Growing Food at the Top of the World: A Case Study of Greenhouses in Khumbu, Nepal

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Fall 2009

…to the farmers who climb Everest

Acknowledgements

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Introduction

INTENT

Nepal is known for its diversity in ethnicity, culture, religion, language and geography. In 200 km, the land rises from 80 m to 8,000 m providing a host of ecosystems for 80% of the population to cultivate for agriculture (Chitrakar)

(Hobbs, 2009). My focus of study is at the highest end of the spectrum in the mountains of Khumbu, located in northeastern Nepal. In this remote mountain area, cold temperatures, high winds and infertile soil make agriculture a formidable task. My intent is to investigate how the local Sherpa people grow their food in these harsh conditions and have adapted to using newly introduced greenhouses by assessing the economic, social and environmental impacts of the greenhouses to the community.

LOCATION

Khumbu primarily consists of Sagarmatha National Park (SNP), which protects 1,200 km^2 of the highest mountain ecosystem in the world (all above 3,000m). Established in 1976, the park adjoins three other protected areas (Qomolangama Nature Preserve in Tibet and the Langtang and Makalu Barun

National Parks in Nepal) encompassing 40,000 km^2 to form the largest amount of protected land in the world (SNP Museum).

Little vegetation survives on the alpine slopes, but Barberry (*Ber beris)* has large thorns to deter grazers protecting its precious leaf growth.

The beautiful landscape is harsh for any form of life as 50-60% is covered by perpetual snow and ice in the Nival Zone (5,000m+) where severe cold winds inhibit plant growth. Only 10% of the park area is covered by vegetation starting in the Alpine Zone (4-5,000m) where low shrubs and grasses survive in the 3-month growing season. Below, in the Subalpine Zone (3-4,000m), fir, birch, juniper and rhododendron trees survive in the 6-month growing season covering the north face of slopes where moisture is more abundant. The park extends to the fringes of the Temperate Zone (2-3,000m) where blue pine and broad-leafed trees grow in the 9-month season on the sunny slopes (SNP Museum). Coupled with the cold climates and short growing seasons, vegetation is inhibited by low soil fertility due to low organic content, erosion and acidity (ICIMOD, 1998, 4). Additionally, the average annual rainfall is only 150-200mm since the cold air holds little moisture (SNP Museum).

The alpine flora sustains little fauna, but Himalayan tahr (*Hemitragus jemlahicus*) and wild yak (*Bos grunniens*) graze the high grassy slopes, hunted by the rare snow leopard (*Panthera uncia*). Birds are more abundant including Nepal's national bird, the Danphe (*Lophophorus impejanus*). Sherpas, meaning "east people," migrated from Eastern Tibet 400 years ago to inhabit the area. Sagarmatha National Park was designated an UNESCO World Heritage Site in 1979 in "recognition of the cultural importance of the Sherpa people, the world's highest mountain and its associated flora and fauna" (SNP Museum).


A pair of Himalayan Tahr.

BUFFER ZONE

A 275 km^2 buffer zone was created in January 2002 to ensure the continued protection of the park's precious ecosystems as recognized by UNESCO (SNP Museum). As Birenda Kandel, the Chief Conservation Officer of Sagarmatha National Park in Namche, explained the layout is unusual because unlike other protected areas, the buffer zone consists of pockets of settlements that lie *within* the core protected area (Kandel). The 5,869 people that live in the buffer zone lack natural resources since they are tightly surround by protected territory. Only the grazing of livestock and the cutting of wood twice a year is allowed, but infringement does occur since the boundaries are not always clear. In compensation for the restriction of resources and incentive to preserve the natural integrity of the landscape, the park donates 30-50% of its Rs. 22 million annual revenue towards community development (SNP Museum). Each settlement can appeal for these funds annually under five different categories of development. Of the allotted funds, 30% can go towards Conservation, 30% towards Community Development, 20% towards Income and

Skill Generation, 10% towards Conservation Education and 10% towards Administration (Kandel).

The village of Thamo (Buffer Zone #5) requested greenhouses to the Namche User Committee who appealed to the Buffer Zone Management Committee and a representative of Sagarmatha National Park (Kandel). In 2007, 10 units were approved under the Income and Skill Generation development category amounting to Rs. 300,000 (Rs. 30,000 each) (Kandel). The greenhouses were transported by helicopter from Kathmandu and distributed among the village according to a community held lottery system. Two other slightly smaller greenhouses were donated around the same time, one by Eco-Himal to the Khumbu Bijuli Headquarters (KBC) and the other by Leeli Bonney. a private donor, to the Khari Gonpa Monastery. The prevalence of greenhouses in Thamo led me live in the village for 10 days researching the economic, social and environmental impacts to ascertain an overall assessment of the success with this new technology.

The World Wildlife Fund (WWF) sponsored a similar greenhouse program about 10 years ago in accordance with Sagarmatha National Park in Chaurikharka to "increase nutrition and income" for the local people by growing vegetables to sell in markets (Lhakpa Gelzen). This Sagarmatha Community Agro-Forestry Project (SCAFP) also grew tree saplings and grass in nurseries for replanting at higher elevations as part of their afforestation project to provide a source of wood since the park's ban. Blue pine was the species of choice and although a relatively fast growing tree and good for firewood, it consumes a lot of water, acidifies the soil and generates no usable fodder (Jefferies, 1982). According to Lhakpa Gelzen, the WWF Program Assistant in Namche, this project as phased out, although new proposals are in place and planted blue pine cover the hillsides slowly growing in the alpine climate.

TOURISM AND CHANGE

The park's restrictions have become more important as the Sherpa's subsistence way of life has shifted with the influx of tourism. Sherpas originally traded extensively with Tibet bartering for their livelihood. The Nepal Government actually granted the Sherpas a trade monopoly by restricting access to Tibet only to Sherpas. However, since the closure of the Tibetan border in 1959 this way of life has been replaced by tourism. The number of tourists rose steadily, especially with construction of an airport in Lukla, attracted by the rich culture and fantastic views along world-renowned trekking routes, namely Sagarmatha (Mount Everest). From 1971 to 2000 the number of trekkers increased from 1,400 to 25,000 and accordingly the number of hotels increased from 5 to 25. Despite the slump in tourism in 2002, resulting from the internal conflict, the number of visitors to the park quickly regained peaking at 30,000 in 2008 (SNP Museum). Tourism has primarily benefited the local communities providing cash income to increase their standard of living through improved access to education, sanitation, health, and other facilities.

However, the shift in lifestyle caused by tourism has had adverse economic, social and environmental impacts. The lure of profit from tourism via shops, hotels, portering and guiding has drawn the labor force from the traditional

Dress is the most apparent change in lifestyle.

agricultural livelihood. As a result, nearly all food has to be imported causing extreme inflation. Livestock numbers have also dwindled with the shift towards the tourist economy due to lack of time and necessity. The lack of manure has decreased the fertility of the land hurting the productivity of the remaining agriculture. Rangelands are also decreasing as shrubs takeover the grasses from lack of grazing. However, the increased income has benefited forests, which have grown in size as the dependence on wood is replaced by alternative energy sources of gas and electric for cooking and heating (Kandel).

Methodology

INTERVIEWS

After trekking around to different villages (Namche, Khumjung, Khunde and Thame) in Khumbu, I discovered that Thamo had the largest number of greenhouses and thus the most potential for investigation becoming my primary area of study. After approaching several farmers and asking questions in my broken Nepali, I realized I would need a translator. Sherpa is the dominant language spoken rendering my minimal Nepali useless to the majority of the population who also only speak minimal Nepali. Furthermore, their rural accent was largely incoherent to my newly trained Nepali ear. They were unable to understand my translated questions in Nepali and I, their answers. After three failed attempts of only answering a couple of my twenty odd questions, I sought an interpreter. I was fortunate enough to find Nawan Sherpa, a trekking guide and local resident of Thamo, who spoke decent English.

I went around the village with Nawan asking people a series of initial questions. I would ask a question in English, or as much Nepali possible to Nawan, who would ask the interviewee in Sherpa and then translate the answer back to me in English. People were interviewed throughout the day whenever available at random in their house or field. The gender of the adults interviewed was random based on whoever was available at the time, but turned out to be 55% male and 45% female. Often more than one member of the family was present in the house, but the male usually answered. According to Sherpa culture it is custom to serve tea to guests, resulting in the consumption of many cups of tea and subsequent bathroom breaks. Although this took extra time, it relaxed the setting and allowed alternate discussions to arise leading to further questions and new discoveries. Shifting from a formal, structured interview to an informal, unstructured interview, I would engage my hosts in as much Nepali as possible and have Nawan fill in the gaps while sipping tea. Every household currently occupied (31) was visited at least twice to unravel new findings and subsequent questions. Interviews were mostly conducted in the mornings and evenings when people were home from work in the field or trail.

FIELD VISITS

Greenhouse and potato field observations were conducted repeatedly both with and without the aid of my translator. One day was spent visiting the higher pastures and village of Thame for comparison. Local markets in Khumbu (Namche Bazaar) and Kathmandu (Boudha) were also visited for price comparison. Visits were made to the Sagarmatha National Park (SNP) head office and museum, the Sagarmatha Pollution Control Commitee (SPCC) office, the World Wildlife Fund (WWF) office and the Shermi Khangba Center, all located in Namche, Solukhumbu. Field notes were transcribed in a journal soon afterwards and have been mapped, charted and graphed in the appendix in addition to being summarized throughout the paper. Photographs were often taken for documentation after receiving verbal permission.

A half-inch of ice that froze overnight from the cold temperatures outside the greenhouse (elevated for photo).

EXPERIMENT

Lacking a thermometer, I conducted an experiment to test the effectiveness of the greenhouses in retaining solar energy. I placed glasses of water inside and outside the greenhouse at three different locations at ground height. The glasses were left overnight and then checked repeatedly throughout the day observing any freezing and water temperatures. A table of results is listed in the Appendix. All glasses of water froze to a certain extent, but only 1/8th inch of ice was found inside the greenhouses compared to 1/2 inch of ice outside. The condensation on the plastic and the leaves of vegetables froze stiff. However, within an hour of sunlight within the greenhouse, everything had thawed.

Whereas, the outside glasses of water took 3 hours to thaw completely and only felt lukewarm compared to the water inside which felt very warm by the end of the day (after 7 hrs). Although freezing did occur within the greenhouses, temperatures rose higher and faster than outside temperatures. Additional methods to prevent freezing are discussed in the Analysis on pg 24. The importance of the sun was also observed by the morning frost, which remained throughout the day in the shade only thawing in areas of sun.

SURVEY

A survey was conducted to assess the standards of living in Thamo through several indicators ranging from education and household amenities to resources owned. The listed indicators were chosen by myself perceived to be indicators of higher standards of living. Importance may vary according to the value system of villagers. For example, in one household a television was favored over a toilet. For this reason I tried to include as many indicators as possible. Data was collected through 31 personal interviews with the aid of my translator and recorded in the Appendix. Percentages were calculated and graphed below. The original intent was to assess the economic standards of households to explain the purchase of a greenhouse. However, since the greenhouses were granted by the buffer zone community development funds, initial wealth was irrelevant to greenhouse ownership. The economic evaluation was also assessed as a potential indicator of additional revenue generated from the greenhouses. However, since only two years have passed since installment and little monetary profit is generated from the greenhouses, it was hard to correlate with the standards of living observed. Despite failing to correlate with the economics of greenhouses, the survey helped illumine development influences from tourism. The individual indicators are discussed below in Research Findings.

ANALYSIS

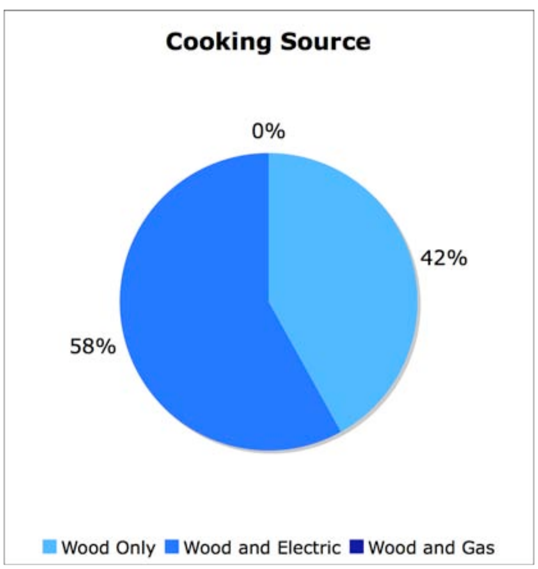
Although I initially planned to conduct all of my research in Nepali one on one with the interviewee, this was not possible due to the language barrier. Translation, even communicating in English with my translator, was problematic at times and is my greatest source of error. I tried to frame my questions as simply as possible without being leading, but further explanation was often necessary. Translator bias is also important to note because Nawan would often answer for the interviewee (possibly knowing the information since it is a small community). I would have to ask again to ensure my information came from my interviewee, my primary source of information. Residing in the small community for 10 days, observing, engaging, and speaking Nepali definitely help build a rapport between the individuals and myself. Everyone was receptive to my inquiries, although having a translator helped explain my intent and gain access to anyone’s door at any time. My own bias may also be noted, framing the questions from an outsider’s perspective.

Research Findings

STANDARD OF LIVING ASSESSMENT

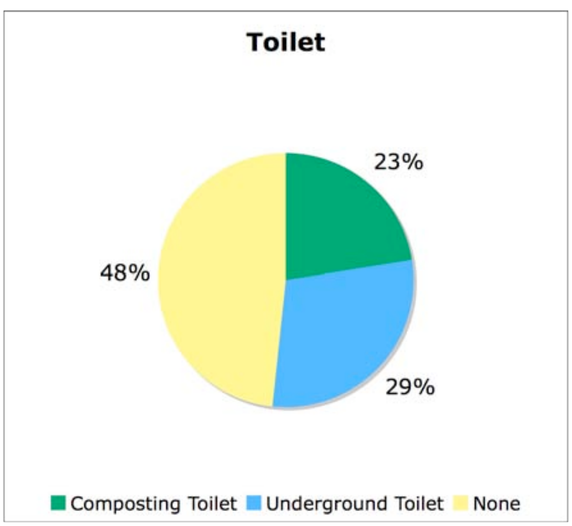
The following information is based on a survey I conducted among the 31 households in Thamo. Every household in Thamo has electricity since a small hydropower plant was installed in 1995 by Eco-Himal, an Austrian-Nepal

development cooperation. Located between Thamo and Thame, it serves 2,000 local people from the tourist hub of Namche to the remote village of Yilajung (Nawan). A small holding tank in Thame channels water to the power plant where two turbines generate 2 units of peltone with 600 kw transmitting 11 kv along 13 km (Khumbu Bijuli Company). The introduction of electricity has had significant impact on the preservation of the forests by providing a key alternative for



cooking and heating. The park encouraged this switch by banning the cutting of timber in the park except for two 15-day periods (December and June 1st-15th)(Kandel, Nawan). During this time, permits are granted to two members per household to collect wood. Families collect approximately 30 *bari* annually from different designated locations dispersing the impact on the forests (Kandel). Nearly every household gathers wood despite the hard physical labor involved because it is cheaper than electricity or gas. There are three different electricity plans depending on usage ranging from Rs 70/month for just light to Rs. 700/month for unlimited light, cooking, TV, etc. and an actual meter system for the lodges (Nawan). Most houses (58%) use a mixture of wood and electricity to cook, although electricity dominates during the monsoon when wood is wet and wood dominates during the winter as it also provides heat (see graph above). Gas is only efficient in lodges in Namche catering to the high flux of tourists costing Rs. 6,000/cylinder. Although every household has electricity, the different plans signify variations in standard of living as indicated by the use of electric burners (58%) and televisions (42%).

Other household amenities, such as plumbing, were surveyed. Although most households have improvised sinks which drain outside, very few (19%) have running water piped into the house and is a luxury found primarily in the lodges. Most people collect water daily from spring-fed community taps and store the water in large metal pots (*Sa*) inside the household for cooking purposes. Bathing and the washing of clothes generally occur at the community taps.



Toilets are traditionally composting consisting of a raised shack separate from the house with a hole in the middle allowing feces to drop below along with dried leaves which are stored until application to the fields in the spring. Modern "underground" toilets have a sewage tank and are found in wealthier households, especially the lodges which cater to foreign tourists (although still squat style and bucket flush). Surprisingly a large percentage of the households (48%) did not have toilets and just go outside.

Metal roofs cover nearly half (48%) of the 31 stone and mud houses replacing the traditional slate roofs, probably due to more effective water repelling and snow removal. The tin roofing sheets are expensive (Rs. 2,000/sheet) transported by air and brow from Kathmandu, thus indicating a significant expense.

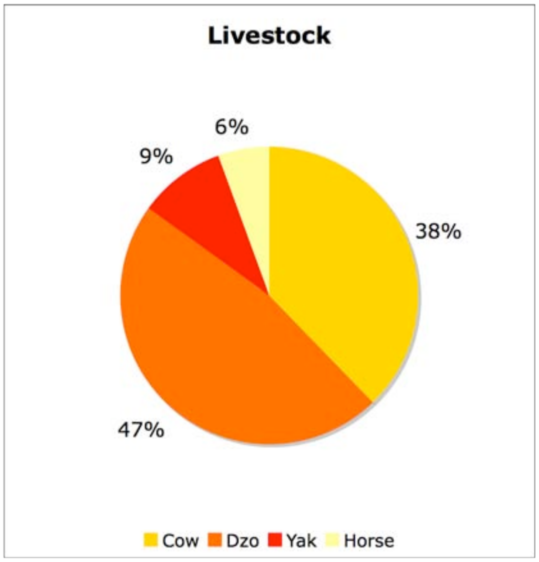
Phones are a recent development with the installment of a Mero Mobile cell tower earlier this year. Landlines were being installed during my visit in November. Despite the recent availability, every household has a mobile phone, primarily to talk to their children boarding in various Kathmandu schools.

The four lodges in Thamo tend to be the wealthiest establishments having electricity, TV, phone, running water, underground toilet and an electric burner for cooking to cater to trekkers. Although prosperous, lodges are considered an indicator of wealth because of the initial investment required. The primary source of funds is generated from lucrative mountaineering expeditions. Dorje Sherpa of Valley View Lodge has climbed Everest 14 times and Chang Wimi of Tashi Dele Guesthouse has climbed Everest 17 times. Ang Nuru of Thamo Guesthouse works at the highest hotel in the world (Everest View, 3880m). The fourth lodge, Maya

Lodge, owned by Maya Sherpa, has the highest potato output. More common forms of tourist employment are guiding trekkers ($10/day) and dzo portering (Rs. 1,000/day) conducted by males. Lodges are less common due to the required investment and are usually run by women (room is Rs. 200/night and board is ~Rs. 300/meal due to high import costs)[rice costs Rs. 600/kg compared to only Rs. 80/kg in Kathmandu and dhal costs Rs. 300/kg and Rs. 130/kg respectively]. Women also run small teashops catering to passing porters and small stalls selling trinkets to tourists. Although tourism is seasonal employment from October to December and March to May, it accounts for 40-60% of their annual income. Thus, nearly every household (87%) is involved in the tourist economy unless members are too old or otherwise incapable.

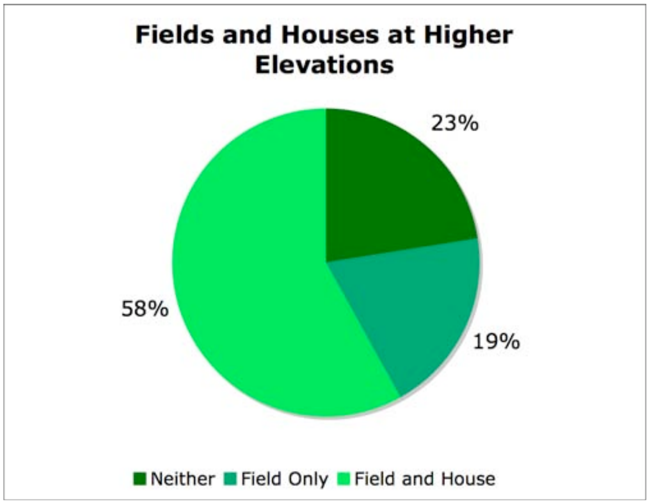
An increased income allows children to attend school unlike the older generations who received no schooling. All children from Thamo of current school age attend school either in Thamo (elementary), Khumjung (middle) or Kathmandu (generally for high school). Attending a boarding school in Kathmandu, especially at earlier ages, is an indicator of higher wealth. Several households have children living and working in America after completing their higher education in Kathmandu. Both boys and girls attend school, which is important because girls are usually the first to be pulled from school when finances are tight. This is occurring across northwestern Nepal due to widespread food scarcity caused by the late monsoon (Hobbs, 2009, 12). Thamo seems largely unaffected still reaping a surplus according to U.N. World Food Program statistics (Hobbs, 2009, 4). In any case, tourism offers insurance against crop failure.

Most families (74%) own livestock, which are a significant investment. The mixed bred dzo are the most common because of Thamo's altitude. Yaks



generally remain above 4,000m adapted to the high altitude, whereas, cows have the opposite problem, but when bred together they produce offspring well suited to the mid altitude location. The dzo are mostly used for portering goods to and from market in Namche and on trekking expeditions earning Rs. 1,000/ day carrying approximately 70 kg. Cows are kept for their milk. All breeds are invaluable sources (and the only source) of organic fertilizer, which is stored in their stalls, mixed with leaves and added to the soil before planting. The manure is also collected from trails and dried for cooking and heating. The ashes are spread on the soil for extra fertilization. The decrease in livestock numbers has lowered soil fertility in both agricultural fields and rangeland (Kandel).

Owning livestock involves migrating to rangeland at higher elevations for grazing during the monsoon. Additional fields and even houses (often in several villages) represent another indicator of wealth. Although the additional houses are



a considerable expense, revenue is generated from the additional potato fields and the grass is necessary for feeding livestock (otherwise bought for Rs. 60/kg).

Although these indicators of standard of living do not correlate with the economics of greenhouses, they do relate to involvement in the tourist economy and high potato yield. Generally, the older generations farm more extensively whereas the younger generations are involved in tourism. Even though the lodges tend to be the most prosperous households, the various "high" standard of living household amenities generally extend to half the village and are by no means limited to the lodges.

TRADITIONAL GROWING PRACTICES

The location of Thamo has limitations and advantages for agriculture. The small village rests at 3,440m on a steep rocky hillside rising 4,000m above the Bhote Koshi Nadi River flowing from Tibet (see Physical Map in the Appendix). The opposing hillside rises steeply from the riverbank to the snow peaks above 5,000m. The high mountains on either side of the valley limit the amount of sunlight to approximately 7 hours during the winter months (7:30 am – 2:30 pm). However, the southern exposure (slope faces south) provides prime light and the

rocky cliff behind the village absorbs heat during the day and radiates it back at night to raise temperatures slightly. Furthermore, the elevated location above the valley floor (~3,000m) reduces frosts as the cold air sinks, settles and freezes in the depths of the valley. Unfortunately, the valley also channels a cold, steady wind up the valley. Overall, the microclimate (particular climate of a secluded area varying from the norm) of Thamo is warmer than surrounding areas.

POTATO FIELDS

Thamo consists of approximately 35 households stretching 2,000 ft along the narrow plateau jutting out from the mountainside. Rising gradually by only 200 ft. the gentle slope is cultivated with numerous small fields of potato – the only crop grown. The fields are planted in late February or early March on the first full moon after the Sherpa new year, *Losar* (Nawan). The infertile fields are primed with cow compost, a mixture of manure and dried leaves stored and decomposed in the livestock sheds all year until planting. Similarly, human feces

decomposed in their traditional compost toilets are added to the fields. Planting is a community event in which neighbors gather together to plant one field at a time. Previously “white” potatoes where grown, but “red” potatoes introduced approximately 10 years ago are more common now. The crop yield depends on the monsoon rains occurring from May to August, the only source of water. Heavy rains saturate the soil and rot the potatoes underground so intervals of morning sun is ideal to reduce soil moisture. The size and number of fields vary greatly depending on the rocky terrain. The average household harvests 40 baskets (average output from all fields owned) of potatoes in late October/early November. Based on this average, roughly 10% (4 baskets/40 baskets harvested) is lost to potato rot and pests. These and other potatoes determined too small are fed to livestock. Medium sized potatoes are saved for replanting next year. Another 25% (10 baskets/40 baskets harvested) are

Baskets of potatoes being buried in earthen pits for the winter.

stored underground for the coming year’s household consumption. The earthen pits, approximately 3 ft deep and 3 ft in diameter, are covered with a mound of dirt to keep the potatoes from freezing and spoiling, which would occur indoors. The rest of the large potatoes are sold weekly in Namche Bazaar for Rs. 350/tin until the surplus is finished. Considered a cash crop, this fetches over Rs. 40,000 (40 baskets x 35 kg/basket ÷ 12 kg/tin x Rs. 350/tin).

HIGH PASTURES

A dzo grazing on rangeland above Thamo.

During the monsoon the grassy hillsides turn lush and green luring families to migrate their livestock to these grassy slopes located at higher elevations above tree line (~4,000m). Most families also have additional potato fields and even a house at these locations forming supplementary settlements. Families plant their fields in Thamo in the spring and then move up the valley to these other villages planting and grazing livestock as they move higher if more than one house is owned. Certain grassy areas are walled off to save the grass for later months. The number of livestock and, subsequently, the health of the grasslands (due to the lack of fertilizing manure) have decreased with the increase of tourism because men leave to guide or porter trekking expeditions. Although the primary reason for migration is grazing, the combined yield of these additional fields accounts for 55% of the annual potato crop.

OUTSIDE GARDEN

Nearly every household (81%) has a small garden planted outside their house providing fresh vegetables for most of the year. The small plots are prepped with cow compost and planted by purchased seed in March as soon as the ground thaws. Green leafy vegetables dominate, but include Chinese cabbage, Nepali cabbage, spinach, cabbage, cauliflower, carrots, garlic and onions. The gardens flourish in the monsoon minus the onslaught of pests and are watered the rest of the year. No pesticides are applied due to the lack of availability. The vegetables are picked daily throughout the year for consumption, but are ultimately harvested in late October/early November before frost damages the leaves. Harvesting is often delayed to late November by covering the plants with dried vegetation, cloth or plastic to protect the vegetables from freezing. The brush also acts as a horizontal windbreak (*wind protection mulch*) in addition to the 3-4 ft stonewalls surrounding the gardens, which act as vertical windbreaks (Coleman 1999, 35). Although the walls were erected to keep livestock out, they dramatically reduce the wind chill (which is worse than freezing temperatures) raising temperatures 2-5^{o}F (Coleman, 1999, 35). Although the vegetables have stopped growing by this point, delaying harvest keeps them fresh in the ground. The vegetables are dried or pickled and stored for addition to

Chinese cabbage partially shaded by a bamboo matt for limited frost protection.

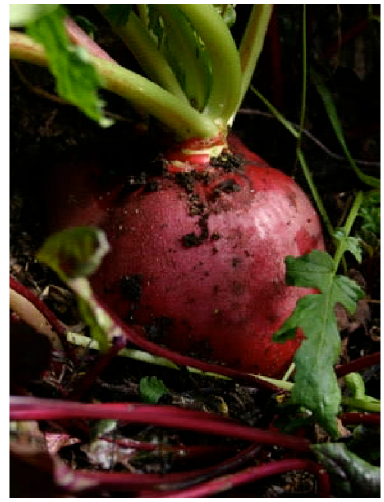
curries during the winter months. Depending on available funds, vegetables are bought from the weekly markets in Namche Bazaar, but grown at lower elevations in Monjo (2800 m), Phakding (2600 m) and Chaurikharka (2400 m). The gardens do not yield enough to sustain an average family of four for four months of winter (December to March) requiring an average expenditure of Rs. 200/person, although the maximum expenditure is Rs. 750/person. These outside gardens render families self-sufficient for vegetables during the growing season but cannot compete with the greenhouses, which luxuriously provide vegetables year round.

GREENHOUSES

Even in the coldest climates, from the Arctic Tundra to the high mountains of Khumbu, only the *growing* season is limited. The *harvest* season can be extended through simple crop protection (vegetables under cover) by creating a protected microclimate warm enough to keep plants alive and fresh for harvest throughout the coldest months (Coleman, 1999, 4, 5). Greenhouses are an effective method of crop protection constructed of translucent material over a frame. The translucent material allows the sun's rays to penetrate for photosynthesis, warm the inside air temperatures and protect plants from the harsh outside elements. Drastic changes of wet/dry, freeze/thaw and gale/calm are more detrimental to plant health than mere cold temperatures, but greenhouses effectively decrease all of these factors lowering plant stress in its microclimate. Miraculously, the winter sun is enough to heat greenhouses to sustain life making additional heating sources unnecessary (passive greenhouse). Even on a cloudy day with outside temperatures well below freezing, inside temperatures remain above freezing (see pg. 48 of Appendix). Greenhouses have the power to render a winter alpine climate to a temperate climate by simply harvesting the sun's energy (Coleman, 1999, 72). According to a study in the Alaskan tundra, the average temperature increase was 2^oC, although maxed at 7^oC, and temperatures below ground also increased (Debevec, 1993, 56). According to my own study conducted in Thamo measuring the amount of ice and observing thaw rates of water, slight freezing did occur within the greenhouses, but much less than outside, and temperatures rose higher and faster than outside temperatures. Greenhouses are advantageous throughout the year extending the growing season by a month in the spring and fall, initiating prime ripening in the summer, and allowing harvesting throughout the winter (Coleman, 1999, 114). The advantage of greenhouses is enormous providing a fresh supply of vegetables year-round, a key source of nutrition, which is otherwise lacking.

The 10 greenhouses donated by the national park consist of a thick, clear plastic tarp over a metal frame 20 x 10 x 6 ft. (see Greenhouse Designs in Appendix). Inside, two rows of raised beds (0.5-1 ft high) run along the sides separated by a narrow path. The raised beds help reduce the freezing of soil elevated from the cold ground and surrounded by warm air. The raised beds also create a path ensuring the soil is not stepped on which is important because air in the soil is crucial for root growth and microorganism activity (Coleman, 1999, 36). A series of succession plantings (sowing vegetables multiple times) occurs in order to reap the most from the greenhouses starting with Chinese cabbage in February. Additional crops ranging from carrots, radishes, garlic and onions to lettuce, spinach, cucumber, zucchini, squash, pumpkin, pepper, beans, tomatoes and even chilies are planted in May benefiting from the warm, moist monsoon season. A second planting of Chinese cabbage occurs in June followed by a third in October. The Chinese cabbage is fast growing and resistant to the cold temperatures allowing for multiple plantings and thus several harvests.

Before each planting, the soil is prepped with cow or vegetable compost, but no human compost for sanitary reasons. The vegetables are planted by seed which are purchased from Namche Bazaar. The plants are normally watered every morning and the flaps (side doors) are opened for ventilation during the day. During the monsoon the flaps are left opened to prevent overheating. Pests are a major problem both inside and outside the greenhouse during the monsoon, which favor the warm, moist conditions. Nothing is done since pesticides are not available, but reportedly would be applied if available. Temperatures drop during the winter months eliminating the pest problem and reducing watering to every couple of days as the lower temperatures reduce evaporation. The flaps are always closed to retain heat.



Color and nutrition radiate from within the greenhouses all year.

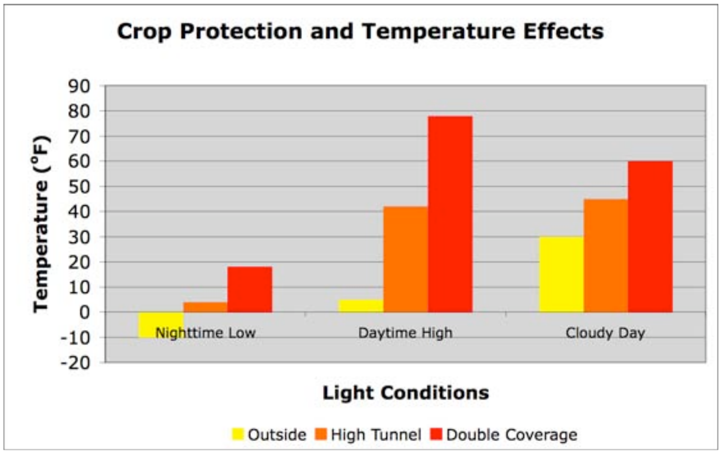
Analysis

GROWING PRACTICES

The main problems described by the greenhouse owners in Thamo are pests in the monsoon and freezing in the winter. They also complain of no chemical or technical greenhouse training to deal with these problems. The greenhouses were simply installed. I have analyzed these problems and included suggestions based on secondary research. The following discussion of potential solutions is meant to provide a starting point for further investigation, since I am not an experienced agriculturalist.

PREVENTING FREEZING

Temperatures drop well below freezing causing the ground to freeze from December to February. Extra heat can be retained within the *high tunnel* structure of the greenhouse with *low tunnel* coverings of cloth placed over a smaller frame just above the plants to provide a *double coverage* (Coleman, 1999, 108)(see Greenhouse Designs in the Appendix). The soil rarely freezes under this method because even if the outside temperature drops to 0^{o}F, the temperature under *double coverage* will only drop to 20-35^{o}F (Coleman, 1999, 109)(see graph at left). The only drawback is less light, but since the plants are only hibernating, this is less important. Even if the vegetables freeze over night, the few hours of sun (even on a cloudy day) warms the greenhouse above freezing keeping the plants healthy (Coleman, 1999, 72). Removing snow cover is important to allow all of the limited light to enter and it removes excessive weight.



Ensuring the plastic tarp is tightly closed and buried into the ground will reduce heat loss. I noticed several loosely closed and unburied tarps during my stay and even though it was only November frosts occurred every morning. Watering should be significantly reduced depending on temperatures because the cold diminishes evaporation and there is no moisture loss from the greenhouse since the flaps are closed. When watering is necessary to retain soil moisture, it should occur in the morning so that it does not freeze to the plants at night (Coleman, 1999, 80). Based on my observations and inquiries these watering practices are followed in Thamo.

Another suggestion for heat retention to reduce freezing is to orientate the greenhouse in an east-west direction for maximum solar radiation utilizing the southern exposure (Norman, 2009)(Coleman, 1999, 36). Only 5 of the 11 greenhouses in Thamo were aligned this way. Most lack available space, but several could be re-orientated to capture as much of the low winter sun as possible.

A more energy intensive method would be to lower the entire greenhouse structure further into the ground. This would lower the warmest air, which rises due to convection, closer to plant level (see Greenhouse Designs in the Appendix). The beds could also be raised higher by simply adding more soil from the digging of a deeper pathway, which would retain easy passage for watering and harvesting (Norman, 2009). The rocky soil may limit the possibility improvising the greenhouse design.

COMBATING PESTS WITH SOIL FERTILITY

Pests, which include insects and disease, are a common phenomenon inherent in the balance of nature. They can be managed naturally by ensuring prime growing conditions to tilt the balance in favor of the plants (Coleman, 1999, 147). According to Elliot Coleman, a 4-season organic farmer from Maine, the simple “cause of pest problems is inadequate growing conditions” for plants because “insects multiply on stressed plants” (1998, 148). Insects normally remain at low populations in relation to the potential amount of food around them because there is inadequate nitrogen in that food for insect nutrition. Plants under stress, caused by any various poor growing conditions, are richer in nitrogen because stress causes the plant to inhibit the synthesis of protein resulting in increased levels of free amino acids (or free nitrogen) in its aerial parts, especially the phloem (vascular tissue in plants) (Coleman, 1999, 148). Normally these amino acids form proteins locking the nitrogen away from pesky pests. Thus, pests are a simple predator-prey relationship in which pests prey on weak plants (Allen). Therefore, the focus should be on the cause – poor growing conditions – through composting and green manure.


Leaves eaten by pests during the monsoon.

Chemical applications are not the best method as exemplified by a study conducted in the mid-hills of Nepal where potatoes are grown extensively as a cash crop. Fertilizers and pesticides were heavily applied despite increasing diminishing effects of the chemicals. Of the households surveyed, 97% used chemical fertilizers and 41% increased their application to maintain current levels of production. Additionally 64% applied pesticides, mainly dithane, fenvalerate and dichlorvos, “all of which are restricted in North America due to adverse affects on human health or aquatic ecosystems”

(Brown & Shrestha, 2000, 222). According to Brown and Shrestha, “this intensive use of pesticides places farmers at risk to acute and chronic poisonings, may result in unacceptable pesticide residues in the soil and crops, in an expansion of pest resistance, and adverse affects on the aquatic environment” (2000, 222). The small scale and contained area of greenhouses would only intensify the harmful effects of chemicals.

Geology and Inherent Soil Fertility

Even if chemical fertilizers were available, the geologic composition of the soils in Khumbu would mitigate the positive effects and render them ineffective. The quartz and feldspar composition of granite, the dominant rock type, weathers to form acidic, sandy soils due to the high silica content (Eusden)(Shah, 1998, 3). The acidic nature of the soil reduces nutrient retention and causes undesired effects (Shah, 1998, 3). Ammonia-based fertilizers only acidify the soil further, because ammonia is oxidized by nitrifying bacteria to form nitrate and a hydrogen ion (pH is the measure of hydrogen ion concentration) (Brown & Shrestha, 2000, 221). The acidic soil decreases microbial activity because phosphorous (required for microbial activity) is rendered insoluble at acid pH. In addition to the already low amounts of phosphorous, the prominence of iron and aluminum make the p-sorption capacity high as they adsorb and thereby immobilize phosphorous making it unavailable for plant or microbial uptake (Ewing). Thus, the input of chemical fertilizers has minimal desired benefit if not creating more problems.

Green Manure

Green manure are plants that increase soil fertility by protecting the soil and adding nitrogen. Growing these nitrogen-fixing plants is the most effective way to naturally re-fertilize the soil. The effect of one ton of nitrogen biologically fixed by legumes is equal to the effect of two tons of nitrogen fertilizer (Ya, 1998, 10). The most common nitrogen fixing plants are legumes, which have a symbiotic relationship with the soil bacteria living in their root nodules. The bacteria provide the roots access to air, while the roots provide nutrients for the bacteria, which capture and store nitrogen in the nodules of the roots (Coleman, 1999, 43).

Traditionally legumes, such as clover, vetch, alfalfa, peas and beans are planted as part of a crop rotation cycle (Coleman, 1999, 43). However, legumes can simultaneously improve the soil quality while growing vegetables through undersowing. Legumes can be planted (sowed) under well-established vegetables (usually after one month) without hindering their growth while simultaneously improving the soil quality (Coleman, 1999, 43). This was not observed in the greenhouses except for a crop of beans during the monsoon.

Although there is not enough growing time to crop rotate legumes with potatoes, intercropping legumes in contour hedgerows (rows planted according to the contour of the land) would be a valuable source of nitrogen, which decays from nodules in the roots. Pruning of the legumes would add nitrogen, phosphorous, potassium and organic material to the soil. The root systems also reduce erosion and subsequent nutrient loss (Ya, 1998, 10).

Compost

Compost is nutrient-rich humus highly valuable for rejuvenating soil fertility resulting from the decomposition of organic matter by organisms (Mangan et al., 2000). Compost essentially turns organic waste into rich soil fertile in the key nutrients of nitrogen, phosphorous and potassium ($N\text{-}P_2O_5\text{-}K_2O$) most commonly limiting plant growth (Ewing)(Mangan et al., 2000). Two types of ingredients are crucial to successful decomposition. *Green* ingredients include young, fresh, moist materials such as food scraps and yard waste, whereas, *brown* ingredients are older, drier materials including dried yard materials (although straw is best because of its hollow structure which generates crucial air space) (Coleman, 1999, 16).

The two ingredients are layered alternately starting with 3 in. of straw followed by 1-6 in. of green topped with ½ in. of soil and then more straw repeating the layers (Coleman, 1999, 18). The extra layer of soil enhances the process already containing microbes (bacteria, fungi and other organisms), which multiply in the warm, moist conditions created by the exothermic reaction of decomposition raising temperatures within the heap to 140-160^{o}F. Straw has a higher ratio of carbon decomposing slowly, whereas, green has a higher ratio of nitrogen acting as the active decomposers. Microorganisms use the nitrogen to help break down the carbon structures of organic material to create humus. Like any fire, air is crucial in this "microbiologically powered furnace" because the decomposing bacteria are aerobic (require oxygen)(Coleman, 1999, 18). The mighty organisms create heat through decomposition and ultimately the conversion of materials.

Smell and heat are important indicators of successful decomposition and should be observed because disproportionate composts can have negative effects on plant growth. Generally there is no smell so any odor is an indicator of inadequate ingredients. A sewage odor results from anaerobic bacteria that thrive in a heap that is too compact or wet. Alternately, an ammonia odor results from bacteria volatilizing (dispersing in vapor) extra nitrogen from too much green material (Coleman, 1999, 20). In either case, re-heaping with appropriate quantities of ingredients is best.

Heat is an important indicator that the compost is “mature” (biological processes are finished)(Mangan et al., 2000). This state is reached when the energy and nutrient materials are stable indicated by the temperature within the heap remaining close to ambient temperatures. Unfinished carbon-rich compost still requires nutrients (thus not available to plants) and nitrogen-rich compost releases ammonium (a toxic substance). Both negatively affect plant growth so allowing one week after adding compost to the soil before planting is advised to reduce these risks (Mangan et al., 2000). Compost should be mixed in shallowly (top 2 in. of soil) adding approximately 1 ft^3 to 12 ft^2 1 inch deep (Coleman, 1999, 27).

Other ingredients can be added to increase the diversity of nutrients. Manure is a rich source of nitrogen beneficial when added dry but otherwise contains too much nitrogen (causing further acidification). It can be added directly to the soil or composted (should compose less than 20% of the material) (Coleman, 1999, 24). Autumn leaves are not a good ingredient in compost because they mat together creating anaerobic conditions, but are another soil enhancer in and among themselves. Fungi decompose moist leaves to create leaf mold after 2-3 years which is especially beneficial for cabbage, carrots and kale. Leaves can also be tilled directly into the soil in the fall (Coleman, 1999, 23).

The primary compost applied to both potato fields and greenhouses is "cow compost." The mixture of manure and dried leaves is high in nitrogen and carbon, but lacks other nutrients (Norman, 2009). Vegetable composting is hardly practiced because any organic waste is fed to the livestock. Of the few the composts observed at households without livestock the heaps were primarily composed of green material causing an acidic nature as explained above. If any brown material was present, it tended to be leaves, which are not recommended in compost heaps because they decrease decomposition by reducing available air (also explained above). All the heaps were covered in a pit, a strategic method to reduce leaching of nutrients from the heavy monsoon rains. Thus, the extent of benefit from these compost heaps is uncertain.

These soil attributes create a complex relationship between potatoes and soil nutrients. The acidic soil is well suited for growing potatoes, which prefer a soil pH of 5.3 (although actual soil pH is

Ladybugs are beneficial pests in greenhouses.

unknown)(Allen). However, the acidic nature of the soil reduces nutrient availability (explained under Geology and Inherent Soil Fertility), which potatoes consume in large amounts. Potatoes require higher levels of N and P_2O_5 than rice or wheat, and more K_2O than rice (Brown & Shrestha, 2000, 221). The exact exchanges between the soil and potato plants are unknown, but I would assume nitrogen is abundant due to the heavy application of manure and phosphorous and potassium are limiting. Crop rotation is not practiced because the short growing season leaves no space for other crops. The planting of potatoes every year in the same location exhausts the soils of the same nutrients, which are now liable to be insufficient. Intercropping of legumes is suggested to replenish nutrients in the soil, especially nitrogen.

Within the greenhouses, the acidic soil is more problematic since most plants prefer a soil pH of 6-7 (only slightly acidic)(Coleman, 1999, 29). The small scale allows the problem to be potentially rectified by adding limestone (calcium carbonate), a buffering agent. Although no mineral additives are available, natural sources of wood ash and egg shells were observed within the greenhouses. Bone meal is another good source of calcium and phosphorous. Small bones were noticed among the soil in several greenhouses, but they were not crushed or ground reducing their potential effect. Trace amounts of potassium may be found in wood ash and granite (potassium feldspar)(Eusden). Both are present in the soil, either added from household stoves or weathered from the bedrock, but potassium is water-soluble and thus easily leached so its actual presence is uncertain.

Pests can also be managed by various growing techniques. Certain Pests are beneficial and can be fostered instead of eradicated with chemical applications. Polycultures (cultivation of more than one crop) are a simple method in lowering the chances of pests by growing a variety of plant species to reduce a favored niche by pests and creating other niches for beneficial pests species (Coleman, 1999, 145). Succession planting or crop rotation also changes the niches continuously important in preventing the build up of pests and disease and the exhaustion of nutrients caused by growing the same crop in the same place year after year. The complete removal of the plastic in the summer to allow exposure to the natural elements would also help lower pest buildup (Coleman, 1999, 41)(Norman, 2009).

PLASTIC AND VENTILATION

Plastic is the preferred choice of material for greenhouses because it is durable, lightweight, cheap, and translucent. The concept and construction of plastic greenhouses was first accomplished by Professor Emery Myers Emmert (1900-1962) of Kentucky, a biochemist and experimental plant horticulturist who is acknowledged as the “father of plastic greenhouses” (Coleman, 1999, 214). He started experimenting with scraps of plastic before it became readily available after WWII. Professor Emmert built his first plastic greenhouse in 1949 and continued experimenting to pioneer the high and low tunnel designs of greenhouses today (Coleman, 1999, 215). The development of greenhouses to utilize solar energy has transformed the limits of agriculture to new heights, literally.

There are a few drawbacks to plastic greenhouses and although outweighed by their enormous benefits, they are worth acknowledging so that precautions can be taken to mitigate their impact. Photosynthesis is decreased, but only by approximately 5% (Debevec, 1993, 56). Studies have also shown a phase

A greenhouse at the local monastery open during the day for ventilation.

shift in light as it penetrates through the plastic changing from a normal low wavelength (blue) to a high wavelength (red). This change affects plant growth to some degree because chlorophyll, which is responsible for absorbing light required for photosynthesis, is more receptive to blue light (Debevec, 1993, 56). These light factors are unavoidable and predominately insignificant compensated by the heat retention.

The impervious material prevents gas diffusion trapping the desired heat, but also affects carbon dioxide concentrations and humidity. Carbon dioxide (CO_2) is an essential component in photosynthesis, which uses light energy to convert CO_2 and water into sugars used for growth within the plant. Increased concentrations up to 1,000 ppm are beneficial to plants increasing the uptake of CO_2 through stomata (tiny pores in leaves allowing the exchange of gases). In the closed conditions of greenhouses CO_2 is often limiting dropping below normal ambient levels of 340 ppm to 200 ppm during the day. Thus, ventilation is important to ensure at least ambient concentrations of CO_2 are available (Blom, 2009).

Humidity increases as plastic traps moisture in the air from evaporation and evapotranspiration (release of water vapor through stomata) induced by the warmer temperatures. The saturated air is generally beneficial for plants affecting stomatal conductance (exchange of gases through tiny pores in leaves) although pests also benefit from the warm, moist climates (Debevec, 1993, 61). Although ventilation causes a loss of heat (which is actually necessary except during winter), it is important in order for the exchange of gases. The key to a greenhouse's success is balancing temperature and air through ventilation (Debevec, 1993, 61). However, constant opening and closing leads to wear and tear enhanced by strong wind causing the plastic to last up to 10 years (Norman, 2009). Cloth is an alternate material that is more breathable, but light transmittance and heat retention is significantly reduced leading gardeners to adapt to the miniscule drawbacks of plastic (Debevec, 1993, 61).

IMPACTS OF GREENHOUSES

ENVIRONEMENTAL

Compared to the outside gardens there is no negative environmental impact observed from greenhouses. The soil fertility in the greenhouses tend to be better than outside simply because the area is protected from the harsh mountain elements. No chemical fertilizers or pesticides are added in either location and proportional amounts of cow compost are added according to size of the gardens. Watering is also reported to be equal, because even though evaporation rates are high in the greenhouse due to higher temperatures, the plastic retains the moisture, which drips off back onto the soil. Thus, the main difference leading to the advantageous growing environment within the greenhouses seems to be temperature and moisture since soil fertilization is equal. Although the protection of the greenhouse creates a drastically different microclimate suited for growing vegetables, it does not affect the larger environment.

ECONOMIC

The monetary benefit of greenhouses varies greatly. Although greenhouses are very beneficial by supplying fresh vegetables throughout the winter, little revenue is generated. The primary reason is because the consumption demand of the relatively large families (average of 4) leaves little surplus from the small $200ft^2$ greenhouses. This is especially true during the four long months of winter when the plants are merely hibernating due to the cold temperatures. Greenhouses have not replaced the outside gardens emphasizing the high demand for produce. Furthermore, owners price their precious resource on average Rs. 5-

10 higher than local markets in Namche, a 2 hr walk away. At the time, a head of Chinese cabbage sold for Rs. 20 compared to Rs. 10 in Namche Bazaar supplied by larger farms at lower altitudes in Phakding and Monjo. It was hard to distinguish the reason for this slightly higher price, but it may be caused by the high demand by the family, more time or resource input to grow vegetables at the colder altitude and the luxury of close proximity. Additionally, the market opportunity in Thamo only occurs in the winter (December to March), because during the rest of the year people rely on their own outside gardens. The greenhouses do not produce enough surplus to make entering the Namche market efficient.

Thus, the average revenue generated from the greenhouses (of those that sell) is Rs. 1,600 over the winter season, although maxes at Rs. 3,000 (the average is only 2% of an estimated household income). The average expenditure of vegetables for families without greenhouses is Rs. 900, although it also maxes at Rs. 3,000. The average per person expenditure is Rs. 200 and maxes at Rs. 750. Vegetables are usually bought in Namche because they are cheaper.

Based on these calculations, Rs. 2,500 is generated/saved in addition to a steady supply of fresh vegetables throughout the winter. Most of the monetary value of greenhouses is from *saving* money rather then *earning* money. However, greenhouses are not efficient *economically* because they cost Rs. 30,000 (nearly half of an estimated yearly income). Based on the annual monetary value of greenhouses it would take 12 years to break even. There are no significant economic inputs into the greenhouses other than its initial purchase cost. Under the circumstances of donation (excluding purchase cost), the greenhouses are overall economically beneficial saving households money.

Alternate greenhouse designs may be more appropriate reducing cost to make greenhouses more widely available and increasing temperatures making them more efficient. A “tent” design has no sidewalls positioning the peaked roof closer to the ground (see Greenhouse Designs in the Appendix). This moves the hottest air, which rises due to convection, closer to the plants and requires less plastic making the greenhouse more thermally and cost efficient. A trench can be dug between the raised beds to compensate for the decreased height keeping access for watering and harvesting easy (Norman, 2009).

Cost can be reduced further by creating a “half tent” where a sheet of plastic is draped from an erected stonewall. Facing south, the stonewall adsorbs and radiates heat within the covered area (see Greenhouse Designs in the Appendix). Alternatively, the plastic could be draped from an existing wall of a house. This would provide easy access and would also heat the house if airways existed between the house and the greenhouse (Norman, 2009). This only works if the house faces south, but most of the houses in Thamo are. The locals seem aware of the importance of southern exposure only having windows on the south-facing wall. The houses are also built to utilize the available heat with the living area situated above an enclosed area for livestock, whose body heat rises warming the living area above. The living area consists of a single room approximately 30 x 15 ft to allow maximum circulation of heat from a woodstove. Reducing the amount of plastic would decrease the cost potentially rendering greenhouses a viable option for wealthier families. However, the annual buffer zone community development funds may act as a disincentive to purchase individually. Although, to my knowledge, no further requests for greenhouses have been made despite being very beneficial.

Lacking sufficient funds, improvised designs of plastic coverings attempting to mimic the beneficial effect greenhouses were noticed in the other villages visited (Namche, Khumjung, Khunde, Thame). Most consisted of scraps of thin plastic stretched over arched bamboo poles (see photo on next page). Although mitigating the cold to some degree, they tended to be tiny and torn due to lack of resources. Plastic has to be UV stabilized or it will not last a single year making improvised constructions only temporary (Norman, 2009). At lower elevations in Monjo, Phakding and Ghat, larger constructions of self-made greenhouses were noticed. Several were actually larger than those found in Thamo profiting from the lower altitude which decreases transport cost and increases surplus from the ample space and higher temperatures. A greater variety of more lucrative vegetables, such as tomatoes, were still being grown in late November. Agriculture at the lower elevations is overall more prosperous due to higher temperatures, a longer growing season, more fertile soil and more cultivatable land. Economics is the main variable and determinant leading to greenhouse ownership.

SOCIAL

Greenhouses were only donated to a third of the community in Thamo due to expense. Although the community members were aware of this and the greenhouses were distributed by lottery, I imagine some social tension arises. However, this was very hard to discern. Even though the village is a close-knit community the low surplus from the greenhouses leads to little sharing or selling of vegetables among the community. The installment of a larger community greenhouse would not be feasible or appropriate considering cost and terrain. The greenhouses are a great benefit providing fresh vegetables throughout the winter and 100% of the population interviewed desires a greenhouse if they do not already own one.

Similar to the household gardens, women predominately work in the greenhouses since they spend most of their time at home while the men porter goods or guide trekkers. Thus, greenhouses do not change existing social orders. The more time spent tending the greenhouse garden appears to yield greater surplus, health and diversity of vegetables. Overall, the disparity of greenhouse ownership has not dissolved community ties in the cohesive village.

Conclusion

The village of Thamo and the larger area of Khumbu are gifted and cursed by the beautiful, rugged landscape situated on the slopes of the world's highest mountains. The cold, arid climate, short growing season and acidic, infertile soil make agriculture a challenge. The Sherpas have managed to utilize the limited available resources to successfully cultivate a single potato crop forming the staple diet, supplemented by small vegetable gardens. The landscape also attracts masses of tourists, which provide additional income increasing standards of living through improved household amenities and education and health facilities. The increased income has also benefited the environment by making alternative energy sources a viable option replacing the dependence on wood. Tourism has also changed lifestyles and affected the environment drawing the labor force and material resources from agriculture. Agricultural productivity and rangeland fertility have decreased with the lack of livestock fertilizing the land.

Additional revenue is collected by Sagarmatha National Park for community development projects for settlements within the buffer zone, which may aid agriculture. This has greatly benefited Thamo, which received ten greenhouses. The greenhouses protect vegetables from harsh winds and freezing temperatures providing a substantially warmer microclimate heated by the sun's energy to yield fresh vegetables year-round. The steady supply of vegetables saves money and luxuriously provides key nutrients, which would otherwise

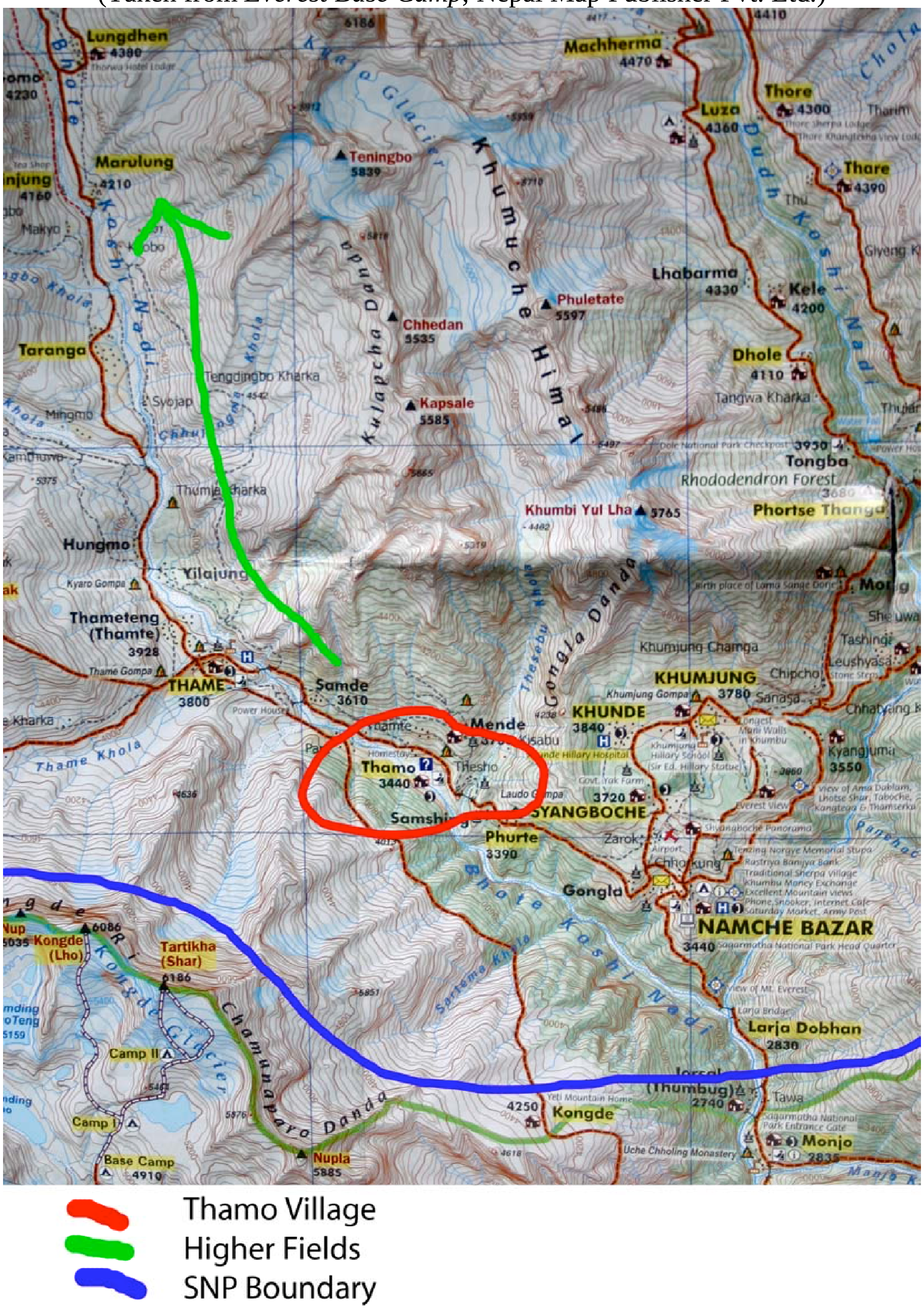
Nawan Sherpa, one of the farmers in Thamo benefiting from his greenhouse.

have to be purchased and tend to be lacking during the winter months. During the rest of the year, the greenhouses supplement the outside gardens with a diverse range of vegetables, from tomatoes to chilies, which are otherwise unavailable. Even though the greenhouses are not economically efficient considering their high cost, they render families completely self-sufficient for vegetables. Although improvements could be made to increase surplus by raising temperatures, combating pests and improving soil fertility, the farmers have the basic principles mastered from farming for generations and successfully feed themselves throughout the winter. Some improvements may not be feasible, but others may potentially increase surplus. Although surplus is relatively low after household consumption and fiscally negligible compared to other sources of income, I think the importance should be stressed and equally recognized on supplying food. I highly recommend and encourage the rest of Thamo and other villages in Sagarmatha National Park to take advantage of the annually available buffer zone community development funds and request the purchase of greenhouses.

Appendix

Physical Map of Thamo

(Taken from *Everest Base Camp*, Nepal Map Publisher Pvt. Ltd.)



Water Experiment Results					
Time	Hours of Sunlight	Greenhouse	Flaps Open/Closed	Inside	Outside
7:00 AM	0	A	closed	1/8 in frozen	1/2 in frozen, 1/2 in mix
		B	open	1/8 in frozen, 1/8 in mix	1/2 in frozen, 1 in mix
		C	closed	1/8 in frozen	1/2 in frozen
8:30 AM	1	A	closed	thawed except for a thin layer of ice	still frozen (shaded)
		B	open	thawed except for a thin layer of ice	still frozen (shaded)
		C	closed	thawed except for a thin layer of ice	still frozen (shaded)
10:30 AM	3	A	closed	fully thawed and lukewarm	still 1/2 in frozen
		B	open	fully thawed and lukewarm	fully thawed but cold
		C	closed	fully thawed and lukewarm	fully thawed but cold
2:30 PM	7	A	closed	warm	fully thawed and lukewarm
		B	open	warm	cool
		C	closed	warm	lukewarm

Metadata

The owner determined whether the flaps were open or closed; I did not intervene.

"Frozen" refers to solid ice and "mix" refers to ice crystals in unfrozen water. Water at the top of the glass froze first exposed to the cold creating a gradient of frozen ice to mixed to unfrozen at the bottom of the glass.

Standard of Living Assessment Data													
		Electricity	Electric Burner	TV	Running Water	Underground Toilet	Metal Roof	Phone	Lodge	Children of Age in School	Livestock	Higher Field	Higher House
Total	YES	31	18	13	6	9	15	31	4	31	23	25	18
	NO	0	13	18	25	22	16	0	27	0	8	6	13
%	YES	100%	58%	42%	19%	29%	48%	100%	13%	100%	74%	81%	58%
	NO	0%	42%	58%	81%	71%	52%	0%	87%	0%	26%	19%	42%

Double Coverage Sample Temperatures (°F)			
	Nighttime Low	Daytime High	Cloudy Day
Outside	-10	5	30
High Tunnel	4	42	45
Double Coverage	18	78	60

(Coleman, 1999, 110)

Temperature Effects on Plants	
Temperature (°F)	Effect
115	upper limit (plants die)
95	maximum photosynthesis (but too hot if continued too long)
75	optimum photosynthesis and plant growth
55	average daytime greenhouse temperature during the coldest months
35	ideal minimum greenhouse air temperature (no freezing)
15	lower limit for quality harvest of most winter salad crops

(Coleman, 1999, 204)

Metadata

NOTE: The KBC and Khari Gonpa Monastery greenhouses were not included in the standard of living survey.
"-" denotes no, none or not applicable.

is for identification (no ranking).
Name refers to the main figure in the household, usually male. Spelling is phonetically written.
Male/Female refers to the gender of the interviewee and does not necessarily correlate with the name listed.
Schooling refers to that of the interviewee.
 # in Family includes children that may be boarding at school, but return for the winter months.
Children of Age in School lists the number of children in school either in Thamo (TMO), Khumjung (KMJG) or Kathmandu (KTM).
House/Lodge distinguishes whether the household is also a lodge or guesthouse.
Running Water refers to water piped inside the house.
# of Livestock is listed by breed: D (dzo), C (cow), Y (yak), H (horse).
Vegetables Bought During Winter provides location if yes (Namche, Thamo or Thamo
Expenditure for Winter Vegetables refers to expenditure for the entire family versus **Expenditure Per Person**
% of Total Crop refers to Thamo's percentage out of the total potato crop yielded from all fields owned.
Higher House(s) and Field(s) lists the location of a house and field(s) situated above Thamo (higher elevation).
Higher Field(s) Only lists the location of field(s) situated above Thamo (higher elevation). No houses are owned at these locations.
Additional Potato Crop refers to the combined yield from all fields located above Thamo.
Total Potato Crop is a summation of the potato yield from Thamo and all higher fields.
Income Generated from Potato is calculated by the number of total baskets multiplied by 35 kg per basket divided by 12 kg per tin multiplied by Rs. 350 per tin.
Additional Employment lists any employment in addition to farming.
Total Estimated Income is merely an estimation for reference purposes calculated from Income Generated from Potato multiplied by two (averaging tourism's approximate 40-60% contribution).

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(Names are listed in alphabetical order according to their first name because everyone's last name is Sherpa. Spelling is phonetically written.)

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