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Solar Greenhouse Technology for Food Security: A Case Study From Humla District, NW Nepal

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Food security is a significant issue for many people who live in remote mountain areas around the world. Most of these people are also poor because of the lack of opportunity to earn cash. Malnutrition is common because the harsh climate restricts production and access to fresh food. Simple conventional greenhouses can provide some improvement of growing conditions, but the benefits are limited because of the high heat losses from these structures. Solar greenhouses, however, which are designed to store some of the heat generated within the structure can overcome these limitations. This article describes the experiences of a nongovernmental organization that has been introducing community and family-owned solar greenhouses into the remote villages of Humla, a mountainous district of northwest Nepal prone to food insecurity. The overall result has been positive. Family-owned greenhouses, which avoid the issues of community ownership and operation, have been more successful. A validated computer model based on the first solar greenhouse has been used to predict the thermal performance of a new family-sized design. Training and education are vital to the success of solar greenhouse technology in remote mountain areas.

Keywords: *Greenhouse; mountains; solar energy; food security; northwest Nepal.*

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Introduction

The 2011 Report of the Secretary General to the United Nations (UN) Assembly acknowledges that many of the world's most impoverished people live in mountain regions and that they are particularly vulnerable to food shortages (UN 2011). Food security is defined as having "the physical, social and economic access to sufficient, safe and nutritious food at all times to meet the dietary needs and food preferences for an active and healthy life" (FAO 2003: 28). One of the UN Assembly Report's recommendations is that strategies and programs for food security in mountain areas be elaborated to protect these vulnerable people from the effects of rising food prices and shortages caused by various factors, such as climate change, water shortages, loss of ecosystems, and other environmental degradation. Solar greenhouses, that is, greenhouses that have been designed to maximize the entry and storage of solar energy, have been shown to be a viable technology for mountain regions, capable of extending food growing seasons, and even to permit year-round cropping, for example, in Bolivia (BAFI 2002) and Tibet (TVP 2012).

This article describes the experiences of solar greenhouse technology in the mountainous district of Humla, located between 29°35′ and 30°70′N; 81°18′ and 82°10′E in northwest Nepal. This article initially reiterates the nexus between food shortage, health, and poverty, and then outlines the social and climatic conditions of Humla. The experiences with solar greenhouse technology in Humla are then described, illustrating the technical, economic, and social factors that can influence the success or failure of this technology.

Food security, health, and poverty

The links between food shortages, impoverishment, and malnutrition have been established for some time (World Bank 1986). The connection between poverty and extreme hunger was also emphasized by the Millennium Development Goals. Despite a reduction in poverty over the past 20 years, the UN acknowledges that progress in relieving food deprivation has either slowed or stalled in many regions (UN 2012). This shortfall is reflected, for example, in the proportion of children under 5 years old who are underweight, which—although now lower—still remains at 18% in developing regions. Insufficient food leads to low energy levels, which, in turn, translates into an inability to work for the hours and/or at the intensity required for an active life, for example, to raise a family, grow food, tend animals, collect firewood, and earn money. The areas of the world that have the lowest levels of labor productivity are also those with the highest

TABLE 1 Climatic, demographic and socioeconomic data for Humla. PPP, purchasing power parity. (Sources: [1]Fuller et al 2009; [2]Government of Nepal 2011; [3]UNDP 2004).

Climatic[1]	
Mean solar radiation (MJ/d/m^2)	15.9
Mean monthly maximum temperature (°C)	18.6
Mean monthly minimum temperature (°C)	6.7
Demographic[2]	
Population	51,008
Population density (person/km^2)	9
Number of households	9494
Socioeconomic[3]	
Life expectancy (y)	58.4
Adult literacy (%)	19.6
Income (PPP US$)	1014
Clean water access (%)	35.8

proportion of people who are undernourished (UN 2012). Malnutrition from inadequate food is particularly insidious. Often called the "hidden hunger," it "afflicts a far greater swath of humanity than insufficient calorie intake" (Cohen et al 2008: 14). Deficiencies in vitamins and minerals can result in a susceptibility to disease and infection, mental impairment, and subnormal growth. For example, according to Black et al (2008), maternal and child undernutrition is the underlying cause for 3.5 million deaths and 35% of the disease burden in children under 5 years old.

Humla

Humla is a district of northwest Nepal adjacent to the border with the Tibet Autonomous Region, which covers an area of 5655 km^2 at elevations between 1524 and 7031 m. Shown in Table 1 are some of the key climatic, demographic, and socioeconomic data for the district; and the typical houses and terrain of Humla are illustrated in Figure 1. Due to the climate, fresh food production outside is limited to just 3–4 months during the year, and this has direct consequences on the health and diet of the Humli people. For example, a survey by Emeriau (2006) found that global acute and chronic malnutrition rates were 12.3% and 63.9% in the children of Humla. Candy (2009) has analyzed the average per capita daily nutritional intake for a typical 5-person Humli family in terms of some key minerals and vitamins (Figure 2). In all cases, the daily intake is well below the recommended dietary intake.

It is not coincidental that Humla has been judged to be one of the poorest districts of Nepal. Of 75 districts and when using a ranking of 1 (best) to 75 (worst), Humla was ranked at 73rd position in terms of poverty and deprivation (HDI 2012 [2003]). According to Roy et al (2009: 214), the livelihoods of Humli people have "remained unchanged or actually worsened despite 3 decades of project support by various donor agencies… " This stark reality led those researchers to develop the concept of the "Humla Development Initiatives," which aims to reduce the dependency of the Humli people on external support by developing local resources. The main focus of the "Humla Development Initiatives" is food security.

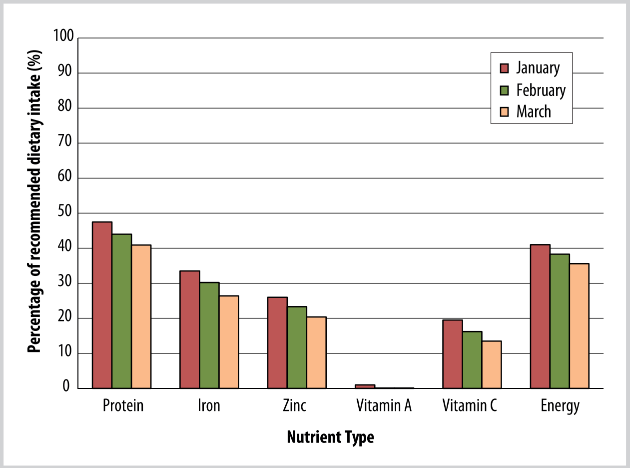
Solar greenhouses in remote mountain areas

Greenhouses of all types are being used in remote mountain areas for crop protection, season extension, seedling production, and growth promotion. Most of these are basic constructions, similar to the plastic-covered tunnel structures used in temperate climates but often using local materials such as bamboo for the frame (Nieuhys 2003). The increased use of these greenhouses to improve dietary intake and even to provide early season vegetables for sale in the high mountain areas of northern India has been observed by Dame and Nüsser (2011).

Solar greenhouses, however, are much less common. These are structures designed to maximize the entry and storage of solar energy to moderate excessive temperature swings, particularly through the use of thermal mass and night-time insulation. Solar greenhouses are being successfully demonstrated and disseminated in the cold regions of Asia. The nongovernmental organization (NGO) GERES-India has developed a solar greenhouse design that has proved to be particularly successful for vegetable production in Ladakh, India (Triquet undated). The basic greenhouse is 4.5-m wide and 9.7-m long. The south-facing wall is glazed with ultraviolet (UV) resistant polyethylene sheets. It is covered at night with straw mats to retain the heat within the structure. In summer, glazing panels can be removed to exhaust excess heat through vents in the walls, which are made from 2 layers of mud brick and a straw-filled cavity to reduce heat losses. The rear and west-facing walls are painted black to increase the heat absorption. The roof is constructed of native willow and poplar logs. Although individual results vary, the performance of the greenhouses has extended the growing season by a minimum of 4 months, with vegetables such as spinach, coriander, and carrot being cultivated in the winter season. Inside the greenhouse, even when outside temperatures reach −20.0°C, the internal air temperature has been maintained above freezing (Mansouri and Guinebault 2005). An economic evaluation of these solar greenhouses indicated that it was possible to earn US$ 50 a month for 2 hours of work per day from the sale of

FIGURE 1 Typical Humli houses and terrain. (Photo by Zahnd 2007)

FIGURE 2 Daily nutritional intake for a Humli family in winter as percentage of the recommended dietary intake (RDI). (Source: adapted from Candy 2009)



vegetables. More than 600 GERES-style greenhouses have been built around the world (solargreenhouse.org).

Solar greenhouses in Humla

RIDS-Nepal is an NGO that has been working in the Humla district since 2002 guided by a model of holistic community development. It now has multiple projects in 13 villages (RIDS-Nepal 2012). Requests from villagers themselves are the basis for project selection, and the contribution of villages depends on the project. General labor and local materials are supplied by villagers. Most imported materials are beyond their financial capacity and thus highly subsidized.

Before a project is implemented, a baseline survey in the village is conducted. Its core program is the "Family of 4" in which basic indoor lighting systems (powered by renewable energy), smokeless metal stoves, pit latrines, and improved water supply are seen as complementary technologies. The success of this program has prompted

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FIGURE 3 External view of HARS Greenhouse. (Photo by Zahnd 2007)

its expansion to the “Family of 4 PLUS,” which includes health and food supply initiatives. As part of the latter, RIDS-Nepal has constructed a number of greenhouses in Humla. Their first greenhouse, built in 2004, is located at their High Altitude Research Station (HARS) in Simikot, the main town of Humla (3000 m altitude).

The HARS greenhouse has been built predominately from local materials; the walls are constructed from stone and mud, and the timber roof frame is sourced from locally prepared beams, which are supported by vertical posts. The double layer UV-stabilized polyethylene glazing material, however, was imported from India. The overall size of the greenhouse is 10 m by 5 m, with a south-facing roof with a 15° slope (Figure 3). This inclination was dictated by the site and proved to be inadequate to shed snow, which damaged both the glazing and roof frame of the greenhouse.

Apart from this limitation, night-time internal temperatures were found to be too low (<5°C) in winter mainly due to infiltration and lack of insulation. Overly large stone walls were also costly. Day-time temperatures were conversely often too high (>30°C) in summer due to a lack of ventilation openings. In response, a second solar greenhouse was built by RIDS-Nepal at their field station at Dharapori (2400 m altitude) in 2008 (Figure 4). The greenhouse was based on the GERES design, although with some adaptation; double-layer rock walls with an insulated cavity were substituted for the mud bricks used in Ladakh. Corner flaps on the front face of the greenhouse and rear roof ventilators are opened to avoid overheating.

Although this greenhouse performs satisfactorily, its size and cost are considered too great for a single Humli family. There is also scope to improve its thermal performance. These factors have prompted the development of a revised design that is more suitable for a single family. The plan view and E-W section of the greenhouse are shown in Figure 5. The final size of the greenhouse is 6.6 × 4.5 m with a practical growing area of approximately 18 m^2.

Instead of double stone walls with insulation between the stone layers, only one layer of stone is used on the inside. Insulation is contained by half-round timbers. This construction method is intended to speed up the building process and reduce costs. The inner layer of stone still acts as thermal mass to absorb incident solar radiation and reduce excessive temperatures swings. The smaller structure also has reduced loads on the walls and the roof timber spans are also smaller. Hinged insulated panels on the south-facing wall are used to reduce heat losses at night from the lower glazed section. This strategy has been successfully used to prevent the freezing of solar water collectors in Simikot (Zahnd and Malla 2006). An internal thermal blanket is drawn over the upper glazing panels to complete the insulation process at night. Although yet to be constructed, the thermal performance of the family-sized greenhouse has been evaluated with the validated simulation model used to evaluate the HARS greenhouse, offering a significant potential improvement in the growing conditions in the smaller greenhouse (see Technical Performance below).

Technical performance

Fuller et al (2009) measured various indicators of the thermal performance of the HARS greenhouse in the winter months (November 2006 to March 2007) and then used some of these data to validate a simulation model of the greenhouse. Measured hourly values of greenhouse soil temperature, internal air temperature, and relative humidity were compared with model predictions, based

FIGURE 4 GERES-style greenhouse at Dharapori. (Photo by Fuller 2008)

on measured hourly climatic data for 1 week in November. The validated model was then used to investigate options to improve the thermal performance of the greenhouse. The measurements showed that, in mid January during the night time, the subsurface soil temperatures within the greenhouse were approximately 7–9°C warmer than at a similar soil level outside. At 600 mm below the surface, the soil temperature in the greenhouse did not fall below 10.3°C. Air temperatures within the greenhouse in mid January were approximately 7.5°C above the outside air temperature. Although not ideal, the measurements over the winter months indicated that the growing conditions were certainly suitable for some vegetable crops such as spinach, carrots, and beans.

The simulation model (TRNSYS) was used to investigate what improvements in growing conditions could be made with some simple energy conservation strategies. These were the following: the installation of a night-screen (or thermal blanket), improved wall insulation, and water-filled tubes (or solar sleeves) placed on the ground between crop rows. Individually, each of these strategies was found to raise the internal air temperature of the greenhouse and, when used in combination, the minimum overnight greenhouse air temperature was raised by 7.1°C. The average greenhouse air temperature between 6 PM and 6 AM was predicted to be 15.5°C during the week investigated (16–22 November). Although this was not the coldest part of the winter, the improvements in internal air temperatures are indicative of what might be achieved in other months.

As mentioned above, the same simulation model was used to investigate the thermal performance of the smaller family-sized greenhouse shown in Figure 5. Direct comparison with the measured performance of the HARS greenhouse in November indicated that the overnight average temperature would be 2.4°C warmer in the

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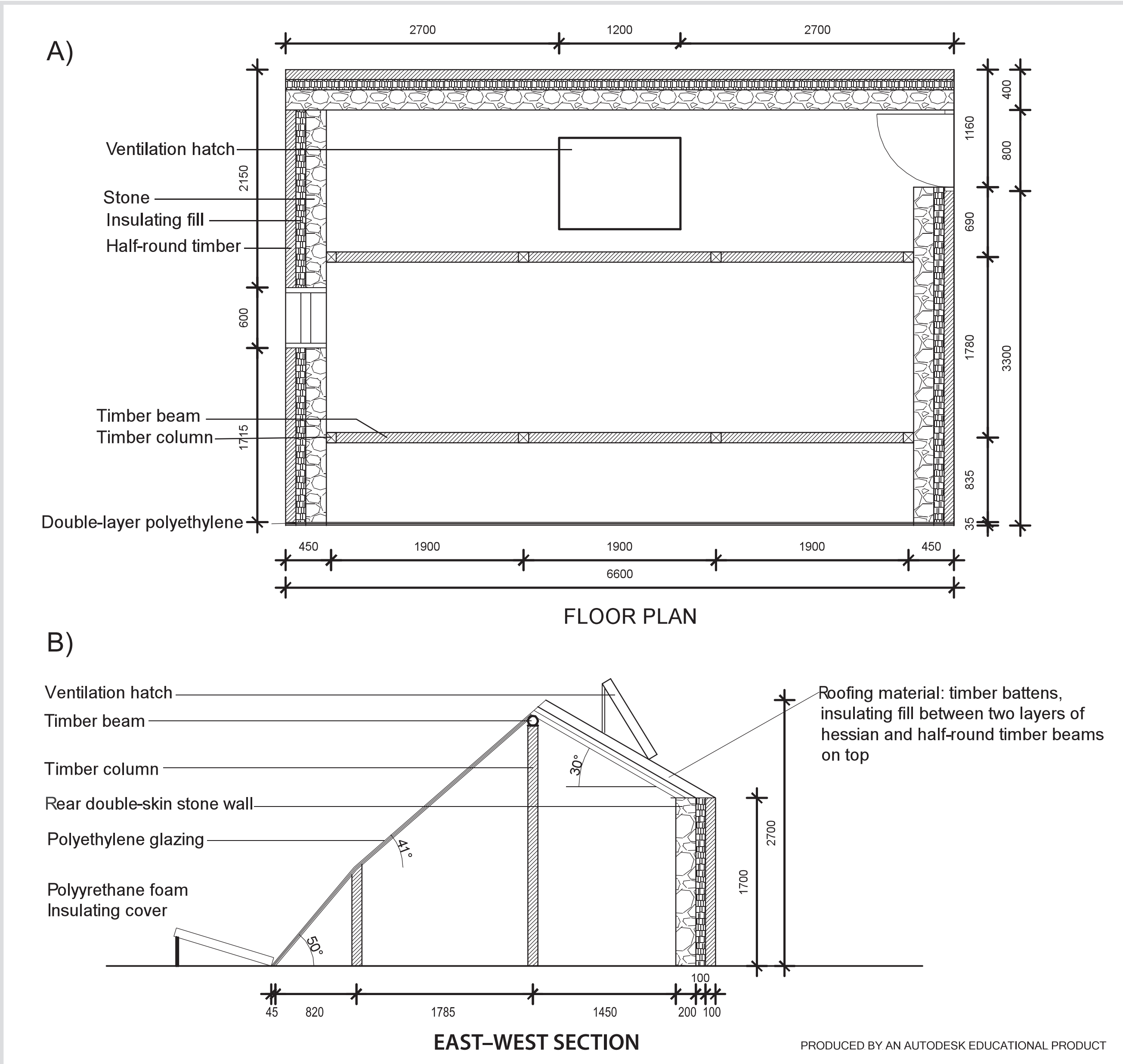
FIGURE 5 Floor plan (A) and East–West section (B) of proposed family-sized greenhouse. (Design by Sawyer and Fuller 2012)



family-sized greenhouse. Predictions of the thermal performance of this solar greenhouse have also been made on a monthly basis. Maximum and minimum temperatures were predicted by using hourly climatic data (solar radiation and ambient temperatures), generated for Simikot by using NASA satellite data (Sawyer and Fuller 2012).

Despite the elevations at which these greenhouses are constructed, overheating can occur if there is inadequate ventilation. This problem is particularly likely to occur in small greenhouses. Individual strategies to improve the minimum overnight temperatures were investigated, including reducing infiltration by supersealing, the use of an internal night screen, and the use of external insulation shutters. Average overnight temperatures between 5 PM and 7 AM were raised to 16.1°C when all these strategies were combined. Similarly, strategies to reduce overheating, that is, 30% shading and increased ventilation (3 air changes per hour) were investigated separately and in combination. In the latter case, maximum daytime internal air temperatures of 31.5°C in summer were predicted. These simulations indicate that good growing conditions could be expected in the small family-sized greenhouse.

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In addition to the thermal conditions in the greenhouse, there are several other technical issues that need to be considered when promoting greenhouses. One is their need for water because the lack of a reliable and easily accessible source of water has been found to be one of the reasons that a greenhouse may not live up to its potential or even fail completely. Although annual average rainfall in Simikot is approximately 800 mm (DHM 2012), piped supply in Humli villages is virtually nonexistent, and accessing water usually involves carrying it in containers. Therefore, a water supply system is crucial to make greenhouses sustainable and successful in the long term.

RIDS-Nepal has found that its "Family of 4" strategy, of which the water supply is an integral part, therefore facilitates and complements the introduction of greenhouses. Good seeds and soil are obviously also essential for the long-term success of a greenhouse. Last year, RIDS-Nepal witnessed the effect of several greenhouses when using poor-quality seeds. The crop did not turn out to be as good as it could have been and means that some investigation by the promoting NGO is needed to ensure that robust and appropriate seeds and seedlings are used. Soil fertility must also be monitored, and the new users need to be educated about maintaining good soil conditions through composting.

Economic evaluation

Although measurements and computer simulation enable a technical evaluation of prototype greenhouses, economic and social evaluations present a far greater challenge. Humla has no roads, and, therefore, villages can be accessed only on foot. Field visits involve walking for hours, or even days, on rocky mountain tracks. Meetings (community or individual) must be arranged on arrival because they cannot be set up in advance due to the lack of electronic communications. Overnight stays are usually mandatory as a result. Due to these difficult conditions, it was not possible to conduct an in-depth and systematic socioeconomic evaluation. However, some of the processes and challenges of introducing new technologies in Humla have been described by McKay et al (2007).

An economic evaluation of greenhouses in these areas is also difficult because of the lack of data and an accurate picture of alternatives, and because the rules of conventional financial accounting do not hold in societies where there is only a small reliance on cash for day-to-day living. When using 2012 data from Simikot, however, some indication of the financial viability of a small family-sized greenhouse can be demonstrated. In winter, fresh vegetables, when they are available and can be delivered, are air freighted to Simikot from the southern town of Nepalgunj near the Indian border. The price of vegetables such as cauliflower, carrots, beans, onions, garlic, and tomatoes ranges from 150–350 NRs (1 US$ = 85 NRs as of 9 June 2012) per kg, whereas spices such as ginger and garlic are 2–3 times these prices.

Most of the components for a family-sized greenhouse are locally sourced and often can be obtained for little or no cost except for family labor. The skills (masonry and carpentry) required for construction are both available locally. The main component that must be imported to these regions is the UV-stabilized polyethylene. The current cost of the material used by RIDS-Nepal is 83 NRs per m^2. The cost of road transport to Nepalgunj and air freight to Simikot is 135 NRs per kg. Delivery to villages is by animal or porter and is usually part of the villagers' voluntary participation. The material is UV stabilized, strong (120 g/m^2), and can last 6 years. A small family-sized greenhouse of the type shown in Figure 5 would use approximately 55 m^2 of polyethylene, which costs approximately 5456 NRs (~65 US$).

Vegetable output (kg) will vary, dependent on a multitude of factors. However, these figures indicate that an output of only 5–6 kg per year is required to achieve a payback of 4 years, similar to the greenhouses in Ladakh (Triquet undated). In the HARS solar greenhouse in Simikot, experience has shown that more than 80 kg of vegetables can be harvested each year. It is therefore estimated that a well-kept and well-managed family-sized greenhouse in a village should be able to produce 30–40 kg per annum. The social benefits of improved health and food security would improve the economic viability of the investment.

Community acceptance

RIDS-Nepal has built 42 greenhouses in 10 villages of Humla over the past 7 years. Another six were constructed in one village in Jumla, a neighboring district. Approximately 25 of these are estimated to be still operating as intended. Another NGO has built some 20 more greenhouses based on the Dharapori design in 4 villages in the upper Humla region. Most (36) of the RIDS-Nepal greenhouses have been for individual use, the remainder being for community use with up to 10 families per community greenhouse. Due to the difficulties of conducting surveys in Humla, the following evaluation is based on the authors' collected anecdotal data and observations in the villages, rather than a comprehensive survey of users.

A community greenhouse, as expected, is much harder to establish and keep functioning well, compared with a family unit. The mutual trust required to operate and to harvest from the greenhouse is significant. It therefore usually takes some time for a community greenhouse project to be successful. If the tasks and benefits are not equally distributed, this will cause social tension and ultimately may lead either to the collapse of the project or result in only one person doing all the work and receiving the benefits. This was the outcome of one community greenhouse project in the village of Sata. In general, therefore, individually owned and managed greenhouses work better in Humla. However,

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despite this observation, some individual families have also failed to recognize the long-term benefits and their greenhouse has not been successful.

In Humla, it has also been observed that sometimes there is a relative lack of enthusiasm for a greenhouse project in the first year of operation. For example, in Chala village (located at 3800 m altitude) vegetables are never seen during the cold winter season. However, after the first winter when some vegetables were available from the greenhouse, the villagers were much more enthusiastic. Thus, after the first winter experience with 2 greenhouses, the local people asked for more, and another NGO has now built a further 8 greenhouses. This illustrates that the initial hurdle of "disbelief," and at times hesitation and/or fear of new inventions, has first to be overcome by results and once villagers have seen and eaten the produce, their motivation and enthusiasm is much greater. In this example, the second batch of greenhouses is already operating more successfully than the first 2 greenhouses did initially. It is important that attention is given to factors such as motivation, enthusiasm, the fear and/or hesitation about new developments, and more technical issues if greenhouse technology is to be implemented successfully.

A long-term follow-up program to ensure that the greenhouse structure and the soil fertility are maintained is also vital to maintain user satisfaction. As mentioned, the "Family of 4 PLUS" program of RIDS-Nepal includes nonformal education and nutrition classes. These are based on the projects being implemented to ensure that their benefits are maximized.

Conclusion

Solar greenhouses for community or family use offer a real prospect for improved food security and nutrition, and, in some cases, income generation, for people living in remote mountain areas. The overall outcome of introducing solar greenhouses into the isolated villages of Humla, a district of northwest Nepal, confirms the results of other programs promoting this technology to people living in the mountainous regions of the developing world. Solar greenhouses can be financially viable, assuming most of the materials can be obtained free of charge or at very low cost, and the greenhouse is built in partnership with the owner or the community.

Although community-owned solar greenhouses can work successfully, the experience in Humla has been that family-owned greenhouses are more likely to succeed because some of the problems associated with community ownership and operation are avoided. Appropriate and improved designs can be informed by computer modeling to predict general growing conditions in both winter and summer. Introducing solar greenhouse technology requires education, training, and long-term follow-up visits, and ideally should be part of a holistic approach to community development. When this is done properly, experience has shown that the owners of solar greenhouses are enthusiastic about the technology. One of the UN Assembly Report's recommendations was that strategies and programs be developed to enhance the food security of vulnerable mountain people. Solar greenhouses should be an integral part of such programs and be actively promoted in these regions by policy-makers.

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