame from a single burner. This flame is capable of heating a pot of water to boiling temperatures. Multiple burners of burners with more than one orifice can be used to heat larger quantities of liquid, for example in cheese making or pasteurization.

The biodigester is to be placed alongside the northern wall of the pig production facility in a pit with a 1% slope toward the outlet. The depth of the pit is 37.5” at the entry end. The walls should be dug at an angle to hold the pressure of the water against the wall of the bag. The biogas is stored in a reservoir of the same tubular polyethylene used to construct the digester. The reservoir will be hung over the digester. The gas is lighter than air and rises within the piping. Elastic bands are to be wrapped around the bag to increase the gas pressure. The biogas will be used to heat the suckling pigs as shown in

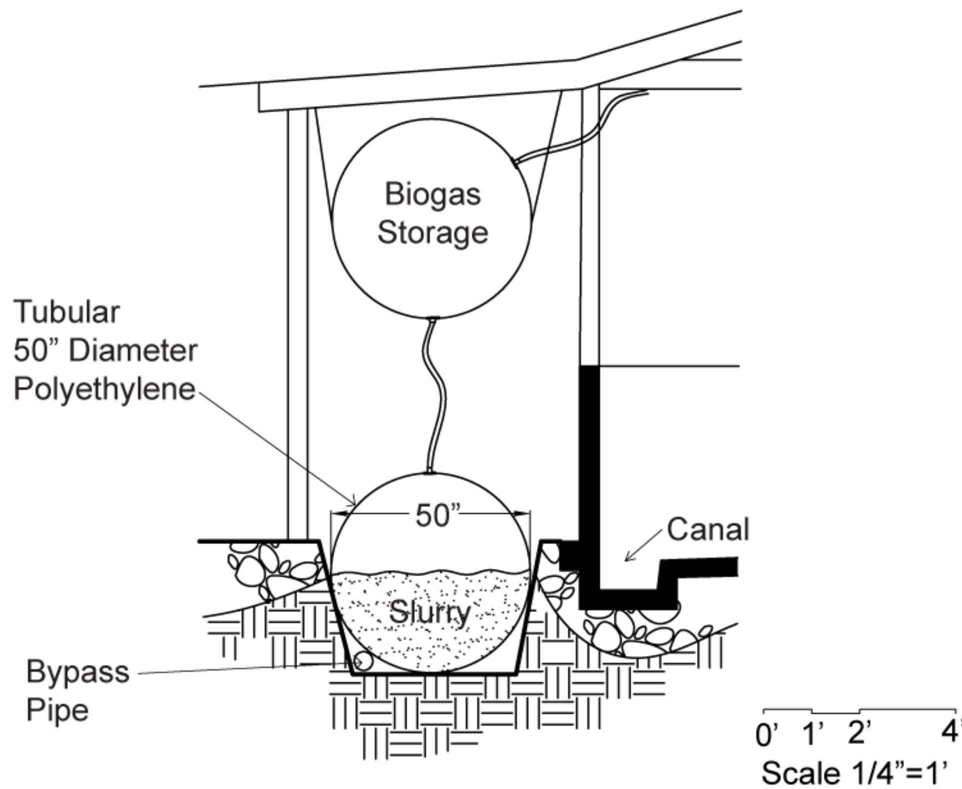
(Figure 31), for the production of cheese and to power the refrigeration of the dairy products. Soaps, chemicals and antibiotics will kill the microbes in the biodigester. To prevent these from entering a bypass pipe is available to route the slurry around to the aerobic treatment lagoons in the case that the animal pens need to be disinfected or treated to prevent the spread of disease. The bypass pipe is to be situated near the opening of the biodigester after the solid waste sieves and just before a metal plate placed in upright slits in the concrete canal which when in place will shunt the water into the bypass pipe preventing the toxic water from entering the bag. As noted in chapter 3, the discharge of untreated effluent has the potential for contaminating waterways. This specific design has little potential for this because of its small size and treatment regime. Should the sedimentation canal and purification lagoons fail, the effluent can be applied to the pastures, gardens and protein banks or least desirably allowed to flow overland through the pasture before it enters the Rio San Luis. In normal operation, the effluent will be channeled into an aerobic sedimentation canal to further treat the water and produce fodder for the animals

Sedimentation Canals

A single sedimentation canal is to constructed as detailed in (figure 4) to further treat the effluent from the biodigester and to grow aquatic plants for animal fodder The sedimentation canal is constructed of four inch thick ferrocement. The water flows into the top and exits from the top on the downhill side so that the sediment is not disturbed. The retention time is approximately 10 days. Sediment is removed from the bottom of the canal as necessary and



(a) Section.



(b) Section.

Figure 30: (a) Section, (b) Section. Biodigester diagram.

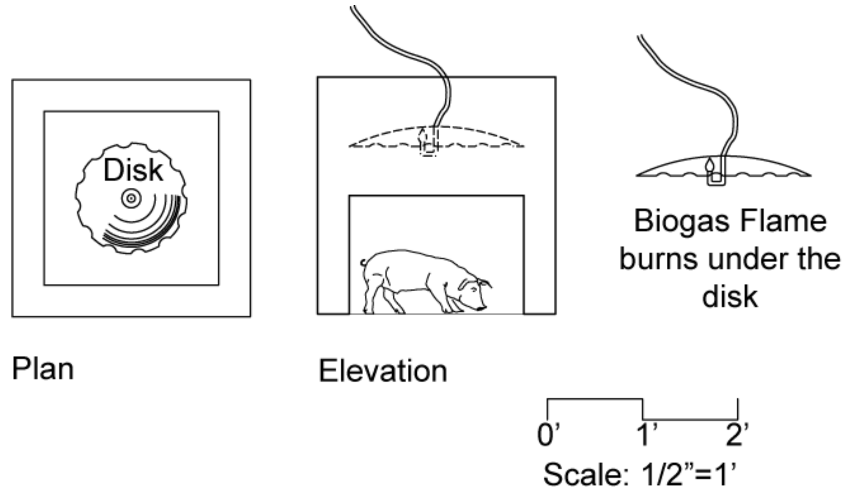


Figure 31: Plan and Section. Pig heater using biogas and disk.

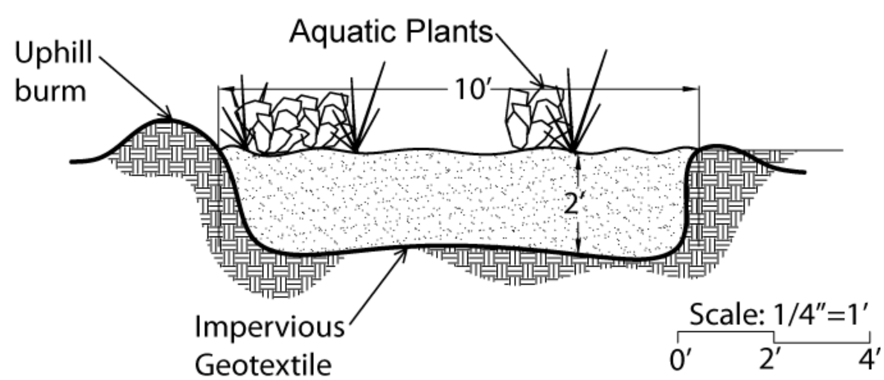


Figure 32. Purification lagoon cross section.

applied to the protein banks.   After leaving the sedimentation canal the effluent is directed into a series of two aerobic lagoons for further treatment...

Purification Lagoons

The purification lagoons (Figure 32) are a free water surface treatment system with an impervious geotextile material to prevent seepage in the freely draining soil. The dimensions are 10’ wide by 55’ long by 2’ deep. The total surface area is 0.025ac/1100sf. They are to be constructed on contour with a berm on the uphill side to divert stormwater. A pipe will connect the upper pond to the lower. The lower pond being on contour will spread the effluent along its length as it drains out into the natural swale. The effluent will travel as sheet flow 1,350’ through pasture and primary forest before it enters the San Luis River along the southern edge of the property allowing any nutrients that may remain after treatment to feed the agricultural system. The plants are to be harvested regularly leaving propogule stock in place.

Tilapia

Initial discussions with the UGA Costa Rica management for the development of the integrated farm system suggested that the production of tilapia be included in the design. Research into this form of aquaculture has shown that tilapia production in temperatures below 71.6°F (22°C) is ineffective (Nandlal and Pickering 2004 and Rokacy 1989). Considering that the average temperatures are well below this threshold and water temperatures are even lower tilapia production is not recommended. Compounding the problem of low temperatures are several other site features that limit the tilapia production. The topography is too steep for the cost effective construction of ponds of adequate size and the soil is ill-suited to hold water given its high porosity and organic matter content. Two farms are producing tilapia in the Bajo San Luis area where temperatures are slightly higher, but yield is low, the ponds are kept full by a constant flow of fresh water and concentrated feeds are used. These practices are not environmentally responsible and do not fit into an integrated farm system which seeks to minimize purchased inputs. It is possible that other species are available to fill this niche. Further research is necessary to identify these and evaluate them for suitability to the climate of the site.

Water

Water for the UGA Campus is currently derived from three sources. It is piped from a year-round spring on the property and from a spring offsite that is shared by the Altos de San Luis community and it is purchased from the Instituto Costarricense de Acueductos y Alcantarillados (AyA), the national water provider. The community built the shared infrastructure themselves and has for years enjoyed an almost unlimited free supply. Recently, AyA completed the construction of the San Luis Aqueduct which is supplied from the same spring. This water is untreated and has been determined to be safe. It is rumored that in the near future the community water infrastructure will be turned off and the sole provider will be AyA. The purpose of creating the metered aqueduct owned by AyA was to provide safe drinking water to the residents of Bajo San Luis and those beyond as there is no reliable well within their immediate vicinity and water borne disease is a problem. This change means that the campus and community will now be charged for a resource that was once perceived as free and will reduce the amount available to each user as it now must provide for more users. This makes the use of water caught in the cistern for the integrated farm even more important.

EM

EM is to be sprayed daily on the floors of the barn and swine facility to reduce odors, to inoculate compost piles and to make bokashi.

Bokashi

Bokashi will be made from the solids strained from the slurry. Activated EM in an 8% solution will be applied on a weekly basis until the material has reached a dry crumbly consistency. It should then be applied to the fields and garden where it will fortify the soil.

Electricity Production

The campus currently receives electricity from the power grid. Blackouts and interruptions are frequent. Wind generated power and micro-hydroelectric power are two technologies which have the potential for being implemented on-site. Of the two, micro-hydroelectric shows the most promise as two waterways flow through the site. They have the required volume, reliability and head needed. The likely site for the micro-hydroelectric power plant is in the vicinity of the pasture number 14 because it is in close proximity to the main campus, road access and the river along this stretch has a high vertical drop.

Study of the wind data collected at the on-campus weather station will be helpful in determining the viability of wind generation. The production of electricity using photovoltaic technology is not a viable option due to the number of days that the sun is obscured by clouds

The San Luis Botanical Garden

The Jardin Botanico San Luis/San Luis Botanical Garden (Figure 33) is a 6 acre portion of the UGA Costa Rica campus composed of trial gardens, a medical plants garden, an edible food crop demonstration garden, green house, secondary forest and trails. The Botanical Garden is one of only a few facilities of its type in Costa Rica open to the public and tourists alike. The greenhouse is part of a collaborative effort with the Costa Rican organization ProNativas to trial and propagate native plants of value to the horticultural/landscape industry. ProNativas specializes in plants occurring in the unique microclimate of the Monteverde area. Native trees are also propagated for planting in the carbon sequestration /reforestation program. Crops are harvested for the kitchen and the herbs are available to the community for the preparation of natural remedies. The plants on display, and many trees and shrubs in the forest, are labeled with the plants genus, species and common names in both Spanish and English to serve as a teaching tool and living laboratory. The Botanical Garden is a prime place to begin the trials of the plants that have been proposed for introduction in the area under the watchful and trained eye of the resident horticulturalist and other knowledgeable researchers. Small demonstration plots of only a few square meters per plant species/variety are ideal for this type of exploratory work and can easily be accommodated. The plants that show potential can then be distributed through the ProNativas network of gardens for further trial. The

Figure 33. Master plan of the San Luis Botanical Garden. Courtesy of UGA Costa Rica.

gardens are full of flowering plants which are not only beautiful, but have a more academic appeal in that they draw a great diversity of pollinators both day and night for study. It is not uncommon to be engulfed in a dancing cloud of butterflies when visiting on a sunny day.

Farm Equipment

UGA Costa Rica has in its possession a front end loader,w, a medium duty utility truck and an all-terrain vehicle. The only other required equipment needed is a motorized shredder to process cut feed.

Educational Considerations

In following with the goals and mission of UGA Costa Rica, the integrated farm has been designed to facilitate learning, teaching and outreach. The horse care area of the barn will function as interpretive center. Interpretive material including signage and labels are to be developed and installed in this area with the goal of providing an orientation to the grounds, an overview of the system, its processes, and its physical structure. Additional educational information that would help promote understanding of the project are productivity reports, and reports of monitoring , ongoing research and results. All portions of the farm are safe to enter, but any areas that are temporarily off-limits due to construction or other condition should be indicated in this area. Visitors and students may move freely around the site with the rule being that any gate be left as it is found.

The best way to learn how to farm is by farming. Employing the services of long-term interns (committing to a minimum of six months) is an ideal way to reduce the costs of farm labor while providing a rich and rewarding educational opportunity for the intern. The farm will be best served with a minimum of two resident interns who will learn the intricacies of food production in the unique and sometimes hostile environment of the campus, serve as interpretive guides and conduct research on the system.

Volunteers can also provide a large amount of labor and simultaneously learn while getting their hands dirty. Participation in the farm activities is a great way to connect visitors with the daily flow of life on the campus. There is little more satisfying than eating a meal that you have helped produce in some way. Activities for appropriate for volunteers are generally those that require no skills or training such as weeding and harvest.

Summary

This design for an integrated farm at the UGA Costa Rica Campus accommodates 15 dairy cows, 12 pigs, 25 laying hens and 3.56 acres of organic vegetable gardens with perennial crops informally distributed throughout. The production of the farm will not fully supply the food needs of the campus but will contribute a much larger portion than is currently being provided using the same amount of land. To achieve this, the intensity of land use has been increased made possible by the recycling and retention of nutrients within the system, on-farm production of high nutritive value animal fodder, and an increase of farmer labor inputs.

CHAPTER 6

CONCLUSIONS

The design is based on the best information available in the literature and was modeled on a system that has been proven to be effective. In light of this, the integrated farm has a good chance of success, though a good deal of investigation will be necessary to refine the operation and management of the system to achieve maximum benefits. Furthermore, the system has a high likelihood of implementation pending a capital funds raising campaign to be undertaken in the coming year. Several roadblocks do exist that could affect the success of the design, namely lack of funds for the creation of infrastructure and improper management. Educating the system operators will be key in ensuring that the system performs optimally. It is imperative that this training be provided at EARTH University prior to the system coming online.

Management of this system will require constant monitoring of each of the cycles independently and in relation to their function within the whole system. Monitoring involves data collection and interpretation, a scientific endeavor that must be fully documented to truly understand and modulate the function of the system over time. This will allow the manager to understand trends that might otherwise be missed. It will also help to inform the decisions that must be made to keep the system working properly. Some necessary monitoring activities/investigations are testing the BOD of the effluent in each stage of the treatment process, testing the efficacy of EM in making bokashi and compost, modeling the energetics of the system in terms of solar input, nitrogen fixation and material flows and looking for erosion and taking corrective action the moment it is detected. Measuring soil fertility and organic matter will indicate the health of this resource and will provide feedback into the efficacy of the soil amendments at regenerating this resource. An economic evaluation will also be an important tool for understanding if the system truly is appropriate technology as measured in its economic benefits. Cultural studies could look at the attitude of local farmers in regards to the technology and techniques as well as how likely they would be to adopt the system based on perceived or real benefits. These questions present a wealth of opportunities for students to become involved in firsthand research which will only stand to strengthen the educational offerings of the UGA Costa Rica Campus and thus strengthen the program as a whole.

In Chapter 2 a definition of the integrated farm was articulated along with a set of characteristics inherent to integrated farms. These characteristics form a set of principles which can be used to guide the design of novel systems. These same traits can be used as a framework for assessing the success of an integrated farm. The following is a self-evaluation of the integrated farm design for the UGA Costa Rica Campus which uses the properties of an ideal system as the framework for assessment.

The first criterion is that animal and crop production be linked by the continuous cycling of materials between components. One processes output must be coupled to another process in such a way that the output is used as material or fuel in the other process. This was accomplished by creating a cyclic flow of carbonaceous material from fodder crop to animal and then back to the crop in the form of manure or compost. The only appreciable losses to the system are from the products that are sold. In the case of UGA Costa Rica, little is sold off farm because the produce is consumed on the property meaning that system losses are minimal. By producing fodder, vegetables and multiple species of animals the system is made more diverse. High biodiversity is associated with system health and resiliency both positive attributes contributing to a more successful system.

The system must satisfy human food and fiber needs. This criteria is satisfied innately in that the very purpose of the system is to create food for the campus. The application of this system will increase yields over current production figures.

The integrated farm must enhance environmental quality and the natural resource base upon which the agricultural economy depends. The system does this in a number of ways. Because the farm is vertically integrated, producing many of the intermediate products required to create the final product (meat, dairy and vegetables) the energy that would otherwise be required to transport the inputs from elsewhere is conserved. Within the system the concept of waste is eliminated. What a conventional system would call waste is treated as a valuable resource which is used to fortify environment. This is accomplished by the return of organic residues to the fields where it facilitates the growth of more plant biomass which is then converted in part to animal biomass when it is consumed. In the process, soil is actively created as carbon and other nutrients are stored as inert matter or in living organisms, leading to a net increase in system energy and nutrients over time.

The use of non-renewable resources is minimized by the processes described above. Because the system is organic, natural biological controls are utilized instead of chemical products. The biodigester is an example of this at work. The methanogenic bacteria kill pathogenic organisms as they pass through the anaerobic environment.

The final trait of the system is that is must enhance the quality of life for farmers and society as a whole. Again the biodigestion process proves a key player in achieving this goal. The biogas produced is clean burning and mitigates the need to cut forest for firewood or purchase propane. Thus, the forest is spared from further disturbance and the impact of the on-campus energy use is not externalized. A greater level of productivity is made possible by intensive land use whether it be by rotational grazing or the use of high yielding protein banks. Both increase the productivity of a given area of land, meaning that to gain the same yield less forest need be cleared for pasture. More forest equals a more intact ecosystems which means that the ecological footprint of the system overall has been reduced. This is especially important for UGA Costa Rica as intact forest is the primary draw to the campus.

Using these system characteristics as design guidelines, the most exciting feature of the integrated farm concept is the possibility of its adaptation across all scales from very small farms to the industrial or regional scale.

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