Abstract of the Thesis of

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Cucurbits are grown in production agriculture in Oregon as well as in smallholder agriculture in tropical South America. Experimental research was performed at the OSU Research Farm in 2001 with direct-seeded cucurbits, and literature reviews were conducted to develop a characterization of smallholder farming in tropical South America. The two descriptions of different farming systems are used to draw comparisons between production agriculture and subsistence agriculture. Sustainability is used as a means of comparison and is defined as the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the natural resource base and avoiding environmental degradation. Direct seeding was determined to be effective at controlling weeds and raising yields in cucurbit monocultures and may also have a positive influence on sustainability. In smallholder agriculture in tropical South America, modified versions of the direct seeding technique may be used to improve or maintain levels of sustainability. Population control and reevaluation of personal "needs" are leverage points with the potential to improve sustainability.

Direct-Seeded Cucurbit Cultivation in Oregon and Tropical South America

by

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I understand that my thesis will become part of the collection of Oregon State University. My signature below authorizes release of my thesis to any reader upon request. I also affirm that the work represented in this Thesis is my own work.

Avery McCombs, Author

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PREFACE

I went to Ecuador in the summer of 1999 with a study abroad program offered through Oregon State University. I spent six weeks in Quito, Ecuador living with a host family and attending an English/Spanish language institute. At Benedict Language School, we worked on grammar and pronunciation as well as learning Ecuadorian history and culture. My host family also taught me Ecuadorian culture first hand and spoke to me in Spanish. I learned how to communicate in Spanish with my host family out of necessity.

The study abroad group from OSU also went on excursions to scenic locations in Ecuador. We visited the jungle and coast for four days each and a day trip to Otavalo, which is a center of commerce. I didn't get to see any of the agricultural practices in action on these expeditions. At the time, I did not know what the topic of my thesis project so I wasn't looking for examples of South American agriculture.

At the end of six weeks in Quito, I left my host family and started traveling with three other OSU students. Taking trains and busses, we journeyed down the coast of Ecuador and Peru. We stopped at the major cities and stayed a night or two. I saw some agriculture in passing but I did not pay it special attention. When we arrived in Lima, Peru, we flew to Arequipa and then took trains and busses on to Cusco. We visited many Incan ruins near Cusco including Machu Pichu. The agricultural practices of these early South Americans were evident from the terraces built into steep slopes for growing crops.

After a week in Cusco we flew from Arequipa to Lima and took busses to Quito in an epic bus-riding marathon that I won't soon forget. Once in Quito, I bid farewell to my host family and caught the return flight home.

When presented with the opportunity to do experimental research on direct-seeded cucurbit cropping systems, I was immediately interested. I knew that cucurbits were grown in smallholder farming systems in tropical South America, and was enticed by the idea of learning more about these systems. The experimental research project planned at the OSU Research Farm in 2001 under the guidance of Ray William and Ed Peachey helped me focus my international research. The experimental and book research gave me the basis for a comparison between subsistence farming systems and production agriculture, something I've always wanted to explore.

Direct-Seeded Cucurbit Cultivation in Oregon and Tropical South America

INTRODUCTION

Cucurbit growers worldwide have to find ways to control weeds in order for their crops to be successful. Tillage is a common form of weed control used in the U.S. and in the tropics (Beets, 1990). This research experiments with a minimum tillage strategy called direct seeding. A cover crop such as barley is planted in fall and allowed to grow until it dies in winter. In spring, the crop (cucurbits) is planted directly into untilled soil and cover crop residue. The direct seeding technique suppresses annual broadleaf weeds in the Willamette Valley, Oregon (Peachey, 1999) and was observed by Beets (1990) in the tropics. However, Beets (1990, P. 459) states that, "minimum tillage can only be successful if accompanied by alternative weed control measures." This experimental research was designed to test the efficacy of alternative weed control measures when used in conjunction with either direct seeding or conventional tillage techniques. The library research was designed to find current applications of the direct seeding technique and alternative weed management strategies to control weeds in cucurbits by smallholder farmers in tropical South America and improve understanding of these farming systems.

This thesis is a description of experimental research completed at the OSU Research Farm in 2001 and a literature review of smallholder farming practices in tropical South America. Peachey and McCombs tested the ability of direct seeding with alternative weed management strategies to control annual broadleaf weeds in cucurbits. Parameters of interest were weed emergence and dry matter, and harvestable yields. The focus was on maximization of productive capacity and minimization of weed emergence and biomass. McCombs researched smallholder farming practices in tropical South America with help from Ray William, who provided guidance and use of his library. The research provides an overview of the climatic and soil conditions, the predominant farming practices relevant to cultivation of squash crops in tropical South America, and the goals of smallholder farming.

This thesis project is intended to facilitate a discussion of the sustainability of different farming systems; the ones used to grow squash in tropical South America and the one used in the experimental research conducted by Peachey and McCombs at the OSU Research Farm in 2001. Sustainability is defined as "the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the natural resource base and avoiding environmental degradation" (Edwards et al; 1990, P. 14). A multilevel analysis will be used to examine the sustainability of both systems and identify impediments. Lastly, leverage points with the potential to improve sustainability on multiple domains will be presented and explained. No attempt will be made to hierarchically order the farming systems in terms of their quality, since that would require a determination of value on multiple parameters.

THESIS STATEMENT

The goal is to contribute to the depth of understanding of agricultural sustainability through a description of experimental procedures used in production agricultural research in Oregon and a characterization of smallholder agriculture in tropical South America, and to encourage the implementation of appropriate sustainability improvements.

EXPERIMENTAL RESEARCH IN PRODUCTION AGRICULTURE

Objectives

Agriculture has been revolutionized by advances in technology and the use of increasingly intensive farming practices. Through the green revolution and genetically modified organisms, agricultural production and efficiency has reached levels unparalleled in history. However, the apparent success of modern agriculture has been brought into question by evidence of natural resource degradation and pollution. Concerns about soil erosion and degradation, bioaccumulation of pesticides, loss of organic matter, and nutrient leaching have put a blemish on agriculture's incredible accomplishments (Gliessman, 2001). These concerns have prompted some scientists to reorient their research toward sustainability rather than productivity. This research project was an attempt to achieve adequate productivity while striving toward sustainability.

Direct seeding has arisen as a potentially beneficial way to reduce tillage, thereby reducing soil compaction and erosion while preserving organic matter, and still maintain a high level of productivity. However, there has been limited adoption of direct seeding by large-scale agricultural producers due to the relative novelty of the technique and the lack of research conducted thus far. Therefore, one of the agricultural objectives of this project is to contribute to the body of knowledge regarding direct seeding.

Another objective is to test alternatives to herbicides in conjunction with direct seeding. The amount of weed control afforded by direct-seeded agriculture can ameliorate the need for herbicides and give farmers other options. By implementing alternative weed control treatments, this research attempts to demonstrate the kind of results that can be achieved without herbicides. Results from hoeing and flaming treatments will be compared with herbicide treatments in terms of their weed control and yields.

The main agricultural objective of this research project is to promote more sustainable agricultural practices by raising awareness and understanding of direct seeding and alternatives to herbicides. In order for farmers to maintain high levels of productivity and efficiency, they need to reduce land degradation and pollution by adopting more sustainable agricultural practices. However, farmers will need the example of carefully designed experimentation to redesign their cropping systems in the most agriculturally, environmentally and economically beneficial ways. This research is an attempt to inform farmers of alternative cropping strategies and help them make the best management decisions possible.

Materials and Methods

Peachey and McCombs conducted experimental research on direct-seeded squash at the OSU Research Farm in the summer of 2001. The research project was designed to test the ability of five different integrated weed management strategies to control annual broadleaf weeds when used in conjunction with direct-seeded (DS) and conventional tillage (CT) agriculture. Peachey and McCombs hypothesized that the direct-seeded plots would have better weed control than the conventional till plots in each treatment group. This hypothesis was based on previous findings by Peachey in 1999.

The five treatments chosen were an untreated control, one hoeing in the DS plots and one hoeing and cultivation in the CT plots, a 0.031 pound active ingredient per acre (lb ai/acre) application of halosulfuron, a 0.047 lb ai/acre application of halosulfuron, and a flaming treatment with one hoeing in the DS plots and one hoeing and cultivation in the CT plots. All five treatments were applied in a randomized block design of 10 plots each, 5 DS and 5 CT. McCombs hypothesized that the hoeing and flaming treatments would be most effective at controlling weeds, especially in the DS plots.

The research site at the OSU Research Farm measured 275 feet long and 160 feet wide and was divided into 40 plots measuring 55 feet long by 20 feet wide. Rows of five plots ran lengthwise, each receiving a different treatment. There were eight rows of plots to allow for four replications of the DS and CT groups.

The entire field was tilled in fall, 2000 and planted with a Micah barley cover crop. Micah barley was selected for its quick establishment of a canopy that blocks light for weed growth. The barley died in winter but the residue remained on the field and contributed to the organic matter content of the soil. Conventional till plots were disk tilled twice and rotara tilled once on May 25, 2001, whereas the DS plots were left unattended. The whole field was planted with about 8,700 cucurbit seeds/acre on May 29, 2001. Seeds were planted with a two-foot spacing between rows, and plots were delimited with flags on the 29th as well. The following day, halosulfuron was applied to designated plots and incorporated into the soil with 0.5-inch irrigation water applied to the whole field.

The flaming treatment was applied on June 9th when the squash had two leaves and weeds were in the cotyledon stage. It was a calm, somewhat cloudy day with temperatures in the mid-seventies. A hand-held flaming device with a propane backpack was used to flame directly over the rows of cucurbits. The flaming equipment was set at 20 PSI and carried at 3 mph in order to kill the weeds in their vulnerable cotyledon stage without harming the larger, hardier squash.

On June 18th crop emergence was counted in all the squash plots. Weed emergence was estimated in the cucurbit plots on June 20th by taking two random samples of one meter square quadrats from each plot and counting all the weeds of each species within the square.

All plots received 0.38-inch rain on June 11th and were irrigated with one-inch water on June 19th.

Hoeing was applied to the hoeing and hoeing + flaming treatments on June 27th. Each plot received the equivalent of $50/acre of labor cost in hoeing at $6.50/hr, which amounted to ten minutes per plot. The hoeing and hoeing + flaming treatments in CT plots also received one cultivation on July 2nd. No cultivation was done in the DS plots to avoid disturbing the soil. The DS technique relies on minimal soil disturbance to prevent weed seeds from germinating, and using cultivation to kill existing weeds might have compromised the suppression of germination.

Ed Peachey applied a postemergence sethoxydim treatment at a rate of 1 pint per acre (pt/acre) on July 6th to kill emerging grasses.

Symphylan traps were put in the squash plots on the 10th of July. Symphylans are soil micro-arthropods which eat plant roots and can be extremely destructive to crops. The trapping method employed was a PVC cap with a potato under it to attract the symphylans. One trap was placed in each plot and marked with a yellow flag. McCombs checked symphylan traps periodically throughout the summer, recording the number of symphylans and centipedes under each trap, and replaced the potatoes when they molded. The yellow flags turned out to be ineffective as markers since they blended in with the yellow squash flowers and got pulled down and obscured by squash plant growth. The yellow flags were subsequently replaced with pink flags and eventually big orange flags when the pink flags proved unreliable as well. However, quite a bit of time was spent wading through squash plants looking for symphylan traps before the flagging system was perfected. Care was taken not to step on or tear squash plants any more than necessary, but some crop damage was indubitably inflicted during the course of the symphylan trapping. The effect of this crop damage on the results of the experiment should be very minimal since all plots were affected roughly equally and relatively insignificantly. The symphylan trapping experiment was a side project of Peachey, which was conducted on the site of the direct-seeded squash research but is not included in this undergraduate thesis project.

On July 16th about 50 lbs of nitrogen/acre was applied to the cucurbit crops in the form of urea pellets. An old, one-wheeled push fertilizer was used to deliver the urea between every other row of squash. The push fertilizer caused a very minor amount of crop damage by running over squash stems that were in the aisles. The crops were watered that evening dissolve the nitrogen.

The biannual OSU Field Tour took place at the OSU Research Farm on July 19th. There were about 25 people in attendance; some farmers but mostly field representatives. The cucurbit crops in my experiment were included in the tour and people were allowed to walk through the field and look at the different plots, which were labeled with treatments. Participants were told to stay on the plot borders, so crop damage from the OSU Field Tour should be negligible.

Cucurbits were harvested on October 5th, and the weight of all squash within a 120 ft^2 area from the center of each plot was recorded. After harvest, samples of weed biomass from two 1 m^2 quadrats in each plot were taken. Weeds were removed from the sample quadrats and separated by species into labeled paper bags. All weed biomass was subsequently dried and weighed.

Results and Discussion

Harvest yields were consistently higher in direct seeded (DS) plots than in conventional till (CT) plots (Fig 1). There was a statistically significant difference ($p < 0.05$) in harvest yields between the CT and DS groups in all treatments except for the hoeing + flaming treatment. The hoeing + flaming treatment was able to achieve yields in the CT plots that were comparable to yields found in DS plots. This is attributed to increased weed control associated with the hoeing + flaming treatment. Peachey (1999) found that squash crops grown using direct seeding had higher yields and better weed control than squash crops grown using conventional tillage. The research done by Peachey and McCombs in 2001 provided further evidence to support these conclusions.

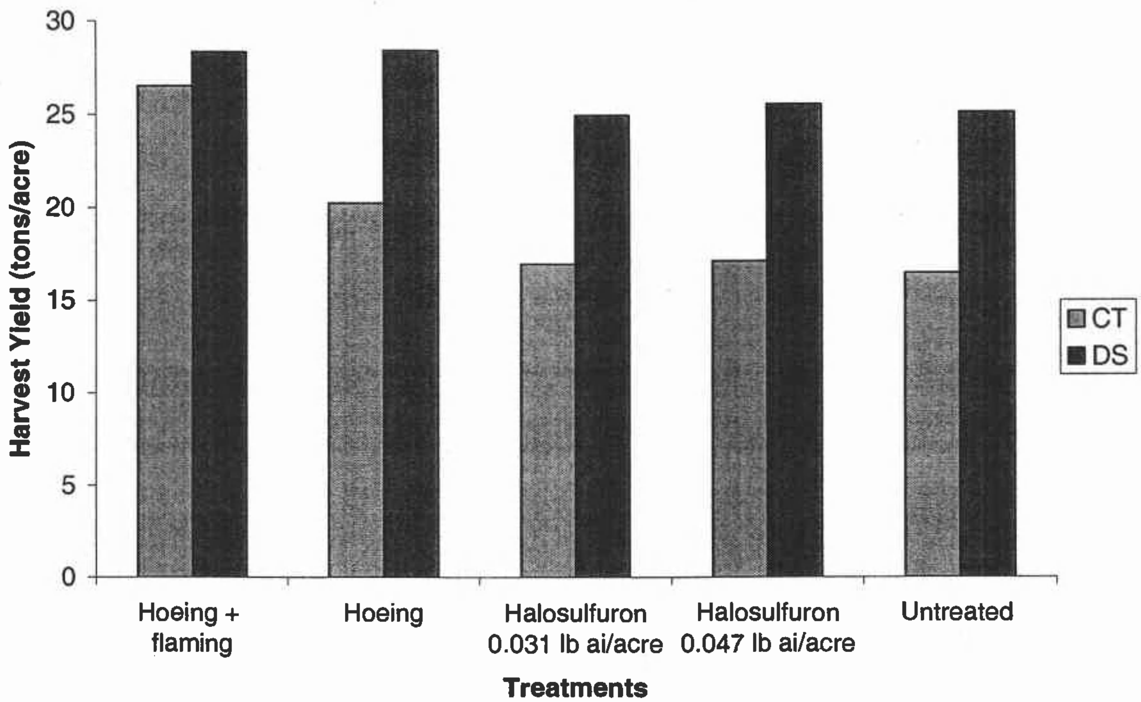

Figure 1. Harvest yields (tons/acre) of treatments within CT and DS blocks ($LSD_{0.05}$ = 7.6 tons/acre).

Weed control in this experiment was assessed by quantifying emergence and dry matter. Special attention was given to nightshade, due to its relatively high abundance. The halosulfuron 0.031 lb ai/acre treatment is omitted from the discussion of weed control and Figures 2-5 due to inconsistency in data, which was probably caused by a deficit in nightshade emergence in plots 304 and 404 CT from previous field trials in that area. The difference in mean nightshade emergence between the halosulfuron 0.031 lb ai/acre treatment and all the other treatments in the CT group was statistically significant ($p < 0.05$), which is why this treatment is excluded from the discussion of weed control. Results reinforced previous findings by Peachey in 1999 and supported the conclusion that direct seeding reduces weed abundance and biomass compared to conventional tillage.

Nightshade and total weed emergence were significantly lower ($p < 0.05$) in DS plots than in CT plots (Fig 2 and 3, respectively). There was no significant difference in nightshade and weed emergence between treatments within CT and DS blocks (Fig 2 and 3). Direct seeding inhibits germination of weed seeds by minimizing soil disturbance (Peachey, 1999). Weed emergence data obtained in this experiment supports this hypothesis.

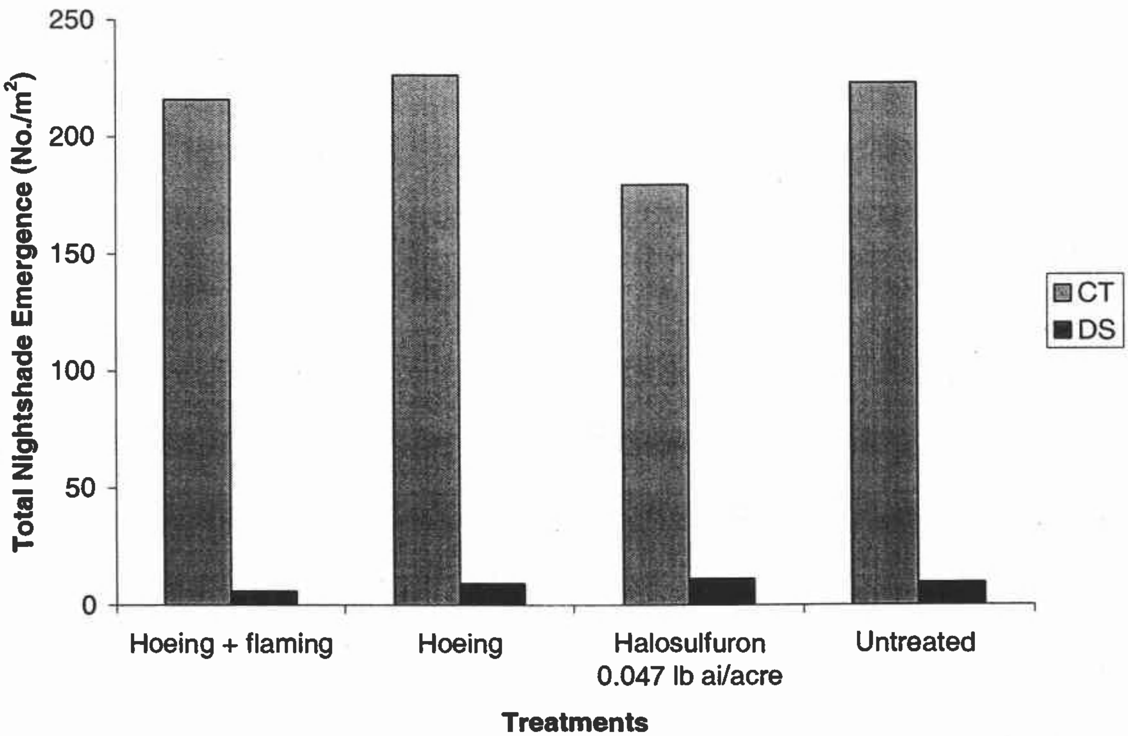

Figure 2. Total nightshade emergence (No./m^2) of treatments within CT and DS blocks ($LSD_{0.05} = 89$).

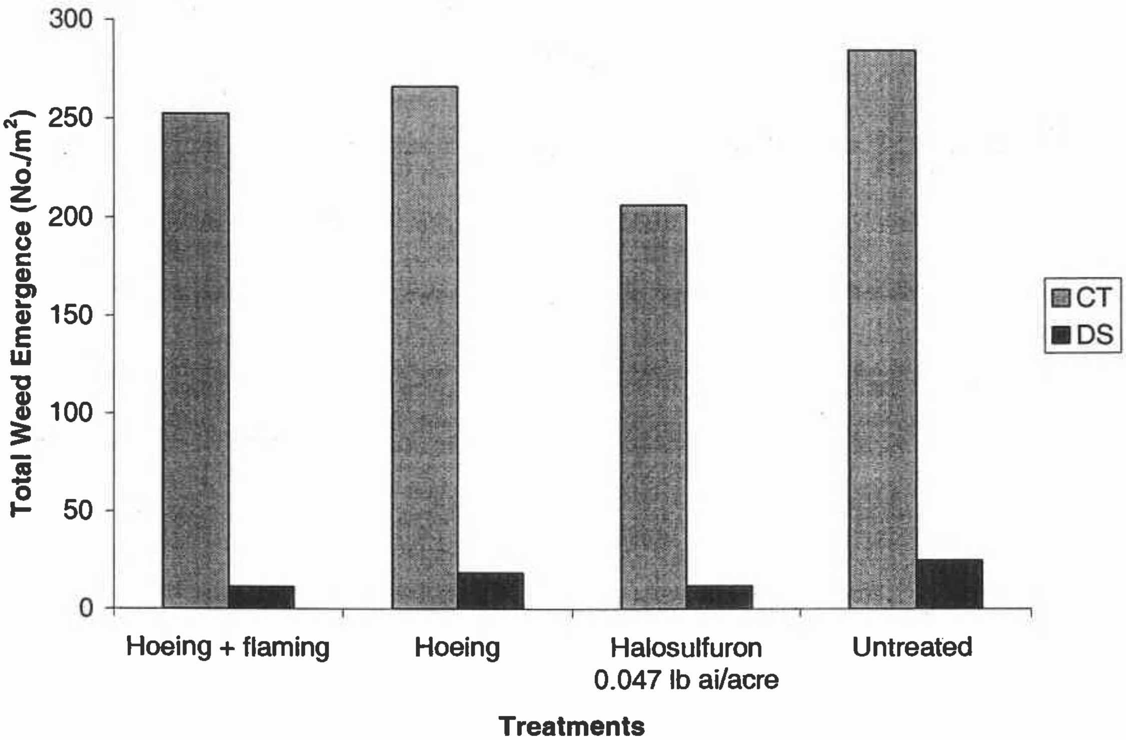

Figure 3. Total weed emergence (No./m^2) of treatments within CT and DS blocks ($LSD_{0.05} = 99$).

Nightshade and total weed dry matter were consistently lower in DS plots than in CT plots (Fig 4 and 5, respectively). However, the differences in nightshade dry matter between CT and DS plots were only statistically significant ($p < 0.05$) in the halosulfuron 0.047 lb ai/acre and untreated treatments (Fig 4). The lack of a statistically significant difference in nightshade dry matter between CT and DS plots in the hoeing + flaming treatment and the hoeing treatment may be due to the difference-neutralizing effect of applying the same treatments to CT and DS groups. Also, the CT plots within these treatments received one cultivation, which may have reduced the relative amount of nightshade dry matter compared to DS plots. The halosulfuron 0.047 lb ai/acre treatment and the non-treatment control did not supply the same difference-neutralizing effect, because halosulfuron is ineffective against nightshade and the control was untreated. The difference in total weed dry matter between CT and DS plots was only statistically significant ($p < 0.05$) in the halosulfuron 0.047 lb ai/acre treatment.

The hoeing + flaming treatment had a trend toward better weed control than the other treatments within their respective CT and DS groups. The remaining treatments were comparable in their degree of weed control to other plots within their tillage groups.

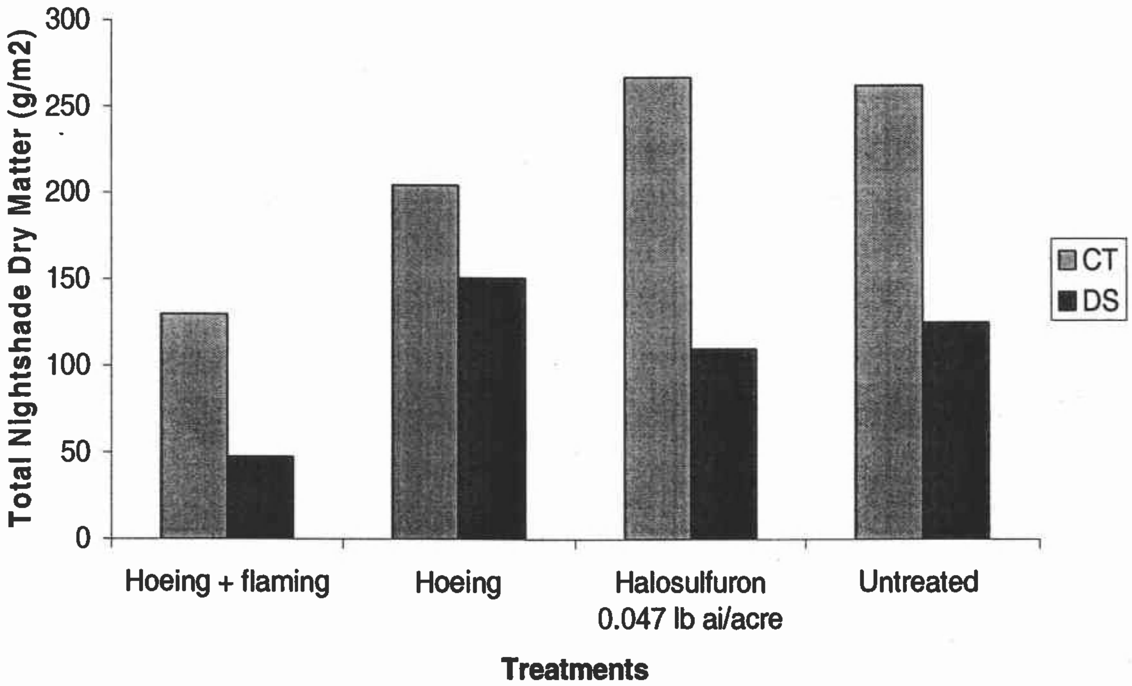

Figure 4. Total nightshade dry matter (g/m^2) of treatments within CT and DS blocks ($LSD_{0.05} = 123$).

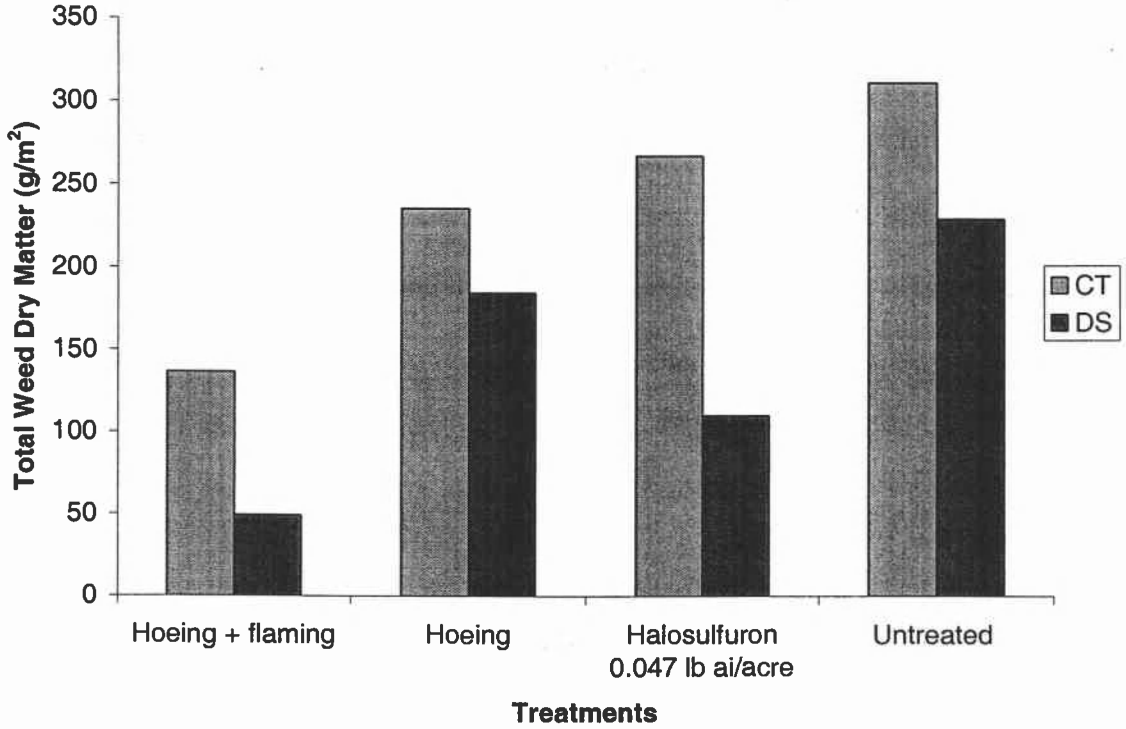

Figure 5. Total weed dry matter (g/m^2) of treatments within CT and DS blocks ($LSD_{0.05}$ = 132).

INTERNATIONAL RESEARCH ON SMALLHOLDER FARMING IN TROPICAL SOUTH AMERICA

Objectives

The international objective of this project is to characterize smallholder farming systems used in tropical South America to cultivate cucurbits. The characterization will include a description of the climatic and soil conditions, a typology of predominant smallholder farming practices, and a discussion of the goals of smallholder agricultural systems. The purpose of this analysis is to facilitate a comparison of direct seeding in smallholder farming systems in tropical South America to cultivate cucurbits and the experimental research performed by Peachey and McCombs in 2001.

Another goal of this project is to demonstrate the merits of direct-seeded agriculture for smallholder farmers in tropical South America. Smallholder farmers often lack the capital necessary to do extensive tillage and buy inputs. The inability of smallholder farmers in tropical South America to invest in herbicides creates a need for alternative weed control methods (Beets, 1990). Direct seeding represents one way that farmers can reduce the need for inputs. By increasing soil organic matter content and weed control, direct seeding may allow smallholder farmers to harvest satisfactory yields without investing a lot of time and money into weeding and inputs.

Sustainability is a global concern and it involves the interplay of many complex adaptive systems acting on different scales (Holling, 2001). Economic, climatic, cultural, environmental, and political systems all operate on the personal, social, societal, and global level to influence sustainability (Holling, 2001). This makes the issue extremely complex, but an acceptance of the complexity and uncertainty of the situation can open avenues of increased understanding. The sustainability of smallholder farming in tropical South America will be examined on multiple levels in an effort to comprehend complexity and elucidate leverage points. Profitability and ability to maintain or enrich the natural resource base will be used to inquire about the sustainability of smallholder farming in tropical South America. The goal is to improve understanding of sustainability and expose opportunities for improvement of sustainability on multiple domains.

Agricultural Conditions

There are three main conditions pertinent to farming, including climate, soils, and biological activity (Ruthenberg, 1976). This research will focus on climatic and soil conditions. Biological conditions such as microarthropod community dynamics and microbial activity tend to be very site-specific and must be assessed on a case-by-case basis.

Climatic conditions in South America are mostly tropical with the exception of the high elevation areas and far south regions. This study will focus on agricultural conditions only in the tropical regions of South America.

Tropical climates are characterized by hot, humid weather with minimal seasonal variation in temperatures. Temperatures rarely go below freezing and crop production may be possible at all times of year (Ruthenberg, 1976). Solar radiation in the tropics is stronger than in areas farther from the equator, due to the more direct path of sunlight through the atmosphere closer to the equator. Therefore, energetic potential for plant production is two to three times higher in tropical than in temperate zones (Ruthenberg, 1976).

Precipitation is greater in tropical than in temperate climates (Ruthenberg, 1976). In most tropical areas precipitation falls in a seasonal pattern (Ruthenberg, 1976). Seasonal climates have well defined wet and dry seasons with annual precipitation rates slightly exceeding potential evapotranspiration (Beets, 1990).

Often precipitation will occur very quickly in a series of heavy storms, resulting in water and soil losses due to extensive runoff (Ruthenberg, 1976). Problems of runoff and inhibited percolation due to poor soil or soil management are reasons why the "proportion of rainfall in the tropics available for crop production is often less than in temperate areas" (Ruthenberg, 1976, P. 20). Therefore, we cannot conclude that because the tropics receive more rainfall than temperate zones plants will receive more water.

Soil conditions in tropical South America "vary enormously in type and suitability for farming" (Ruthenberg, 1976, P. 21). However, some generalizations can be drawn from the climatic conditions and predominate soil types. Ruthenberg (1976, P. 21) states that, "(m)any soils particularly in humid areas have a low level of natural...fertility." Oxisols and ultisols are the dominant soil types in tropical South America, and they are typically acidic, low fertility, and red or yellow in color (Edwards et al; 1990). Aluminum saturation may be a problem in the more acidic oxisols and ultisols (Edwards et al; 1990). "The high temperatures of the tropics tend to accelerate virtually all soil processes: oxidation of organic matter, leaching and erosion" (Beets, 1990, P. 198). Heavy rainfall also contributes to low soil organic matter content because organic matter deteriorates quickly when moist (Ruthenberg, 1976). The reduction in organic matter content decreases soil porosity, thereby increasing bulk density. This can lead to the formation of a surface crust or "cap," which inhibits aeration and water infiltration (Beets, 1990). Nutrient leaching is also a major problem since heavy rainfall can carry most of the soluble nutrients below the root zone and even form subsurface hardpans, which can impede drainage and restrict root growth (Ruthenberg, 1976).

The poor structure of many tropical soils, due to low organic matter content and soil runoff, makes them unsuitable for exploitation, because they may not be resilient under intensive cultivation (Ruthenberg, 1976). Therefore, farming practices that minimize tillage, provide adequate ground cover to protect soil from direct rain and sun, and promote development of organic matter will be more successful at achieving sustainable results than farming practices that leave soils exposed to the elements and allow erosion and oxidation of organic matter to proceed more rapidly.

Cucurbit Cultivation Systems

The three main farming systems, which are used to grow squash in tropical South America, are shifting cultivation, mixed farming, and agroforestry systems (Beets, 1990; Francis, 1986). A brief description of each of these systems will elucidate some of the characteristics relevant to direct seeding and alternative weed management strategies in cucurbits.

Shifting cultivation is an ancient form of agriculture that has proven highly sustainable in terms of its ability to provide for the needs of a human population and maintain or enrich agricultural resources (Beets, 1990). The sustainability of the system hinges on having an adequate fallow period for soil nutrients and tilth to be restored

(Beets, 1990). According to Beets (1990, P. 352), "(t)he cropping to fallow ratio should never be allowed to fall below 1:10." However, he typifies a common system of shifting agriculture in the tropical rainforest in which 20 year cycles consist of three years of cultivation followed by 15-20 years of fallow, which is sufficient for the rainforest to recover (Beets, 1990). The extensive duration of the fallow period creates a land requirement ten times greater than the area cultivated per year (Beets, 1990). This equates to a land requirement of about 20 hectares for a family farm (Beets, 1990).

"Shifting cultivation is the least commercialized of all farming systems" (Beets, 1990, P. 349). Lack of markets and inadequate infrastructure often bar commercial sale of agricultural products in tropical areas of South America such as the Amazon rain forest (Edwards et al; 1990). Nevertheless, about 40% of the total agricultural population in the third world depends on shifting cultivation for their subsistence (Beets, 1990). The extensive use of shifting cultivation in the third world is probably due to its high energy efficiency ratio and long-term sustainability. The energy efficiency ratio, defined as "the output of joules in the edible yield divided by the energy input supplied by man, is higher in shifting cultivation than in any other farming system" (Beets, 1990, P. 357). Weeding requirements are low because the weed seed bank is diminished by an adequate fallow period and new land is cleared when weed populations become a hindrance to economic sustainability (Denevan, 2001). All of the labor required in shifting cultivation is done manually and no external inputs are added (Beets, 1990). However, the slashing and burning of vegetation can cause "a decrease in exchangeable aluminum and an increase in pH and available nitrogen, phosphorous, potassium, calcium, magnesium, zinc, and copper" (Edwards et al; 1990, P. 396). The soil neutralizing and fertilizing effect of ash from slash-burning may enrich the agricultural potential of acidic, low fertility soils such as the oxisols and ultisols dominant in tropical South America (Edwards et al; 1990). Burning may even be postponed until after the first rains, the weed seeds have germinated, and new shoots have sprouted… "(b)urning destroys these young plants and the need for subsequent weed control is reduced" (Beets, 1990, P. 357).

Slash-and-burn agriculture may be able to sustain or enrich agricultural resources indefinitely in areas of land abundance. "Unfortunately, land shortage has become a global problem" with fallow periods becoming shorter (Beets, 1990, P. 346). Labor efficiency decreases with increased permanence and intensification and long-term soil fertility declines with shortening fallow periods (Beets, 1990). Reductions in efficiency and soil fertility associated with land shortage threaten the economic and natural resource sustainability of shifting agriculture in areas of population pressure.

If land availability is limited, shifting cultivation may be modified from a slash-and-burn technique to a slash-and-mulch strategy. In this system, "vegetation cut for a clearing is not burned, but rather is allowed to decompose" (Denevan, 2001, P.69). The mulch has positive effects on soil such as erosion reduction, moisture conservation, soil temperature reduction, and inhibition of weeds and some diseases. The improved weed control and growth conditions furnished by the mulch may sustain yields sufficient for profitability with only periodic additions of new mulch and short fallow periods (Denevan, 2001). A low-density crop is produced, but weed competition is restricted by the mulch and the technique is very labor efficient (Denevan, 2001).

In situations where land pressure is fierce enough to prevent the use of slash-and-burn or slash-and-mulch agriculture, more intensive agricultural systems such as agroforestry and multiple cropping may be considered as a means to economic and natural resource sustainability. These systems are not more intensive in terms of external inputs or mechanization, but rather in terms of labor inputs and management complexity.

Agroforestry is "a land-use or farming system in which trees are grown on the same land as crops and/or animals, either in a spatial arrangement or in a time sequence, and in which there are both ecological and economic interactions between the tree and non-tree components" (Beets, 1990, P. 428). There are a plethora of distinct agroforestry systems and incalculable combinations of tree and non-tree components that can be exploited. Specific agroforestry practices will not be detailed, but the underlying characteristics of agroforestry systems as they relate to productivity, sustainability, and land utilization will be discussed and the place of squash in these systems considered.

Agroforestry systems consist of trees and multiple crops grown on a single piece of land with complementary ecological relationships, including possibly livestock. The trees are able to access nutrients that are below the root depth of agricultural crops and recycle them into the upper soil levels (Beets, 1990). Some nutrients mined by trees contribute to soil surface fertility in the form of litter fall, while some tree biomass is used as animal fodder, adding nutrients to the soil surface as manure (Beets, 1990). Agroforestry promotes agricultural sustainability by reducing land requirements, maintaining soil fertility, controlling erosion in undulating terrain and improving soil structure (Beets, 1990). Trees may also be used as live fences to protect crops from foragers or as support for climbing commercial crops (Beets, 1990). However, "with few exceptions, annual crops suffer from shading by trees" (Beets, 1990, P. 438). Shading can be minimized by manipulating the spatial and temporal arrangement of the tree/annual crop association (Beets, 1990). Even with some yield reduction from shading, the overall productivity of the land should be high and the complementary ecological and economic relationships between system components should allow the agroforestry system to persist sustainably (Beets, 1990).

Dalrymple (1971, Abstract) defines multiple cropping as "the practice of growing more than one harvested crop in sequence on the same piece of land in the course of one year." However, one crop often overlaps another crop temporally in the sequence (relay cropping), or more than one crop is grown at the same time (intercropping). Squash crops are not well suited to multiple cropping as Dalrymple defines it, because the growing season is too long. The length of the growing season is "one of the most important factors" for determining suitability of a crop for multiple cropping (Dalrymple, 1971, P. 23). Multiple cropping can be successful with corn and beans, but the integration of squash into the system requires intercropping of the three crops together.

Intercropping of corn, beans, and squash is an ancient agricultural system that is still used today by people in South and Latin America, Africa, and Asia. The corn, beans, and squash polyculture has been historically sustainable for many reasons. "Corn yields could be stimulated by as much as 50% beyond monoculture yields when planted in beans and squash" (Francis, 1986, P. 91). More importantly for subsistence farmers, "(t)here is a much lower probability of income falling below a disaster level in intercrops than in the equivalent sole crops" (Francis, 1986, P. 133). Yields for beans and squash are often reduced as a result of intercropping, probably due to shading from the corn, but the total yield is usually high for the amount of land used (Francis, 1986). The squash is not competitive with the taller corn and bean crops but it does shade weeds beneath the squash canopy. "The squash forms a continuous cover over the low lying weedy species" (Francis, 1986, P. 89). The maize/bean/squash polyculture seems to be mutually beneficial for the three system components. The beans increase soil nitrogen content through their association with nitrogen fixing bacteria, the corn provides a structure for the beans to climb on and causes the beans to nodulate more and potentially fix more nitrogen, and the squash suppresses weeds and contributes organic matter to the soil (Francis, 1986). There are some possible drawbacks of intercropping such as increased disease development due to more shade, which may favor the pathogen (Francis, 1986). However, shade can be managed by manipulating the density and row orientation of crops (Francis, 1986).

"Since multiple cropping systems are often used by farmers with limited land and power resources, much of the tillage is done by hand or with animal traction. Minimum tillage schemes are common, and may involve cutting the existing plant cover, burning, or less often controlling weeds with herbicide" (Francis, 1986, P. 164). Burning is the most common non-tillage method of land preparation, because it is the most labor efficient, it deposits a nutrient-rich layer of ash, and it helps control disease pathogens (Denevan, 2001). However, it may be advantageous for the seedling to cut the existing plant cover and leave it on the field, because greater residue cover on the soil surface lowers soil temperatures and decreases water stress (Francis, 1986).

Goals and Productivity

Smallholder farming systems in tropical South America tend to be oriented toward subsistence rather than production agriculture. Some crop surpluses may be sold at markets, bartered, or shared with the community, but in general the infrastructure is not available to support commercial sale of agricultural commodities (Edwards et al; 1990). Therefore, primary goals of smallholder farmers in tropical South America are usually risk-avoidance and labor efficiency or labor minimization, rather than productivity and profit (Ruthenberg, 1976). Of course, higher yields are almost always preferable and surpluses may generate income that can be saved for times of shortage or used to improve quality of life.

"Diversification of production to grow a range of crops is a typical risk-spreading device used the world over" (Ruthenberg, 1976, P. 25). Agroforestry, intercropping, and usually shifting cultivation involve the production of multiple crops, which reduces the probability of income falling below a disaster level (Francis, 1986). Diversity was also correlated to resilience by Holling (2001).

The emphasis on risk-avoidance by smallholder farmers may partially explain the uncommon use of inorganic fertilizers and synthetic herbicides. The investment in inputs may be too great a risk for smallholder farmers in tropical South America, considering the uncertainty of yields and markets and the frequent lack of infrastructure. Another explanation is that smallholder farmers simply cannot afford the price of fertilizers and herbicides (Beets, 1990). "External inputs can only be promoted if local infrastructure is sufficiently developed to supply them on a continuous basis and if there is scope for farmers to move from pure subsistence to semi-commercial farming" (Beets, 1990, P. 62).

Labor efficiency is very important in smallholder farming systems in tropical South America, because labor is usually done manually (Beets, 1990). Land preparation, planting, and weeding all compete for the farmer's limited time and labor at the beginning of the rainy season (Beets, 1990). "Where…labor is the main variable input into farming, its availability can be the limiting factor to production" (Ruthenberg, 1976, P. 25). Manual and even draft power are often incapable of cultivating dry lands before the first rains of the season (Beets, 1990). The time required for land preparation using traditional methods can delay planting dates and lower yields. Also, time invested in tillage and planting may detract from the farmers' ability to attend to weeding demands (Beets, 1990). "An improvement is to do land preparation immediately after the harvest of the previous years crop since the soil still contains sufficient moisture. Weed growth during the dry season is limited since there is very little moisture in the soil" (Beets, 1990, P. 457). In spring, vegetation may be burnt or cut and used as mulch, and crops are direct-seeded into the ash or mulch. The time saved in the spring by direct seeding crops can lead to optimization of planting date and improved crop husbandry, and therefore higher yields.

When commercial sale of agricultural products is minimal and labor comes from within the farming family, labor efficiency can be directly equated to profitability. Minimum tillage strategies such as direct seeding can reduce the amount of labor required to produce sufficient food for subsistence, and thereby enhance economic sustainability. Risk-avoidance through cultivation of multiple crops may also improve economic sustainability by decreasing the probability of income falling below a disaster level (Francis, 1986). Therefore, the primary goal of smallholder farmers in tropical South America, as with production farmers, is profitability or economic sustainability. "Subsistence farmers with very limited resources usually have a short-term planning horizon" (TAC, 1989, P. 7). As long as land availability is sufficient for traditional agricultural systems to operate in the accustomed way, then natural resource sustainability may be maintained along with profitability. However, when land pressures reduce fallow periods and push people onto increasingly marginal lands, natural resource sustainability may decline and profitability diminish or system modifications may be required to fulfill the changing needs of people.

SUSTAINABILITY OF AGRICULTURAL SYSTEMS

Smallholder farming in tropical South America and production agriculture in Oregon are extremely different. The climate, soils, technology, culture, goals, and yields are all different in a tropical subsistence setting than they are in a temperate production system. However, both systems have in common a concern for sustainability. Sustainability is typically defined as "the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the natural resource base and avoiding environmental degradation" (Edwards et al; 1990, P. 14). There are two elements of this sustainability definition, economics and natural resources, which coincide with the two components of agricultural systems, socioeconomic systems and natural ecosystems (Gliessman, 2001). The satisfaction of changing human needs implies the ability to make a profit or at least achieve self-sufficiency. Therefore, this element of the sustainability definition requires that agricultural systems be profitable, or at least able to support the farming enterprise. The second part of the sustainability definition requires that the natural resource base be maintained or enhanced. On a global scale, this component of the sustainability definition would be very hard to comply with, because any use of non-renewable fossil fuel energy would be a depletion of the natural resource base. However, on the individual farm level it may be possible to maintain or enhance agriculturally desirable soil characteristics through careful management. This may be achieved through site-specific nutrient management programs using GPS technology and inorganic fertilizers or through traditional farming practices using indigenous knowledge and organic inputs.

The definition of sustainability is open to diverse interpretations. Some people believe that we will always be able to satisfy changing human needs because science will find replacements for depleted natural resources. At the other end of the spectrum there are people who believe that organic agriculture is sustainable but agriculture that utilizes inorganic fertilizers and chemical inputs is unsustainable. In order to assess the validity of any claim to sustainability it is important to consider both the economic and natural resource components. If sustainability is not examined on multiple levels, then it becomes "very easy to devise models that simply suggest shifting a particular problem between different descriptive domains" (Gliessman, 2001, P. 183). In response to concerns about the sustainability of fossil fuel-derived fertilizer use in modern agriculture, one could easily suggest that we discontinue usage of inorganic fertilizers. While this would allow for the maintenance of the natural resource base, it would not be sustainable because farmers could not get adequate yields to make a profit using modern techniques and varieties (Edwards et al; 1990). Therefore, the unsustainability of the system would simply be shifted from one domain (natural resource) to another (socioeconomic) and no real progress would be made.

Many environmentalists feel that modern agriculture, which depends upon "high inputs of inorganic fertilizers and synthetic chemicals for pest control and tends towards monoculture of cash crop varieties that require such inputs," is unsustainable (Edwards et al; 1990, P. xiii). Gliessman (2001, Preface) says that "(m)odern agroecosystems have become unsustainable for a variety of reasons having to do with economics, history, social and political change, and the nature of technological development. Redirecting agriculture in a sustainable direction requires research and change in all these areas." It is beyond the scope of this project to research all of the factors involved in making agriculture in developed countries the way it is today and suggest system modifications or improvements. In fact, Gliessman (2001, P. 182) argues that "(i)t is impossible for practical reasons to handle the amount of information that would be required to describe the sustainability problems." Therefore, the focus of this research will be on elucidating leverage points that can have an impact on multiple domains and perhaps improve overall sustainability of agricultural systems.

One major difference between modern production agricultural systems and smallholder subsistence agricultural systems is the degree of openness. Modern production systems tend to be more open, because they rely on fertilizer and chemical inputs from outside of the farm system. These inputs may increase yields and decrease labor requirements while maintaining profitability (Gliessman, 2001). However, overproduction of cash crops may lower prices and decrease profitability (Edwards et al; 1990; Jolliff, 1999). Open agricultural systems produce more than subsistence requirements and are able to export agricultural commodities off-farm (TAC, 1989). Smallholder agricultural systems in tropical South America tend to be less open. Nutrients from the system are recycled back into the system in the form of ash, mulch, compost, or manure, few external inputs are applied, and little more than subsistence requirements are produced and exported away from the farming system (Edwards et al, 1990; TAC, 1989). Proponents of "closed" system agriculture argue that it is more sustainable because there is increased resource utilization efficiency and internal nutrient cycling and less reliance on fossil fuel energy (Edwards et al; 1990). However, others contend that "reliance on more closed systems has more dangerous ecological consequences because it can satisfy the need for agricultural products only by expanding into areas that are less and less suitable for agriculture, destroying the natural ecosystems in the process" (TAC, 1989, P. 8). A switch from more to less open agricultural systems seems to represent a shift of the problem from one domain to another and not an actual leverage point, although some adaptation of systems toward more or less openness could improve their socioeconomic and natural resource sustainability if compatible with socioeconomic and cultural constraints. For example, opening the system to applications of locally available rock phosphate may increase yields and profitability for smallholder farmers in tropical South America, whereas purchase of mechanical harvesters for use on intercropped land would be an inappropriate acquisition of technology and an unprofitable outflow of capital. Likewise, cover cropping with leguminous species may allow production farmers to sustain or increase yields while closing the system from inorganic nitrogen fertilizers and excessive soil losses, but complete disuse of chemical pesticides may be unprofitable in monocultures due to decreased yields from weed competition and/or increased expenses for manual weed control (Paoletti et al; 1993).

By examining the sustainability definition it is possible to identify leverage points. The definition requires the satisfaction of changing human needs today and the maintained ability to do so in the future. Obviously this becomes increasingly difficult with increasingly large populations. Therefore, one leverage point for sustainability is population control. "(T)he concept of sustainable agriculture involving decreased use of inorganic fertilizers and pesticides is unlikely to survive increasing population pressure" (Edwards et al; 1990, P. 497). The sustainability of traditional subsistence agricultural systems, such as shifting cultivation, is also threatened by population pressure, as soils become degraded by inadequate fallow periods (Beets, 1990).

Another leverage point evident in the sustainability definition is the nature of changing human needs. Some human needs may be more sustainable than others, and it will be the challenge of humanity to adapt human needs to be compatible with the maintenance or enrichment of the natural resource base. "The problems are complex and the attitudes of farmers and governments are crucial" (TAC, 1989, P.6). However, it is incumbent upon the citizenry of democratic nations to express their disagreement with national policies and attitudes because their silence signifies consent. People who truly want to make a contribution to agricultural sustainability must examine their own perceived needs and work to change the attitudes of farmers and policy-makers.

CONCLUSION

Direct seeding with alternative weed management strategies has proven to be a viable option for production agriculture in Oregon. There are distinct advantages in weed control for direct-seeded cucurbits compared to conventional tillage. As a result, squash crops are subjected to less competition from weeds and are able to produce higher yields than in conventional till plots. There may also be long-term reductions in soil erosion and compaction afforded by the decrease in tillage from twice a year in conventional tillage systems to once a year in direct-seeded systems. The reduction in tillage events associated with direct seeding has the potential to increase the sustainability of cucurbit production systems on multiple levels. The decreased cost of cultivation and improved weed control can increase profitability, while the conservation of tillage may improve water infiltration rates, moisture retention, and organic matter content of the soil (Beets, 1990), thus maintaining or enriching agricultural natural resources.

Although no specific examples of direct-seeded cucurbit cultivation by smallholder farmers in tropical South America were found in the literature, the use of minimum tillage schemes in multiple cropping systems was documented by Francis (1986). However, the use of cover crops may be limited by the availability of suitable varieties and the price of seeds. The cost of seeds "specifically for incorporation into the soil to effect some agronomic improvement" (Paoletti, 1993, P. 227) may be unsustainable in an economic sense for minimum tillage intercropped systems, which already have adequate weed control, organic matter content, and nitrogen availability. It may be possible to achieve similar agricultural resource enrichment as documented in production agricultural systems through the use of cover crops (Paoletti, 1993) in smallholder farming systems in tropical South America by cutting winter vegetation and using it for mulch (Gliessman, 2001).

"If we are interested in…'improving,' traditional agriculture, we must first understand, appreciate, and build on that agriculture that is to be changed, rather than simply replace it" (Denevan, 2001, P. 305). It is no more appropriate to suggest that smallholder subsistence farmers control weeds with herbicides and increase yields with inorganic fertilizers than it is to suggest that production farming systems based on mechanized planting and harvesting equipment and high-yielding varieties intercrop corn, beans, and squash. To increase economic and natural resource sustainability of agricultural systems it is important to delimit system modifications with socioeconomic, technological and cultural constraints. Only through conservation of a balance between prevailing system constraints and innovation of system improvements can agriculture evolve toward greater sustainability (Holling, 2001).

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